Multicellular High-Order Active Recursive Filter Using MMIC Technology

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Abstract

This paper concerns active filters of the recursive type. A new design approach is presented which consists in a cascade association of unitary recursive cells in order to obtain higher-order filters and to achieve selective responses. The advantage of this approach resides in the study of simple structures (i.e. first-order recursive cells). This concept is then illustrated with an experimental active bandpass filter in the X-band, using MMIC technology.

Introduction

With the increase of mobile communications filters must be miniaturised in order to be integrated into MMIC modules with other microwaves functions such as amplifiers, mixers or oscillators. Because conventional passive filters consume too much space or provide too many losses, active filters appear as a promising solution.

In this article, recursive and transversal filters are concerned [1]. Indeed, such filters derived from low frequencies principles have been successfully developed at microwaves frequencies. Recently first-order active recursive filters have been developed as well in hybrid technology[2] as in monolithic technology[3].

The purpose of our work is to achieve more selective responses with such filters. As classical high-order recursive filters design becomes rapidly complex, we focus here on a new design approach for high-order MMIC recursive filter based on a cascade association of first-order recursive cells. We illustrate our approach with simulated and measured results for a multicellular active recursive filter in MMIC technology.

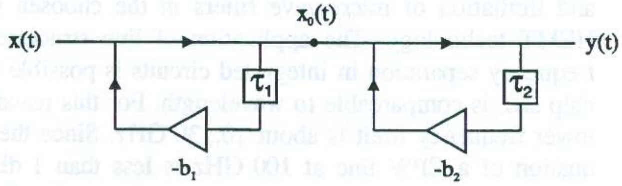
Principle

The classical transfer function H(z) of a recursive filter (1) can be turned in the Z-notation (2). H(z) then 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.

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

$$H(z) = a_0 \frac{(1 - Z_0 Z^{-1})(1 - Z_1 Z^{-1}).....(1 - Z_N Z^{-1})}{(1 - \rho_0 Z^{-1})(1 - \rho_1 Z^{-1}).....(1 - \rho_P Z^{-1})} \quad (2)$$

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 characterised by its delay-time parameter τ_i. The transfer function is then expressed as a product of first-order transfer functions. As an example (figure 1), we consider a cascade recursive filter as the cascade association of two unitary cells.



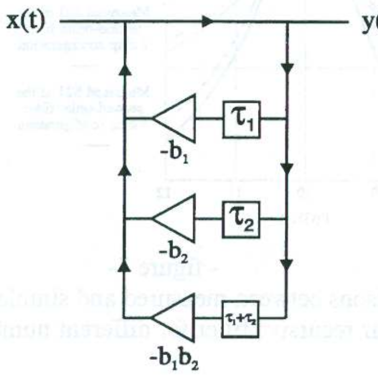
- figure 1 -
2-cell cascade recursive filter

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

$$H(f) = \frac{1}{1 + b_1 e^{-2j\pi f\tau_1} + b_2 e^{-2j\pi f\tau_2} + b_1 b_2 e^{-2j\pi f(\tau_1+\tau_2)}}$$

(3)

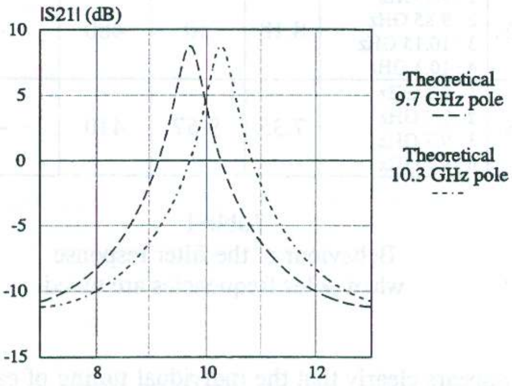
This expression has a recursive transfer function form, and the corresponding filter can be put into a conventional ladder representation (figure 2) which complexity depends on the choice of each delay-time parameter τ_i. Indeed, when comparing figures 1 and 2, it appears that for the same filter order, when τ_1 and τ_2 are not equals, but when they are multiple, 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

Furthermore, when τ_1 differs from a multiple of τ_2, each first-order cell introduces its own individual pole, and H(z) characterises a second-order recursive response.

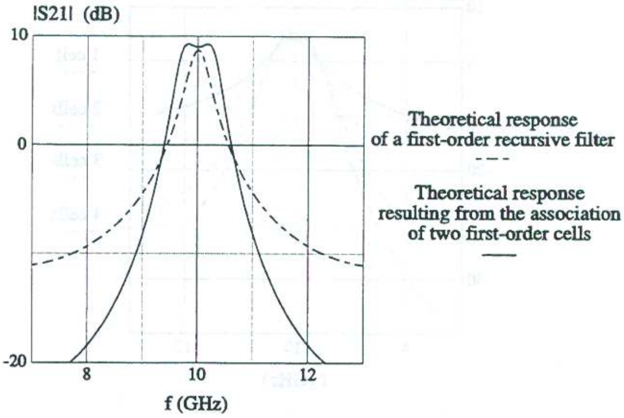
Following this remark, we illustrate our approach by cascading two ideal first-order recursive cells, one with a 9.7 GHz centre frequency, the other one with a 10.3 GHz centre frequency as shown in figure 3.



- figure 3 -
Individual contribution of the two cells

Figure 4 presents a comparison between an ideal first-order recursive filter response and the resulting second-order filter response, for which each pole contribution clearly appears.

By comparing these two responses, we notice an improvement of the selectivity behaviour when the degree of the filter increases.



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

The interest of this cascade approach is 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 : it is only necessary to separately control the stability of each independent cell, in order to insure the stability of the filter. In other words, stability of these filters only means first-order recursive filter stability study which can be easily performed with the help of CAD softwares using the new NDF function recently introduced by A. Platzker [4],[5].
Finally, by cascading several elements of the same type, this approach takes advantage of MMIC technology reproducibility.

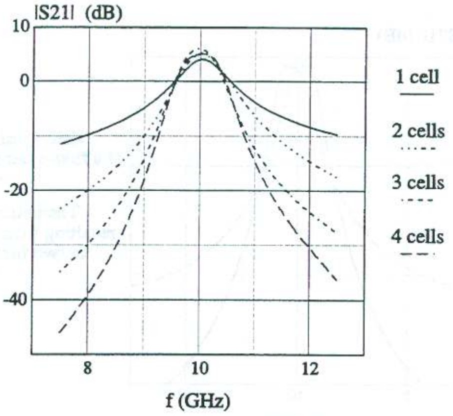
High-order recursive filter design

Following the principles introduced above, simulations are first performed using first-order active tunable recursive filter measurements [3].

By first cascading two first-order cells, which centre frequencies are respectively 9.7 GHz and 10.3 GHz, the out-of-band rejection is near -20 dB at 8 and 12 GHz and the gain is about 2.5 dB at the centre frequency 10 GHz.

In order to emphasise individual poles contribution, we cascade two others first-order cells, so as to superimpose two poles at 9.7 GHz and two others at 10.3 GHz.
In this way, response selectivity is improved : out-of-band rejection is about -40 dB, gain is around 4.7 dB at the centre frequency and -3 dB bandwidth is about 7%

of f_0 versus 10% in the two cells configuration (figure 5).



- figure 5 -

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

Moreover, bandwidth can be reduced and gain increased by making poles getting closer.

Physical implementation

For physical implementation, four first-order recursive MMIC cells, which dimensions are $2x2mm^2$ are finally cascaded (figure 6). Two of the four chips are first connected then three and finally four. All measurements are performed on a probe station.

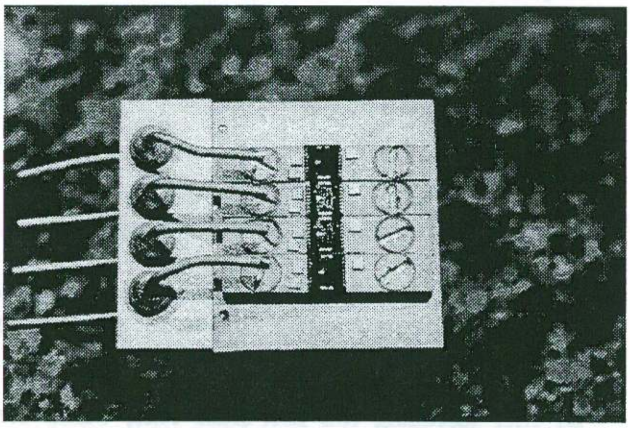
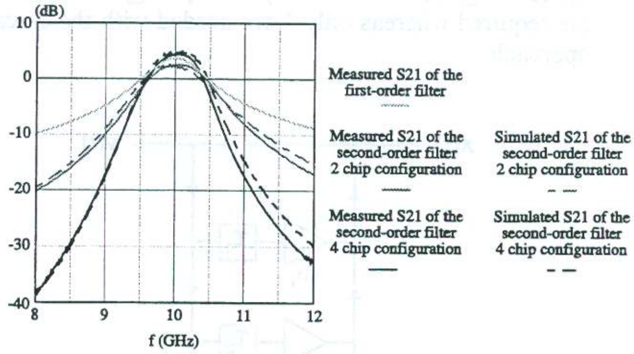


figure 6

Physical implementation of the 4 MMIC chip cascade filter

Measurements, when two and four MMIC chips are connected, are compared with simulated results and with first-order recursive filter measurement in figure 7. In this two and four chip configurations, centre frequencies of the poles are respectively 9.7 GHz and 10.3 GHz.

When the number of cells increases, the selectivity and the gain are improved, the bandwidth of the response is reduced, as return losses are maintained lower than -7 dB in the band.



- figure 7-

Comparisons between measured and simulated S_{21} of the cellular recursive filter for different number of cells

To confirm previous theoretical points table 1 gives, in the four chip configuration, the filter experimental response behaviour when centre frequencies of poles are tuned.

	Poles centre frequencies	$\lvert S_{21}\rvert$ (dB)	f_0 (GHz)	Δf_{-3dB} (MHz)	Rejection (dB) at $f_0 \pm 2$ GHz
1	1 : 9.7 GHz 2 : 9.7 GHz 3 : 10.3 GHz 4 : 10.3 GHz	4.37	10.03	680	-40
2	1 : 9.7 GHz 2 : 9.85 GHz 3 : 10.15 GHz 4 : 10.3 GHz	8.18	10	480	-40
3	1 : 9.7 GHz 2 : 9.7 GHz 3 : 9.7 GHz 4 : 9.7 GHz	7.35	9.67	410	-40

- Table 1 -

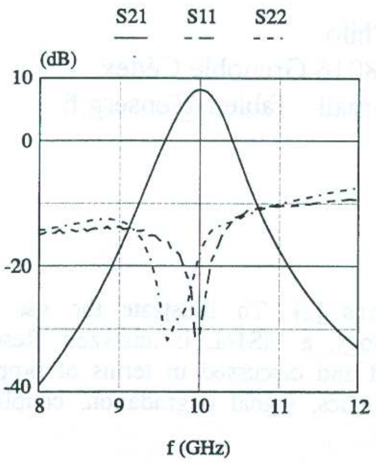
Behaviour of the filter response when poles frequencies are tuned

It appears clearly that the individual tuning of each pole allows a great flexibility in terms of tunability and selectivity behaviour of the response.

Example 1 of this table corresponds to the four chips configuration presented in figure 6.

Example 2 shows that when poles are closer to the centre frequency, the selectivity is improved; the gain is increased (around 8 dB in this case), and the -3dB bandwidth is reduced to 5% of f_0. The filter response, in this configuration, is given in figure 8.

Furthermore, example 3 shows that the individual tuning of each pole frequency allows the tuning of the filter response : a filter response with a 9.7 GHz centre frequency, 7dB gain and 4% bandwidth can be obtained.



- figure 8 -
Measured response of the cascade recursive filter when poles frequencies are 9.7, 9.85, 10.15 and 10.3 GHz

Moreover, compression measurements have been performed for the first-order filter and for higher-order filters. The 1dB compression point has been obtained for a 0 dBm input power in the 4-chip configuration (figure 8).

Conclusion

A cascade approach for high-order recursive filters has been presented and illustrated with a high-order active recursive bandpass filter implementation in the X-band, using 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.

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