HIGH-ORDER MONOLITHIC ACTIVE RECURSIVE FILTER BASED UPON MULTICELLULAR APPROACH

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ABSTRACT

This article deals with a multicellular approach for high-order monolithic active recursive filter design. The transfer function results from a cascade association of first-order recursive cells, each characterizing a single pole. We illustrate our approach with simulated results for a higher-order bandpass filter in the X-band and finally present measurements for the corresponding structures resulting from the cascade association of first-order recursive tunable filters, in MMIC technology.

INTRODUCTION

With the increase of mobile communications, size of devices are getting smaller and smaller. In that way, filters must be miniaturized in order to be integrated into MMIC modules with other microwaves functions such as amplifiers, mixers or oscillators.

Advantages of GaAs MMIC active filters are small size, reliability, reproducibility and an easy integration with other microwave functions. Nevertheless, with the use of active elements, new considerations must be taken into account, such as electrical stability, noise figure, non linearity and the need for DC power.

Because conventional passive filters consume too much space in distributed configuration and provide too many losses in lumped configuration, active filters appear as a promising solution. These last ten years, the most important techniques reported in the literature about microwave active filters use actively coupled passive resonators, negative resistance elements and transversal and recursive filters using FETs [1][2].

Our work concerns transversal and recursive filters above mentioned. We focus on a new recursive filter design approach based on a cascade association of first-order recursive cells, each working as a single pole, in strict accordance to low frequency recursive and transversal principles. We then compare this new approach with the classical one, and present simulated and measured results for a high-order bandpass recursive filter in MMIC technology.

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I-Design approach

Expression (1) shows the general transfer function H(z) of a recursive filter in the Z-notation. H(z) can be also written as (2).

$$H(z) = \frac{\sum_{k=0}^{N} a_k Z^{-k}}{1+\sum_{p=1}^{P} b_p Z^{-p}} \qquad (1)$$

$$H(z) = a_0 \frac{(1-Z_0 Z^{-1})(1-Z_1 Z^{-1}).....(1-Z_N Z^{-1})}{(1-\rho_0 Z^{-1})(1-\rho_1 Z^{-1}).....(1-\rho_P Z^{-1})}$$

(2)

In this last expression H(z) appears as a set of zeros {Zi} and more importantly of poles {ρi}, which location in the complex plan entirely defines the corresponding filter and its stability.

In our approach, we extend the classical recursive filter concepts by considering H(z) as a set of unitary functions. Each of these corresponds to a first-order function and is characterized by its own delay-time parameter τ_i. As an example, we consider a

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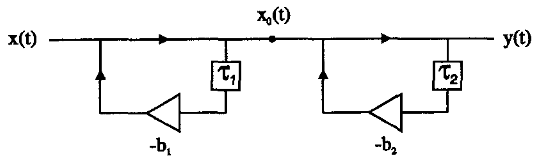
cascade recursive filter as the cascade association of two unitary cells, as shown in figure 1.

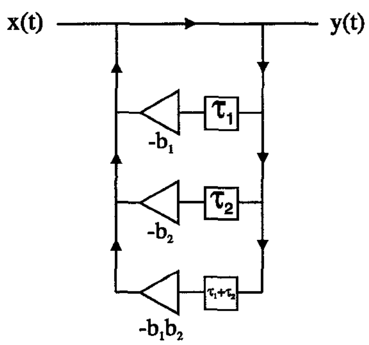


- figure 1 -
2-cell cascade recursive filter

For such a structure, the transfer function is given by (3).

$$H(f)=\frac{1}{1+b_1e^{-2j\pi f\tau_1}+b_2e^{-2j\pi f\tau_2}+b_1b_2e^{-2j\pi f(\tau_1+\tau_2)}} \quad (3)$$

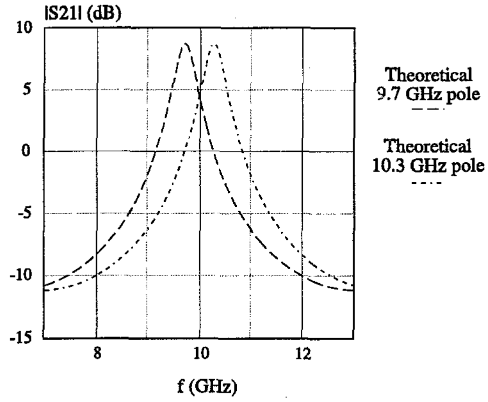
This last expression corresponds to a recursive transfer function form, and the corresponding filter can be put into a conventional ladder representation (figure 2). When comparing figures 1 and 2, it appears that for the same filter order, the classical approach gives a more complex topology : 3 branches are required whereas only 2 are needed with the cascade approach.



- figure 2 -
Equivalent conventional recursive filter

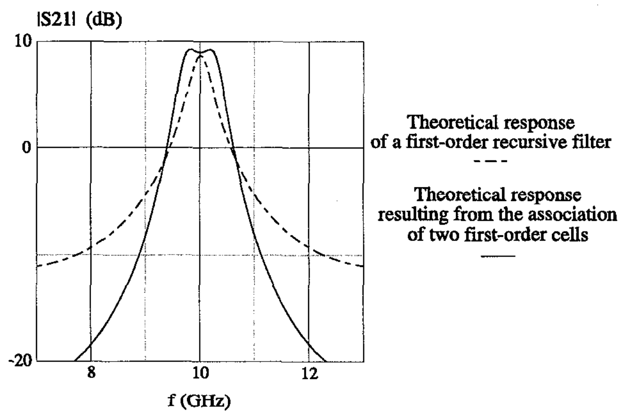
Nevertheless, the response complexity (i.e. the filter order), directly depends on the choice of τ_1 and τ_2. Indeed, if τ_1 differs from a multiple of τ_2, each first-order cell introduces its own individual pole, and H(z) characterizes a second-order recursive response. But if τ_1 and τ_2 are equals or multiples, the two poles introduced by the two first-order cells are combined, and can consequently lead to a recursive response of order that can be greater than 2.

We illustrate this approach by cascading two ideal first-order recursive cells with an identical τ parameter, one with a 9.7 GHz center frequency, the other one with a 10.3 GHz center frequency as shown in figure 3. Difference between the two center frequencies is obtained by shifting the responses with classical transmission analog phase shifter [3].



- figure 3 -
Individual contribution of the two cells

By comparing a single first-order recursive filter response and the recursive filter response resulting from two first-order cells, we can notice an improvement of the selectivity (figure 4).



- figure 4 -
Comparison between first-order and composite second-order filter responses

The interest of this cascade approach leads in the fact that each pole of the resulting transfer function, associated to a unitary cell, can be adjusted individually. This enables to tune the bandwidth and the center frequency whereas the classical approach does not give such flexibility.

Another advantage of this design approach is relative to stability consideration. As H(z) can be considered as a set of individual poles, each one characterized by its own independent parameters, stability can be easily maintained. Indeed, it is only necessary to separately control the stability for each independent cell. In other words, stability of these filters only means first-order recursive filter stability study. Finally, by cascading several elements of the same type, this approach takes advantage of MMIC technology reproducibility.

II-First-order recursive filter

Feasibility of first-order recursive filters, using low frequency concepts, is now well-established, in MMIC technology as well as in hybrid technology [3]. Recently, two first-order recursive filters have been presented, one with a fixed center frequency, and the other one tunable [2]. Both are entirely designed with lumped elements for MMIC compatibility ; they require two power dividers/combiners, an amplifier stage using a single FET, a delay-time element and a varactor diode to tune the filter response. Both are implemented on a 100µm-thick GaAs substrate, and dimensions of the two MMIC chips are respectively 2mmx1.5mm for the non-tunable filter and 2mmx2mm for the tunable one.

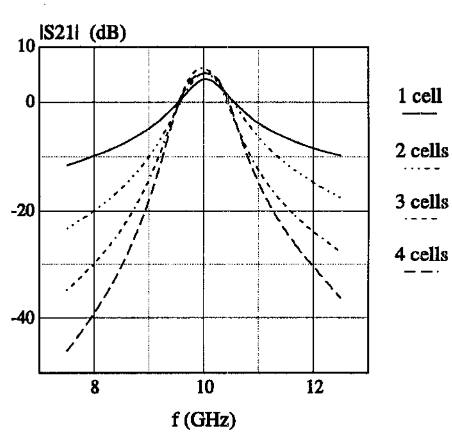
For this last one, a 600 MHz frequency tuning band around 10 GHz is obtained, thanks to the varactor diode bias voltage.

For the cascade approach previously introduced, several of these first-order recursive cells can now be associated in order to achieve more complex and selective tunable responses.

III-High-order recursive filter

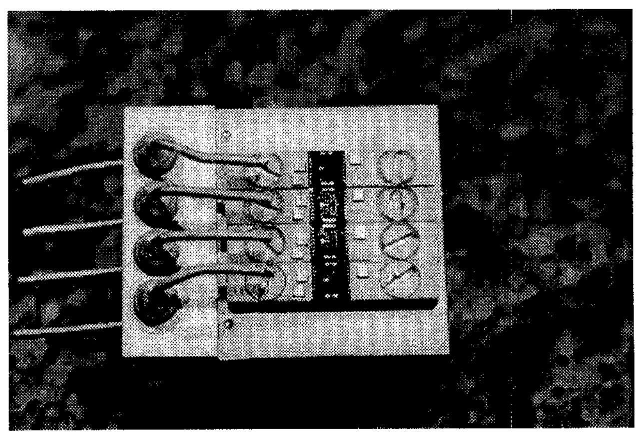
To validate our methodologies, simulations have been performed using first-order recursive filter measurements. By first cascading two first-order cells, which center frequencies are respectively 9.7 GHz and 10.3 GHz, we notice a selectivity improvement (figure 5) : out-of-band rejection is near -20 dB at 8 and 12 GHz and gain is about 3.5 dB at the center frequency 10 GHz.

In order to emphasize individual poles contribution, we cascade two other first-order cells, so as to superimpose two poles at 9.7 GHz and two other at 10.3 GHz. In this way, response selectivity is again improved (figure 5). Moreover, bandwidth can be reduced and gain increased by making poles getting closer.



- figure 5 -
Simulated S_{21} of the cellular recursive filter
for different number of cells

For physical implementation, four first-order recursive cells are finally cascaded (figure 6). Two of the four chips are first connected then a third one and finally the fourth one. All the measurements are performed on a probe station.



- figure 6 -
Physical implementation
of the 4 MMIC chip cascade filter

In the two-cell configuration, excellent agreement between simulated and measured results is obtained when poles are centered at 9.7 and 10.3 GHz. Nevertheless best results are obtained in this configuration when poles introduced by each first-order cell are centered at 10 GHz : gain is about 5.5 dB and bandwidth is about 640 MHz.

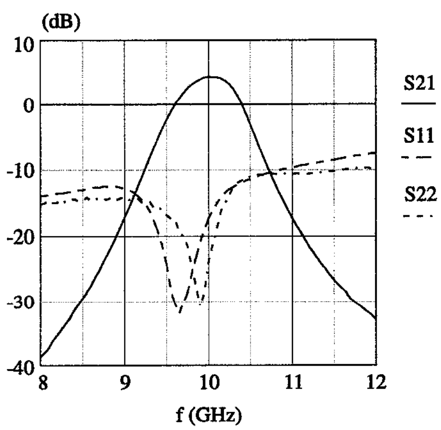
When the number of cells increases, selectivity is improved. Indeed, bandwidth of the response is reduced, gain increased, out-of-band rejection improved, and finally, flatness within the band can be achieved. Moreover, return losses are maintained lower than -7 dB in the band.

Table 1 gives a comparison between first-order filter measurements and composite second-order measurements for different configurations.

	First Order	High-Order		
		2 chips	3 chips	4 chips
$\lvert S_{21}\rvert$ (dB)	3.7	2.5	4.56	4.4
F_0 (GHz)	10	10	10	10.03
Δf_{-3dB} (MHz)	800	820	770	680
Rejection [8-12 GHz] dB	-10	-20	-30	-40

Table 1
Comparison between first-order filter and higher-order filter measurements

Figure 7 presents the measured results of the higher-order active recursive filter in the 4-chip configuration when two poles are superimposed at 9.7 GHz and two other at 10.3 GHz.



- figure 7 -
Measured S_{21} of the cellular recursive filter for different number of cells

Moreover in this configuration the compression point is obtained with a 0 dBm input power.

CONCLUSION

A cascade approach for high-order recursive filters has been presented here and illustrated with a high-order active recursive bandpass filter implementation in the X-band, using respectively two, three and four MMIC first-order recursive cells.

Whereas wideband applications are generally concerned with this kind of filters, we have demonstrated here, that relatively narrowband applications can also be considered by cascading recursive first-order cells. Using the same approach, cascade association of recursive and transversal first-order cells could be used to obtain more complex and selective responses with narrower bandwidths.

Moreover noise and power handling behaviors of this higher-order active filter will be determined by measuring noise figure and third order intermodulation point.

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