LOW-NOISE MICROWAVE ACTIVE FILTERS IN PLANAR REALIZATIONS

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ABSTRACT

Design and results of active filters based on low-loss suspended stripline filter resonators and MeSFET gain blocks realized in microstrip are presented. The coupling between filter resonators and microstrip gain blocks is performed electromagnetically acting, at the same time, as matching structures for input and output of the transistor. In this way, very low noise active filter circuits with a single gain stage and two stages at 10 GHz as well as a single stage 35 GHz active filter were realized.

INTRODUCTION

With decreasing bandwidth, passive filters - especially in planar integrated form - become more and more lossy, their edges are rounded, and the filter slopes become less steep.
Filters in the input of a front-end typically should suppress adjacent signals to avoid intermodulation products or even saturation of the input amplifier. Due to their position in the system, losses as low as possible and a low noise figure are of a major importance, while the form of the filter response is not as critical as losses or noise. On the other hand, sharp edges and a steep filter slope are of prime interest for signal separation in channelized receivers or for the reduction of noise bandwidth to a minimum. This mostly, however, is done after preamplification, therefore losses and especially noise figure are not as relevant.

To reduce filter losses by active elements, a number of efforts have been published, e.g. [1] - [11], with different types of filters and based on lumped elements or transmission line structures together with MeSFETs as discrete devices or even using monolithic circuits. As the active elements add noise to the filter circuit, noise figure might be considerably high - higher than the insertion loss of a respective passive circuit. In many papers, noise figure is not considered, or noise figures up to even 15 dB are reported. A detailed investigation of noise in active filters is presented in [8].

In this contribution, design and results of active band pass filters (or frequency selective amplifiers) is reported with prime attention to low noise figure, as it is necessary in the input of a receiver.

DESIGN OF THE FILTER

To achieve best performance of the low-noise active filter, a basic structure according to Fig. 1 was chosen. A first filter resonator does some preselection to reduce intermodulation problems, a gain block provides low-noise amplification, and a further resonator improves selectivity [12]. More gain blocks and resonators may be added in the same way [13]. For optimum performance, the following set-up was chosen:

– Suspended stripline as planar transmission line with lowest loss was employed for the resonators.
– Microstrip line with very short line segments was used for the gain block, resulting in easy via-hole realization and good thermal performance, as the microstrip part of the whole circuit can easily be placed on a metal block.
– Multilayer structures with electromagnetic coupling between filter resonators and gain blocks were chosen [14]. In this way, at the same time and with one coupling structure only, the inverter function, gain block input or output matching, and DC isolation are achieved with minimum loss. Furthermore, a capacitive load close to the transistor gate or drain will, in many cases, improve stability, especially at low frequencies.

The basic layout of such a filter with one gain block is shown in Fig. 2.

The multilayer transition between suspended stripline and microstrip (inset of Fig. 3) is calculated using spectral domain techniques [15]. The overlap d of both „hot“ conductors mostly determines the performance of the transition, while the gap width g between stripline and microstrip ground has a minor influence. As can be seen from Fig. 3, a wide range of coupling coefficients can be adjusted.

FILTER RESULTS

A first test filter according to Fig. 2 was realized for 10 GHz, using a MeSFET CFY25 (Siemens) with 0.5µm gate length and 6 x 40 µm gate width. The measured minimum device noise figure for several transistors ($I_{DS} = 0.3I_{DSS} = 10$ mA) was in the range from 1.9 to 2.2dB; the maximal available gain about 12 dB. The filter was fabricated on a soft substrate of 254 µm height and a dielectric constant of 2.22, mounted to a brass housing (channel dimensions 5 mm x 5 mm) with SMA coaxial connectors.
Two of these filters were fabricated, showing a maximal gain of 10.7 and 11.9 dB (Fig.4) and noise figures of 2.3 and 2.0 dB, respectively, at center frequency. Compared to the device performance, only a slight degradation can be stated due to the filter and amplifier circuitry. As the circuit exhibits a considerable gain, the noise contribution of further components added to the output of the filter is reduced remarkably.

In a second step, a filter with two gain blocks and three filter resonators was designed (Fig.5). The first transistor was biased for minimum noise figure, the second one for maximally gain ($I_{DS} = 0.5I_{DSS}$). This two-stage active filter exhibited a gain of 22.1 dB (Fig.6), associated with an overall noise figure at center frequency of 3.2 dB. This noise figure is slightly higher than expected from cascading another gain block and another filter element to the structure according to Figs. 2 and 4; but with this filter, bandwidth was much lower than in the first example (100 MHz compared to 420 MHz) resulting in increased losses.

To demonstrate the performance of this type of active filter in the mm-wave range, a circuit according to Fig.2 was designed at 35 GHz employing a pseudomorphic HEMT with 0.25 µm gate length and 120 µm gate width from the Daimler Benz Research Institute. The S-parameters of the resulting circuit are plotted in Fig.7, showing a gain of 4.2 dB. In this case, however, the transistor performance was degraded, to some extent, while placing it into the circuit, therefore the gain was relative low, and the noise figure amounted to 4.0 dB only. Nevertheless, the operating principle could be demonstrated at this frequency, too.

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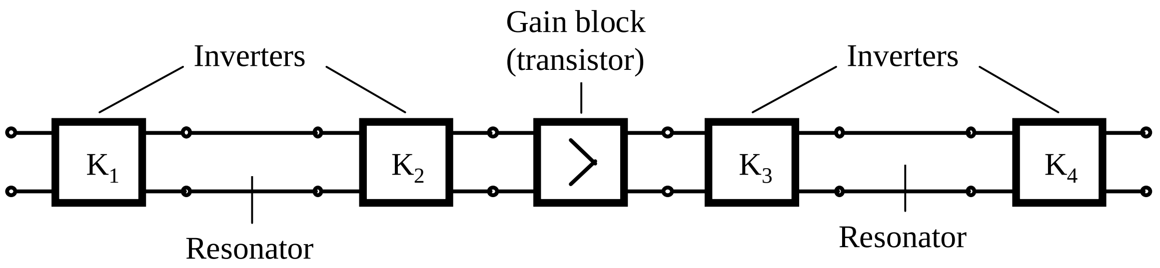

Fig. 1: Basic structure of active filter circuit.

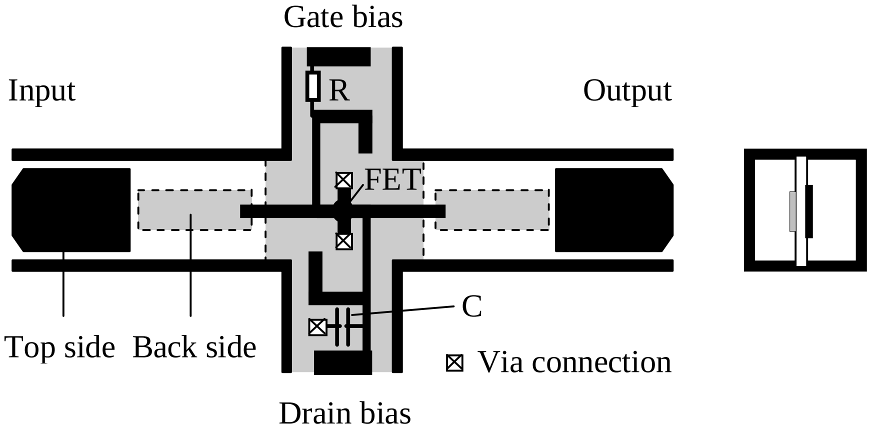

Fig. 2: Basic layout of active filter circuit.

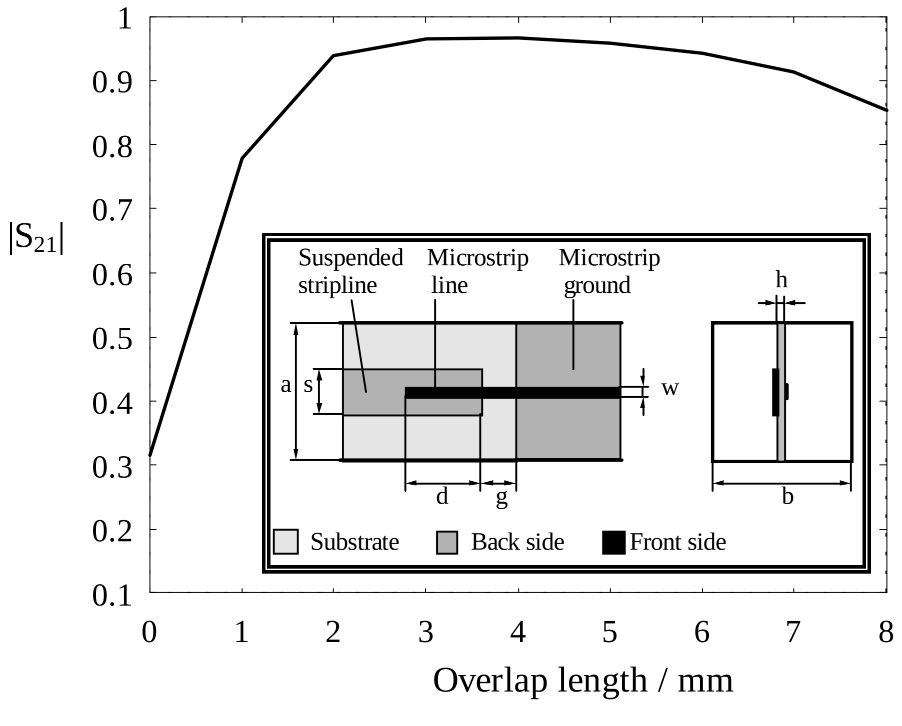

Fig. 3: Basic suspended stripline - microstrip coupling structure and coupling behavior as a function of coupling length (f = 10 GHz, a = b = 5 mm, s = 1.75 mm, w = 0.76 mm, g = 1 mm, h = 0.254 mm, ε_r = 2.22).

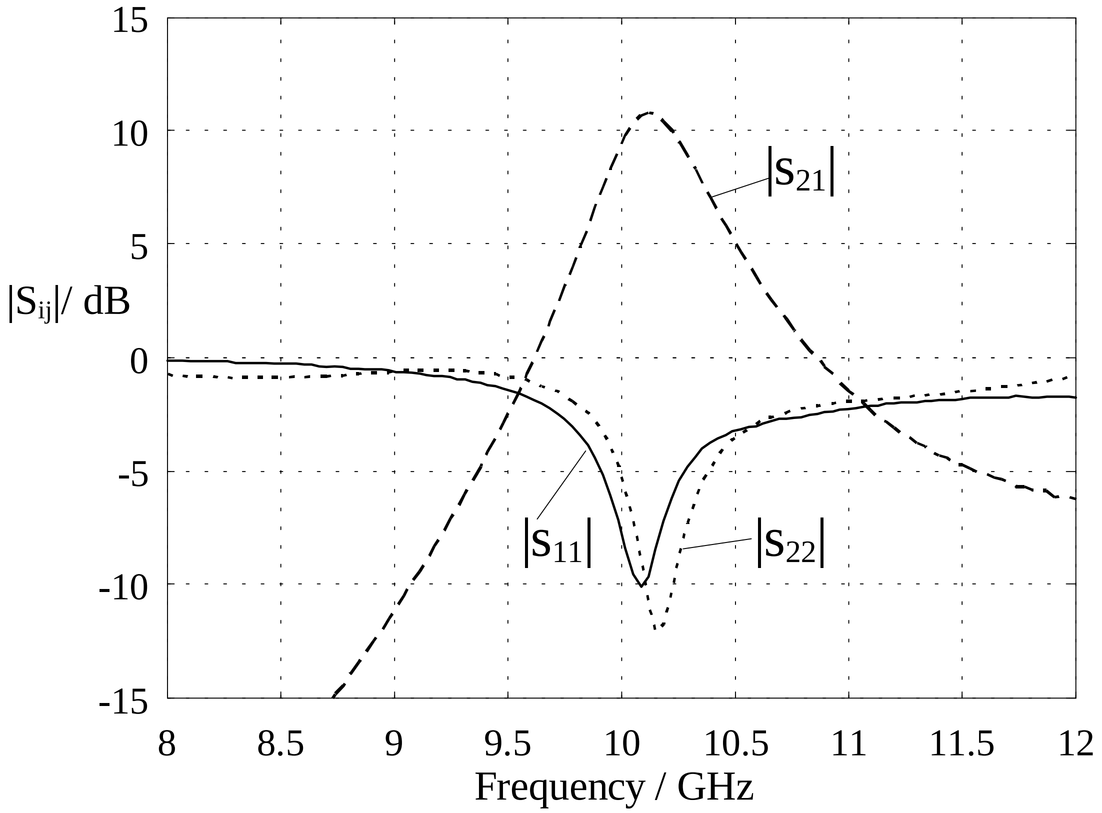

Fig. 4: Input and output return loss and gain of one stage active filter.

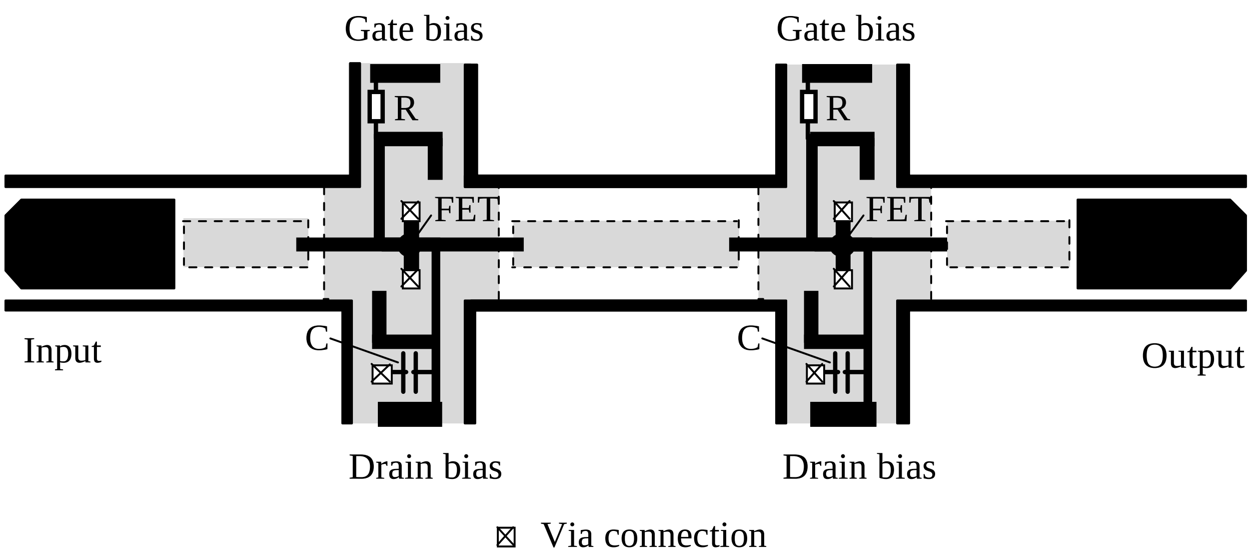

Fig. 5: Basic layout of two stage active filter circuit.

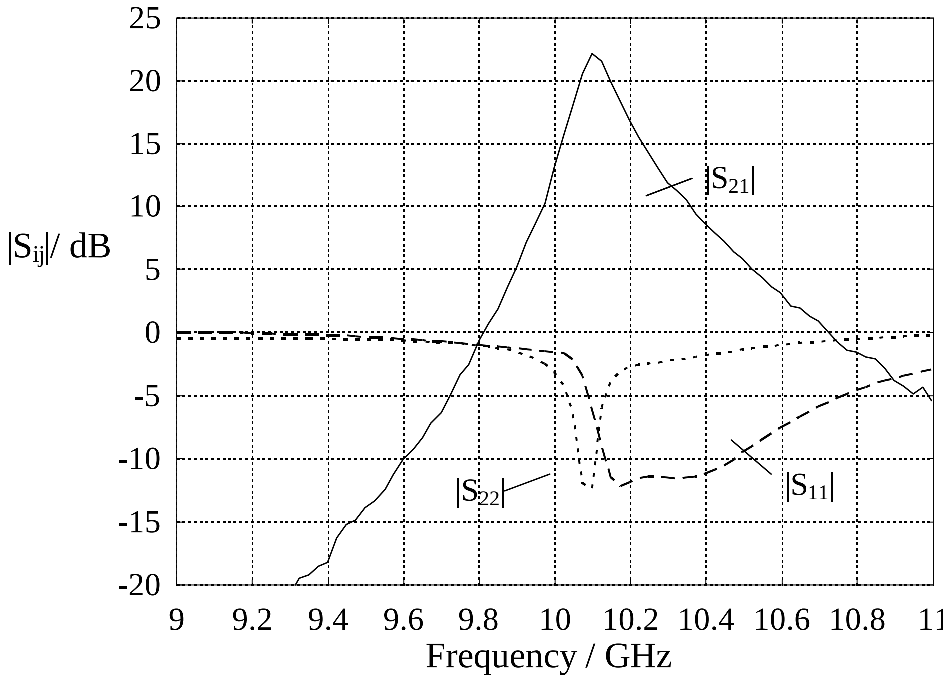

Fig. 6: Input and output return loss and gain of two stage active filter.

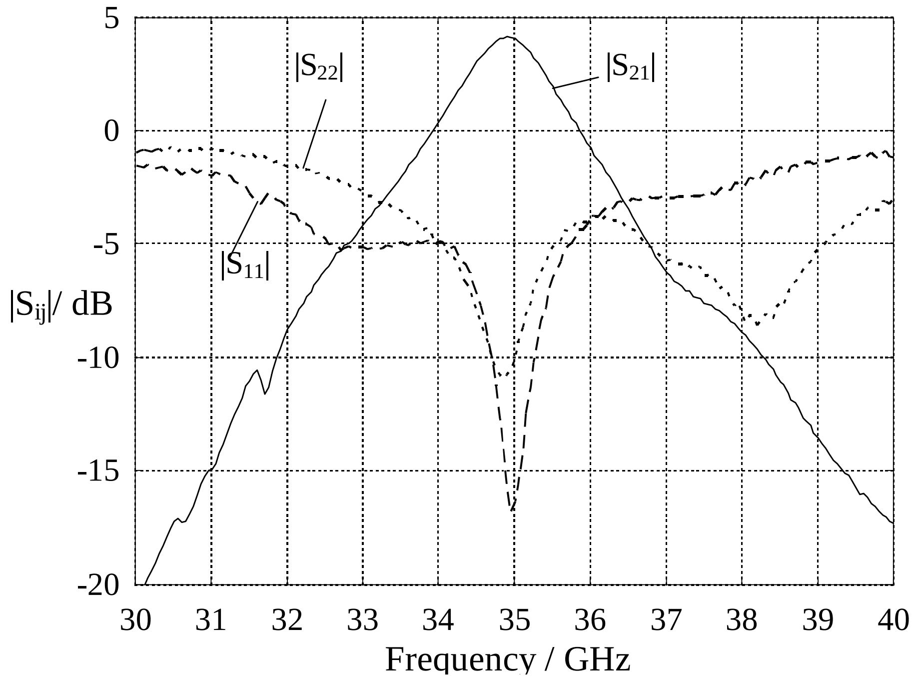

Fig. 7: Input and output return loss and gain of 35 GHz active filter.