Low Power, Monolithic Tunable Recursive Filters having Variable and Uniform Gain

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Abstract

We suggest the new monolithic, tunable, recursive filters having variable, uniform, and high gain. We change the location of amplifier to achieve higher gain. We use the cascode amplifier as VGA to get the variable, uniform and high gain. To achieve higher Q and low power consumption, we make also the 2nd-order filter using only one amplifier. The measured results are similar to our estimations.

INTRODUCTION

High Q bandpass filter has been made by bulky passive elements until now because passive elements can set the desired center frequency (f_c) correctly. However, this passive bandpass filter prevents fully monolithic one chip for system. Therefore, many researchers have endeavored to make monolithic high Q bandpass filter using active MMIC [1]. Some of them tried to implement this by recursive filter concepts [2]-[5].

Usually, the varactor was used to change f_c in tunable recursive filter [4]. However, the gain of this filter was not uniform varying with f_c because the impedance of varactor was varied by each tuning voltage.

In this paper, we suggest low power, monolithic tunable recursive filter having variable and uniform gain. We use cascode amplifier as VGA in our filters. The cascode amplifier has large gain control range and has comparatively uniform phase characteristic varying with gain and input power [6]. This constant phase characteristic is important in recursive filter because the modified phase changes f_c as described in [4].

COMPARISON OF TOPOLOGIES

To increase the total gain, we change the location of amplifier into forward branch (*Forward I, II* in Fig. 1), although the previous works [4],[5] located the amplifier at the reverse branch. To achieve higher gain and higher Q, we make also the 2nd-order filter using only one amplifier (*Forward II*). The 1st-order filter used in [3] located the amplifier at forward branch, however, it was not monolithic circuit and could not tune the center frequency.

Transfer characteristic of each topology in Fig. 1 can be characterized by Mason's gain formula [7] as shown in Table 1. Here, α,β and γ are the loss of combiner and divider, respectively, and τ_{cd} is the phase delay of combiner and divider.

Table 1 shows that the total gain of amplifier located at forward branch is increased $|S_{21}|$ times as much as one of amplifier located at reverse in case of 1st-order filter. The calculated theoretical gains by using equations in Table 1 are drawn in Fig. 2 to compare with one another. Fig. 2 shows that our 2nd-order filter has more gain than the others. Therefore, our topologies consume lower DC power than previous topologies [4],[5] at the same gain.

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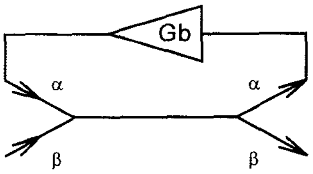
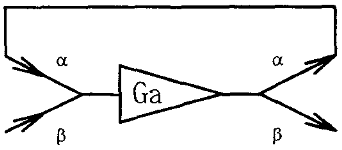
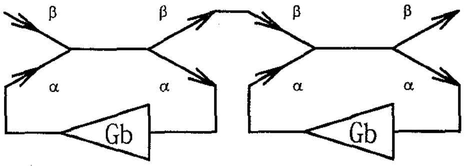


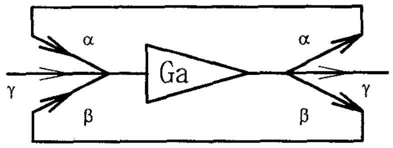
(a) *Reverse I* [4]



(b) *Forward I*



(c) *Reverse II* [5]



(d) *Forward II*

Fig. 1. The comparison of recursive filter topologies.

	Reverse [4],[5]	Forward
1st	$\dfrac{\dfrac{1}{2}e^{-j\omega(2\tau_{cd}+\tau_a)}}{1-\dfrac{\lvert S_{21b}\rvert}{2}e^{-j\omega\tau)}}$	$\dfrac{\dfrac{\lvert S_{21a}\rvert}{2}e^{-j\omega(2\tau_{cd}+\tau_a)}}{1-\dfrac{\lvert S_{21a}\rvert}{2}e^{-j\omega\tau)}}$
2nd	$\dfrac{\left(\dfrac{\lvert S_{21b}\rvert}{2}e^{-j\omega(2\tau_{cd}+\tau_b)}\right)^2}{1-2\times\dfrac{\lvert S_{21b}\rvert}{2}e^{-j\omega\tau}+\left(\dfrac{\lvert S_{21b}\rvert}{2}e^{-j\omega\tau}\right)^2}$	$\dfrac{\dfrac{\lvert S_{21a}\rvert}{3}e^{-j\omega(2\tau_{cd}+\tau_a)}}{1-\dfrac{2\lvert S_{21a}\rvert}{3}e^{-j\omega\tau}}$

Table 1. The comparison of transfer function ***T*** at each topology. ($\tau = 2\tau_{cd} + \tau_a + \tau_b$)

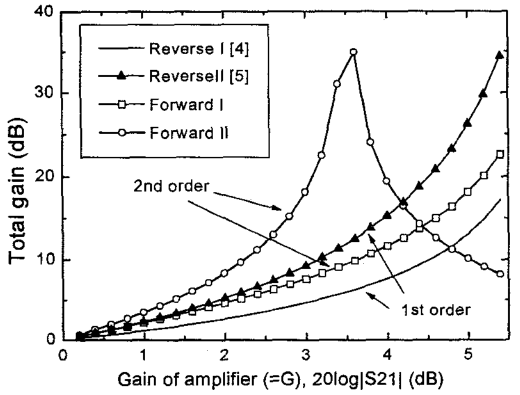
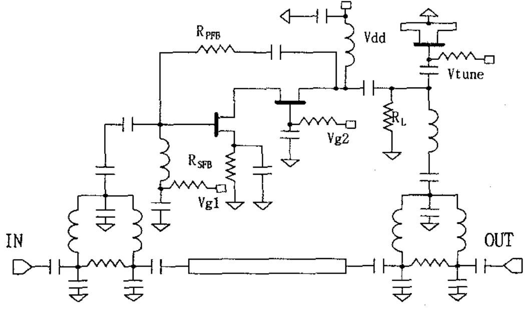


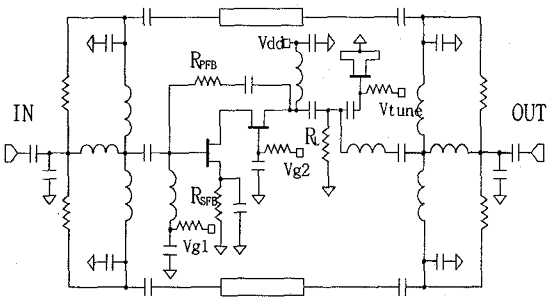
Fig. 2. Calculated total gain *vs* gain of amp.

IMPLEMENTATION AND MEASUREMENT

The designed schematics and photographs of our new 1st-order and 2nd-order recursive filters are drawn in Fig. 3 and Fig. 4, respectively.

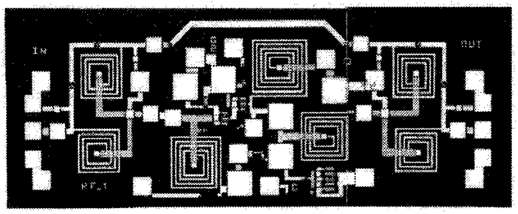


(a) 1st-order recursive filter (*Forward I*)

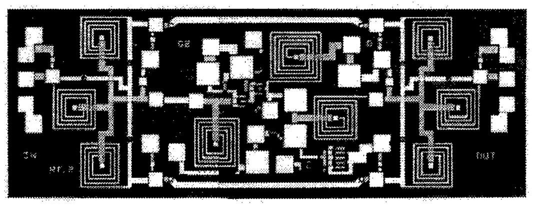


(b) 2nd-order recursive filter (*Forward II*)

Fig. 3 The schematic of new recursive filter.



(a) *Forward I*



(b) *Forward II*

Fig. 4. Photograph of fabricated
(a) 1st-order recursive filter
(b) 2nd-order recursive filter.

The parallel and series feedback resistor, and load resistor are used to stabilize circuit and the monolithic 2-way and 3-way power combiner/divider are implemented as lumped passive elements [8] in our circuits. Fig. 5 shows that gain and Q are varied by gate bias (Vg2) of common-gate part and that the center frequencies are almost constant varying with gain control. The latter fact proves that phase characteristic of cascode is constant varying with gain control. The range of variable gain can be controlled from -9.7 dB to 10.0 dB and the range of variable Q can be from 9.1 to 37.7.

Fig. 6 and Fig. 7 show frequency characteristics of 1st-order and 2nd-order filters, respectively. Figures show that f_c can be shifted (1st-order: 3.74~3.86 GHz, 2nd-order: 3.51~3.66 GHz) by tuning varactor voltage and the gain is constant at each f_c by controlling gain of cascode. If the desired total gain is more decreased, tuning bandwidth can be more increased. The return loss is good as less than 7.5 dB and is dependent on not characteristic of amplifier but one of combiner/divider.

To characterize our new topologies, we compare the cascode amplifier with 1st-order recursive filter and 2nd-order one in Fig. 8. The recursive filters have higher Q and larger gains than cascode amplifier. The measured gains are more decreased than the simulated gains because of the loss of combiner/divider and length of transmission lines at reverse path. Although the gain of 2nd-order recursive filter becomes decreased, we can find that 2nd-order has higher Q than 1st-order at the same gain. The power consumption of the lower lines in Fig. 8 at all circuits is the same as 19.2 mW (Vdd= 4.7 V, Ids= 4.1 mA) and ones of the upper lines are 46.8 mW (Vdd= 5.5 V, Ids= 8.5 mA). When the series and parallel feedback resistor is excluded, the increased gain can reduce the DC power consumption further.

CONCLUSION

We have proposed low power, new monolithic, tunable recursive filters having variable and uniform gain. The measured results of 1st order filter are similar to our estimation and ones of 2nd order filter show that it has higher Q at the same gain. Our recursive filters can be applied to low power, monolithic, tunable narrow bandpass filters in modern telecommunications.

References

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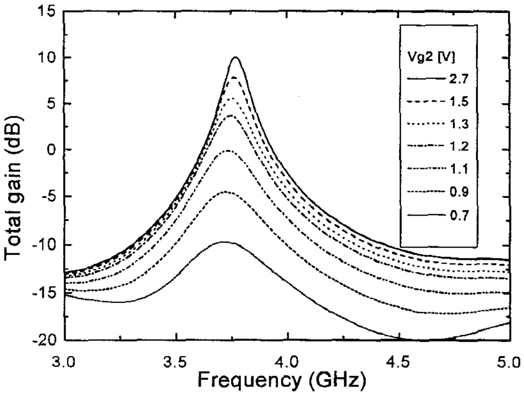

Fig. 5. Measured variable gain of 1st-order recursive filter varying with gain control of cascode.

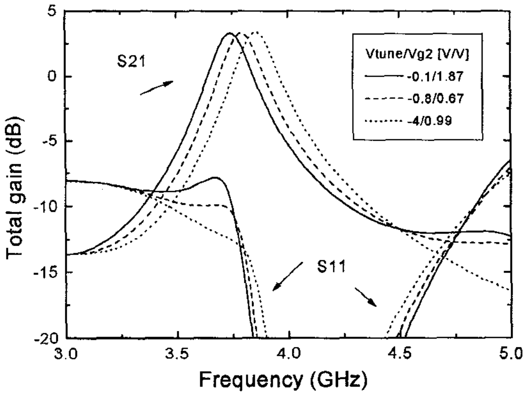

Fig. 6. Uniform gain and return loss char. (measured) of 1st-order recursive filter varying with center frequency.

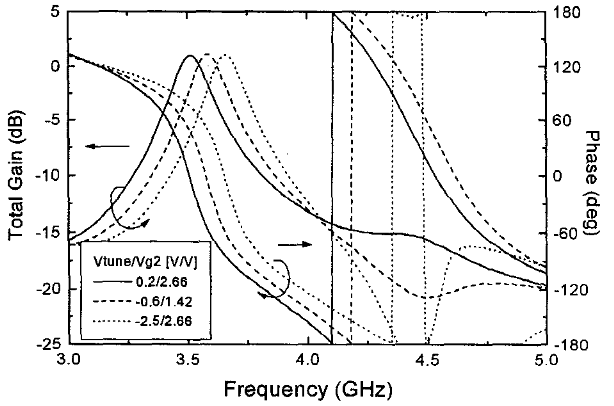

Fig. 7. Uniform gain and phase characteristic (measured) of 2nd-order recursive filter varying with center frequency.

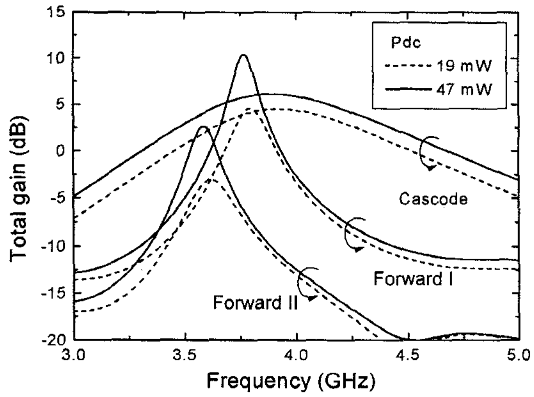

Fig. 8. Measured performances of our topologies about gain and frequency characteristic.