Waveguide Filter Integrated into a Planar Circuit

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***Abstract* - Design and results of a waveguide filter are presented. The filter is integrated into the carrier block of a planar microstrip circuit. The coupling from the planar microstrip circuit to the waveguide filter is achieved via slots in the ground plane; these coupling structures, at the same time, act as first and last inverter of the filter. The remaining inverters and all filter resonators are realized using reduced height metal waveguide. In this way, low loss of waveguide resonators is combined with planar circuits and a compact setup.**

INTRODUCTION

Bandpass filters often are required in micro-wave and mm-wave systems to reject out-of-band signals or to reduce noise bandwidth. To a great extent, systems are based on planar circuits; planar bandpass filters, however, often exhibit high losses and are increasingly sensitive to tolerances if high dielectric constant substrates are used (e.g. $\varepsilon_r \approx 10$) to keep circuit size small. Metal waveguide filters, on the other hand, are difficult to integrate into planar circuits. In [1], a first idea has been presented to solve such a problem. A waveguide resonator was fabricated (by micromachining) in the carrier block of a circuit and connected to the planar circuit using slot coupling. In a similar way, a complete waveguide filter can be integrated. To this end, two basic procedures can be chosen. The first one requires a matched transition from the planar circuit to metal waveguide. A simple slot coupling to a reduced-height waveguide is described in [2]; a transition of this kind shows, however, some critical radiation losses. These losses can be reduced by shortening the coupling slot at the expense of an increased return loss of the transition. A solution to this new problem is given by the second approach described in this contribution. The transitions are included into the filter design as the first and last inverter circuit.

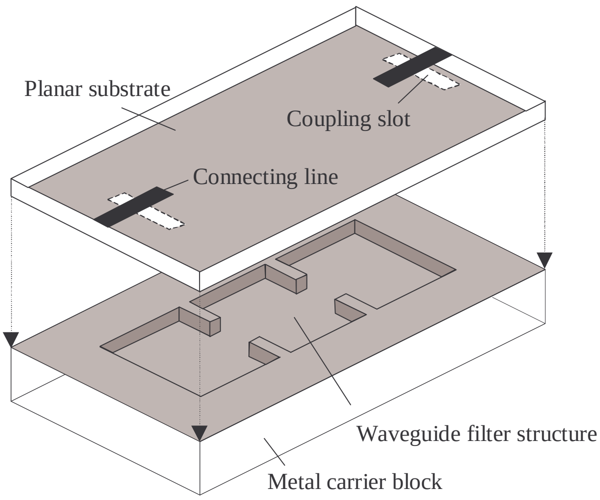

Fig. 1: *Principle setup of the waveguide filter integrated into a planar circuit.*

DESIGN OF THE FILTER STRUCTURE

A sketch of the realized filter is shown in Fig. 1. The reduced height waveguide filter structure is machined into the metal carrier block for a planar circuit. Interconnect lines and coupling slots are etched from front and back side of the planar substrate, respectively. The planar substrate then is glued or soldered onto the carrier block.

The design of the filter starts from a filter based on waveguide resonators separated by inductive irises. This waveguide filter was designed using a mode matching procedure. The first and last iris then are replaced by the coupling structure to the planar circuit. To design this transition properly, the absolute value of the transmission coefficient of the transitions must be equal to that of the outer waveguide iris; phase differences then are compensated by appropriately adjusting the lengths of the outer waveguide resonators.

The properties of the transition were computed with a commercial simulator [3]. Typical 2-D or 2½-D simulators for planar circuits, however, allow ports only at planar transmission lines, not waveguide ports. Therefore, two transitions were placed back to back, connected with waveguide sections of two different lengths (structure as shown in Fig. 1, but without the waveguide irises). From two calculations of these composite structures, the scattering matrix of a single transition can be extracted ([4], Fig. 2) in the following way:

$$s_{11} = \frac{s_{11}^{I} s_{21}^{II} e^{-j\beta l^{II}} - s_{11}^{II} s_{21}^{I} e^{-j\beta l^{I}}}{s_{21}^{II} e^{-j\beta l^{II}} - s_{21}^{I} e^{-j\beta l^{I}}} \qquad (1)$$

$$s_{22} = \frac{s_{11}^{II} - s_{11}^{I}}{s_{21}^{II} e^{-j\beta l^{II}} - s_{21}^{I} e^{-j\beta l^{I}}} \qquad (2)$$

$$s_{21} = s_{12} = \pm\sqrt{s_{21}^{II} e^{+j\beta l^{II}} - \left(\frac{s_{11}^{II} - s_{11}^{I}}{s_{21}^{II} e^{-j\beta l^{II}} - s_{21}^{I} e^{-j\beta l^{I}}}\right)^{2} s_{21}^{II} e^{-j\beta l^{II}}}\,, \qquad (3)$$

where s_{ij} are the required scattering parameters of the single transition. s_{ij}^{I} and s_{ij}^{II} are the scattering parameters of the composite structures with connecting line lengths l^{I} and l^{II}, respectively, and β is the phase constant of the connecting waveguide.

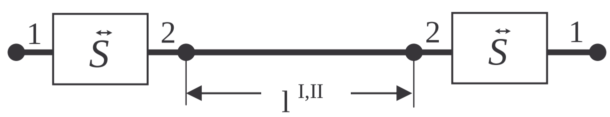

Fig. 2: *Back-to-back arrangement of two transitions with connecting line.*

The results of this procedure for the transition finally used in this filter are indicated in Fig. 3.

It can be seen that the transmission coefficient of the single transition is not very much dependent on frequency in the frequency range of interest. For the filter design, the transmission coefficient at the center frequency of the filter was calculated for different lengths of the coupling slot, and the required length was determined graphically (Fig. 4) and verified with an additional simulation (see Fig. 3). After adjustment of the resonator lengths according to the exact S-parameters of the transition, the final filter structure was fixed, a sample filter fabricated, and the results compared to a complete full-wave simulation [3] of the filter.

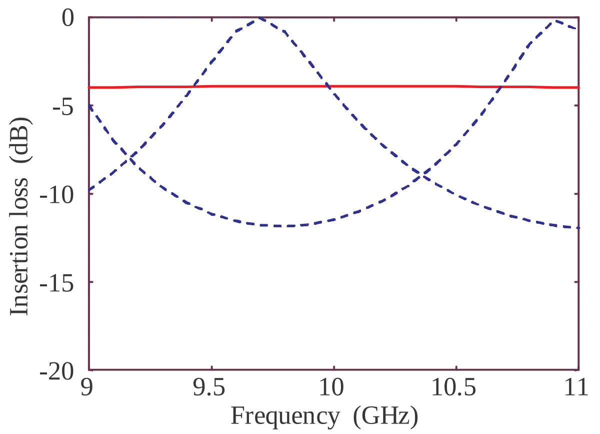

Fig. 3: *Experimental insertion loss of two back-to-back transitions from microstrip to waveguide with two different lengths (dashed lines) and the extracted result for a single transition (solid line).*

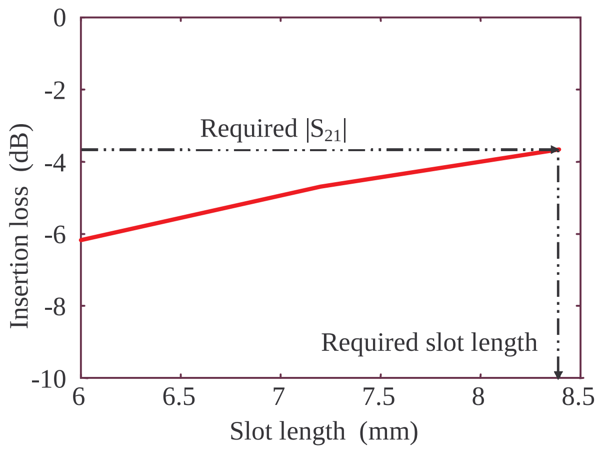

Fig. 4: *Insertion loss of a single transition from microstrip to waveguide as a function of slot length (frequency 10 GHz).*

RESULTS

A photograph of the realized test filter for X-band (10 GHz) is shown in Fig. 5. Theoretical and experimental return and insertion loss of this filter are shown in Fig. 6. Waveguide width and height are 22.86 mm and 2.5 mm, respectively; substrate thickness of the planar structure is 0.76 mm with a dielectric constant of 2.5.

A good agreement can be seen, except for some deviation of the insertion loss in the lower and upper stop bands. Test showed that some surface waves are launched by the transitions from the coaxial measurement system to the planar circuit (surface waves launched by the slot transitions basically are included in the simulation). Therefore, the filter was measured once again with an absorber placed on top of the substrate between input and output coupling slot (Fig. 7). The experimental insertion loss now matches very well with theory. Passband insertion loss amounts to 1.3 dB, including two transitions from the coaxial measurement system to the planar lines (with their surface wave losses) and about 20 mm of additional microstrip line length.

In addition to fabrication tolerances of the planar substrate and the waveguide structure, adjustment tolerances of the planar substrate on top of the waveguide block may affect filter performance. Therefore, calculations were performed assuming a longitudinal displacement of the substrate of 0.1 mm. As the slots were placed at the edges of the waveguide resonators, this additionally leads to a reduction of slot width at one filter end from 1 mm to 0.9 mm (in a further design, the slots should be separated slightly from the resonator edges). The results of these computations are plotted in Fig. 8 in comparison with the original data. Insertion loss practically remains unchanged, and return loss is affected only in a minor way. A lateral displacement of the substrate by the same distance should lead to a comparable of even lower effect, as for a central position of the transition to waveguide, the derivative of the coupling coefficients is zero due to symmetry.

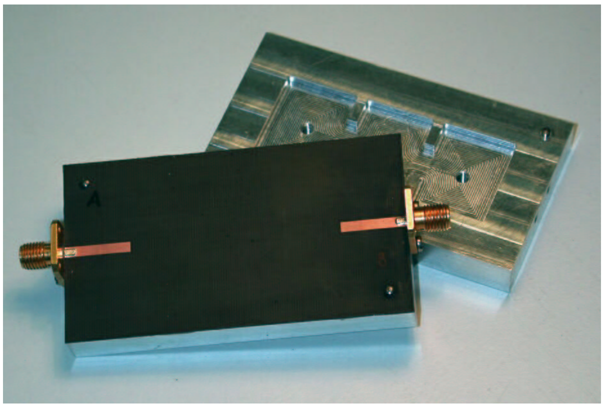

Fig. 5: *Photograph of the realized X-band test filter.*

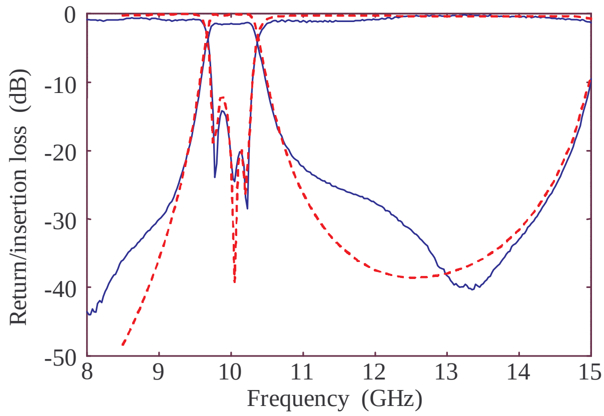

Fig. 6: *Theoretical (dashed lines) and experimental (solid lines) return and insertion loss for the three-resonator X-band filter.*

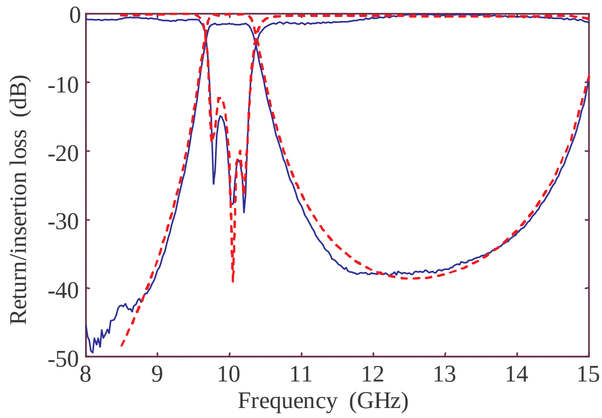

Fig. 7: *Theoretical (dashed lines) and experimental (solid lines) return and insertion loss for the three-resonator X-band filter with an absorber on top of the substrate.*

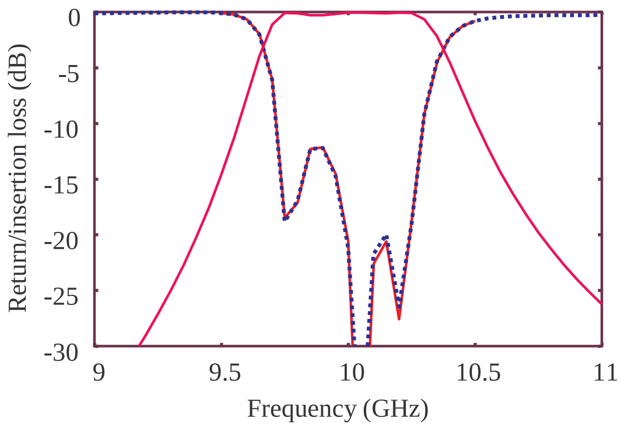

Fig. 8: *Comparison of filter results for longitudinal displacement of the planar substrate of 0.1 mm. (Dotted line: original results, solid line: 0.1 mm longitudinal shift of the planar substrate).*

CONCLUSION

Design and results of a waveguide filter integrated into the carrier block of a planar microstrip circuit have been presented. Such a carrier block finally even could be fabricated using plastic injection molding and electro-plating as has been demonstrated for waveguide filters in [5]. The coupling from the planar circuit to the filter is achieved via slots in the ground plane; these coupling structures, at the same time, act as outer inverters of the filter. In this way, low loss of waveguide resonators is combined with planar circuits and a compact setup.

Overall insertion loss of the X-band filter is 1.3 dB, including the transitions to the coaxial measurement system and 20 mm of additional microstrip line length. Positioning tolerance have been investigated, too, and have proven to be uncritical. Such a filter therefore may be an interesting alternative to lossy planar filter structures, even suited for mm-wave frequencies.

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