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PRACTICAL INVESTIGATIONS ON MONOLITHIC INTEGRATED MICROWAVE FILTERS

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Abstract

Filters at microwave frequencies today normally are built in hybrid technology. In this paper principles for the monolithic integration of frequency selective structures without any external component are investigated. Monolithic Filters at frequencies about 10 GHz based on lumped LC-structures and about 30 GHz in coplanar waveguide technology are presented. Both filter concepts need active components to compensate the insertion loss of the filters. All components are interconnected by coplanar lines without reverse metallization. The performance of these filters is investigated experimentally.

Introduction

Filters at microwave frequencies today normally are built in hybrid technology. In this paper principles for the monolithic integration of frequency selective structures without any external components are investigated. The structures use coplanar interconnects for best integration in modern CPW circuitry. Such filters could be part of modern microwave based communication and remote sensing systems. By integrating more components into a MMIC it is possible to manufacture these products more effectively and to realize new circuit principles.

The project has been carried out in cooperation between the Microwave Department of the Technical University Ilmenau and the Fraunhofer Institute for Applied Solid State Physics in Freiburg. Design, modelling and measurement of the stuctures were performed in Ilmenau, the wafers were processed with the GaAs-HEMT technology of Freiburg. The work is supported by the German Resarch Ministry.

The research project first of all was directed to the search for microwave filter structures suited for monolithic integration. Such filters are for instance needed for bandwith limitation, signal separation and selective feedback networks ([1], [2]). The second goal was to integrate several filters with graduated bandpass characteristics on one chip to built a "frequency analyzer IC" for the microwave band. This chip should contain several bandpass filters connected with biased schottky diode detectors. Such a circuit has regard to the growing interest in the selection and classification of microwave oscillations. It could be usefull for qualitativ signal analysis as well as for harmonics detection in large signal applications.

Recently reported filter implementations in integrated GaAs technology are limited to the design of filters for some special tasks and are based on microstrip lines ([4] - [6]). The use of coplanar interconnects and coplanar coupler layouts in comparison to microstrip technology allows a reduced chip size, easy grounding of components and better transition between filters and active amplifier stages. Fig. 1 shows a typical 50 Ω coplanar line for a Gallium Arsenide substrate including a taper structure with contact pads for coplanar probe tips.

Filters with coupled coplanar waveguides

Monolithical integration allows to manufacture inductors and capacitors at microwave frequencies. But the quality factor of these elements is decreasing with increasing frequency. Additionally the realizeable range of values is restricted. Both results in a limited operation frequency range for lumped filter concepts.

A second principle useful at higher frequencies seems to be utilizing line structures for signal filtering.The filter synthesis with distributed elements at lower frequencies is restricted by the relation between a common chip size of 4 x 4 mm² and the needed length of line. On GaAs-substrate material the effective dielectric constant for a CPW line ($\varepsilon_{r\,eff}$ = 6,2) results for instance in a wavelength of λ = 12 mm at 10 GHz.

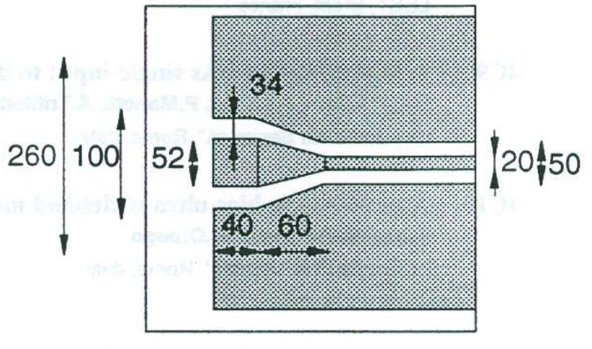

Fig. 1: Layout of a coplanar waveguide with taper for on wafer testing (dimensions in μm)

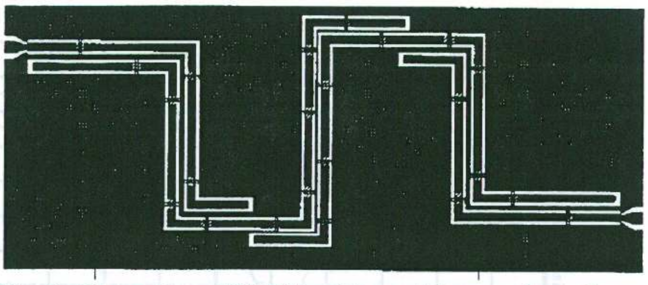

Fig. 2: Three stage CPW line filter with ground conductor in coupling section

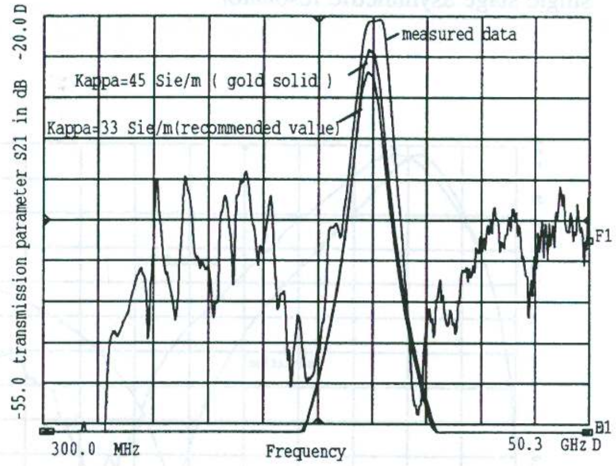

Fig 3: Measured and modelled transmission factor S_{21} of a three stage CPW filter with ground conductor in coupling section

If two coplanar lines are guided closely together, there is a frequency variant coupling depending both on width of the ground conductor and on spacing between lines. This coupling results only in a slight distortion of the CPW field. Therefore explicit mathematical models exist for circuit design. Fig. 2 shows the layout of a three stage broadside coupled CPW filter designed for a passband center frequency of 30 GHz. The length of about 900 μm per coupling section necessitates the meander shape of the structure. Fig. 3 shows the measured transmission characteristic and the data received from simulations for two different models of line losses. The passband frequency is modelled correctly. But both models estimate the rather large passband attenuation of about 20 dB too high. Eliminating the ground conductor in the coupling section reduces the passband attenuation by making the coupling so tight, that no sufficient selectivity remains. Besides in this case the field of the coplanar waveguide is distorted too heavily and an explicit model is no longer available. Also an program based on the method of moments did not deliver results verifiable experimentally.

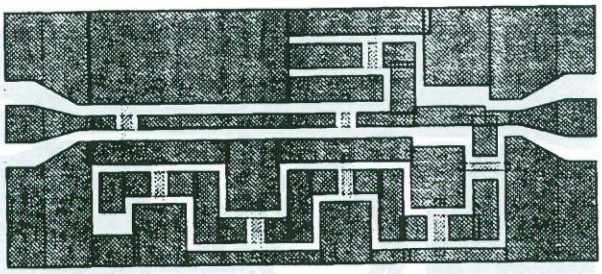

Fig. 4: Layout of a coplanar stub filter

Coplanar stub filter

Another bandpass filter structure consists of a transmission line with a shorted and an open stub. Fig. 4 shows the cir cuit layout of such a filter realization. The characteristic impedances of the lines differ from 50 Ω normalized impedance. For the frequency response of a 20 GHz stub filter measured with 50 Ω port impedances see fig. 5.

The structure has a relativ small insertion loss with rather poor slope. The periodical passband typically for line structures is visible.
Low losses and simple construction make this filter type suited for biasing networks and input filter in amplifiers.

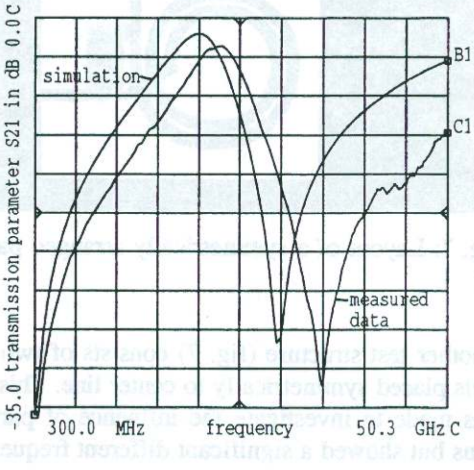

Fig. 5: Measured and simulated frequency characteristic of a 20 GHz coplanar stub filter

Filters with lumped LC elements

In Fig. 6 the schematized layout of a parallel resonator formed by an inductor (L=342 pH) and a capacitor (C=871 fF) is shown. This circuit was used as one of the basic structures in lumped LC filters at microwave frequencies. The inductor is surrounded by a grounded frame to realize a defined environment as demanded for best conformity with model library. This frame also contains the capacitor visible as small rectangle. The measured frequency characteristic (fig. 8) differs notably from the modelling results.

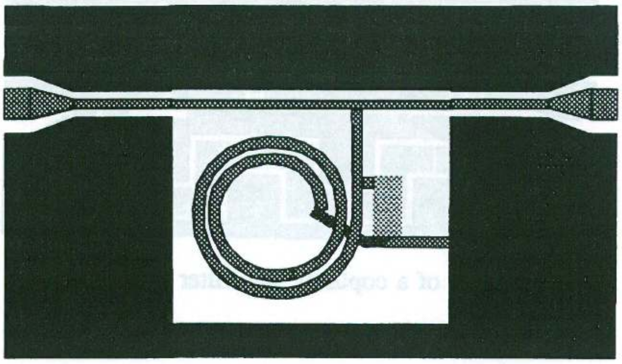

Fig. 6: Layout of an asymmetric parallel resonator

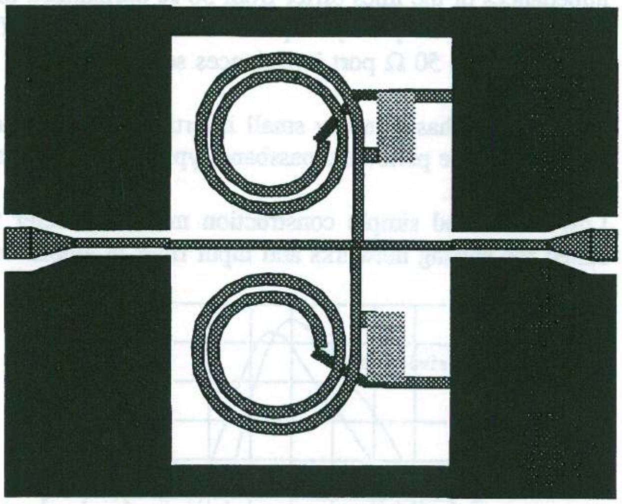

Fig. 7: Layout of a symmetrically arranged parallel resonator

Another test structure (fig. 7) consists of two resonant circuits placed symmetrically to center line. This modification was made to investigate the influence of parameter variations but showed a significant different frequency response.

The circuit has the same resonant frequency as fig. 6 (L= 611 pH; C= 435 fF). The frequency charakteristic of this structure (fig. 9) is similar to that of the asymmetric structure but the "second passband" is missing. The symmetric layout geometry avoids the undesirable bypass effect at 25 GHz. Above 30 GHz the decreasing quality factor causes the measured and modelled lower stopband attenuation.

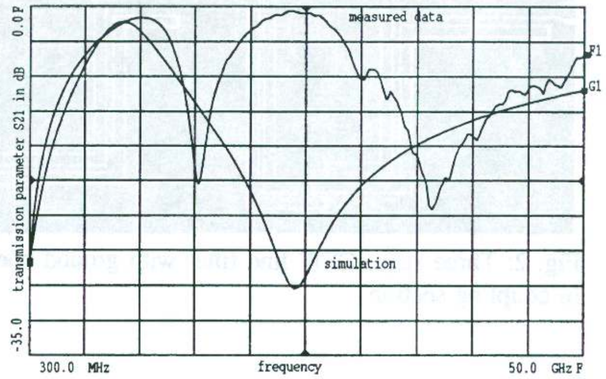

Fig 8: Measured and modelled transmission factor S_{21} of a single stage asymmetric resonator

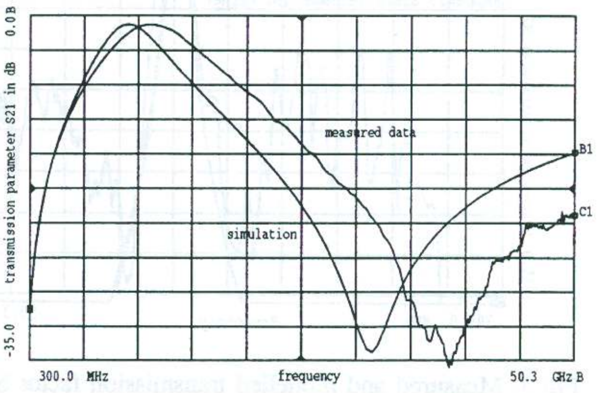

Fig 9: Measured and modelled S_{21} of a symmetrically placed parallel resonator (one stage)

A possible reason for the "second passband" at a frequency of 25 GHz could be seen in the through going slot along the upper ground plane of the asymmetric structure (fig 6). This slot is able to guide waves different from the supposed coplanar type. Such slot line modes could guide energy bypassing the resonant circuit and would appear at higher frequencies. Modelling these structures with the method of moments could verify this effect only qualitatively, the measured frequency dependency is not shown. The layouts beeing too complex to perform 3D finite elements method, suitable layout modifications more effective than the area consuming symmetrization have to be found experimentally.

The filters discussed are loaded by 50 Ω port impedances during measurement. By using coupling capacitors the load transformed into the resonant circuits can be reduced, i.e. the selectivity can be improved. Fig. 10 shows the circuit diagram of a three stage LC bandpass filter at 10 GHz. The

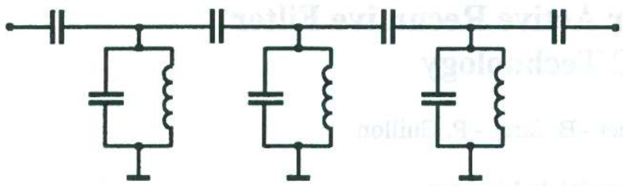

Fig. 10: Circuit diagram of a three stage lumped element filter

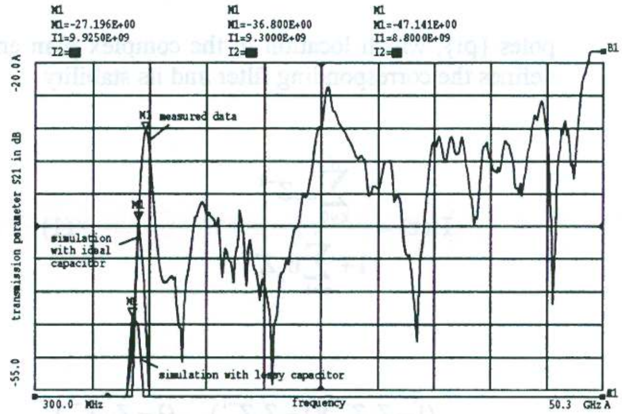

Fig. 11: Measured and simulated transmission factor S_{21} for a three stage LC-filter

layout of this structure is still asymmetrical, so the second pass-band at 25 GHz exists. Cascading three resonant circuits improves selectivity, but the passband attenuation is rising too and amounts to a value of -27 dB.

Conclusions

The analysis of produced test structures showed the chances and limitation of microwave filters in the choosen GaAs HEMT technology. The application of line structures for frequency separation in integrated circuits is possible if the chip size is compareable to wavelength. For this reason the lower frequency limit is about 10...30 GHz. Since the attenuation of a CPW line at 100 GHz is less than 1 dB/mm ([3]) the upper frequency limit is reached at such a frequequency.

Filters based on lumped elements were designed at 10 GHz. This filter concept is limited by the quality factor of the LC elements decreasing with frequency. Though it should be possible to suppress the bypass effect observed in the asymmetric structure, the filter effect is lost for frequencies higher than 20 GHz. These limits depend strongly on technological parameters of metallization and substrate. All integrated filters in comparison to hybrid realizations have much higher passband attenuation. Therefore the compensation of filter losses by amplifier stages should be nessessary. The project is continued toward this direction.

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