TRANSIMPEDANCE TYPE SIGNAL PROCESSING USING OPERATIONAL TRANSRESISTANCE AMPLIFIER (OTRA)

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ABSTRACT

Operational transresistance amplifier (OTRA) is an inherently suitable active building block for transimpedance type signal processing because of its current input / voltage output nature. It is due to the fact that both input and output terminals of OTRA are characterized by low impedance. In this paper, we present an OTRA based transimpedance type biquadratic filter configuration. It realizes all five different filtering functions, namely low-pass, high-pass, band-pass, notch and all-pass. The configuration can be made fully integrated based on MOS-C realization by making use of current differencing and internally grounded inputs of OTRA.

I. INTRODUCTION

Many sensors give current signal information at their outputs related to the quantity they measure. In those cases, it is needed to transform the current signal into voltage if voltage mode signal processing is going to be carried out at the following stages. Transimpedance type signal processing allows accomplishing these two steps, i.e. converting into voltage signal and then voltage mode signal processing, at the same time. By this way, the number of active and passive elements used in such circuits can be reduced drastically.

Operational transresistance amplifier (OTRA) is an important active element in analog integrated circuits and systems. It is very suitable for transimpedance type signal processing since it inherently functions in this mode. Both input and output terminals of OTRA are characterized by low impedance, thereby eliminating response limitations incurred by capacitive time constants. The input terminals are internally grounded leading to circuits that are insensitive to the stray capacitances. Thus, it is possible to obtain very accurate transfer functions by using OTRA in contrast to its unity gain active device counterparts. Furthermore, it has been shown that the differential current input nature of this device considerably simplifies the implementation of MOS-C analog integrated circuit [1].

The OTRA is commercially available from several manufacturers under the name of current differencing amplifier or Norton amplifier. Recently, it has started to gain considerable attention with the introduction of several high performance CMOS OTRA realizations [1-5], which are simpler and more efficient than the commercially available ones.

Many applications of OTRA have been reported in the literature [1-12]. Most of them are based on voltage mode operation. Only in [12] an OTRA based transimpedance type first-order all-pass filter is presented. However, the input current source of this circuit is not applied to one of the input terminals of OTRA, which are at ground potential. In this paper, we present a transimpedance type biquad configuration, which enjoys both low input and output impedances. Therefore, it is very convenient to apply current as the input and take voltage as the output.

II. BASIC TRANSIMPEDANCE TYPE SIGNAL PROCESSING BLOCKS WITH OTRA

The port relations of OTRA, circuit symbol of which is shown in Figure 1, can be characterized by the following matrix form

$$\begin{bmatrix} V_p \\ V_n \\ V_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_z \end{bmatrix} \tag{1}$$

where R_m is the transresistance of OTRA.

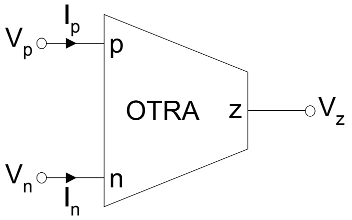
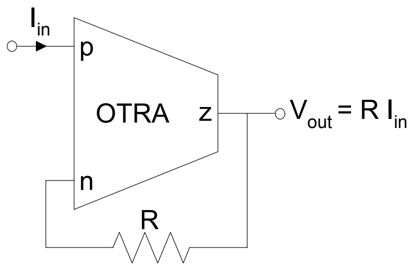


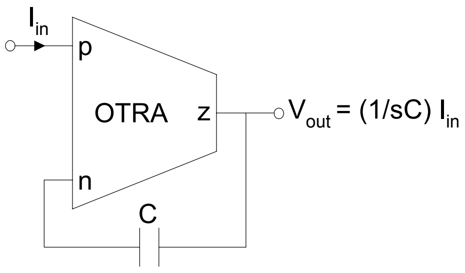
Figure 1. Circuit symbol of OTRA

Since input terminals of OTRA are internally grounded, most effects of parasitic capacitances at the input disappear. For ideal operation, the transresistance (R_m) approaches infinity forcing the input currents to be equal. Thus the OTRA must be used in a feedback configuration in a way that is similar to the classical op-amp [1].

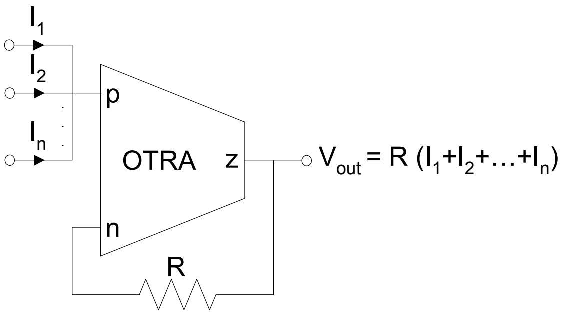
Basic transimpedance type signal processing blocks, i.e. amplification, integration and summation, can simply be realized with OTRA as shown in Figure 2. Note that all of these blocks, even the one for summation, need only one passive element, either a resistor or a capacitor. Most of the other active elements would use at least two passive elements for realizing these basic signal processing blocks. On the other hand, both input and output terminals of the blocks in Figure 2 are at low impedance. Therefore, it is very convenient to apply current inputs and take voltage outputs.



(a) amplification



(b) integration



(c) summation

Figure 2. Basic transimpedance type signal processing blocks with OTRA

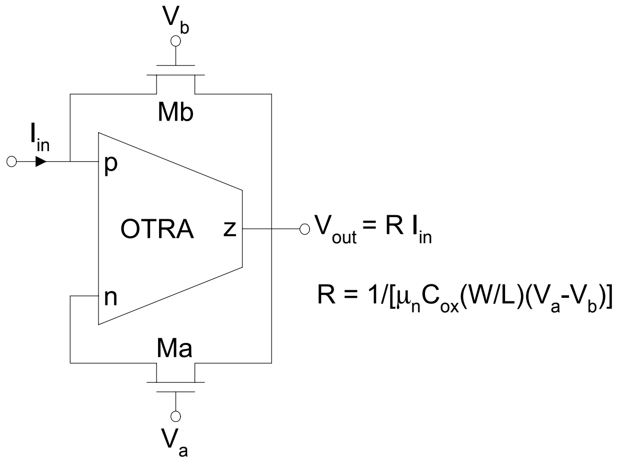


Figure 3. OTRA based transimpedance type amplification with MOS-C realization

It is important to reduce the area of the integrated circuits. In modern CMOS technology, resistors and capacitors occupy large areas on the chips. In this respect, it could be attractive to implement the resistors using transistors, which would reduce the size considerably.

It has been shown earlier [1] that the internally grounded and current differencing input terminals of OTRA make MOS-C realization possible. That is, the resistors connected to the input terminals of OTRA can easily be implemented using MOS transistors with complete non-linearity cancellation [1]. The resulting circuit will consists of only MOS transistors and capacitors, hence is called MOS-C realization. This will save a significant amount of chip area and lead to circuits that are electronically tunable. That is, the resistance values and hence the related filter parameters can be adjusted by simply changing the bias (gate) voltages. The fully integrated version of the OTRA based transimpedance type amplifier block is shown in Figure 3. Note that the equivalent resistance value, which appears between negative input terminal and output terminal of OTRA, is given as

$$R = \frac{1}{\mu_n C_{ox}(W/L)(V_a - V_b)} \qquad (2)$$

where μ_n is the electron mobility, C_{ox} is the oxide capacitance per unit gate area, W is the effective channel width, L is the effective channel length and V_a and V_b are the gate voltages.

III. TRANSIMPEDANCE TYPE FULLY INTEGRATED BIQUADRATIC FILTER CONFIGURATION USING OTRA

In [13] a general signal flow graph for the second-order transfer function synthesis is given. This graph is modified for the OTRA based transimpedance type signal processing. The resulting current input / voltage output structure is shown in Figure 4 as a block diagram.

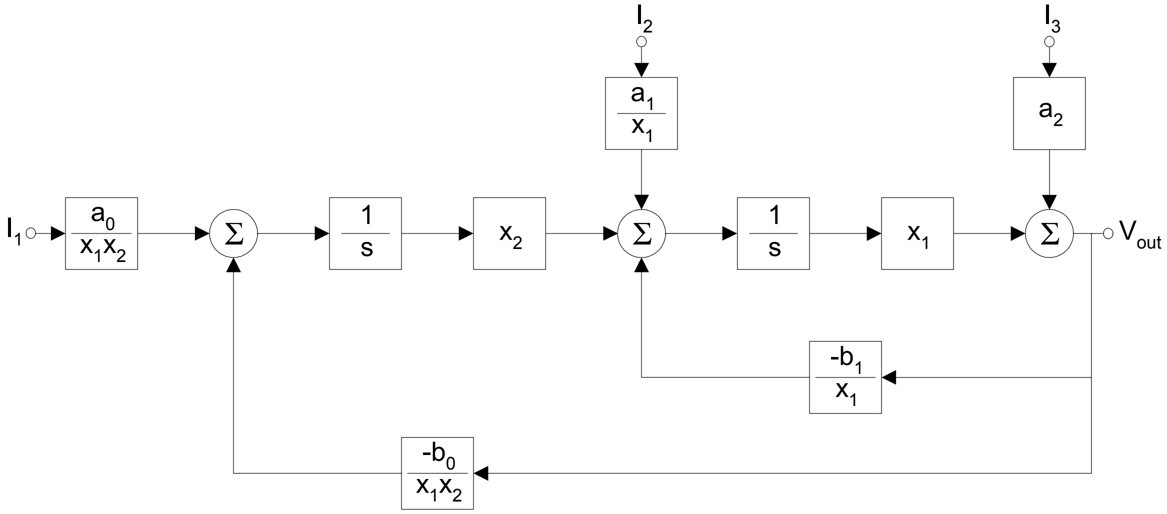


Figure 4. Block diagram for the synthesis of transimpedance type biquadratic transfer function

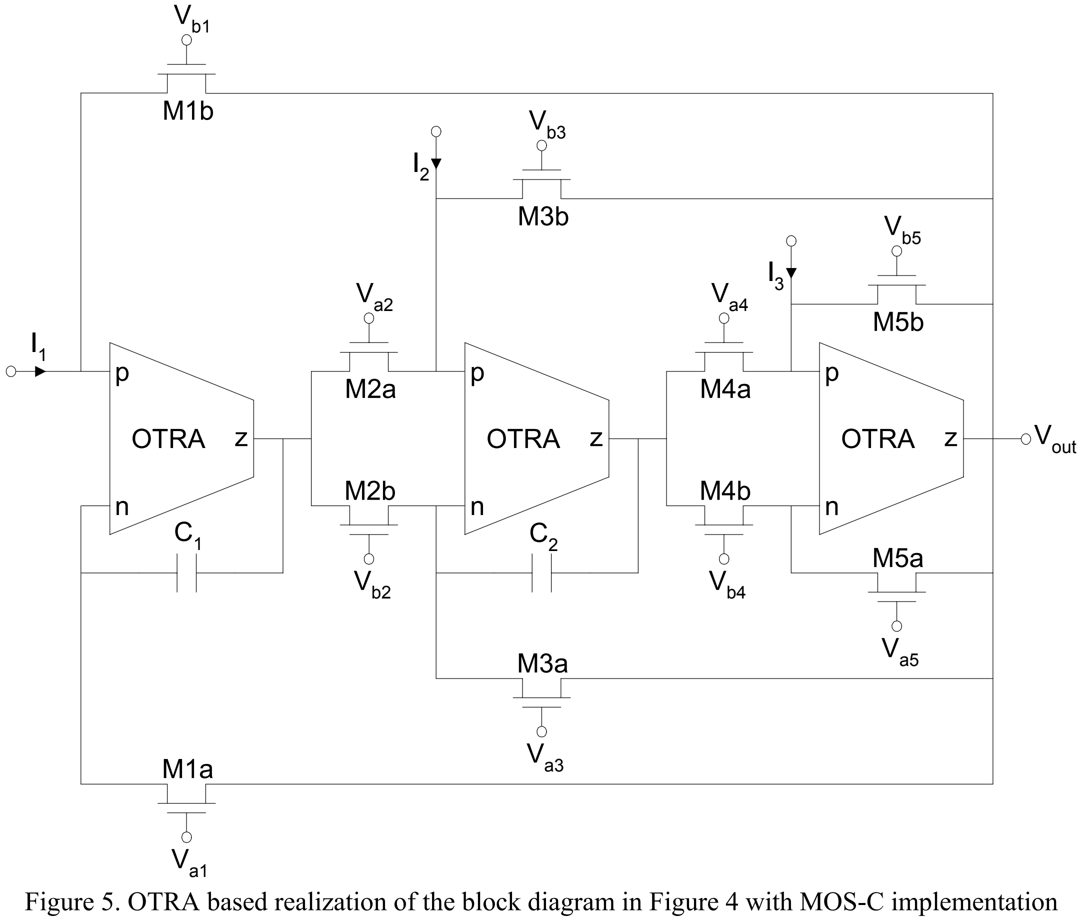


Figure 5. OTRA based realization of the block diagram in Figure 4 with MOS-C implementation

For the block diagram of Figure 4 output voltage is

$$V_{out} = \frac{a_2 s^2 I_3 + a_1 s I_2 + a_0 I_1}{s^2 + b_1 s + b_0} \tag{3}$$

If $I_1 = I_2 = I_3 = I_{in}$, transimpedance transfer function becomes

$$\frac{V_{out}}{I_{in}} = \frac{a_2 s^2 + a_1 s + a_0}{s^2 + b_1 s + b_0} \tag{4}$$

Figure 5 depicts the OTRA based realization of the block diagram in Figure 4. For the circuit of Figure 5, output voltage is

$$V_{out} = \frac{R_5 s^2 I_3 + \dfrac{R_5}{C_2 R_4} s I_2 + \dfrac{R_5}{C_1 C_2 R_2 R_4} I_1}{s^2 + \dfrac{R_5}{C_2 R_3 R_4} s + \dfrac{R_5}{C_1 C_2 R_1 R_2 R_4}} \qquad (5)$$

where $R_i = \dfrac{1}{\mu_n C_{ox} (W/L)(V_{ai} - V_{bi})}$ and i=1, 2, …, 5.

With proper selection of I_1, I_2 and I_3, Equation (5) gives low-pass, high-pass, band-pass, notch (band-stop) and all-pass filtering functions. Table 1 shows the combinations.

The resonant frequency and quality factor are

$$\omega_0 = \sqrt{\frac{R_5}{C_1 C_2 R_1 R_2 R_4}} \qquad (6)$$

$$Q = R_3 \sqrt{\frac{C_2 R_4}{C_1 R_1 R_2 R_5}} \qquad (7)$$

As it is seen from Equations (6) and (7) quality factor can be controlled without disturbing resonant frequency. Also, the sensitivity analysis reveals that sensitivities of filter parameters (Q and ω_0) to the passive component values are all less than unity in magnitude.

IV. SIMULATION RESULTS

To verify the theoretical study, the second-order low-pass (LP), high-pass (HP), band-pass (BP), notch or band-stop (BS) and all-pass (AP) filters are simulated with PSPICE program. In the simulations, a CMOS realization of OTRA [1], which is shown in Figure 6, is used with the same transistor aspect ratios as in [1]. Supply voltages are taken as V_{DD}=2.5V and V_{SS}=-2.5V.

Table 1. Input current source combinations for the filters

Filtering function	I_1	I_2	I_3	Condition
Low-pass (LP)	I_{in}	0	0	-
High-pass (HP)	0	0	I_{in}	-
Band-pass (BP)	0	I_{in}	0	-
Notch (BS)	I_{in}	0	I_{in}	R_1=R_5
All-pass (AP)	I_{in}	-I_{in}	I_{in}	R_1=R_3=R_5

Note that I_i=0 where i=1, 2, 3 means there is no current source connected to relevant node, i.e. it is open circuited.

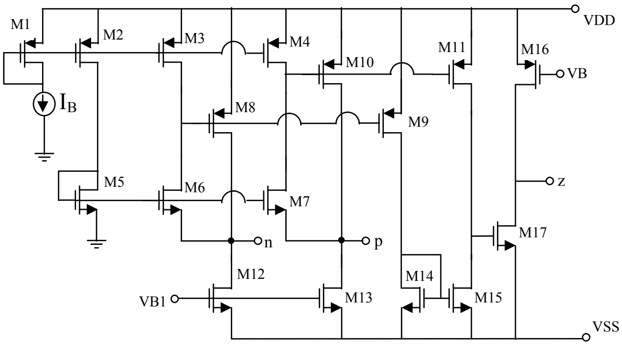


Figure 6. A CMOS realization of OTRA

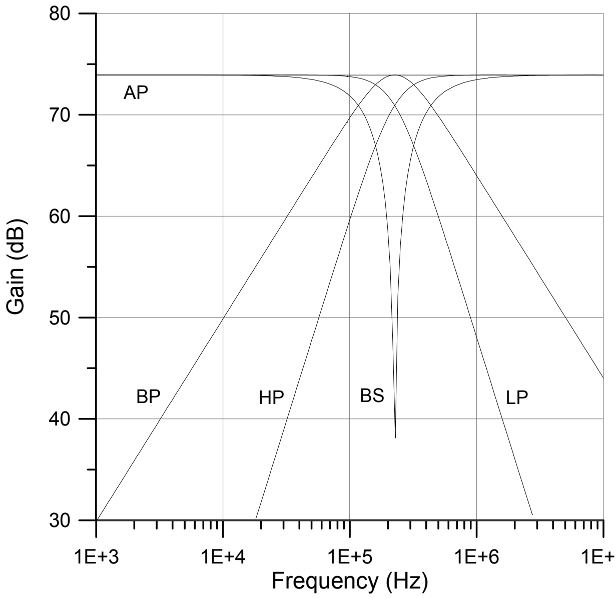


Figure 7. Simulated gain responses for biquadratic filters

In the simulation AMI 1.2µ CMOS technology parameters are used. According to this parameter set, gate oxide thickness is given as T_{ox}=2.96x10^{-8} m. Since the oxide dielectric constant is ε_{ox}=3.46x10^{-11} F/m, oxide capacitance is found as C_{ox}=ε_{ox}/T_{ox}=1.689x10^{-3} F. Electron mobility, μ_n, can be taken as equal to electron low-field mobility, μ_0, for long-channel devices and it is μ_n=μ_0=675.4 cm^2/V.s for AMI 1.2µ technology. In the simulations, we take W_{drawn}=14.4 µm and L_{drawn}=4.8 µm for all transistors realizing the resistors. The effective values for the size of these transistors would be W=W_{drawn}-2$WINT$ and L=L_{drawn}-2$LINT$ where $WINT$=9.276x10^{-7} m and $LINT$=9.091x10^{-10} m. We also take V_{ai}=2.3 V and V_{bi}=1.3 V for all i=1, 2, …, 5. Therefore, all of the resistor values are calculated as R_i≈4.85 kΩ where i=1, 2, …, 5. The capacitor values are taken as C_1=200 pF and C_2=100 pF. From these values, the theoretical resonant frequency is found as f_0≈232 kHz. Figure 7 shows the simulation results for all of the five filters. The simulated resonant frequency is equal to f_0≈229 kHz, which is very close to theoretical one. As it is seen from Equation (5) gain of the filters is equal to $R_5 \approx 4.85$ kΩ for equal resistance values. This corresponds to a theoretical gain of 73.715 dB where the simulated one is 73.925 dB.

V. CONCLUSION

OTRA based transimpedance type analog signal processing is discussed. A general signal flow graph for the synthesis of second-order transfer functions is modified to obtain its transimpedance version. Then, this block diagram is realized using three OTRAs, two capacitors and five resistors. Each resistor is implemented with two NMOS transistors by making use of current differencing and internally grounded input terminals of OTRA. This makes the presented filters electronically tunable, i.e. filter parameters can be adjusted by changing the bias (gate) voltages. On the other hand, the resulting circuits would consume less area on the chip. The theoretical analysis is verified with PSPICE simulations.

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