LOW-NOISE ACTIVE RECURSIVE MMIC FILTERS

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ABSTRACT

This paper presents a novel design technique that allows the noise figure of active recursive microwave filters to be reduced to a level approaching that of low-noise amplifiers (LNA). The measured noise figure of a MESFET-based 10 GHz first order MMIC filter is 4.3 dB, less than 1 dB higher than that of the LNA included in the filter. The filter is compared to a more conventional recursive filter with respect to noise and power behavior. A fifth-order filter with a simulated noise figure of 5 dB is also presented.

INTRODUCTION

In recent years, interest in active microwave filters has increased considerably because they may solve the problem of implementing high selectivity filter designs in monolithic microwave integrated circuits (MMIC). Another positive aspect of active filters is that most of them can be made tuneable. Both these advantages can lead to increased integration and new possibilities in various microwave communication systems.

One interesting application is to use tuneable active filters to reduce the vulnerable band width in the array antennas of frequency hopping radars. In this type of system, the filter noise figure together with the power linearity, both inside and outside the passband, are of great importance.

The recursive active filter [1][2][3] is one of the promising candidates for this kind of application.

THEORY

A recursive filter of the first order is schematically described in figure 1.

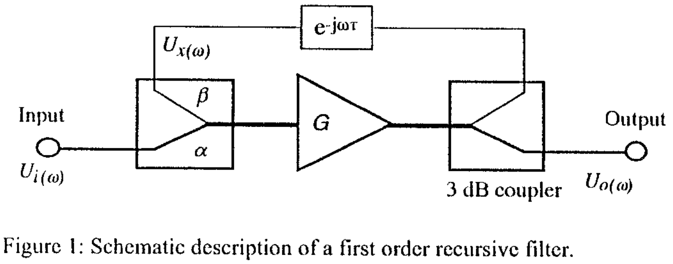

Figure 1: Schematic description of a first order recursive filter.

G is the gain of an ideal amplifier and τ is the time delay of an ideal delay element. The ideal coupler connected to the input has a voltage coupling factor of β with $|\alpha|^2+|\beta|^2=1$, and the ideal coupler connected to the output has a voltage coupling factor of $\sqrt{1/2}$. U_i, U_o, and U_x are the signal voltages at the input, output and in the feedback loop respectively. From the schematic, the filter transfer function, $H(\omega)$, can be derived as:

$$H(\omega)=\frac{U_o(\omega)}{U_i(\omega)}=\frac{\sqrt{1-|\beta|^2}}{\frac{\sqrt{2}}{G}-\beta e^{-j\omega\tau}} \quad (1)$$

β and G determine the filter's ultimate rejection, ΔH, which is given as:

$$\Delta H=\frac{|H|_{max}}{|H|_{min}}=\frac{\sqrt{2}+\beta G}{\sqrt{2}-\beta G} \quad (2)$$

To obtain a stable condition, it is necessary that the denominator in equation (1) is larger than zero, i.e. $G<\sqrt{2}/\beta$.

The noise figure for this type of filter depends mainly on how much the signal power level decreases before it enters the amplifier and on the noise figure of the amplifier itself. Hence, by decreasing the coupling factor β, a lower noise figure can be achieved. However, to maintain a high ΔH, the decrease in β must be compensated for by an increase in amplifier gain G, which will result in a higher filter amplification $|H(\omega)|_{max}$. This can be compensated for by changing the output coupling factor.

The amplifier can also be placed in the feedback loop as in [2]. This gives lower $|H(\omega)|_{max}$ and $|H(\omega)|_{min}$ which sometimes can be advantageous, but on the other hand, this configuration will result in an increased noise figure.

FILTER DESIGN

To evaluate the proposed low-noise design technique, two different types of recursive MMIC filters of the first order were designed.

Type I: With a Wilkinson 3 dB power divider at input and output [1], as shown in Figure 2.

Type II: An improved type with a 10 dB λ/4-coupler at the input and a Wilkinson power divider at the output, as shown in Figure 3.

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The filters were processed at the GEC Marconi foundry using the F20 0.5 μm MESFET process.

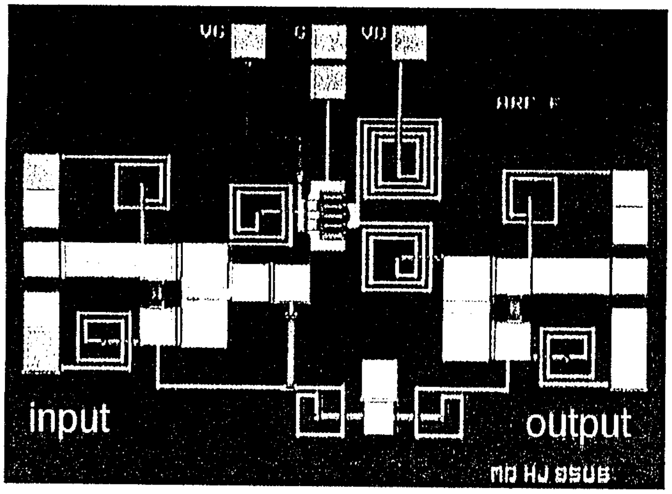

Figure 2: Photo-print of the recursive MMIC filter (type I). Chip size: 2.1 x 1.5 mm^2

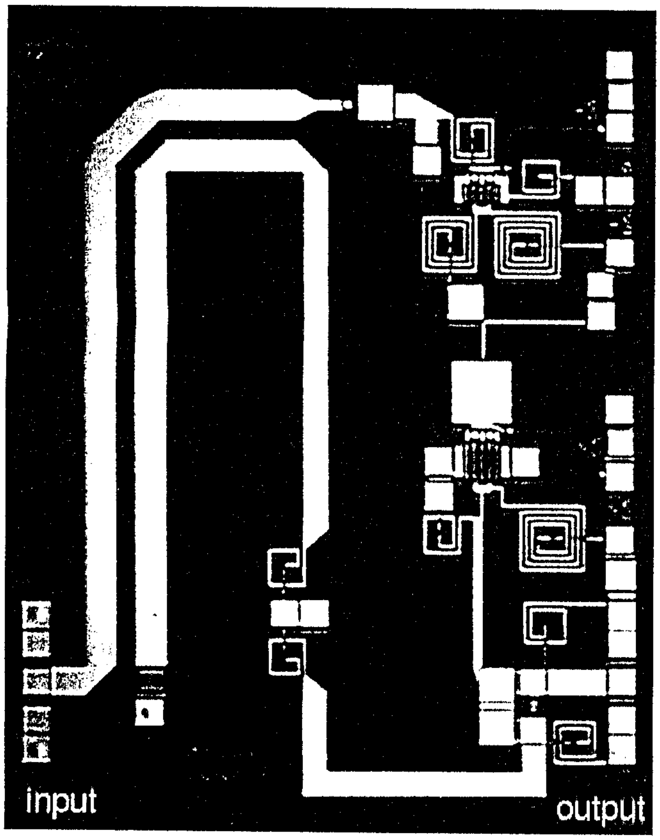

Figure 3: Photo-print of the low-noise recursive MMIC filter (type II). Chip size: 2.5 x 3.1 mm^2

The amplifiers included in the designs have the following simulated[1] gain, S_{a21}, and noise figure, NF_a:

- Filter type I: S_{a21}= 6 dB, NF_a=2.5 dB at 10 GHz
- Filter Type II: S_{a21}= 11 dB, NF_a=3.3 dB at 10 GHz

EXPERIMENTAL RESULTS

Simulations, on-wafer S-parameter and noise figure measurements on filter I and II are shown in the figures 4, 5 and 6.

The measured small signal performance of the filter type I at 10 GHz center frequency is:

- filter gain, S_{21}= 5 dB
- input matching, S_{11} = -9.5 dB
- output matching, S_{22} = -7.5 dB
- filter noise figure, NF = 5.4 dB
- 3 dB band width, B= 650 MHz (6.5%)

The measured small signal performance of the low-noise filter (type II) at 10.2 GHz center frequency is:

- filter gain, S_{21}= 16 dB
- input matching, S_{11} = -5 dB
- output matching, S_{22} = -12 dB
- filter noise figure, NF = 4.3 dB
- 3 dB band width, B= 400 MHz (4%)

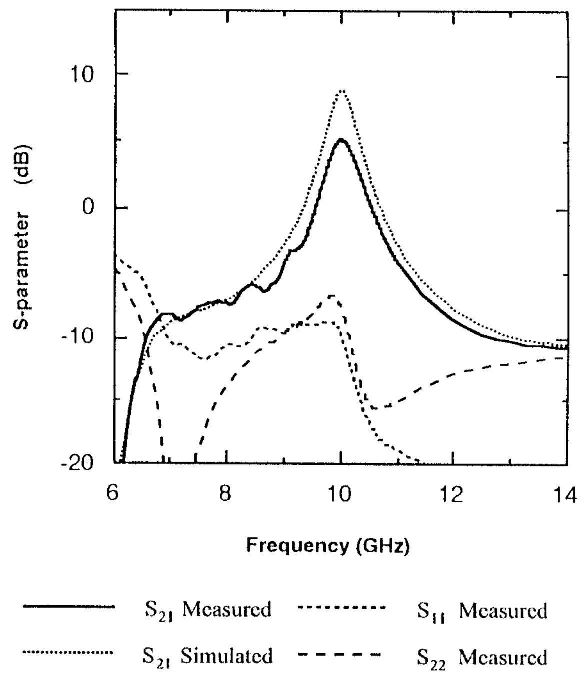

Figure 4: Simulated and measured S-parameters for filter type I.

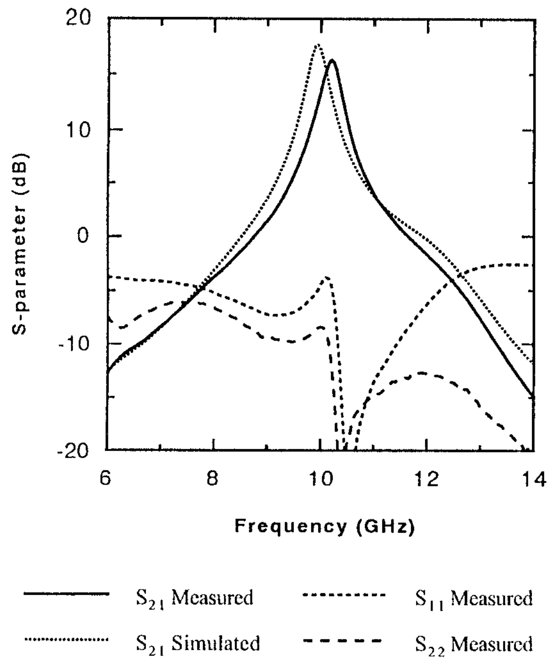

Figure 5: Simulated and measured S-parameters for filter type II (low-noise).

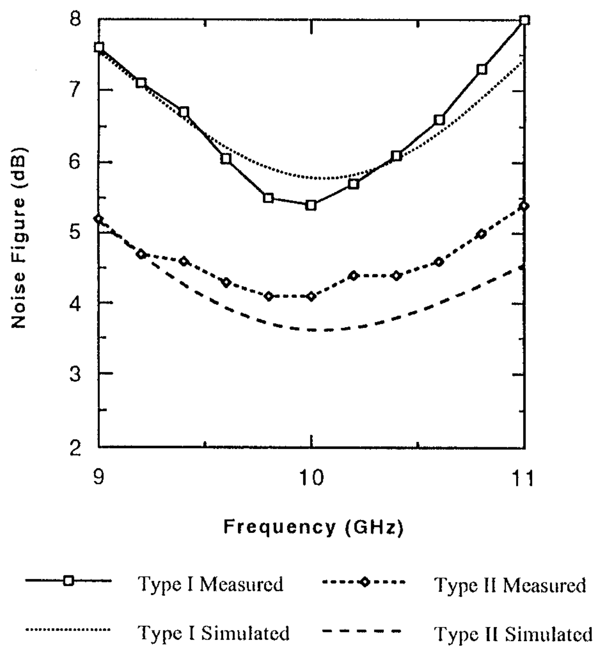

Figure 6: Simulated and measured noise figure for both filter types. Estimated measurement error: ± 0.3 dB (absolute), ± 0.1 dB (relative).

As shown in figure 6, the noise figure of the filter type II is improved by about 1 dB compared to the filter type I. The improvement was less than what was predicted by the simulation. One explanation, together with inaccurate device noise models, could be that the two filters were processed in different process runs.

For both filter types, the agreement between experimental results and simulations on S_{21} is relatively good. For the filter type II, however, measurements showed a slight shift in center frequency compared to the simulation.

Since this type of filters are based on positive feedback, stability considerations and bias sensitivity are important.

FIFTH-ORDER FILTER

A fifth-order filter at 9 GHz has been designed using a multicellular approach [3], where several first order filters, slightly separated in frequency, are connected in cascade. The first cell is a low-noise cell, similar to the Type II filter but with less gain, followed by four cells, similar to the Type I filter. Simulated S-parameters and noise figure are shown in figure 7. Also shown is S_{21} for the first filter cell.

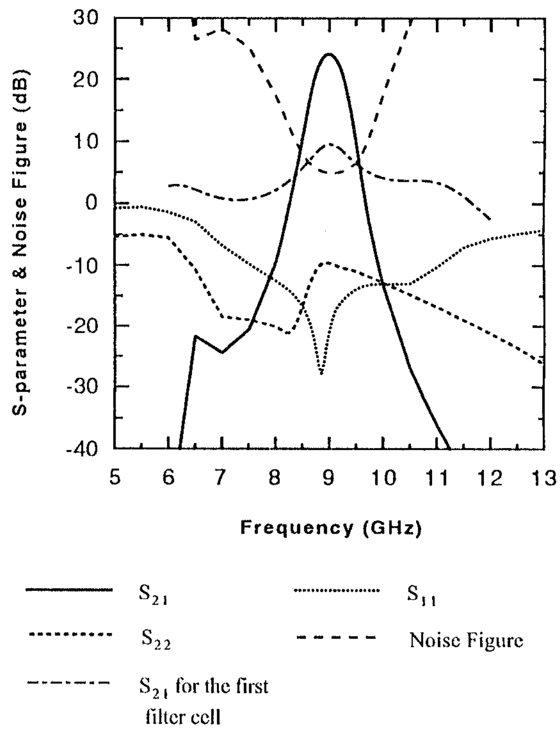

Figure 7: Simulations on a fifth-order low-noise filter and S_{21} for its first cell.

POWER BEHAVIOR

In many applications, filter performance in the presence of high-power signals both inside and outside the filter passband is of great importance. The power linearity for the filter type I is shown in figure 8 for different frequencies.

The output power compression point is 10 dBm and the input compression point was found to increase by about the same amount as the small signal rejection of the filter. (Compare figure 8 to figure 4)

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The measured intercept point (IP3) at the input of the filter type I is 13 dBm at center frequency. This agrees well with the simulations shown in figure 9.

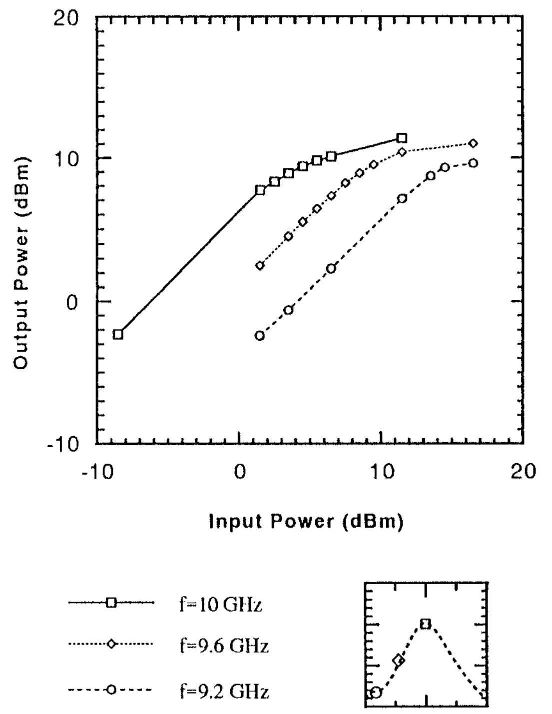

Figure 8: Measured power linearity at different frequencies for filter type I.

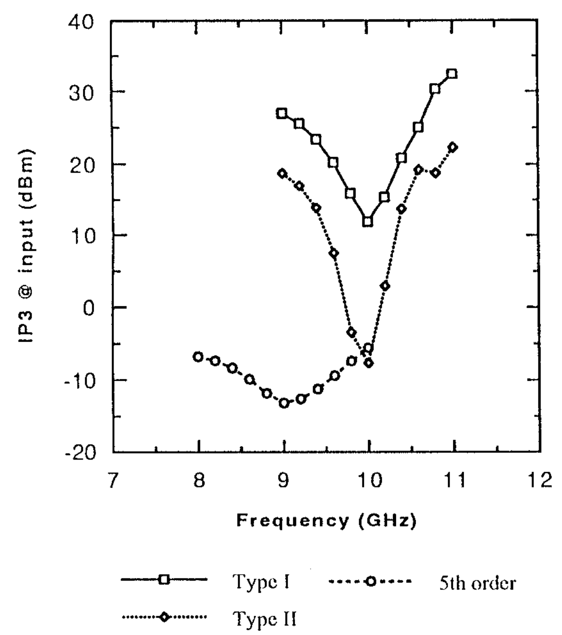

Figure 9: Simulated intercept point (IP3) for the different filter types.

Figure 9 also shows the simulated frequency behavior of IP3 for all three filters.

As seen, IP3 increases with the filter rejection for filter type I and II. This behavior is similar to the one observed for the input power compression of the filter type I (compare with figure 8).

On the other hand when figure 9 is compared to figure 7 it is seen that the simulations on the fifth-order filter show that IP3 at the band edges doesn't increase by the same amount as the filter rejection. This is due to the fact that it is the active components in the first filter cell that mainly determine the power behavior of the complete cascade, i.e. the band width of this single cell will decide the filtering properties of large signals for the complete filter.

This presents a drawback in applications where filtering of strong signals is desired. But for image rejection it still can be appropriate.

CONCLUSIONS

A new method of improving the noise performance of active microwave filters based on recursive principles has been presented. A reduced noise figure is achieved by minimizing the coupling coefficient of the coupler at the filter input. In order to evaluate the method two different types of first order filter were designed using MESFET MMIC technology.

Measurements on the low-noise filter showed a 16 dB gain and a noise figure of 4.3 dB. The noise figure is improved by about 1 dB compared to a more conventional recursive filter, with a 3 dB power combiner at input, and is less than 1 dB higher than the LNA included in the filter. The method was further applied on a fifth-order filter showing a simulated noise figure of 5 dB.

By using a standard HEMT process instead of a MESFET process the noise figure can be further improved.

Tuneability can easily be achieved in recursive filters by means of small modifications, opening up many applications in various microwave systems.

REFERENCES

[1] L. Billonnet, B. Jarry, P. Guillon, "Theoretical and experimental analyses of microwave tunable recursive active filters using power dividers", IEEE MTT-S Int. Microwave Symp. Dig., Atlanta, USA, June 1993, pp 185-188

[2] M. Delmond, L. Billonnet, B. Jarry, P. Guillon, "Application of MMIC technology and new stability concept for recursive filter design", European Microwave Conference, Bologna Italy, September 1995, pp 1123-1128.

[3] M. Delmond, L. Billonnet, B. Jarry, P. Guillon, "High-order monolithic recursive filter based upon multicellular approach", IEEE MTT-S Int. Microwave Symp. Dig., San Fransisco, USA, June 1996, pp 623-626

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