MICROWAVE TUNABLE ACTIVE FILTER DESIGN IN MMIC TECHNOLOGY USING RECURSIVE CONCEPTS

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ABSTRACT

In this article, two active filters in the X-band, using low frequency transversal and recursive principles are presented. Previously implemented in hybrid technology, those two structures are developed here using MMIC technology. In a first step, studies of the different functional blocks leading to the design of such original structures are described. Then we validate our approach with the measured results for these two filters.

INTRODUCTION

The use of recursive and transversal principles directly derived from the low frequency domain, at microwaves, have been introduced many years ago [1][2]. Application of such concepts to filtering structures intends to be used with MMIC technology. Indeed, firstly this technology allows a great integration scale for the circuits, and secondly, the compensation for the parasitic losses of the passive components with the use of active components such as GaAs FET's. Resulting from the direct identification of low frequency recursive concepts, we consider in this paper, in the microwave domain, two active filters both designed in MMIC technology : one with a fixed center frequency, and the other one tunable including a simple phase shifter structure. After some theoretical points, we present simulated and measured results for the two filters in the [7-13 GHz] band.

I -Theory

Recursive and transversal filters are governed by the following time-domain (1) and frequency domain (2) equations, where x(t) [y(t)] is the input [output] of the system :

$$y(t) = \sum_{k=0}^{N} a_k\, x(t-k\tau) - \sum_{p=1}^{P} b_p\, y(t-p\tau) \qquad (1)$$

$$H(f) = \frac{Y(f)}{X(f)} = \frac{\sum_{k=0}^{N} a_k\, e^{-2j\pi f k\tau}}{1+\sum_{p=1}^{P} b_p\, e^{-2j\pi f p\tau}} \qquad (2)$$

Implementation of the corresponding (N;P) order filter requires multiple constant delay-increments τ, amplitude weighting elements $\{a_k\}$ and $\{b_p\}$ and a mean of combining the elementary delayed signal components, which we identify at microwaves, as power dividers/ combiners. Indeed, this approach enables filter branches to be easily associated and then to be designed separately, naturally leading to the identification of the weighting parameters as microwave amplifiers. Recursive and transversal filters can simply provide tunable responses thanks to arbitrary analog phase shifter structures. As an example, we present the expression of the transfer function (3) shifted over a frequency band noted Δf :

$$H(f-\Delta f) = \frac{\sum_{k=0}^{N} a_k\, e^{-2j\pi (f-\Delta f) k\tau}}{1+\sum_{p=1}^{P} b_p\, e^{-2j\pi (f-\Delta f) p\tau}} = \frac{\sum_{k=0}^{N} a_k\, e^{-2j\pi f k\tau}\, e^{jk\phi}}{1+\sum_{p=1}^{P} b_p\, e^{-2j\pi f p\tau}\, e^{jp\phi}} \qquad (3)$$

with $\phi = 2\pi\, \Delta f\, \tau = 2\pi\, \Delta f / f_0$

The last expression clearly shows that recursive responses can be tuned by the introduction of a phase shift in each branch of the filter.

A slight increase of the return losses can be noticed compared to simulated results and can be explained by a capacitance values drift during the final step of the design process at the foundry.

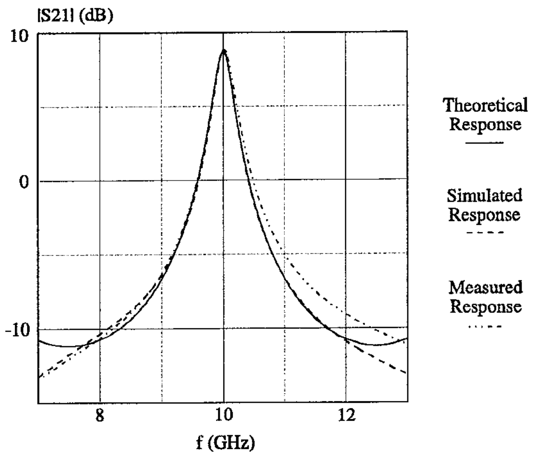

Figure 4 : Comparison between simulated and measured S_{21}

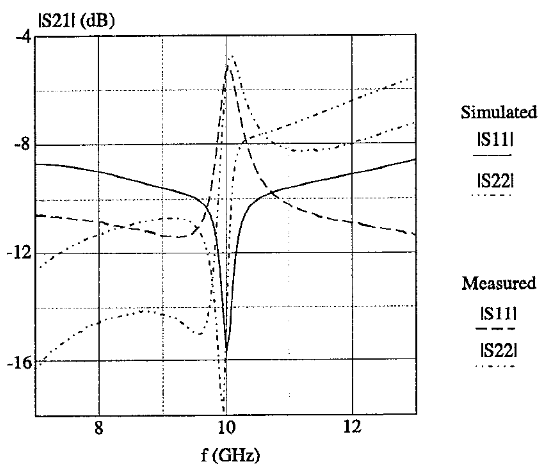

Figure 5 : Comparisons between simulated and measured S_{ii}

III - Tunable filter

The tunable filter is directly derived from the previous non tunable filter structure. As shown in figure 6, a phase shifter is now introduced into the feedback loop. The delay element τ and the phase shifter are simultaneously implemented using the lowpass T-cell where the capacitance C_l is substituted with a varactor diode to provide the phase shift within the loop.

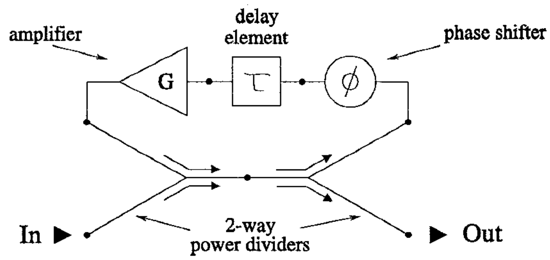

Figure 6 : Topology of the tunable recursive filter

Then, a ±20% variation of the capacitance C_l around its initial value performs a 400 MHz phase shift of the filter response around the initial center frequency. Figure 7 shows the equivalent electrical circuit including the bias elements at the end of the optimization step. Dimensions of the final MMIC chip, which layout is given in figure 8 are 2.0mmx2.0mm.

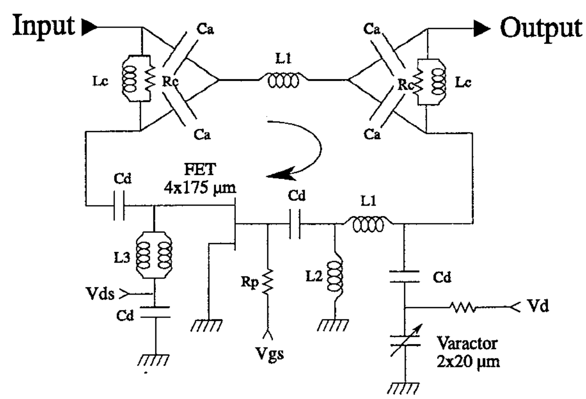

Figure 7 : Electrical schematic of the first order tunable recursive filter

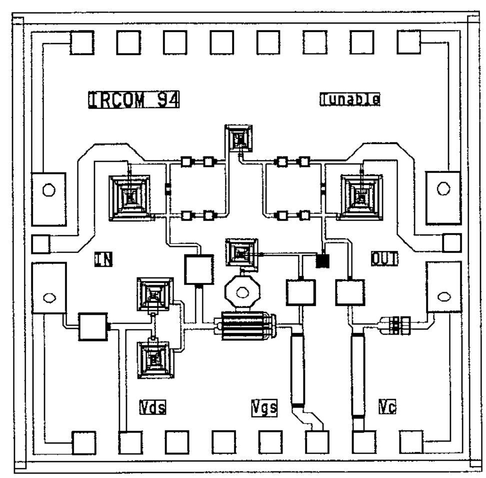

Figure 8 : Layout of the tunable recursive filter

Figure 9 illustrates the simulated effect of the capacitor variations on the filter response. The simulated phase shift is approximately 400 MHz around the center frequency as previously mentioned.

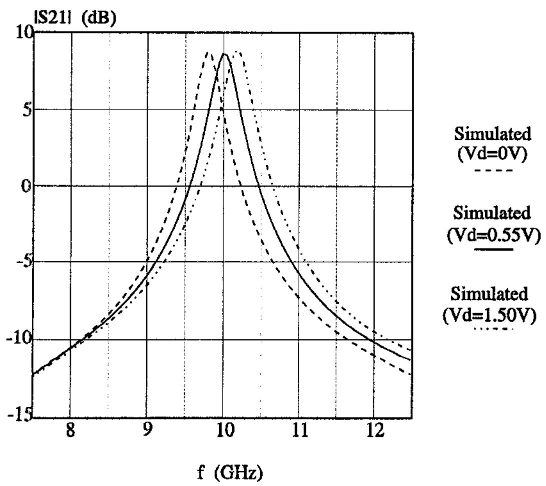

Figure 9 : Simulated S_{21}
of the tunable recursive filter
for different varactor diode bias voltages

Figure 10 shows the corresponding measured S_{21} parameter. Even if a small shift of the center frequency and of the corresponding S_{21} value can be observed between simulated and measured results, tuning performances of the filter are in perfect agreement with the expected results.

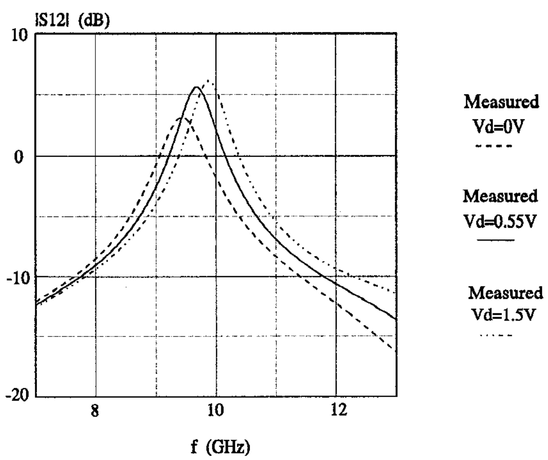

Figure 10 : Measured S_{21}
of the tunable recursive filter
for different varactor diode bias voltages

ACKNOWLEDGEMENT

In this work, the whole set of MMIC chips has been realized by Philips Microwave foundry (Limeil-Brevannes France) with the financial support of the french organism CNES.

CONCLUSION

In this paper, two active filters based on recursive principles and using monolithic technology have been developed : a first order non tunable filter and the corresponding tunable structure. Both structures implemented on a 100μm-thick GaAs substrate require less than twenty five lumped components including the bias elements. Indeed, in the tunable case, only one capacitor has been substituted with varactor diode to realise the tuning function within the structure thus validating our methodology. Excellent agreement is shown between computer-simulated and measured S-parameters. To the best of our knowledge, this is the first time that such a tunable microwave monolithic recursive filter, designed in strict accordance to low frequency concepts, is presented.

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Using this set of low frequency concepts we now focus on the design of a first-order non tunable structure and the corresponding tunable filter.

II - Non-tunable filter

Following the principles previously introduced, we now consider a first-order non tunable recursive filter. Figure 1 presents the topology of this filter. Such structure which we have already designed using hybrid technology [3] is now studied considering separately each functional block within the global structure, according to MMIC technology design constraints and rules.

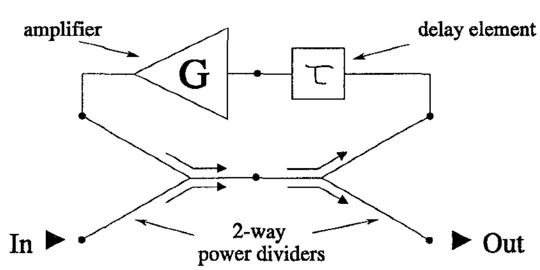

Figure 1 : Topology of the filter

The elements used in hybrid technology, such as distributed components (Lange couplers or Wilkinson dividers for the signal summation, microstrip line lengths for the delay-time elements), are substituted in MMIC technology with lumped element cells in order to minimize the size of the final device.

We first focus on power dividers/combiners structures based on the use of lumped components. For the chosen topology, each power divider/combiner requires only five lumped components : 2 inductors, 1 resistor and 2 capacitors. In a second step, a one stage pseudo-resistive configuration is chosen for the amplifier [4], including two RL series circuits for the matching of a single FET. Thanks to optimization constraints and parasitic losses of the inductors, we note in figure 2 that the resistors do not appear in the equivalent circuit of the final filter. Indeed, they are taken into account in the inductor model given by the foundry. This kind of configuration for the amplifier thus leads to reduce significantly the size of the final circuit. Moreover for stability reasons, the amplifier gain is adjusted to obtain the ratio $|S_{21}|_{max} / |S_{21}|_{min} = 10$ (20dB) in the [7.5-12.5 GHz] frequency range [5]. Finally, the delay-time element τ is built with a lowpass T-cell [6], thus reducing again the dimensions of the resulting circuit.

Our approach now consists in associating all the designed blocks to obtain the final circuit shown in figure 2. Note in this figure that the bias components have also been included and chosen to emphasize the dimensions of the global structure. Consequently, the gate bias voltage is provided through a high value resistance, and the drain bias voltage through the L_3 inductor of the amplifier block. Classical high value capacitors have also been introduced to complete bias circuitry.

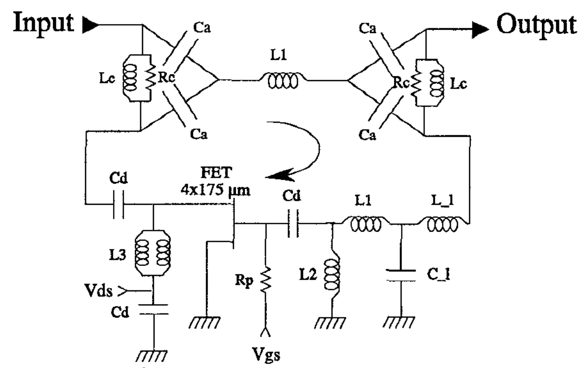

Figure 2 : Electrical schematic of the first-order non tunable recursive filter

Figure 3 shows the layout of the non tunable recursive filter finally designed, following the MMIC design process rules. The circuit is implemented on an 100µm-thick GaAs substrate, and dimensions of the MMIC chip are 2.0mmx1.5mm.

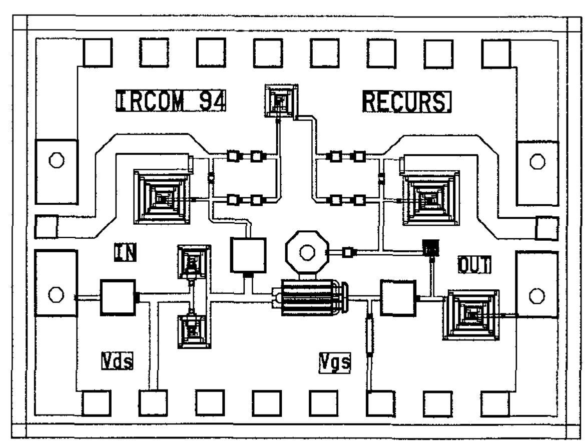

Figure 3 : Layout of the non tunable filter

For the bias voltages Vds=3V and Vgs=-1V, perfect agreement between simulated and measured results are shown in figures 4 and 5.