A CMOS OTA FOR VOLTAGE CONTROLLED SIGNAL PROCESSING APPLICATIONS

QIN SHICAI and RANDALL L. GEIGER
Texas A&M University
Department of Electrical Engineering
College Station, Texas 77843

ABSTRACT

A new CMOS OTA is introduced. The OTA is characterized by an unmatched differential pair at the input. It has a wide linear input/output relationship over a large range of external dc bias currents. Computer simulations indicate that the OTA is useful in voltage-controlled filter applications in which the characteristic frequency can be varied over nearly four decades by adjusting an external dc bias current.

1. INTRODUCTION

Operational Transconductance Amplifiers (OTA) lend themselves to a host of linear and nonlinear applications [1]. The inherent nonlinear transfer characteristics of MOS differential pairs, which are used for the input stage in conventional OTAs, limit their linear input range to from a few tens to a few hundreds of mV. Some research has recently been done to extend the linear input voltage range [2] - [4]. This paper presents a new OTA architecture which adopts unmatched differential pairs as the input stage. As a result, the dynamic range is extended greatly beyond that attainable with conventional OTAs. Computer simulations of second-order current-controlled filter utilizing the new OTAs indicate that the practical adjustable frequency range is nearly four decades.

2. CIRCUIT PRINCIPLE AND ARCHITECRURE

The linear input range of a traditional MOS OTA is very narrow. If the input of a conventional OTA is preceeded by a special circuit which possesses large input dynamic range and attenuates the input signal linearly to $\pm$50mV or less, then the whole circuit will act as an OTA with improved input swing capabilities. A special attenuation circuit which uses unmatched source-coupled pairs is introduced in this paper.

Fig. 1 shows two unmatched pairs consisting of M1/M2 and M3/M4 respectively. Assume the MOSFETs are characterized by the ideal square-law characteristics and that the devices are sized according to the relationship $K_2 = nK_1$ where K_1 and K_2 are the transconductance paramaters of M1 and M2 respectively and the paramater n characterizes the mismatch and is equal to $\frac{W_2}{L_2}\frac{L_1}{W_1}$. It follows that if $V_{T1} = V_{T2} = V_T$, then

$$I_1 = K_1 \left(V_{GS_1} - V_T\right)^2 \tag{1}$$

$$I_2 = nK_1 \left(V_{GS_2} - V_T\right)^2 \tag{2}$$

$$V_i = V_{GS_1} - V_{GS_2} \tag{3}$$

and

$$I_1 + I_2 = I_{ss} \tag{4}$$

Solving these equations, we obtain for $V_i > 0$

$$I_1 = \frac{I_{ss}}{1+n} + \frac{n(n-1)}{(1+n)^2}K_1V_i^2 + \frac{2nK_1V_i}{1+n}\sqrt{\frac{I_{ss}}{(1+n)K_1}}\sqrt{1-\frac{nK_1V_i^2}{(1+n)I_{ss}}} \tag{5}$$

$$I_2 = \frac{nI_{ss}}{1+n} - \frac{n(n-1)}{(1+n)^2}K_1V_i^2 - \frac{2nK_1V_i}{1+n}\sqrt{\frac{I_{ss}}{(1+n)K_1}}\sqrt{1-\frac{nK_1V_i^2}{(1+n)I_{ss}}} \tag{6}$$

The relationships between I_1, I_2 and V_i for n=8.125, $\frac{W_1}{L_1} = \frac{8}{13}$, $I_{SS} = 100\mu A$ and $V_T = 0.827V$ are shown in Fig. 2. Comparing with those of matched pairs, these curves have two noteworthy features: large offset voltage and a region of greatly improved linearity. So, if we connect two unmatched pairs as shown in Fig. 1 and take $(I_1 - I_3)$ as the output current, we obtain a transfer curve with wide linear input range, as shown in Fig. 2.

Fig. 3 is a diagram of the complete OTA. Unmatched differential pairs, M1/M2 and M3/M4, constitute the first part of the OTA. Drain currents of M1 and M3 are changed into voltage signals by active resistors (M9/M10 and M11/M12) [3]. After level shifting, these voltage signals enter a conventional OTA.

In order to reduce output offset voltage caused by channel length modulation effects and increase the output impedence, the conventional OTA uses the stacked output structure [5]. The whole OTA circuit consists of 32 MOS transistors and the active chip area is $416 \times 368(\mu M)^2$

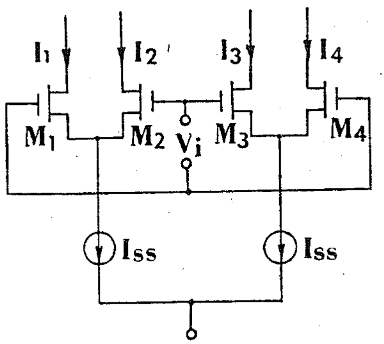

Fig. 1 Input Stage of Unmatched Source-coupled Pairs

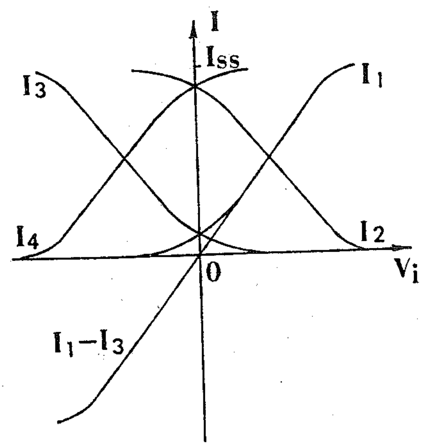

Fig. 2 Transfer Characteristics of Unmatched Pair

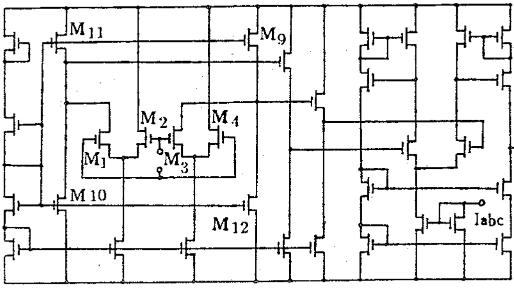

Fig. 3 Complete OTA

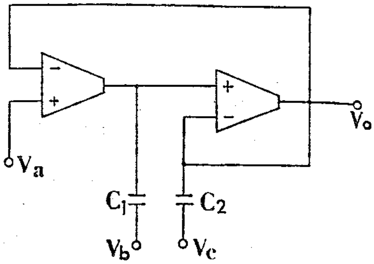

Fig. 4 OTA Filter Structure

3. SIMULATION RESULTS

The characteristics of this OTA have been simulated by SPICE. For a $\pm$ 3V input voltage (supply voltage is $\pm 5V$) and $1n$ A — 100μ A controlled currents, I_{abc}, the nonlinear errors the of transfer curves are less than $\pm 1.18\%$ relative to the full scale output current corresponding to $|V_i| = 3V$. The input power dissipation, P_w, depends on I_{abc}. When $I_{abc} \leq 1\mu$A, $P_w = 2.13$mW; when $I_{abc} = 100\mu$A, $P_w = 4.05$mW. The -3dB bandwidth and transconductance are I_{abc} dependent. When I_{abc} varies from $1n$ A to 10μA, f_{-3dB} varies from 1kHz to 1.5MHz, gm varies from 9.6×10^{-11} mho to 2.7×10^{-6} mho.

A second-order Butterworth filter [1] comprised of two of these OTAs and two capacitors (see Fig. 4) was simulated on SPICE. The major results follow:

LP and HP : $C_1 = 2$pF, $C_2 = 1$pF. When I_{abc} varies from 3nA to 10μ A, the characteristic frequency f_o changes from $25H_z$ to $100\text{k}H_z$.

BP: $C1 = 2$pF, $C2 = 1$pF: When I_{abc} varies from 3nA to 10μ A, the peak frequency changes from $f_o = 25H_z$ to $100\text{k}H_z$

If $C1 =$10pF, $C2 =$ 5pF, then for $I_{abc} = 3n$ A, f_o is $6H_z$.

Both the OTA and the filter circuit have been submitted to MOSIS for fabrication. Experimental results will be presented in the near future.

REFERENCES

1. R.L. Geiger and E. Sánchez-Sinencio, IEEE, CD-1, No. 2, 70(1985)

2. A. Nedungadi and T.R. Viswanathan, IEEE, CS-31, No. 10, 891(1984)

3. Mark Van Horn and R.L. Geiger, MS Thesis, Texas A&M University, Dept. of Electrical Engineering, (1985)

4. David Soo and R. Meyer, IEEE, SC-17, 1174(1982)

5. R.J. Hurst, R.W. Broderser, IEEE, SC-19, 1022 (1984)