

A CMOS Fifth-Order Low-Pass Current-Mode Filter Using a Linear Transconductor

Mohamed O. Shaker

Electronics and communications
Dept. Cairo University.
Giza, Egypt
moh_o_a@hotmail.com

Soliman A. Mahmoud

Electrical Engineering Dept.
Fayoum University.
Fayoum, Egypt
amahmoud@frcu.eun.eg

Ahmed M. Soliman

Electronics and communications
Dept. Cairo University.
Giza, Egypt
asoliman@ieee.org

Abstract

In this paper, the design and analysis of a CMOS fifth-order low-pass GM-C filter are presented. It has a cutoff frequency of 4.3 MHz to accommodate the wideband CDMA standard. The transconductor used in this filter is based on a four-transistor cell operating in triode or saturation mode. It achieves high linearity range of ± 1 V at ± 1.5 V supply voltages. PSpice simulations show that total harmonic distortion at 1 Vpp and 1 MHz is equal to 0.1% with 1.234 mW standby power dissipation. The proposed filter and the transconductor are simulated using 0.35 μ m technology.

Keywords

Transconductor, current mode filter.

I. INTRODUCTION

Integrated analog filters can be realized using two different approaches, discrete-time switched capacitor (DTSC) and continuous time (CT) implementations. The DTSC filters are limited to low frequency applications due to the sampling process and the need to high supply voltage operation due to turning MOS switches on and off and maintaining proper op-amp operation. On the other hand, the CT filters have a significant speed advantage over discrete-time counterparts because no sampling is required. There are three main techniques to implement integrated continuous-time filters: active-RC, MOSFET-C and Gm-C. Active RC configurations use op-amps, resistors and capacitors as passive frequency-determining components. They present very good linearity, but usually require large die area for resistors and capacitors. The tuning can be achieved only in a discrete manner by using arrays of passive components, and the large value resistor can introduce substantially thermal noise. Another class of continuous-time filters is derived from classical active RC filters and uses MOS transistors, capacitors and op-amps. They are thus referred to as MOSFET-C active filters [1]. These implementations have poor linearity due to the nonlinear characteristics of the MOS transistors. Although linearity can be improved by using linearization techniques to the current of MOS transistor in the triode mode [2], the input dynamic range is reduced in order to keep the MOSFETs in the triode region. The use of transconductors and capacitors to implement integrators is another technique to realize continuous time filters. The Gm-C

configurations [3] have better frequency response compared to the active-RC and MOSFET-C realizations. They have also electronic tuning capability but are characterized by a rather poor linearity. Therefore, additional circuitry is needed to linearize the transfer characteristic of the transconductor. This paper presents a CMOS implementation of a fifth-order low-pass current-mode GM-C filter derived from RLC ladder filter using lossless and lossy integrators. In section II, the transconductor used in this filter, which is based on the four-transistor cell operating in triode or saturation mode, is introduced. In section III, current mode lossless/lossy integrators and the design of a fifth-order low-pass current-mode GM-C filter is presented. Finally, conclusion is stated in section IV.

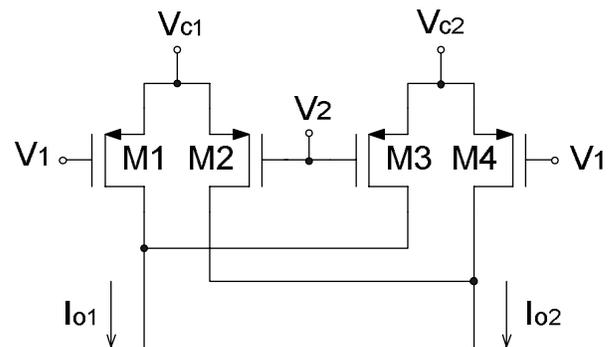


Figure 1(a). The CMOS circuit of the four-transistor cell.

II. THE PROPOSED CMOS TRANSCONDUCTOR

The structure of the proposed CMOS transconductor depends on the four-matched transistor cell shown in Figure 1(a). This cell was first used in [4] to realize fully integrated CT filters under the condition the four transistors operating in the triode region and the drain voltages of the four transistors are equal. Using the current in the triode region of the transistor as a function of the gate (V_G), drain (V_D), source (V_S) and threshold (V_{TP}) voltages given in [1] by:

$$I = K_P (V_G - V_{TP})(V_D - V_S) + \alpha_1 (V_D^2 - V_S^2) + \dots \quad (1)$$

distortion. Two single tone signals of frequency 69 MHz and 71 MHz were applied to the inputs of the transconductor. The IM3 is around 35 dB. The power supply rejection ratio (PSRR) from positive supply is around 90 dB and from the negative supply is around 120 dB.

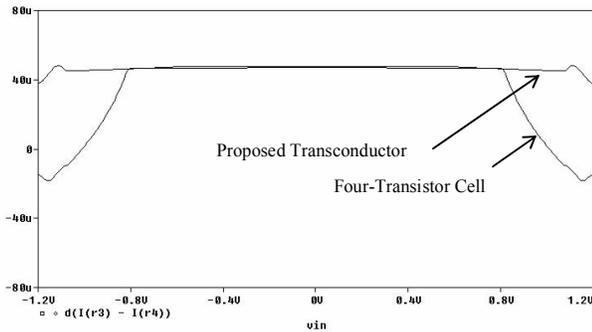


Figure 2(a). The transconductance of the transconductor and the four-transistor cell.

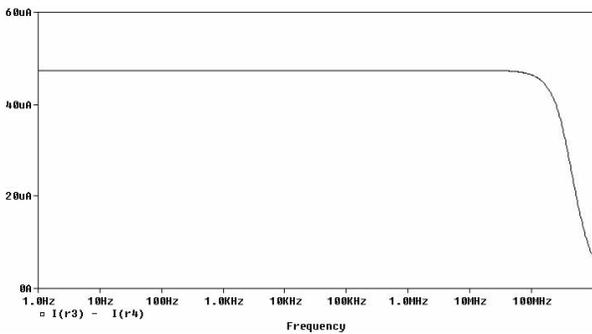


Figure 2(b). The magnitude response of the transconductor output.

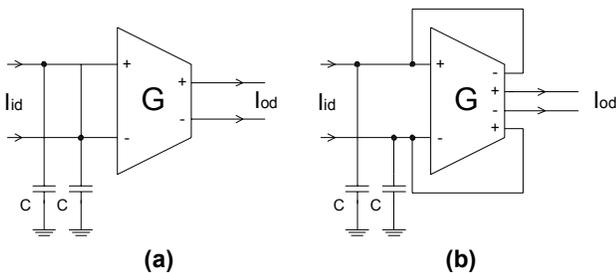


Figure 3. The block diagram of the (a) lossless integrator. (b) lossy integrator.

III. CURRENT MODE TRANSCONDUCTOR BUILDING BLOCKS

Current mode circuits of the first order are required to realize any active filter [5], [6]. Many current mode circuit modules such as transconductor and current conveyor can be used in the realization. Here, transconductor has been chosen because of its structural simplicity and convenient tunability.

A. Current mode lossless integrator

Current mode lossless integrator is a basic building block, which is used in the filter synthesis. The input current is applied to a capacitor to implement the integration

operation and the voltage across the capacitor is applied to the transconductor to generate the required integrated output current. The circuit is shown in Figure 3(a) with the following transfer function:

$$\frac{I_{od}}{I_{id}} = \frac{G}{sC} \quad (7)$$

where I_{od} , I_{id} are the differential output current and the differential input current respectively.

B. Current mode lossy integrator

Current mode lossy integrator is another basic building block used in the synthesis method. It can be implemented in the same way as the lossless integrator but the output current is replicated and added to the input current through negative feedback to generate the required output current. The circuit is shown in Figure 3(b) with the following transfer function:

$$\frac{I_{od}}{I_{id}} = \frac{1}{1 + s(C/G)} \quad (8)$$

The magnitude responses of the lossless and lossy integrator outputs are shown in Figure 4(a) and Figure 4(b) respectively.

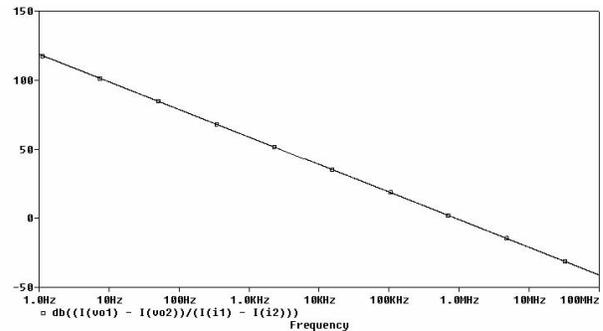


Figure 4(a). The magnitude response of the lossless integrator output.

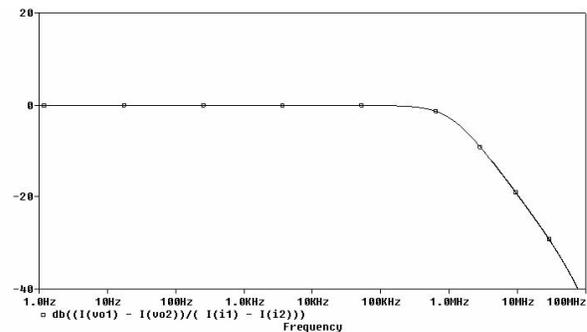


Figure 4(b). The magnitude response of the lossy integrator output.

C. Fifth-order low-pass filter

Consider the fifth-order RLC ladder filter in Figure 5(a). Using a branch-current analysis with a scaling impedance R_0 [6] leads to transfer expressions, which can be represented by the lossless and lossy blocks as shown in Figure 5(b). Typical values for the components of the

Butterworth and Chebyshev passive filters are used to implement their active counterparts with the aid of the well-known relations in Table 1. The magnitude responses of the fifth order Butterworth and Chebyshev active filter outputs compared with their passive counterparts is shown in Figure 6(a) and Figure 6(b) respectively.

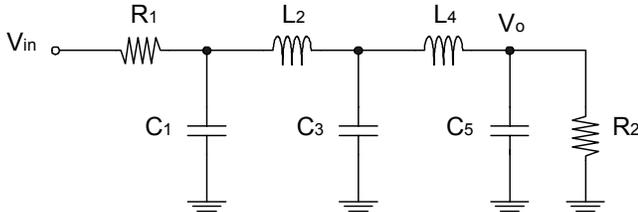


Figure 5(a). The double terminated RLC filter.

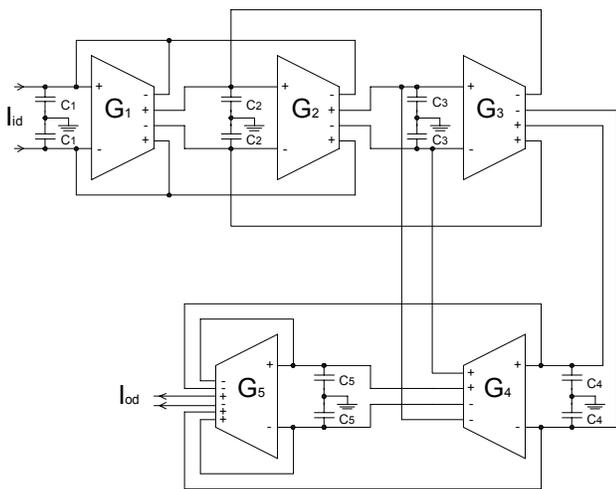


Figure 5(b). The active realization of the ladder filter.

Table 1. The transformation table from passive elements to active elements.

Passive Form	Active Form	Passive Form	Active Form
R_1	$1/G$	C_3	C_3
R_0	$1/G$	C_5	C_5
R_2	$1/G$	L_2	C_2/G^2
C_1	C_1	L_4	C_4/G^2

IV. CONCLUSION

In this paper, a tunable transconductor; which can operate in linear or saturation region; has been presented. A fifth order Chebyshev and Butterworth low pass filter with minimum number of blocks; which is based on lossless/lossy integrators; has been introduced. The proposed blocks and their applications have been confirmed using PSpice simulation.

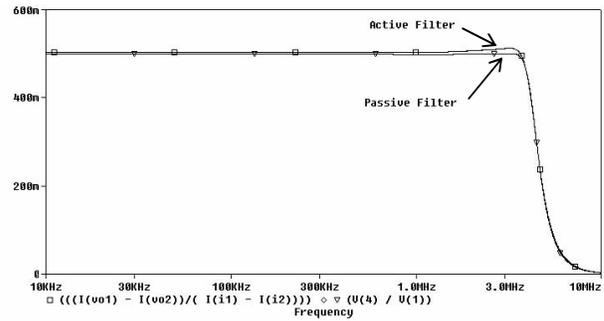


Figure 6(a). The magnitude response of the fifth order passive and active Butterworth filter output.

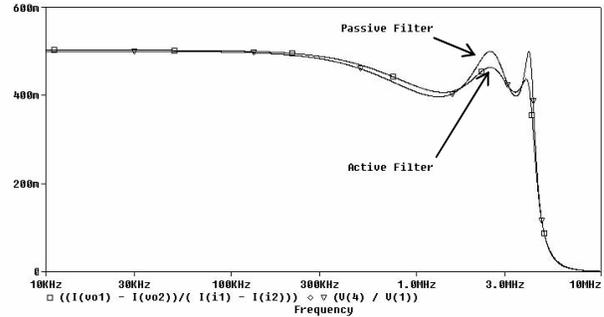


Figure 6(b). The magnitude response of the fifth order passive and active Chebyshev filter output.

V. REFERENCES

- [1] M. Banu and Y. Tsvividis, "Fully integrated active RC filters in MOS technology," *IEEE J. Solid-State Circuits*, vol. SC-18, pp. 644-651, Dec 1983.
- [2] Z. Czarnul, "Modification of Banu-Tsvividis continuous-time integrator," *IEEE Trans. Circuits Syst.*, vol. CAS-33, pp. 714-716, July 1986.
- [3] S. A. Mahmoud and A. M. Soliman, "New CMOS programmable balanced output transconductor and application to a mixed mode universal filter suitable for VLSI," *Analog Integrated Circuits and Signal Processing*, vol. 19, pp. 241-254, 1999.
- [4] Z. Czarnul, "Novel MOS resistive circuit for synthesis of fully integrated continuous-time filters," *IEEE Trans. Circuits Syst.*, vol. 33, pp. 718-721, 1986.
- [5] S. A. Mahmoud and I. A. Awad, "New CMOS Balanced Output Transconductor and Application to Gm-C Biquad Filter," in *Proc. IEEE Int. Sym. Circuits Syst.*, 2003, pp. 385-388.
- [6] J. Wu and E. I. El-Masry, "Design of current-mode ladder filters using coupled-biquads," *IEEE Trans. Circuits Syst. II*, vol. 45, pp. 1445-1454, 1998.