Passive and Active Microwave Filter Design Using Transversal Filter Principles

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***Abstract* - Transversal filter principles together with phase reversal techniques are applied to microwave filter design. After some optimization, a passive as well as an active filter are designed, providing wide bandwidth, steep filter slopes, spurious passbands only at odd harmonics, and moderate losses only.**

I. INTRODUCTION

While transversal filter principles intensively are used in digital signal processing and surface acoustic wave structures, only relatively few efforts have been made to include these concepts into microwave filter design. Reasons for this are large circuit size, high losses or poor filter performance. Some work has been done to combine transversal filters with active elements (e.g. [1] – [3]).

A further difficulty with standard planar microwave circuits like microstrip is the realization of negative filter coefficients existing in filter design [1], as typically, only shunt junctions are available. This leads to strong restrictions in filter design. In most cases, an additional lowpass performance exists, and the next higher order passband appears already at twice the desired center frequency.

In this contribution, negative coefficients are introduced by phase reversal [4] using transitions from microstrip to slotline and back [5]. In addition, these negative coefficients allow the design of filters without principal passband at zero frequency, and with spurious passbands only at odd multiples of the design frequency.

II. GENERAL DESIGN CONSIDERATIONS

A principle block diagram of a transversal (bandpass) filter is shown in Fig. 1. The transfer function is given by

$$H(f) = \sum_{i=0}^{n} a_i \cdot e^{-j2\pi i f \tau} . \quad (1)$$

An ideal filter performance often looks like that in Fig. 2, top. The filter function is periodic and includes passbands around DC and at multiples of f_0. The respective impuls response is plotted in Fig. 2, bottom. While the positive coefficients easily can be realized using a pure microstrip network, some tricks are necessary to implement at least some of the negative coefficients [1]. Furthermore, the lowpass performance and the spurious passbands already at twice the desired passbands are rather disadvantageous.

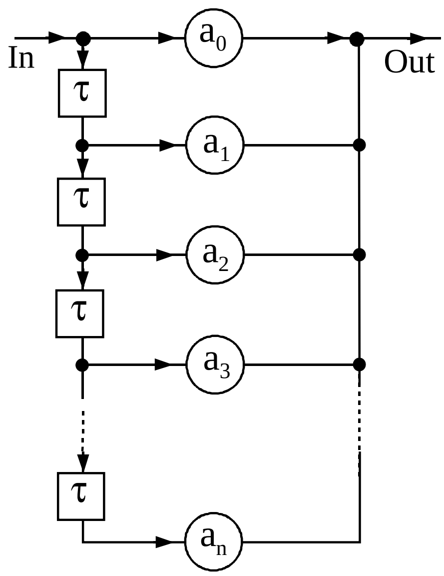

Fig. 1: Principle block diagram of a transversal filter.

While rather broadband bandpass filters easily can be realized using transversal filters, the high number of branches for good performance leads to large filter structures with increased losses. To overcome these problems, transversal filter principles often are combined with standard filter elements as it is done in this contribution. The lowpass performance can be removed, and the spurious passbands can be shifted to higher frequencies using a modified concept as shown in Fig. 3. In this case, however, strong negative coefficients are required which have to be realized by a series type junction in a planar circuit.

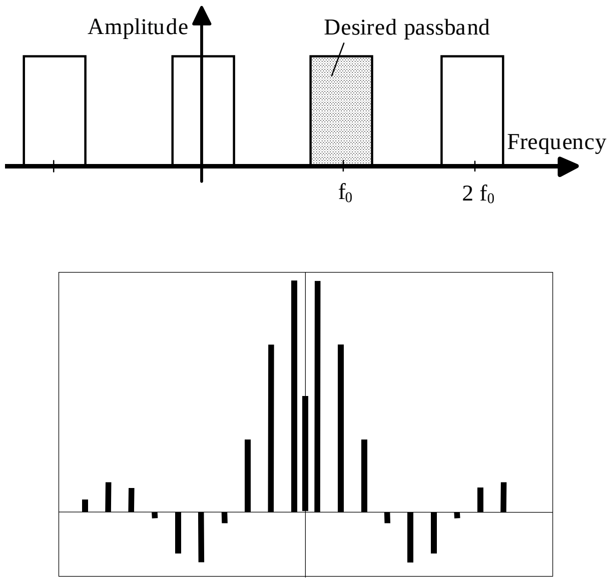

Fig. 2: Idealized transfer function (top) and impulse response (bottom) of a transversal filter as mostly realized in planar circuit technology.

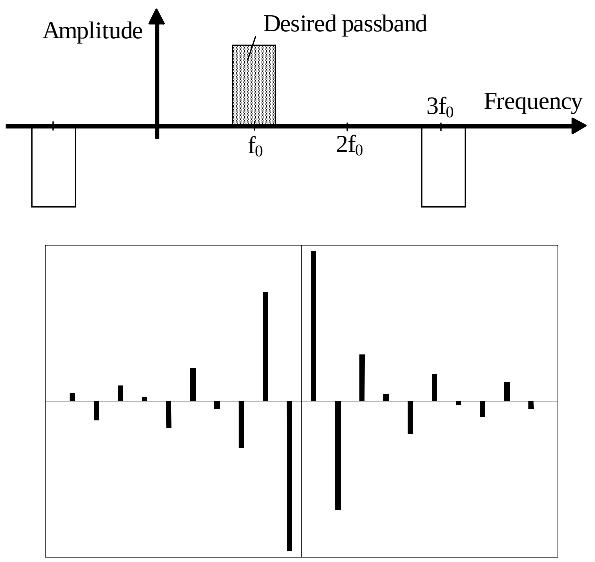

Fig. 3: Idealized transfer function (top) and impulse response (bottom) of a transversal filter as it is used in this paper.

III. PASSIVE FILTER

The basic layout of the passive filter presented in this paper is given in Fig. 4. The signal is coupled from a microstrip line to a short section of a slotline, and following this, to a three-port junction to microstrip again. The power is split to the microstrip ports with equal amplitude, but opposite phase, and is combined again with a delay of half a wavelength. No matched power combiner is used, thus the ring formed by the microstrip lines not only introduces transversal filter principles with a negative coefficient contribution, but also additional sharp resonances as can be seen in Fig. 5, leading to very steep filter slopes. A standard stub then provides some out-of-band shaping of the filter curve, followed by a second transversal filter stage – this time using positive coefficients only, but once again adding some resonator function. The elements of this filter were optimized for best filter performance using a commercial CAD program [6]. The results of the filter are plotted in Fig. 6 both in narrow and in a wide frequency range. Relative bandwidth is approximately 50 %. Design results and experiment agree very well. Steep filter slopes are achieved due to the additional ring resonances; some compromise had to be made with respect to return loss and out-of-band isolation. With 1 dB ... 1.5 dB compared to the theoretical values, losses are relatively low. As can be seen from the bottom diagram (wide frequency performance), there is no passband around 20 GHz, only at 30 GHz, the next passband is showing up. Some spurious peaks can be seen around the passbands; these are the remainders of the relative flat filter performance of the transversal filter portions, which are not completely suppressed by the ring resonances.

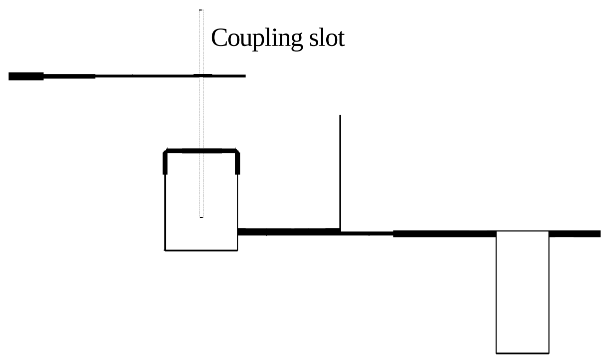

Fig. 4: Layout of the passive filter using transversal filter principles.

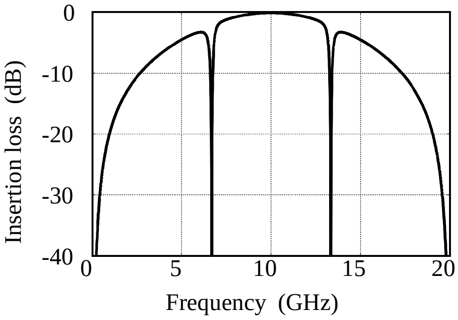

Fig. 5: Calculated insertion loss of the first filter ring (Fig. 4, left ring) including the slot coupling.

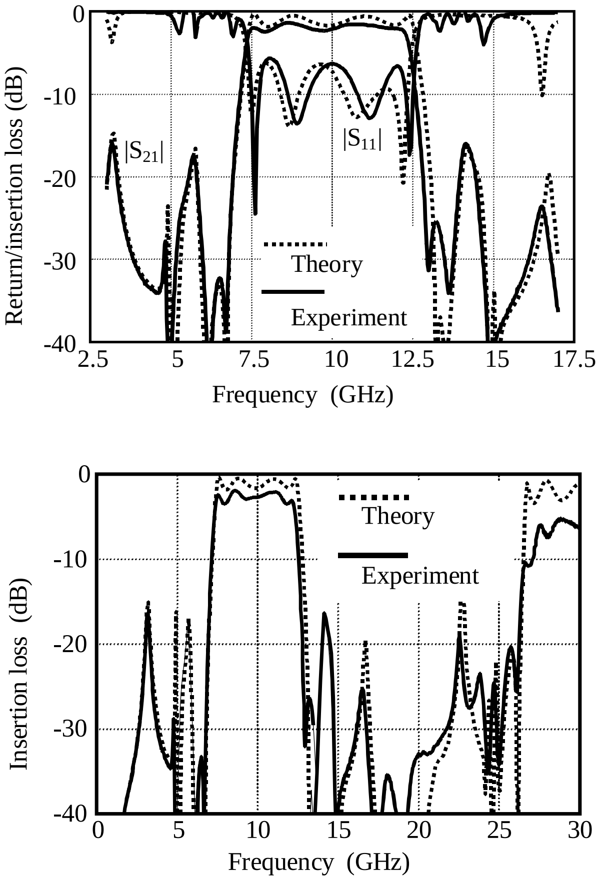

Fig. 6: Narrowband return and insertion loss (top) and wideband insertion loss (bottom) of the passive filter using transversal filter principles. (Substrate material TMM3, substrate thickness 0.38 mm, ε_r = 3.25).

IV. ACTIVE FILTER

In a next step, the stub in the center part of the passive filter (Fig. 1) was replaced by a simple FET amplifier (Fig. 7). This amplifier, at the one hand, provides gain and loss compensation, on the other hand, its band limited performance improves the attenuation of the filter far off the passband. Both theoretical and experimental results for return and insertion loss of this active structure are plotted in Fig. 8. Theoretical passband gain amounts to 5 dB ... 7.5 dB, in practice, 4 dB ... 5 dB have been achieved. The amplifier gain considerably drops at higher frequencies, thus the spurious passband around 30 GHz is suppressed by about 20 dB. A noise figure measurement of amplifier alone and active filter structure (Fig. 9) reveal only a moderate increase of the noise figure due to the filter circuit.

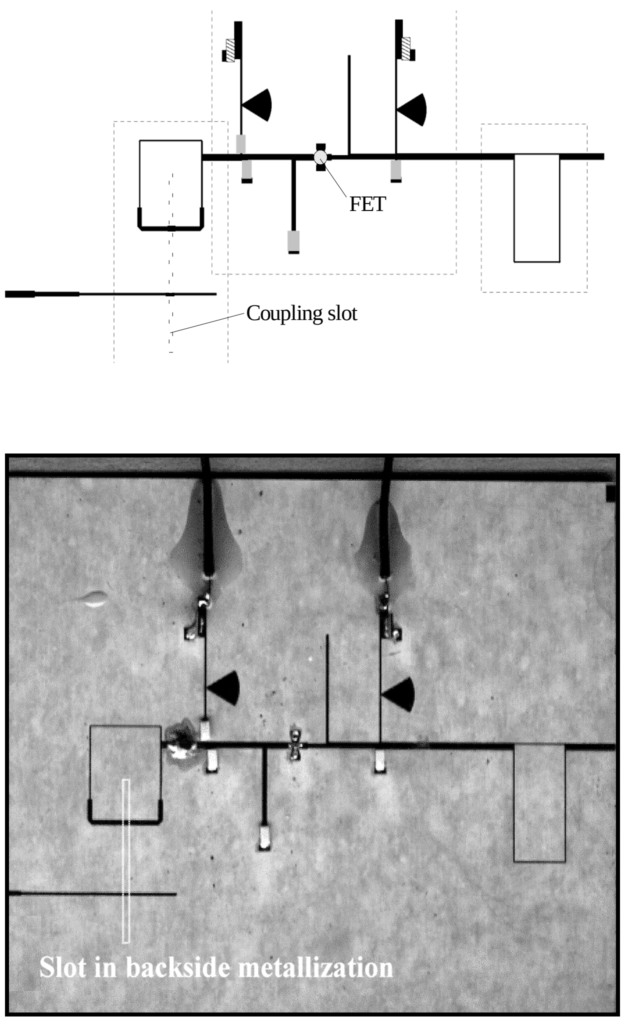

Fig. 7: Layout and photograph of the active filter using transversal filter principles.

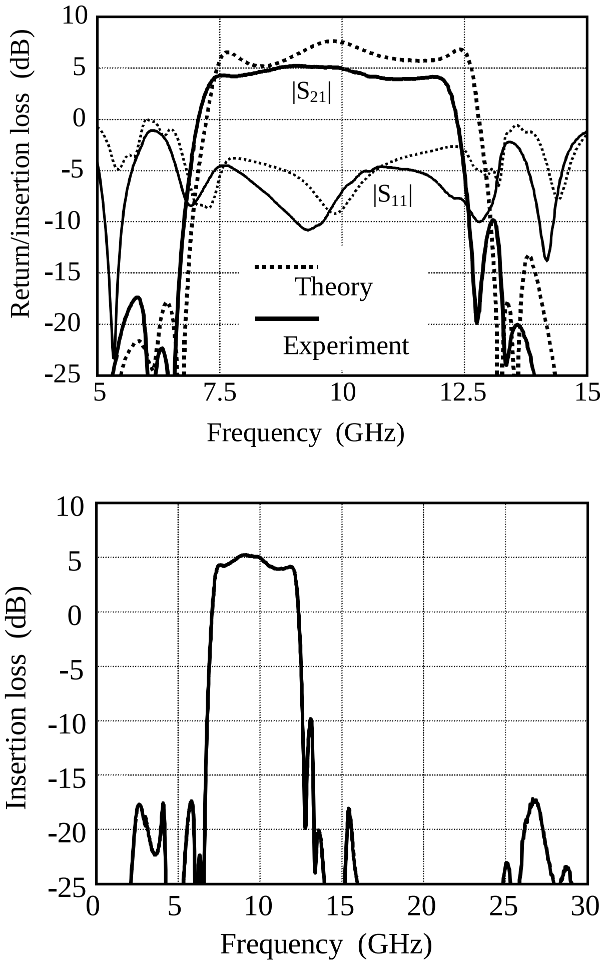

Fig. 8: Narrowband return and insertion loss (top) and wideband insertion loss (experiment, bottom) of the active filter using transversal filter principles (Substrate material TMM3, substrate thickness 0.38 mm, $\varepsilon_r = 3.25$).

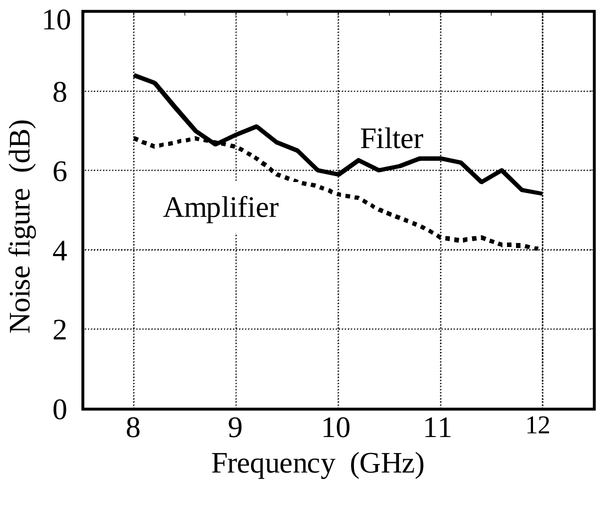

Fig. 9: Noise figures of amplifier and active filter.

V. CONCLUSION

A passive and an active filter are reported using modified transversal filter principles introduced for microwave circuits, together with some classical filtering structures newly. Rather steep filter slopes could be realized, no spurious passbands occur at even harmonics, and losses are relatively low compared to other transversal microwave filters.

VI. REFERENCES

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