Improvement of microwave planar active filters with MMIC technology

L. Billonnet - A. Brucher - C. Cenac - M. Delmond - Ph. Meunier - B. Jarry - P. Guillon

I.R.C.O.M - Université de Limoges
123, Avenue Albert Thomas - 87060 Limoges Cedex - FRANCE

S.E. Sussman-Fort

Department of Electrical Engineering
State University of New York at Stony Brook - Stony Brook, New York 11794-2350 - USA

Abstract

In this paper, new ranges of GaAs MMIC circuit applications at microwaves are presented with the development of original planar active filters in this technology. The first step is to improve intrinsic performances of planar microstrip resonators with the help of MMIC amplifier or negative resistance chips [1]. Finally, a novel active recursive structure is also demonstrated as an MMIC.

Introduction

GaAs MMIC technology has already been employed to great advantage in the design of various active circuits [2], such as matching networks, multipliers, circulators and phase shifters. Because of the low Q of the inductors and the capacitors in this technology (Q's are usually lower than 25), MMIC filters structures employ active components such as GaAs FET's to compensate for the parasitics of both the passive components and the GaAs FET's themselves. MMIC design approaches can then be divided into five categories :

- ❶ the use of negative resistance to cancel passive element intrinsic losses in narrow band resonators.
- ❷ the use of amplifier in cascaded or feedback configurations to generally compensate for losses
- ❸ the cascade of biquadratic sections for high-order filter design
- ❹ the substitution of spiral inductances with active inductances (this can be done by using microwave gyrators, which themselves can be derived from NIC's previously mentioned in ❶ [3])
- ❺ finally, the use of transversal and recursive principles derived from low frequency domain [4].

In this paper, methods 1,2 and 5 are developed with the design of a one-FET negative resistance chip in the L-band (method 1), a 3-pole planar resonator bandpass filter using an MMIC active loop in the X-band (method 2) and a first-order tunable recursive filter chip in the [7.5-12.5 GHz] range (method 5). Note that the MMIC designs described here for methods 1 and 2 do not concern the resonators themselves but only the active parts of the filters.

Improvement of planar resonators performances

A. Negative resistance based planar filter

This first part focuses on MMIC negative resistance employed to compensate for intrinsic losses of planar microstrip resonators structures. Both simulated results and layout are presented for a MMIC chip implemented on a 100µm-thick GaAs substrate (ε_r=12.9). This device is based upon the serial feedback of a single FET [5]. Corresponding circuit is shown in Fig. 1. Simulated results for Re(Z_e) are given in Fig. 2.

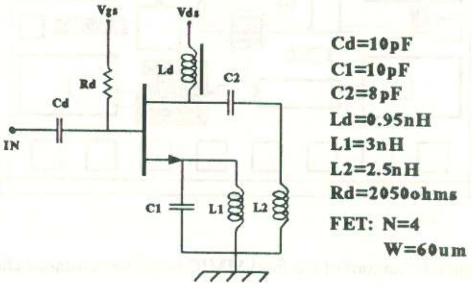

Figure 1 : Schematic of the 1-FET based negative resistance

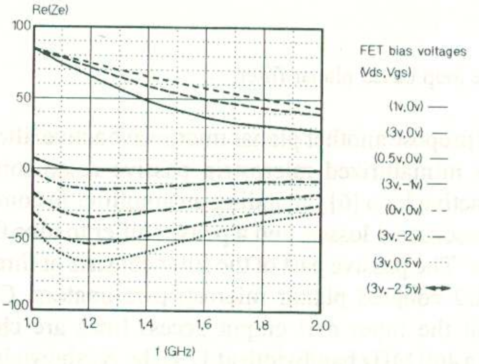

Figure 2 : Simulated real part of Z_e

These results can be clearly compared with measurements presented in Fig. 3 where a shift of the input negative resistance value can be observed due to a voltage drop into the parasitic resistance of the bias spiral inductance L_d.

Note furthermore that a non-negligible imaginary part of the input impedance will have to be taken into account in the planar resonator design. Dimensions of the final circuit, which layout is shown in Fig. 4, are 1.5mm x 1.0mm.

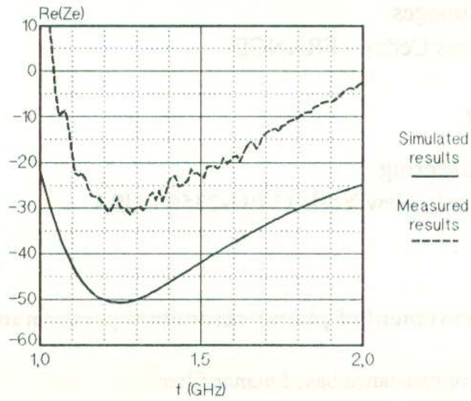

Figure 3 : Comparison between measured and simulated real part of Z_e (V_{ds}=3V; V_{gs}=0V)

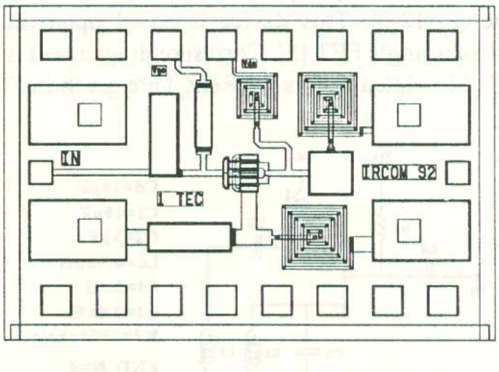

Figure 4 : Layout of the final MMIC negative resistance chip

The next step in our work is now to achieve a planar tunable active filter in the L-band by associating our negative resistance chip to a planar microstrip resonator structure.

B. Active loop based planar filter

We now propose another planar microwave active filter which employs miniaturized microstrip passive resonators and a MMIC active loop [6], including an amplifier to compensate for the resonators losses, and a phase shifter to tune the filter response. The passive part of the filter consists of three open-ended λ/2 coupled planar microstrip resonators. Coupling values at the input and output access lines are chosen to achieve a 400 MHz bandwidth at 12 GHz. As shown in Fig. 5, compensation of losses is performed on the central resonator of the filter. MMIC chip used is a matched dual-gate FET amplifier providing a 0 to 5 dB variable gain at 12 GHz. Unitary bandpass T-cells are cascaded at the input and output ports of the amplifier. Each cell uses the variable C_{gs} capacitance of a single FET for the tuning of the active device, thus performing a ±30° phase shift of the initial phase state of the global MMIC chip at center frequency. Simulated results for the active filter are presented in Fig. 6 for amplifier gain values of 0 dB and 5 dB.

The global structure has been implemented on a 0.127mm-thick Duroïd substrate (ε_r=2.33) and we present measured results in figure 11. A gain of 1dB at center frequency illustrates the perfect compensation of the resonator losses. Corresponding measured results are presented in Fig. 7.

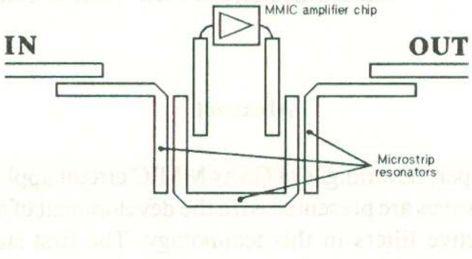

Figure 5 : Circuit of the 3-pole planar filter

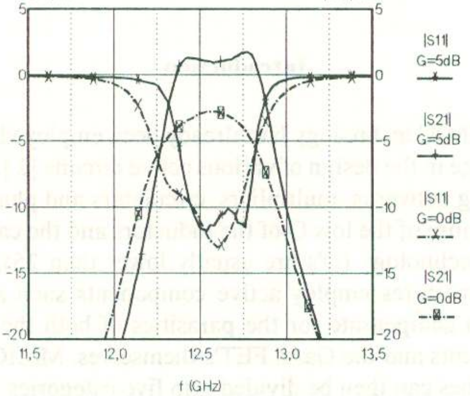

Figure 6 : Simulated results of the 3-pole filter

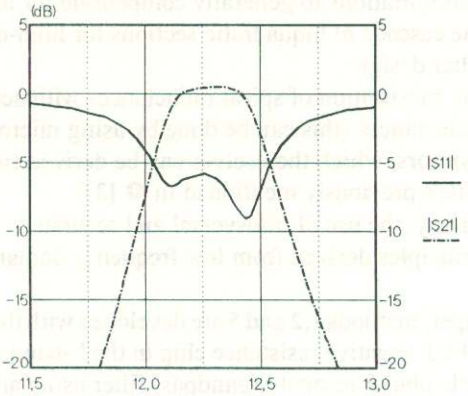

Figure 7 : Measured results of the 3-pole filter

Recursive filter design in MMIC technology

In this paragraph, we analyse the advantages of MMIC technology versus hybrid technology with the design of an original first-order filter structure of the recursive type.

Preserving low frequency principles [4], implementation of the structure in Fig. 8, at microwaves, requires one delay component τ, an amplifier G and two power dividers/combiners for the elementary signals summations within the global structure.

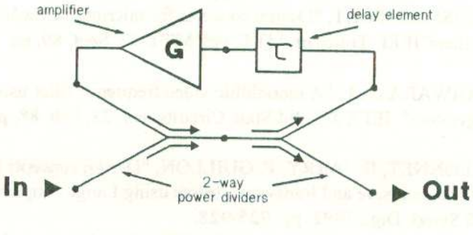

Figure 8 : General schematic of the recursive filter

In hybrid technology, the amplifier can be easily built in a balanced configuration, while the high integration scale in MMIC technology allows the use of cascaded resistive or feedback stages to improve the filter yield and performances. The delay element τ, classically made up of a microstrip line length in hybrid technology, is built with T or Pi highpass or lowpass MMIC lumped cells, thus reducing the resulting circuit dimensions. In the same way, classical planar power dividers such as Lange or Wilkinson couplers are substituted with lumped component structures, again emphasizing size.

One other disadvantage of hybrid technology is the non-reproducibility of parasitic connections, bond-wire or via-holes parasitic effects. In MMIC design, circuit performances are assumed to be reproducible while lumped component values are maintained compatible with the inherent limits of a given foundry process to ensure component models validity, and to minimize the parasitic couplings between these components.

Then, according to [4], the filter has been synthesized and optimized to obtain :

$$|S_{21}|_{MAX} / |S_{21}|_{MIN} = 10 \quad (20\text{dB})$$

where : $|S_{21}|_{MAX} = |S_{21}(f_c)|$
$|S_{21}|_{MIN} = |S_{21}(f_c \pm f_0/2)|$

with : f_c=10 GHz the center frequency
f_0=5 GHz = 12.5 GHz - 7.5 GHz
the width of $S_{21}(f)$ pattern

$$\Downarrow$$

$$\tau = 1/f_0 = 0.2\text{ns} \;;\; f_c = 2\, f_0$$

$$|S_{21}|_{MAX} = 8.8\text{dB} \;;\; |S_{21}|_{MIN} = -11.2\text{dB}$$

Following these principles, Fig. 9 and Fig. 10 respectively show the simulated S_{21} and S_{11} , S_{22} parameters for the MMIC recursive filter according to the Philips Microwave D07a process design rules, and where all the parasitics have been taken into account in the [7.5-12.5 GHz] band. A one stage resistive configuration [7] has been chosen for the amplifier, including two R-L series circuits, an inductor and a capacitor for the matching of a single FET. Fig. 11 present the layout of the final MMIC chip which size is 2.0mm x 1.5mm.

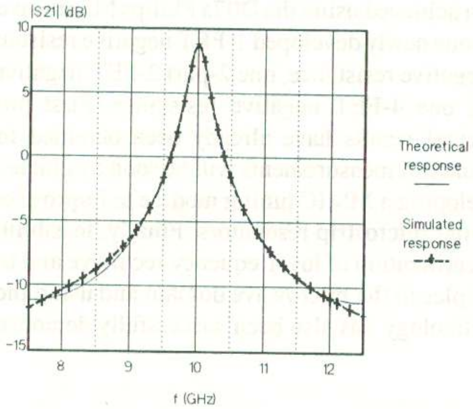

Figure 9 : Simulated S_{21} of the recursive filter

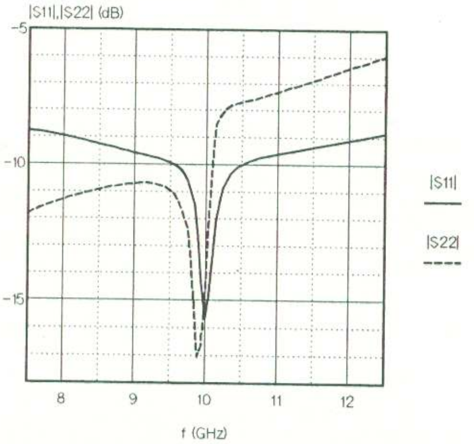

Figure 10 : Simulated S_{11} and S_{22} parameters of the recursive filter

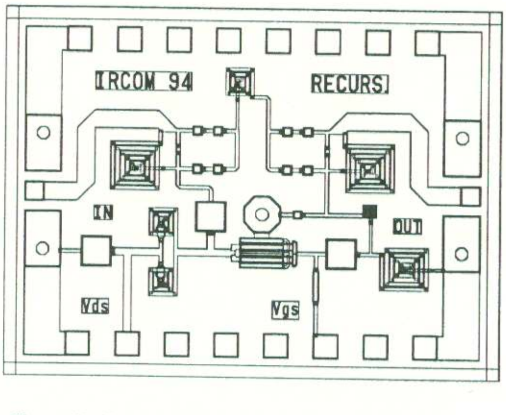

Figure 11 : Layout of the final MMIC recursive filter chip

Conclusion

In this paper, recent domains of MMIC technology applications for planar active filters have been briefly described. Experimental results for a X-band coupled microstrip resonator active filter using a MMIC variable gain and phase loop have been presented. The other solution proposed is to compensate for losses and to tune passive filters with variable negative resistance and reactance monolithic circuits. With this methodology and in conjunction with the 1-FET negative resistance chip presented in this paper, four others circuits have been achieved using the D07a Philips Microwave design process : one newly developed 1-FET negative resistance, one 2-FET negative resistance, one 2-port 2-FET negative resistance and one 4-FET negative resistance. First promising experimental results have already been obtained for these circuits and full measurements will be soon available. We are now developing a MMIC tuning module to improve compensated planar microstrip resonators. Finally, feasibility of the direct identification of low frequency recursive and transversal principles in the microwave domain and using the monolithic technology has also been successfully demonstrated.

Acknowledgements

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 national organism CNES. The active loop based planar filter has been realized with a Thomson-TCS (Orsay France) MMIC amplifier chip.

References

[1] R.S. PENGELLY et al., "Monolithic broadband GaAs FET amplifiers", Electronics letters, vol. 12, May 76, pp. 251-252

[2] S.E. SUSSMAN-FORT, "Design concepts for microwave GaAs FET active filters"IEEE Trans. on MTT, vol. MTT-37, Sept. 89, pp. 1418-1424.

[3] H. HAGIWARA et al., "A monolithic video frequency filter using NIC-based gyrators", IEEE J. Solid-State Circuits, vol. 23, Feb. 88, pp. 175-182.

[4] L. BILLONNET, B. JARRY, P. GUILLON, "Design concepts for microwave recursive and transversal filters using Lange couplers", IEEE MTT-S Symp. Dig., 1992, pp. 925-928.

[5] R. SOARES, J. GRAFFEUIL, J. OBREGON, "Applications of GaAs MESFET's", Artech House

[6] X.H. JIAO, P. GUILLON, B. JARRY and B. MADRANGEAS, "Microwave frequency agile active filters for MIC and MMIC applications", IEEE MTT-S Symp. Dig., 1990, pp. 503-506.

[7] P.K. IKÄLÄINEN, "An RLC matching network and applications in 1-20 GHz monolithic amplifier", IEEE MTT-S Symp. Dig., 1989, pp. 1115-1118.