MOS-Only Allpass Filters Modified for Low Operating Frequency Range

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Abstract

The objective of this paper is to present a modification technique that can be used to alleviate the low-frequency limitations of MOS-only filters. The technique is based on adding an additional pair of cross-coupled transistors to modify the time constant of the filter. In this case, lower frequency operations is attainable without having to use large transistors with higher intrinsic capacitors; hence the chip area occupied by the circuit is kept low. Two existing MOS-only filter circuits are modified to illustrate the versatility of the idea and Spectre simulation results are provided in order to show the proper operation of the circuits.

1. Introduction

Filters which do not employ any external passive components, resistive or reactive (i.e. capacitors or inductors), but rather that exploit the intrinsic capacitors within the MOS transistors are called as MOS transistor-only active circuits (or MOS-only circuits) and have received significant interest in the last decade [1-8]. From integrated circuit realization of point of view, these circuits offer some significant advantages: i) low occupied chip area as a result of not using any intentional, external capacitors, ii) capability of operating at high frequencies as most significant parasitic capacitances are taken into account during the synthesis procedure, iii) electronic tuning property of the important filter parameters.

However, MOS-only active filters have inherent low frequency limitations since the filters' natural frequencies are in general proportional to g_m/C_{gs}, where g_m is the device transconductance and C_{gs} is the gate source capacitance. However, for low frequency operation either the value of g_m, i.e. the MOS biasing current should be decreased or the value of C_{gs} should be increased. The MOS biasing current cannot be decreased beyond the values where the transistors operate in subthreshold regions since exponential nonlinearities may lead to large THD at filters' outputs. On the other hand, to increase the value of C_{gs} implies the use of large devices that increase the chip area occupied by the circuits.

In this paper, in order to remedy this problem, we propose a simple technique that can be used to increase the time constant of any MOS-only active filter. In this way, the operating frequency range of these filters can be shifted towards lower frequency regions.

In order to verify the proper operations of the proposed technique, two illustrative examples are considered. Spectre simulations of the considered circuits in Cadence design environment are also provided in order to verify the usefulness of the technique.

2. Proposed Technique for Low Frequency MOS-Only Filter

Recently, a MOS-only allpass filter depicted in Fig. 1a is proposed [9]. Assuming that all MOS transistors operate in saturation region, transconductances from the body, g_{mb} are neglected, and gate drain capacitances, C_{gd} and parasitic junction capacitances C_{sb} and C_{db} of the devices are neglected i.e. only the gate source capacitances, C_{gs} are considered, routine analysis of the circuit yields to the following transfer function:

$$\frac{V_{out}^{+}-V_{out}^{-}}{V_{in}^{+}-V_{in}^{-}}=\frac{sC_{gs2}-(g_{m1}-g_{m2})}{sC_{gs2}+g_{m2}} \qquad (1)$$

which is an allpass function for $g_{m1}=2g_{m2}$ with a pole of $f_p = g_{m2}/2\pi C_{gs2}$.

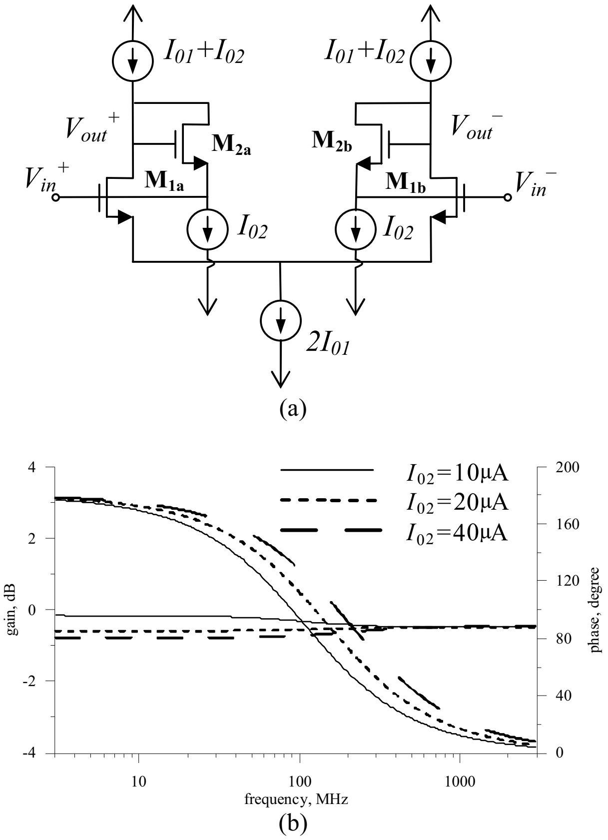
Frequency characteristics of the filter derived from simulations results are given in Fig. 1b. The frequency characteristics are obtained for three different biasing values, in order to illustrate the tunability capability of the filter. From these results, it is seen that the filter pole can be adjusted between 100MHz and 220MHz by adjusting the biasing currents.

The proposed technique is depicted in Fig. 2 which is based on using cross coupled MOS transistor pairs, in order to alleviate the low frequency limitations mentioned above.

Assume that the circuit in Fig. 2 is a balanced MOS-only filter, the transistor pairs M_{ip} and M_{in} are perfectly matched and the filter's pole frequency is determined by the transconductance of this transistor pair, i.e. $f_p \sim g_{mi}/C$.

By adding the cross-coupled transistor pair M_{jp} and M_{jn} as shown in Fig. 2 and provided that $(W/L)_{jp}=K(W/L)_{ip}$ and $(W/L)_{jn}=K(W/L)_{in}$, or equivalently $gm_{ip}=gm_{in}=Kg_{mjp}=Kg_{mjn}$, the new filter pole is obtained as

$$\hat{f}_p = f_p(1-K)\,.$$



(a)

(b)

Fig.1. a) Conventional MOS-only first order allpass filter [9] b) Cadence Spectre simulation results of the first-order allpass filter for different biasing currents.

By applying this technique, the modified MOS-only filter with low frequency operation region can be obtained as in Fig 4b. Routine analysis of this circuit leads to the following transfer function:

$$\frac{V_{out}^{+}-V_{out}^{-}}{V_{in}^{+}-V_{in}^{-}}=\frac{sC-(g_{m1}-g_{m2})(1-K)}{sC+g_{m2}(1-K)} \qquad (2)$$

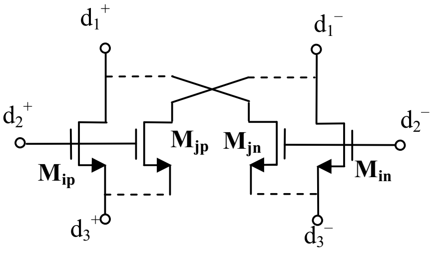


Fig. 2. The proposed technique for realizing low frequency filters.

where $K= g_{m3}/ g_{m2}= g_{m4}/ g_{m1}$. The function is first-order allpass function for $g_{m1}=2g_{m2}$ and the filter pole frequency is now becomes $f_p=\frac{g_{m2}(1-K)}{2\pi C_{gs2}}$.

For different values of K, the values of the pole frequencies obtained from simulation results are plotted in Fig. 3. Obviously, the closer K approached to unity, the larger the filter sensitivity. In order to assess the sensitivity performance of the filter, we have performed Monte-Carlo mismatch and process analysis using the statistical mismatch model of the employed MOS process provided from the foundry. For this purpose, the allpass filter is simulated 100 times and the maximum and the minimum values of the filter pole are obtained and shown in Fig. 3 within dashed lines. From these results, for K=0.96, the deviation in the filter pole remains smaller than 5%, which is an acceptable value. Note that for K=0.96, the value of f_p is reduced by a factor of 25.

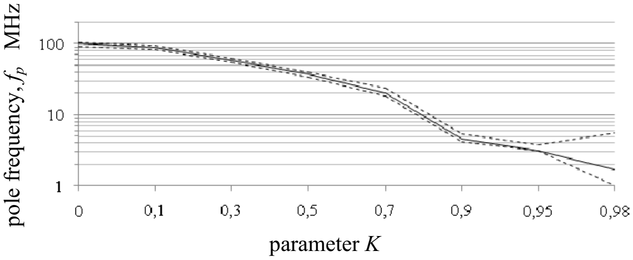


Fig.3. The filter's pole versus the value of K (—— nominal values - - - - - deviated values).

3. Simulation Results

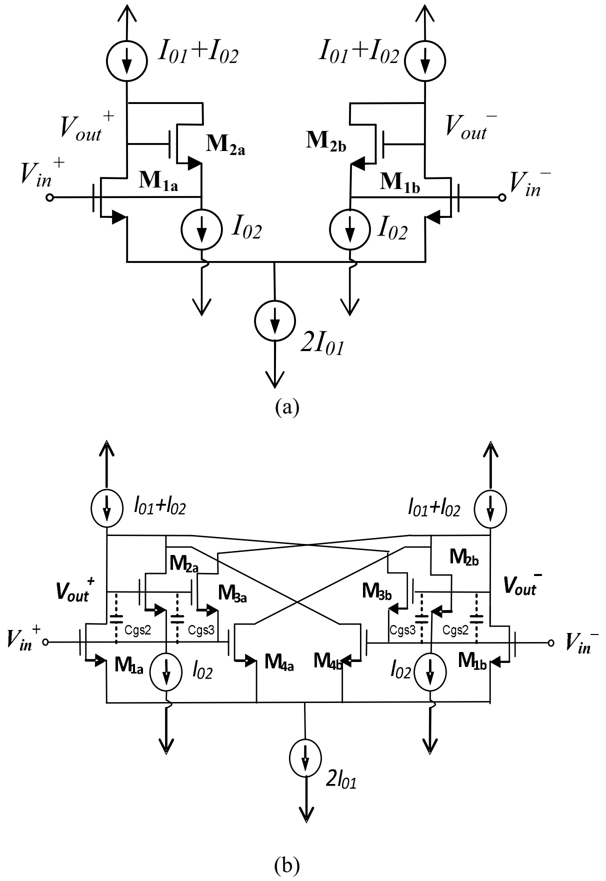
In the proposed circuit shown in Fig.4b, the value of the biasing current I_{02} is 10µA. In order to realize allpass condition, I_{01} was simultaneously varied according to $I_{01}=4I_{02}$. The values of the parasitic gate-source capacitance and transconductances of the transistors in first-order allpass filter were calculated as $C_{gs1}=C_{gs2}=132\,fF$, $C_{gs3}=104\,fF$, $g_{m1}=147\ \mu S$ and $g_{m2}=70\ \mu S$. The ratio of the transistor dimensions was adjusted as K=0.8. Using these parameter values in the transfer function in Eqn. (2), the pole frequency , f_0 turns out to be 9.4MHz. From the simulation results givien in Fig 5a, the pole frequency was measured as 9.5 MHz, which is in good agreement with the expected value.

Active inductor can be used as the building blocks of differential magnitude filters [3]. As a very simple application, simulations results of a second order band pass filter embedding the active inductor are given in the sequel.

The resonant frequency of the second order band pass filter in Fig. 6 is given by:

$$\omega_0=\frac{1}{\sqrt{LC}} \qquad L=\frac{2C_{gs3}}{g_m g_{m3}} \qquad (3)$$

$$g_{m1}=g_{m2}=g_m \qquad C=\frac{C_{gs1}}{2}=\frac{C_{gs2}}{2}$$



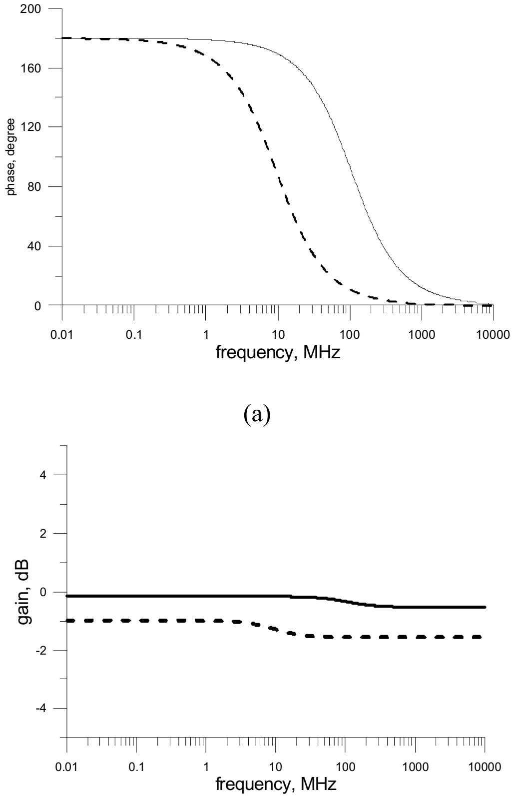
(a)

(b)

Fig. 4. a) Conventional MOS-only first-order allpass filter [9]. b) The modified circuit with lower operating frequency range.

The proposed technique was applied in the band pass filter such as MOS only allpass filter. To verify the theoretical study, both of band pass filters were simulated using Spectre simulation tool in CADENCE design environment using the parameters of a standard CMOS 0.35µm p-well process. The filters were biased with ±1.65V DC power supply and all the current sources shown in Fig.6 and were realized using simple CMOS current mirrors. The aspect ratios of all the NMOS transistors were set to W/L=30µm/1µm. Simulation results are shown in Fig. 7.

Using the parameter values in Eqn. (3), the resonant frequency, f_0 turns out to be 446MHz. After using the cross coupled MOS transistor pairs in this filter with the ratio of the transistor dimensions K=0.85, the resonant frequency was measured as 24MHz, which is in good agreement with the expected value.



(a)

(b)

Fig.5. Simulation results of the modified circuit with lower operating frequency range (—— initial - - - - - modified).

Our numerical results indicated that low attenuations in the low frequency range in Fig.7 are due to finite output resistances appearing in parallel with C_{gs3}. This issue can be coped by replacing M_{1p} and M_{1n} with cascode devices and by using cascode current mirrors.

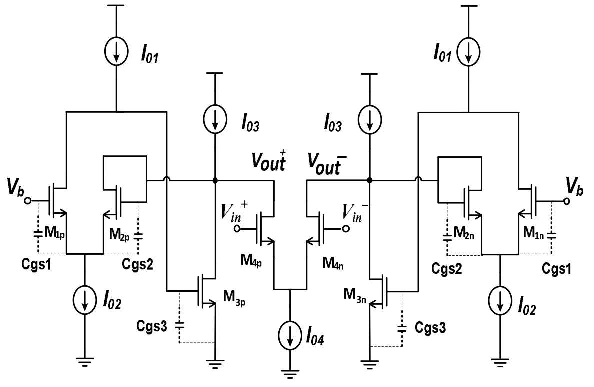


Fig. 6. Fully differential active inductor bandpass filter built around the active inductor in [3].

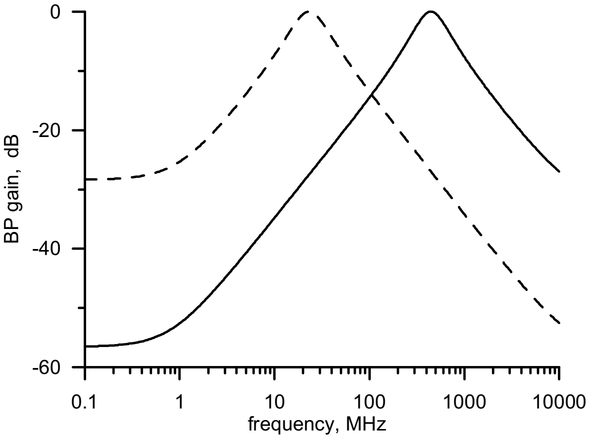


Fig.7. Simulation results of the modified circuit with lower operating frequency range (—— initial ----- modified).

4. Conclusions

In this paper, it is aimed to alleviate the low frequency limitations of the filters by using cross coupled MOS transistor pairs.

It is seen that the use of the proposed technique to implement a filter allows the realization of a pole frequency as low as 9.4 MHZ. It is also concluded from the filter simulation results that allpass filter has an electronic tuning range of over one dacade.

5. References

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