HIGHLY SELECTIVE NOVEL MMIC MICROWAVE ACTIVE RECURSIVE FILTER

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Abstract— **This paper describes a new original microwave filter design using low frequency recursive concepts and fully integrable in MMIC technology. Our approach offers a convenient way to realize miniature filter circuits for narrowband filtering applications. A 7 GHz fixed center frequency MMIC active bandpass filter with two percent bandwidth is realized and experimental results are presented which validate the accuracy of the novel design methodology.**

I. INTRODUCTION

The development of monolithic technology had recently introduced new concepts for microwave filtering and a number of active filtering techniques have been proposed over the years [1] [2] [3] [4]. More recently, interest has been focused on transversal and recursive concepts, and are presented in the litterature [5] [6] [7] [8]. They tend to be less constrained by time delay considerations associated with microwave transistors. Such filters have been already designed in MMIC technology using two power combiners/dividers based on the use of lumped elements [8]. For this structure, each block is assumed to be $50\ \Omega$ matched and the designed transfer function is the power gain S_{21} of the circuit. The study reported in this paper focuses on the design of a voltage complex transfer function, in MMIC technology, using a direct transposition of recursive filters low frequency concepts to the microwave range. It tends to eliminate unwidely elements used in [8] such as power combiners/dividers, thus reducing the size of the final device. Moreover, voltage matching can be more easily obtained over wide frequency bands than power matching especially for input and output signals combining. Therefore, selective recursive filter response can be achieved.

II. THEORY

The signal flow diagram of figure 1 schematically depicts the following time-domain (1) and frequency-domain (2) equations of a conventional first-order recursive filter

$$y(t) = a_0.x(t) + b_1.y(t-\tau) \quad (1)$$

$$H(f) = \frac{Y(f)}{X(f)} = \frac{a_0}{1 + b_1.e^{-j2\pi f\tau}} \quad (2)$$

where x(t) [y(t)] is the input [output] signal of the system. The coefficients a_0, b_1 represent the amplitude weighting factors and τ refers to a constant time delay introduced in the feedback branch of the filter.

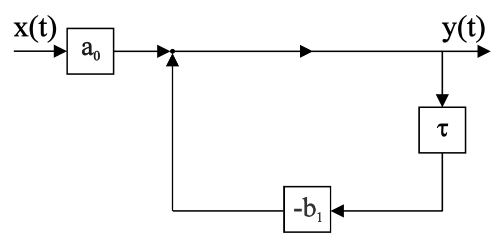

Fig. 1. Signal flowgraph of a first-order recursive filter

Physically, the weighting parameters are identified to microwave amplifiers and τ is introduced by lumped or distributed elements [9]. The recursive filter of figure 1 is identified to the idealized series-shunt feedback model shown in figure 2. $\mu(j\omega)$ represents the transfer function of the unilateral forward active path, while $\beta(j\omega)$ represents the transfer function of the passive path. The ideal adder means that there is no loading effects at the input of the active path. Under these assumptions, it can be easily shown that the overall transfer function is given by

$$A(j\omega) = \frac{\mu(j\omega)}{1 - \mu(j\omega).\beta(j\omega)} \tag{3}$$

The equation (3) can be identified to the transfer function (2) of a first-order recursive filter if $\mu(j\omega) = 1$ and $\beta(j\omega) = -b_1.e^{-j\omega\tau}$. In practical, the feedback network causes loading effects at the input and the output of the basic forward amplifier. Even in this case, the basic recursive properties of the feedback loop are preserved.

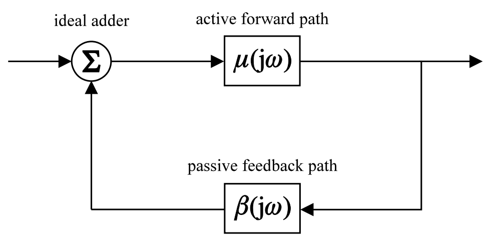

Fig. 2. Ideal block scheme of a feedback loop

The design procedure begins by first determining the circuit that realizes the voltage summation function (Σ) at the input of the feedback. Then, the passive feedback device must provide the necessary time delay imposed by the recursive process. Finally, an unilateral microwave active device must be employed in the forward branch in order to allow the feedback scheme to operate as intended. Figure 3 shows the general form of the recursive filter.

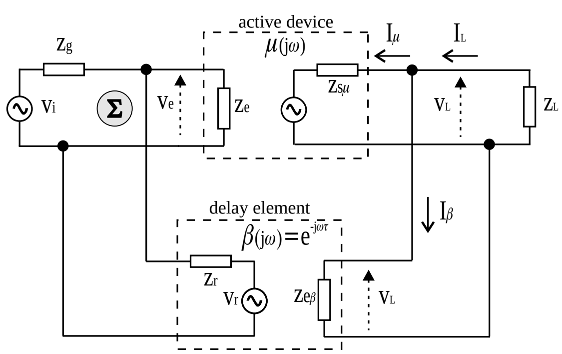

Fig. 3. General scheme of the recursive filter

Summation of voltages V_i and V_r at the input of the active device gives

$$V_e = \alpha_1.V_i + \alpha_2.V_r \tag{4}$$

with

$$\alpha_1 = \frac{(Z_e//Z_r)}{(Z_e//Z_r) + Zg} \tag{5}$$

$$\alpha_2 = \frac{(Z_e//Z_g)}{(Z_e//Z_g) + Zr} \tag{6}$$

and

$$V_r = \beta.V_L = e^{-j\omega\tau}.V_L \tag{7}$$

Summation of currents I_μ and I_β at the output gives

$$I_L = I_\mu + I_\beta \tag{8}$$

Then we have

$$\frac{V_L}{V_e} = \frac{\mu}{Z_{s\mu}.(\frac{1}{Z_L} + \frac{1}{Z_{s\mu}} + \frac{1}{Z_{e\beta}})} = \mu.\frac{Y_{s\mu}}{Y_i} \tag{9}$$

with

$$Y_i = Y_L + Y_{s\mu} + Y_{e\beta} \tag{10}$$

From the different equations (4), (7), and (9), we thus determine the overall voltage gain of the circuit

$$G_v = \frac{V_L}{V_i} = \frac{(\alpha_1.\frac{Y_{s\mu}}{Y_i}).\mu}{1 - (\alpha_2.\frac{Y_{s\mu}}{Y_i}).\mu.\beta} \tag{11}$$

The recursive transfer function (11) may be significantly simplified if conditions below are satisfied

$$|Z_e| \gg |Z_r|,\ |Z_{e\beta}| \gg |Z_{s\mu}| \tag{12}$$

$$|Z_g| \gg |Z_r| \tag{13}$$

$$|Z_L| \gg |Z_{s\mu}| \tag{14}$$

Verifying conditions above, parameters of the circuit become

$$\alpha_1 = \frac{Z_r}{Z_g},\ \alpha_2 = 1,\ Y_i = Y_{s\mu} \tag{15}$$

and the filter response may be written as

$$G_v = (\frac{Z_r}{Z_g})(\frac{\mu}{1 - \mu.e^{-jw\tau}}) \tag{16}$$

For stability reasons, the active element gain μ must be adjusted to obtain $|\mu| < 1$.

The factor $|\frac{Z_r}{Z_g}| \ll 1$ introduces supplementary insertion losses and can be compensated by a cascade association of a microwave amplifier stage with a voltage gain higher than $|\frac{Z_r}{Z_g}|$. The position and the nature of the amplifier stage depends either on its input or output impedance meeting either assumption (13) or (14).

III. Physical implementation and circuit measurements

The given recursive filter concept may be translated into an actual physical design in many number of ways. Of particular interest in the present context are simple filter solutions that fit the block diagram format presented in figure 3. First the active device placed in the feedforward branch is assumed to be a commun drain MESFET stage T2. Then, the delay element is built with lumped high-pass T-cell and low-pass cell providing the required time delay τ. Note that both passive filter segments and the active device are integral parts of the feedback loop. Their intrinsic time delays assume constructive roles in the recursive process. The center frequency of the filter is thus fixed by the total delay of the feedback loop. Unfortunately each block is not matched to $50\ \Omega$, this obviously leads to a strongly mismatched circuit even within the passband. To overcome this problem and for convenience, we then add a commun gate MESFET stage T1 at the input and a commun drain MESFET stage T3 at the output of the feedback loop. The main goal is to provide simultaneously active matching [10] [11] and to satisfy both conditions (13) and (14), thus reducing again the resulting circuit dimensions. The power gain S_{21} of the matched filter is then proportional to the voltage gain formula (16). Another attracting outstanding feature is the capability of the input stage T1 to produce gain, high output impedance and the almost low noise figure of the overall circuit. Associating all the designed blocks, we finally obtain the circuit given in figure 4, including bias circuitry capacitors.

The recursive bandpass filter is implemented on a 100 μm-thick GaAs substrate and dimensions of the MMIC chip are $1mm$x$1.5mm$. Figure 5 shows the layout of the MMIC chip. Note in this figure that the low values inductances L_h and L_b are substitued with high impedance microstrip lines thus reducing significantly the final circuit size. The circuit includes three transistors T1, T2 and T3 of 0.2 μm gate length, respectively biased through their gate and drain accesses, with a total dc power consumption of 30 mw. Figure 6 illustrates the comparison between measured and simulated responses of the first-order recursive filter. As it can be seen the measured circuit is operating at 7 GHz with 5.5 dB gain at the central frequency and 140 MHz 3 dB-bandwidth. The out of band rejection is better than 20 dB 2 GHz from either passband edge. The curves clearly demonstrate the perfect agreement between measured and simulated transmission and output $VSWR$. However the measured input return loss differs from the expected result due to the inaccuracy of the commun gate transistor model used for the simulation step.

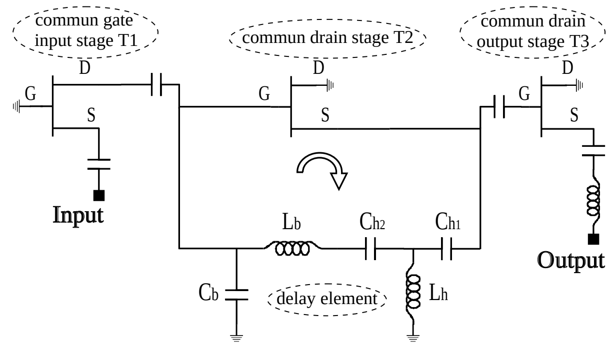

Fig. 4. Electrical circuit of the microwave recursive band-pass filter

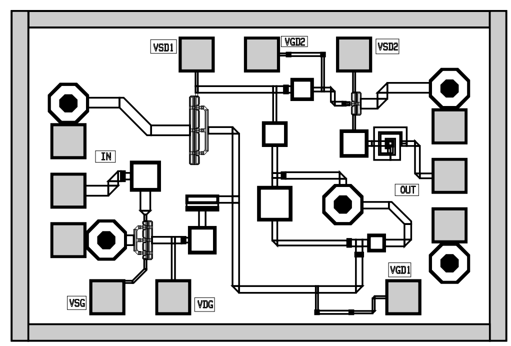

Fig. 5. Layout of the MMIC chip ($1mm$x$1.5mm$)

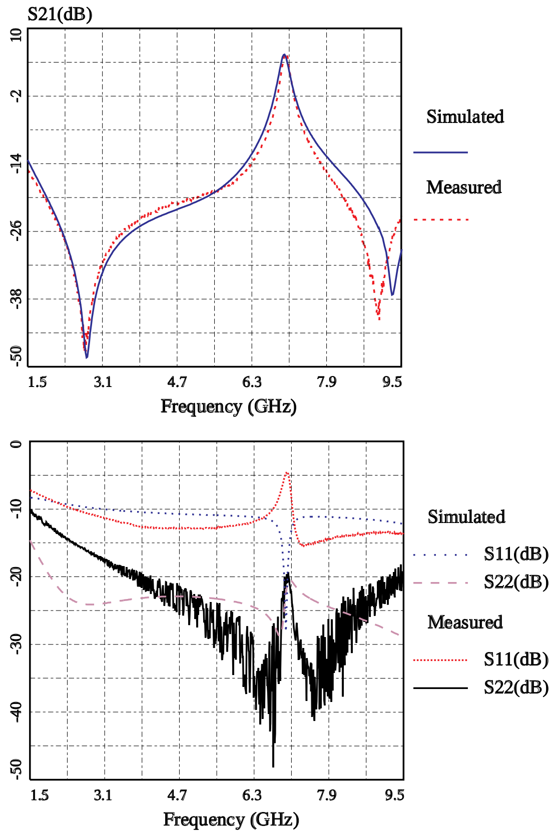

Fig. 6. Experimental and simulated filter performances

The measured 1 dB compression point occurs at an input power of -15 dBm and the simulated noise figure is 5.5 dB at the central frequency. The active filter could be designed to operate at higher power levels by optimizing its input and output stages.

IV. Conclusion

The use of both passive and active devices for recursive filtering appears to be suitable to achieve highly selective response characteristics. The objective is to keep working frequencies principally controlled by passive elements, while active circuits compensate for the effect of passive elements losses. An active filter using recursive principles is designed and fabricated using a monolithic process. Active matching devices appear to be a mondatory solution to achieve input and output match over a wide frequency range, compactness and high reproducibility. Besides, this approach is less sensitive to variations in components values of the filter compared to that a passively matched solution. The excellent agreement between computer-simulated and measured S-parameters demonstrates the versatility and practicability of the novel approach. The miniature MMIC chip size and the highly selective filter response make our active recursive filter competitive with other development of active filter structures in monolithic technology. Moreover, this technique can contribute significantly to the further miniaturisation and integration of advanced microwave subsystems.

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