COMPACT BROADBAND PLANAR FILTERS

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ABSTRACT

Based on impedance steps and coupled line sections as inverter circuits, novel wide band and very compact filters are presented. Based on alternately high and low impedances presented to the connected transmission line resonators by these inverters, the resonator lengths are reduced to a quarter wavelength only. Both suspended stripline as well as microstrip filters were designed, fabricated, and tested, proving this concept in an excellent way.

INTRODUCTION

Recently, a coupling structure as shown in Fig. 1 was proposed and investigated as inverter element for bandpass filters [1]. With strong coupling, this structure already provides one or two return loss zeroes, and thus is a good candidate for very compact and broadband filter design. The strong frequency dependence of this structure, however, prevents the application of state-of-the art filter design procedures, and an extensive optimization procedure is necessary.

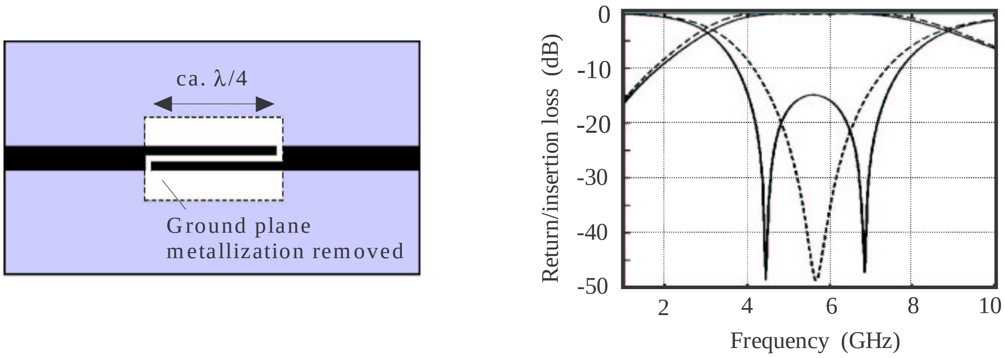


Fig. 1: Coupling/inverter structure and computed scattering parameters for two different widths of the ground plane gap (from [1]).

In this paper, a modified approach for understanding the behavior of this structure is presented, leading to better filter synthesis and even new ideas for the design of very compact broadband filters. According to the two pole response, the structure equally can be decomposed into three different discontinuities (two impedance steps and a coupling section) and two narrow transmission line sections. Regarding the discontinuities as elementary impedance inverters, and the transmission line sections as quarter-wave resonators, the structure as described above can alternatively be interpreted as a two resonator filter. In this case, the two resonant frequencies may be overlapped or split, depending on the geometrical conditions of the structure as shown in Fig. 1. With these ideas, more complex and high performance filter structures can be conceived.

NOVEL DESIGN OF BROADBAND FILTERS

Based on the considerations given above, a five resonator filter as shown in Fig. 2 can be designed. Once again, impedance steps – now of different geometries – and coupling sections form six inverters, and the resonators are formed by four coupled quarter-wave and one (low impedance) half wavelength sections. According to the inherent strong coupling coefficients of the elementary inverters (mainly the impedance steps), broadband-featured filters are expected. According to the application of quarter wave resonators, the filter becomes quite compact, too.

Preliminary designs of both a suspended stripline (SSL) and a microstrip filter were done on the basis of standard filter design [2], [3], followed by a number of optimization steps ([4] - [6]).

Filter layouts and theoretical as well as experimental results for the filters are given in Figs. 3 and 4. Center frequency is 6 GHz, bandwidth is about 2.5 GHz for the SSL filter and 3 GHz for the microstrip filter. Insertion loss is better than 0.5 dB for the SSL filter (including the transitions to coaxial line) and better than 0.3 dB for the microstrip filter (reference plane on the microstrip level). While the theory and experiments agree very well for the SSL filter, a greater discrepancy can be stated for the return loss of the microstrip filter. Metallization thickness (important in the coupling sections) is not included in the computation, and the small size of the filter structures and the extremely low return loss are very sensitive with respect to computation accuracy (discretization of the structure) and fabrication tolerances. With a length of only about 20 mm and a width of 5 mm, the microstrip filter is extremely compact.

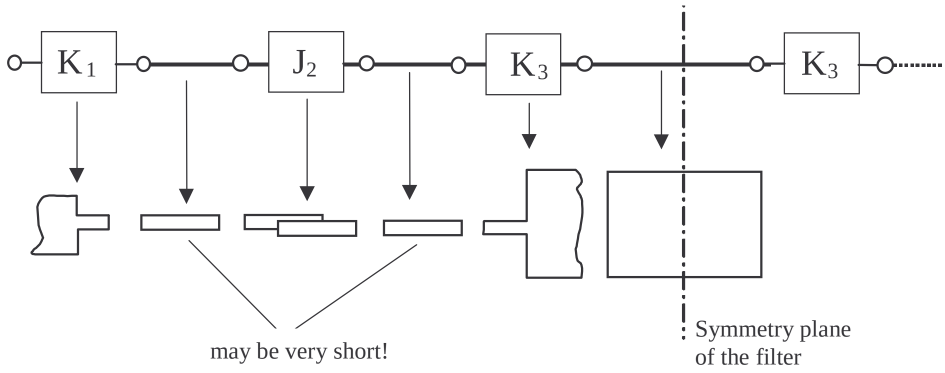


Fig. 2: Concept of the novel five resonator filter.

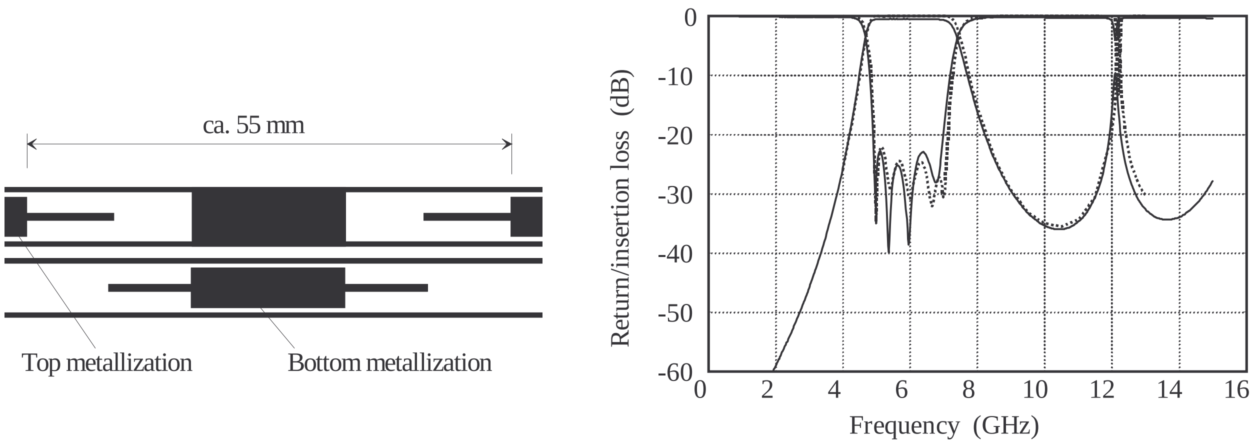


Fig. 3: Layout, theoretical and experimental results of a SSL filter (substrate material RT Duroid 5880, h = 0.254 mm, mounted in a channel 5 mm × 5 mm, ······ theory, —— experiment).

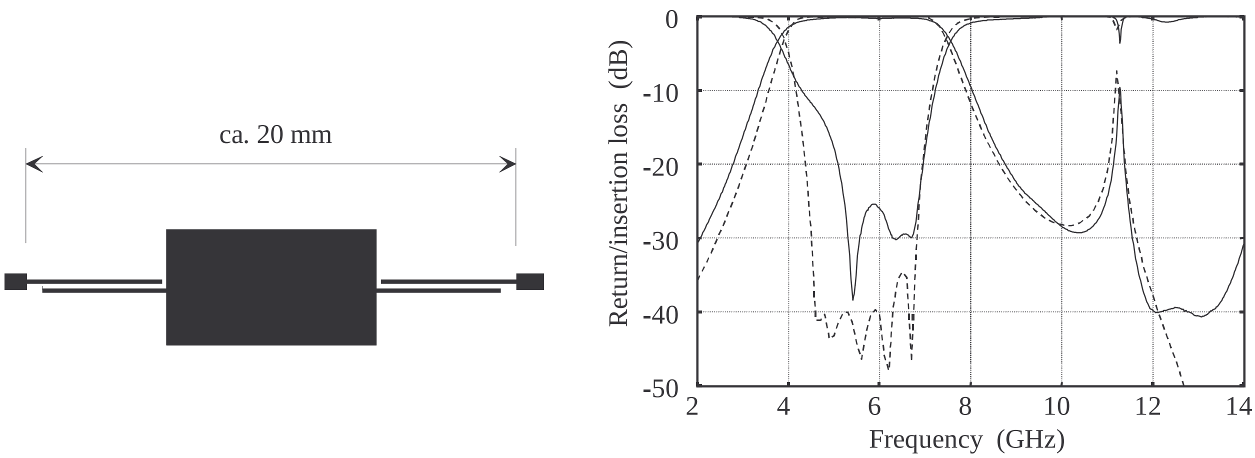
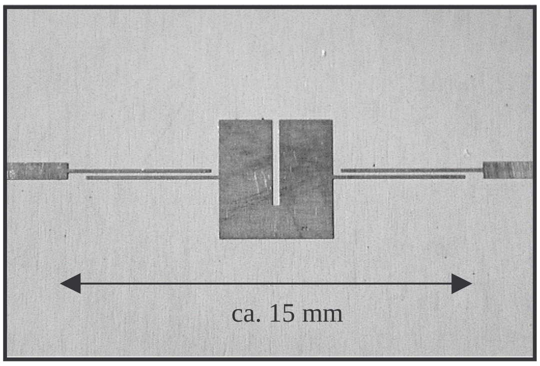


Fig. 4: Layout, theoretical and experimental results of a microstrip filter
(substrate material RT Duroid 6010, h = 0.635 mm, ······ theory, —— experiment).

One major disadvantage of this type of filter, however, is the spurious response at the first harmonic frequency of the passband caused by a full wavelength resonance of the central resonator. This spurious response, however, can be removed in two ways. The first method reduces the excitation of the full wavelength resonance by connecting the center resonator at points where the voltage of this resonance is zero. This structure will be demonstrated at the example of the microstrip filter. In the second approach, the filter is extended to six resonators. As central inverter, a shunt inductance is chosen, realized by a (very short) short circuited shunt stub. As this inverter provides a rather low impedance, compared to the quite high impedance of the next inverters (impedance steps from low to high transmission line impedances), the resulting central resonators become quarter wavelength resonators, too. Thus, the next spurious response occurs only at three times the passband frequency. This design is shown at the example of the suspended stripline filter.

IMPROVED FILTER DESIGN

If a transmission line resonator is fed a quarter of its length away from the ends, the fundamental half wavelength resonance is excited, but for the full wavelength resonance, the feed point is at a voltage zero, so that the resonator is not coupled at this frequency. Therefore, this technique is been applied to suppress the spurious passband of the microstrip filter as shown in Fig. 4. Furthermore, to achieve a compact size of the filter, the central resonator is folded. The resulting coupling between the ends of the resonator, in addition, leads to a passband pole above the center frequency. During the optimization of this filter, no effort was taken to reproduce the five pole behavior. A photograph of this filter together with the filter performance is shown in Fig. 5. The filter is even smaller than that presented before. A very good agreement is found between theory and experiment. In the stopband region, some surface waves launched by the transitions to the coaxial measurement system provided some problems; these, however, could be reduced by absorbing material placed at the substrate edges (about 3 ... 4 mm away from the filter). Passband insertion loss amounts to 0.2 dB only, and a measured stopband attenuation of more than 30 dB can be found in the frequency range from 9.5 GHz to 14.5 GHz. The insertion loss peak at around 13 GHz stems from a 1.5 wavelength resonance of the central (folded) resonator.



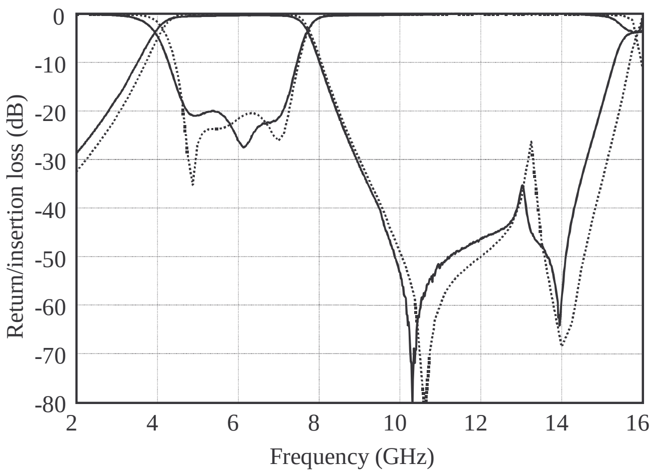


Fig. 5: Photograph and filter characteristics of the microstrip filter with suppressed full wavelength resonance (substrate material RT Duroid 6010, h = 0.635 mm, ······ theory, —— experiment).

Another method to improve the filter characteristic is the extension to a six pole filter, as mentioned already above. A generalized block diagram and the layout of such a filter based on suspended stripline is shown in Fig. 6. Basically, this type of filter can be regarded as a half wavelength impedance step filter [2] where series capacitances are introduced in the center of the high impedance lines and shunt inductances in the low impedance lines. In this way, the order of the filters is doubled, half wavelength resonators are turned into twice the number of quarter wavelength resonators within the same or even reduced space (when the capacitances are realized by side coupling) and, what is very important, the spurious response at twice the passband frequency is removed.

The suspended stripline design of such a filter has been done including optimization based on [4]. The shunt inductance in the center simply was realized by (symmetrical) shorting sections towards the mounting channel. The results are plotted in Fig. 7. No spurious response remains at around 12 GHz, and the filter edges are steeper as before due to the additional resonator. An excellent agreement can be stated between theory and experiment. This six resonator filter is even smaller than the five resonator one.

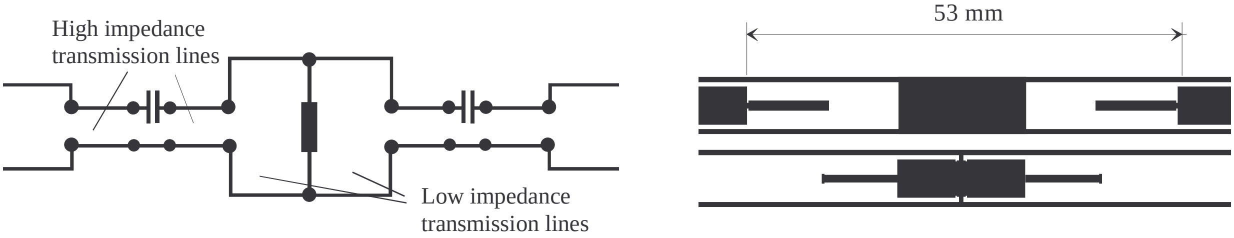


Fig. 6: Equivalent circuit and basic layout of a modified six resonator SSL filter.

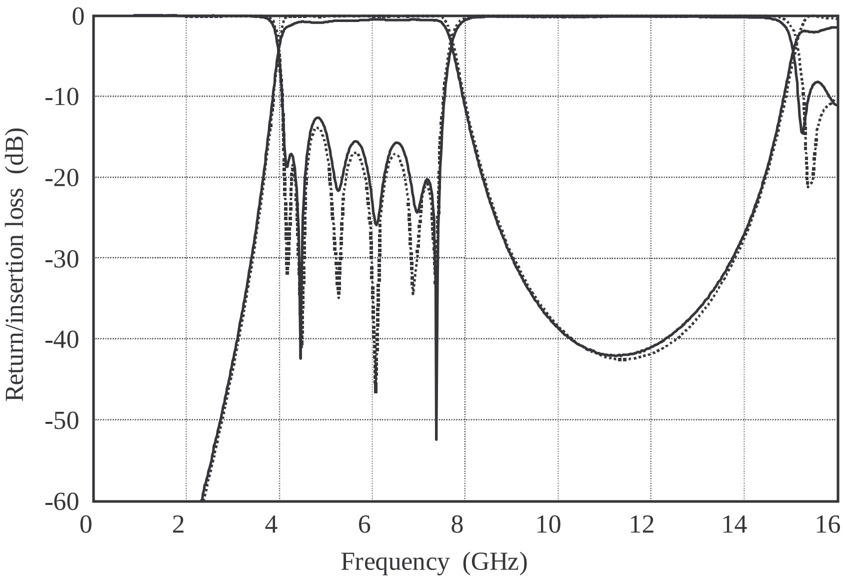


Fig. 6: Theoretical (dashed lines) and experimental results (solid lines) of a modified six resonator SSL. (Substrate material RT Duroid 5880, h = 0.254 mm, mounted in a channel 5 mm × 5 mm, ... theory, —— experiment).

CONCLUSION

Design and results of two five resonator filters and one six resonator filter have been presented. Based on a novel filter architecture and quarter wave resonators, very compact wide band filters have been realized. An excellent agreement between design and measurement, combined with low losses is found for the given examples, especially for the suspended stripline filters.

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