A HIGH-DRIVE FULLY DIFFERENTIAL CURRENT MODE OPERATIONAL AMPLIFIER PROVIDING HIGH OUTPUT IMPEDANCE AND FILTER APPLICATION

Mustafa Altun Hakan Kuntman
e-mail: altunmus@itu.edu.tr *e-mail: kuntman@itu.edu.tr*
Istanbul Technical University, Faculty of Electrical and Electronics Engineering, Electronics and Communication Engineering Department, 34469, Maslak, Istanbul, Turkey

Key words: Current-mode circuits, current-mode operational amplifier

ABSTRACT

In this study, fully differential CMOS current-mode operational amplifier (COA) which provides high drive capability and output impedance is presented. The proposed COA is operated under ±1.5 V voltage supplies and designed with 0.35-µm CMOS process. As using class AB input and output stages, the amplifier can drive a 1kΩ load resistance with a maximum bipolar output current of about 350 µA while the quiescent current of all the branches are only 20 µA. Furthermore it exhibits 100dB DC gain, 85 MHz gain-bandwidth product and 6.1 GΩ output resistance. Finally, a second order notch filter is realized to demonstrate the performance of the proposed COA.

I. INTRODUCTION

Compared to the voltage-mode counterparts, current-mode circuits are preferred especially for their wider bandwidth, lower power consumption and larger dynamic range [1, 2]. Current-mode operational amplifier (COA) is one of the most important current-mode devices and it is the exact current-mode counterpart of the traditional voltage-mode amplifier (VOA). It means that almost all VOA-RC analog circuits can be alternatively implemented as COA-RC ones by using adjoint network principle [3].

The circuit symbol of fully differential COA is reported in Figure 1. COA ideally exhibits zero input resistance and infinite output resistance and current gain.

Differential signalling has many advantages such as; better noise performance, reduced even-odd harmonics and increased dynamic range. However limited number of the COA designs is fully differential in the literature [4 - 6]. Unfortunately, these COA's do not offer both high drive capability and wideband operation, crucial point of current-mode circuits.

In continuous-time filter design, high output impedance current-mode active devices are needed to enable filtering at low frequencies and reduce filtering errors [7, 8]. As many COA-based filters are presented in the literature [9 - 11], it would be very useful to design a COA with very high output impedance.

In this paper, high-drive high-output impedance COA is presented. Both the input and output stages present class-AB operation which enables high drive capability with low quiescent current. At the output stage of the proposed COA instead of simple cascode one regulated cascode (RGC) [12] stage is used to achieve very high output resistance.

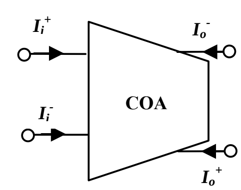

Figure 1. Circuit symbol of fully differential COA

II. PROPOSED COA

Figure 2 shows the CMOS realization of the proposed two-stage COA with the transistor dimensions and DC values reported in Table 1 and Table 2 respectively. Both input and output stages operate in class-AB which enables high input-output current swing and drive capability. Input resistance equations of the proposed COA are:

$$r_{in+} \cong \frac{1}{g_{m5} + g_{m6}} \tag{1}$$

$$r_{in-} \cong \frac{1}{g_{m3} + g_{m4}} \tag{2}$$

Compensation capacitance (Cc) is inserted at the high impedance node series with M13 which operates like a resistance. M13 is modelled with the resistance - Rc.

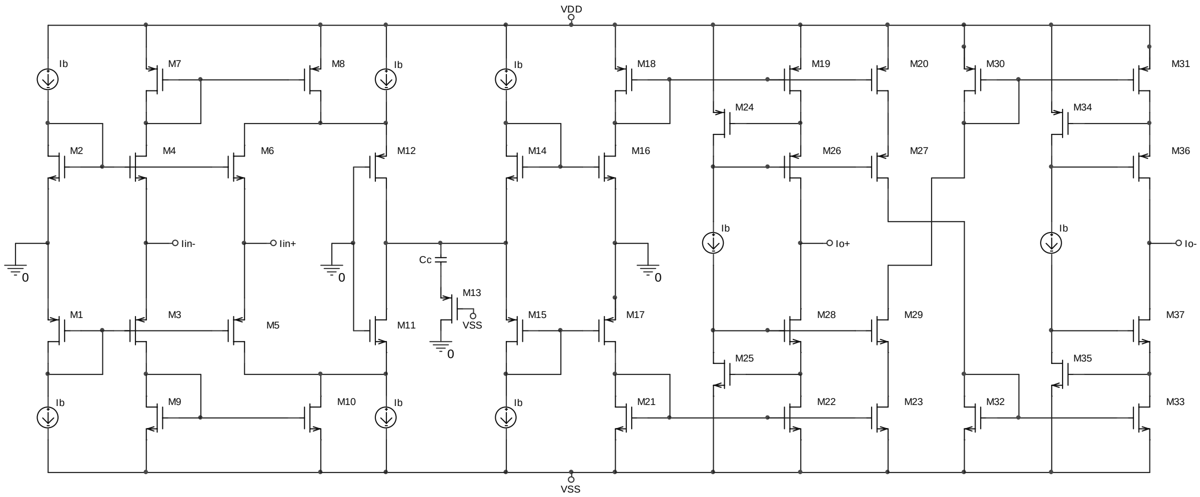

Figure 2. Schematic of the proposed COA

At the output stage, by using regulated cascode structure output resistance values are improved and obtain nearly $g_m r_o$ times higher values compared to the those of simple cascode one. Output resistance equation of the proposed COA is:

$$r_{out+} = r_{out-} \cong \left[\frac{g_{ds26} g_{ds19} g_{ds24}}{g_{m26} g_{m24}} + \frac{g_{ds28} g_{ds22} g_{ds25}}{g_{m28} g_{m25}} \right]^{-1} \quad (3)$$

DC current gain and gain-bandwidth product of the proposed COA are given by (4) and (5) respectively.

$$A_i(0) \cong \left[g_{m16} + g_{m17} \right] \left[\frac{g_{ds12} g_{ds8}}{g_{m12}} + \frac{g_{ds11} g_{ds10}}{g_{m11}} \right]^{-1} \quad (4)$$

$$f_{GBW} \cong \frac{1}{2\pi} \frac{g_{m16} + g_{m17}}{Cc} \quad (5)$$

III. COA-BASED NOTCH FILTER REALIZATION

As an application example, COA-based notch filter (band-stop) is offered. Shown in Figure 3, single COA is used for realization and matching conditions are selected $C_2=2C_1$, $R_1=2R_2$.

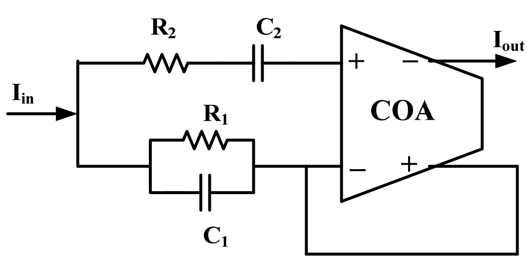

Figure 3. COA-based notch filter topology.

The node analysis of the circuit of Figure 3 yields current transfer function as follows

$$A(s) = \frac{i_{out}}{i_{in}} = \frac{s^2 + \frac{1}{4R_2^2 C_1^2}}{s^2 + s\frac{2}{R_2 C_1} + \frac{1}{4R_2^2 C_1^2}} \quad (6)$$

IV. SIMULATION RESULTS

A. Simulation results of the proposed COA

Simulations were performed with SPICE using the BSIM3v3 model parameters of an 0.35µm n-well CMOS process. Transistor threshold voltages are 0.5 V for NMOS and -0.7 V for PMOS.

The frequency response of the loop-gain of the amplifier is reported in Figure 4. The dc loop-gain is 100 dB, the gain-bandwidth product exceeding 80 MHz and the phase margin is greater than 60˚.

Table 1. Transistor dimensions

Transistors	**W(µm)/L(µm)**
M2, M4, M6, M14 M15, M16, M17, M28, M28, M37	20/0.7
M1, M3, M5, M18, M19, M20, M24, M26, M27, M30, M31, M34, M36	30/0.7
M21, M22, M23, M25, M32, M33, M35	10/0.7
M7, M8	30/1
M9, M10	10/1
M11	20/1.4
M12	40/1.4

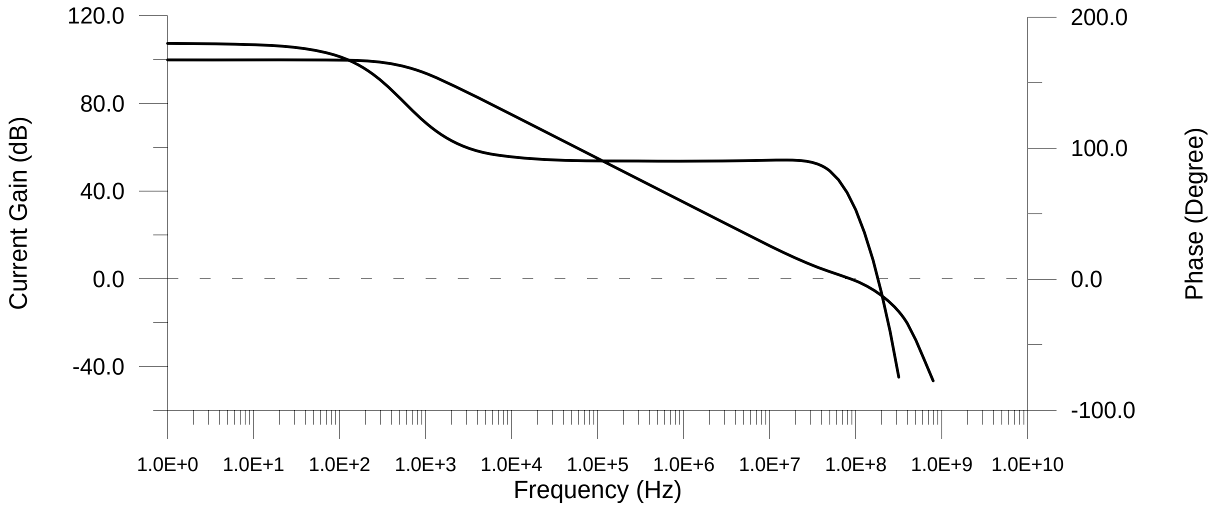

Figure 4. Open-loop frequency response of the COA

Table 2. DC values of the COA

Parameter	Value
$V_{DD} - V_{SS}$	±1.5 V
Ib	20μA

The input-output transcharacteristic in unity-gain configuration, with a load resistance of 1 kΩ is depicted in Figure 5, where a maximum achievable output current of about 350 μA is clearly shown. A good power-conversion is therefore obtained since the quiescent current in each branch is only of 20 μA (Ib=20μ).

The transient response to a step input current of ±200μA is shown in Figure 6. As we neglect the outer capacitances, compensation capacitance (Cc) dominates the slew rate performance of the COA. As Cc is selected 1.5 pF, it also means that adding output capacitance not bigger than 1.5 pF does not considerably worsens the speed of the proposed COA.

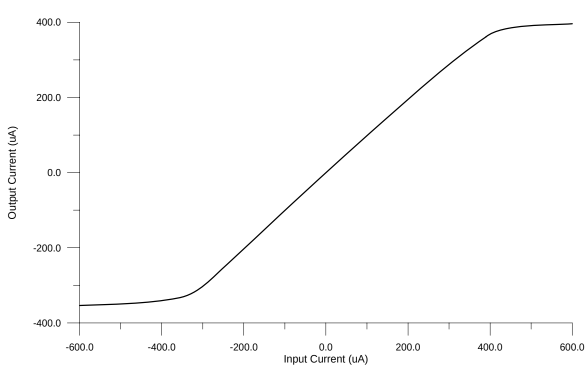

Figure 5. Input-output transcharacteristic of the amplifier in unity-gain configuration

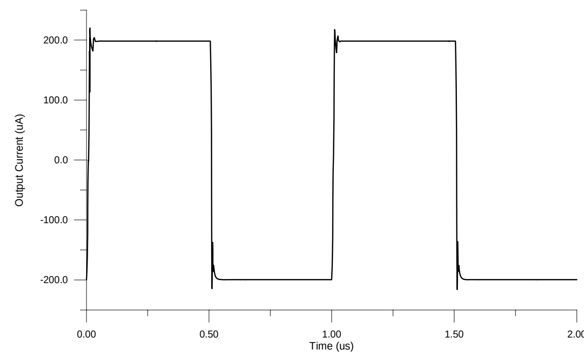

Figure 6. Response of the COA in unity-gain feedback to a ±200 μA input step (f=1MHz)

The main performance of the COA is summarized in Table 3. Note that with using impedance improvement, output resistance values become very high - 6.1 GΩ.

Table 3. Performance parameters of the COA

Parameter	Value
Power Dissipation	0.72 mW
Open-Loop Gain	100 dB
GBW	85 MHz
Phase Margin (Cc=1.5p Rc=2.2kΩ)	62˚
Output Voltage Range	±1 V
Output Current Range	±250 μA
Slew Rate	100uA/ns
Input Resistance (n, p)	1.6 kΩ
Output Resistance	6.1 GΩ
Input Voltage Offset (n,p)	≈ 0.1mV

B. Simulation results of the COA-based filter

The following values are selected to realize a COA based band-stop filter. Quality factor (Q) is 1/4, center frequency is ≈ 400 kHz and element values in the circuit are chosen as $R_2 = R_1/2 = 10\ k\Omega$, $C_1 = C_2/2 = 20\ pF$.

As shown in Figure 7, simulated and ideal filter responses are almost same up to ≈ 10MHz.

Fig. 8 explains the transient characteristic of the filter. Up to nearly 700 µA peak to peak input signal value, THD is small enough to allow band-stop filter work properly.

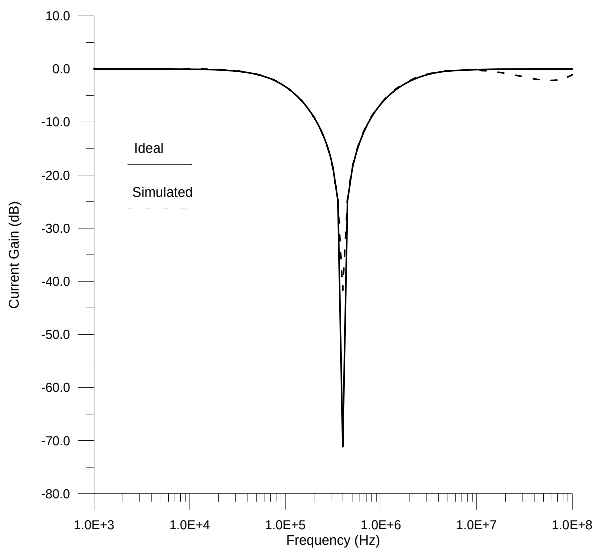

Figure 7. Simulated and ideal band-pass filter responses

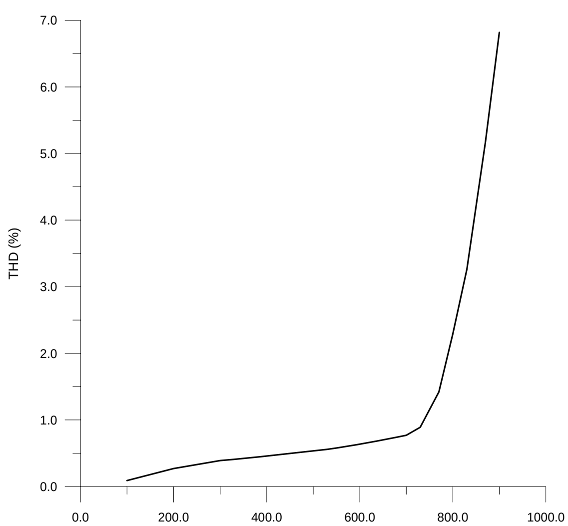

Figure 8. Total Harmonic Distortion (THD) values of the filter versus input peak to peak current at 10 kHz frequency with R_L=1kΩ

V. CONCLUSION

In this work, a high performance fully differential COA is presented. High current swing range is achieved both for input and outputs of the proposed COA which means high-drive capability. Furthermore, very high output resistance is obtained by modifying simple cascode output stage. The proposed COA also offers 85 MHz GBW and 100dB DC gain. As an application example, a new COA-based 2^{th} order band-stop filter is proposed. Simulation results of the filter agree with the theoretical analysis demonstrating accuracy of the proposed fully differential COA.

REFERENCES

1. G. Palmisano, G. Palumbo, S. Pennisi, CMOS Current Amplifiers, Boston MA:Kluwer Academic Publishers, 1999.
2. C. Toumazou, F. J. Lidgey, D. G. Haigh, Analog IC Design: The Current-Mode Approach. London- Peter Peregrinus Ltd, 1990.
3. G. W. Roberts, A. S. Sedra, Adjoint Networks Revisited, Proc. ISCAS, vol. 1, pp. 540-544, 1989.
4. T. Kaulberg, A CMOS Current-Mode Operational Amplifier, IEEE J. Solid-State Circuits, Vol.28, No.7, pp. 849-852, July 1993.
5. K. H. Cheng, H. C. Wang, Design of Current Mode Operational Amplifier with Differential Input and Differential Output, Proceedings of IEEE International Symposium on Circuits and Systems, Hong Kong, pp. 153-156, 1997.
6. S. Jun, D. M. Kim, Fully Differential Current Operational Amplifier, Electronics Letters, vol. 34, pp. 62-63, 1998.
7. H. Khorramaraoi, P. R. Gray, High-frequency CMOS Continues Time Filters, IEEE J, Solid Slate Circuits, SC-19, (6), pp. 939-948, 1984.
8. A. Zeki, H. Kuntman, High-Output-Impedance CMOS Dual-Output OTA Suitable for Wide-Range Continuous-Time Filtering Applications, Electronics Letters, 16, pp. 1295-1296, 1999.
9. G. Souliotis, A. Chrisanthopoulos, L. Haritantis, Current Differential Amplifiers: New Circuits and Applications, Int. J. Circ. Theor. Appl., vol. 29:6, pp. 553 – 574, 2001.
10. S. Kilinc, U. Cam, Current-Mode First-Order Allpass Filter Employing Single Current Operational Amplifier, Journal of Analog Integrated Circuits and Signal Processing, pp. 4147-4153, 2004.
11. M. Altun , H. Kuntman, A Wideband CMOS Current-Mode Operational Amplifier and Its Use for Band-Pass Filter Realization, Proceedings of Applied Electronics, Pilsen. pp. 3-6, 2006.
12. E. Sackinger, W. Guogbniiuhl, A High Swing High Impedance MOS. Cascode Circuit, IEEE J. Solid Statd Circuits, SC-25, (I), pp. 289-298, 1990.