NOVEL CURRENT-MODE ACTIVE-ONLY ELECTRONICALLY TUNABLE MULTIFUNCTION FILTER USING COAs AND OTAs

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ABSTRACT

In this study, a new current-mode active only multifunction filter is presented. The proposed circuit employs current-mode operational amplifiers as current-mode integrators. OTAs are also used in the circuit to provide electronically tunability. The proposed circuit realizes lowpass, bandpass and highpass responses simultaneously all at high-impedance outputs. Simulation of the circuit is performed using SPICE with 0.5µm MIETEC parameters. Simulation results show the versatility of the circuit.

I. INTRODUCTION

There are a lot of continuous-time filter designs without using external passive elements. These circuits are referred to as active-only filters and use voltage operational amplifiers (VOAs) and operational transconductance amplifiers (OTAs) [1-11].

In active-only filters, finite and complex gain nature of VOAs is used. The open loop gain of a VOA shows the characteristics of a voltage-mode integrator hence permits to design "active-only" topologies.

In all of the active-only filters in the literature, both voltage-mode and current-mode, a voltage-mode operational amplifier (VOA) is used to realize an integrator. These circuits have disadvantages caused from VOAs like

i) VOAs show integrator characteristics between about a few hundred Hertz to a few MHz typically.
ii) VOAs are not suitable to be used in current-mode circuits because; VOAs block the main advantage of current-mode operation, namely high bandwidth.

In this paper, a novel current-mode active-only multifunction filter is presented using current-mode operational amplifiers (COAs) and operational transconductance amplifiers (OTAs). The proposed multifunction filter simultaneously realizes lowpass, bandpass and highpass responses without any matching conditions. The filter characteristics can be electronically tuned using the biasing currents of OTAs. Also, the active sensitivities of filter are low.

II. COMPARISION OF INTEGRATOR-TYPE BEHAVIOURS OF VOLTAGE OAs AND CURRENT OAs

In all of the active-only structures in the literature, a voltage operational amplifier's integrator type behaviour is employed to achieve the desired transfer function. In other words, these active-only filter structures can operate properly in the frequency range in which the VOAs show integrator-type open-loop behaviour. Consider the voltage operational amplifier shown in Figure 1.

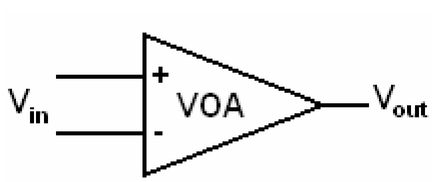

Figure 1. A voltage operational amplifier symbol

The open-loop gain of the VOA of Figure 1 can be expressed as

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{B}{s} \tag{1}$$

Eq. (1) is referred as to integrator-type characteristics. B is the gain-bandwidth product of VOA. Eq. (1) is valid from a hundred Hz to a few MHz. This frequency limit is caused from the parasitic poles formed by the high impedance nodes in the VOA structure. For example consider the simple CMOS VOA topology of Figure 2 given in [9].

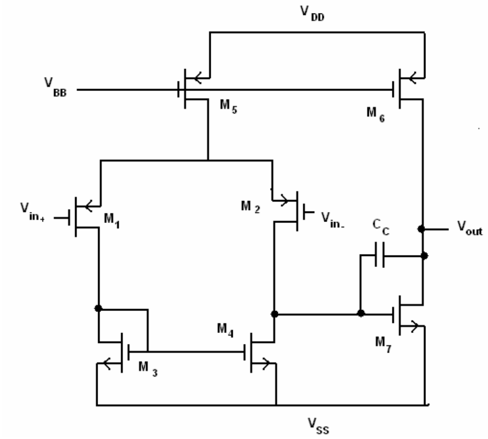

Figure 2. Simple VOA topology [9]

The open-loop characteristic of the circuit of Figure 2 is obtained using SPICE with 0.5µm MIETEC parameters [9]. The supply voltages are taken as ±2.5V and biasing voltage V_{BB} is chosen as 1.67V. The open-loop characteristic is shown in Figure 3.

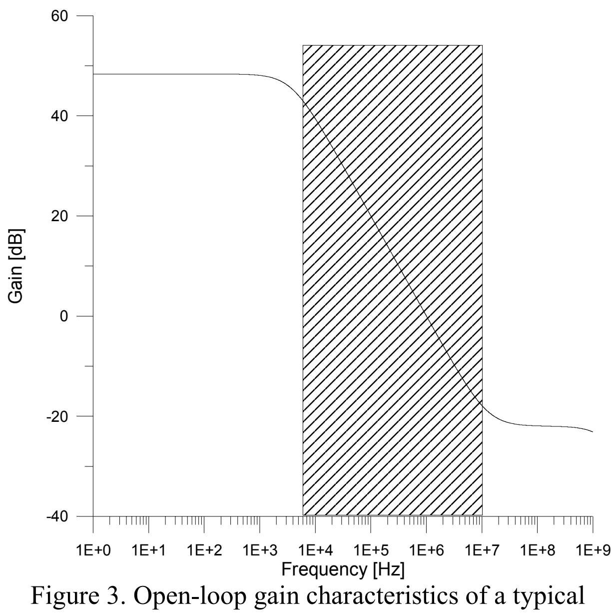

Figure 3. Open-loop gain characteristics of a typical VOA.

As it is seen from Figure 3, VOA shows integrator characteristic in the shaded area which is in the frequency range from 5kHz to 10MHz. In other words, the VOA can be used in active-only filters for this frequency range.

Current-mode dual of VOA is referred as to current operational amplifier [12-16]. Current operational amplifiers are derived to obtain high bandwidth and true current-mode operation in current-mode circuits. The circuit symbol of COA is shown in Figure 4.

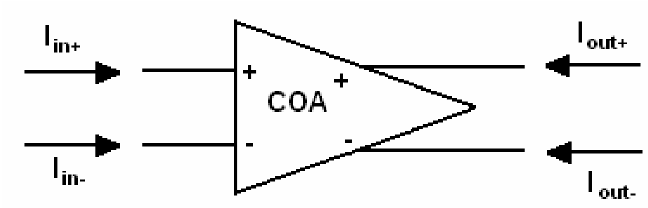

Figure 4. Circuit symbol of a dual output differential current operational amplifier

The open loop gain of the COA can be expressed as

$$A(s) = \frac{I_{out+}(s)}{I_{in+}(s) - I_{in-}(s)} = -\frac{I_{out-}(s)}{I_{in+}(s) - I_{in-}(s)} = \frac{X}{s} \qquad (2)$$

In order to determine the frequency range in which COA can be used as an integrator, the simple COA structure proposed in [16], which is shown in Figure 5 is simulated using SPICE with 0.5µm MIETEC parameters. Supply voltages and biasing voltage is selected as ±2.5V and –1.67V, respectively. The open-loop gain response is shown in Figure 6.

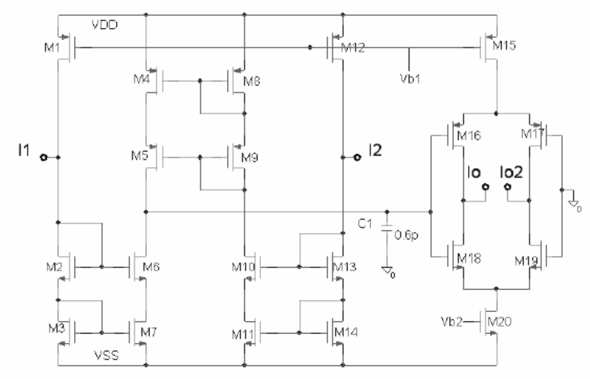

Figure 5. A simple COA structure [16]

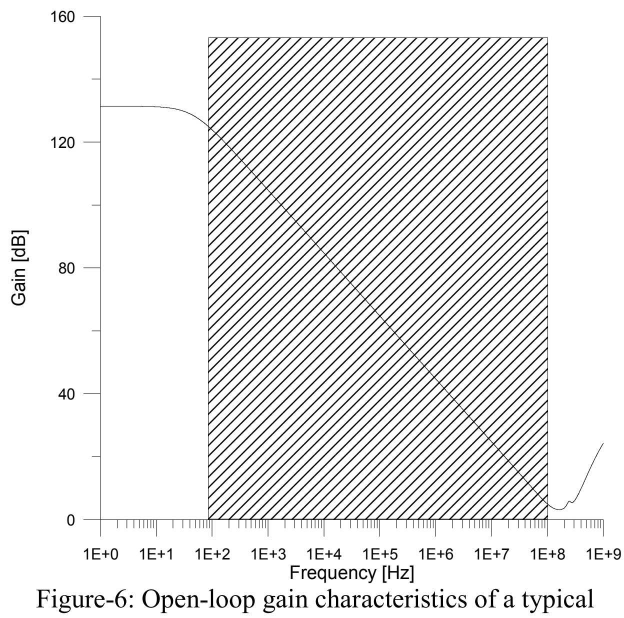

Figure-6: Open-loop gain characteristics of a typical COA.

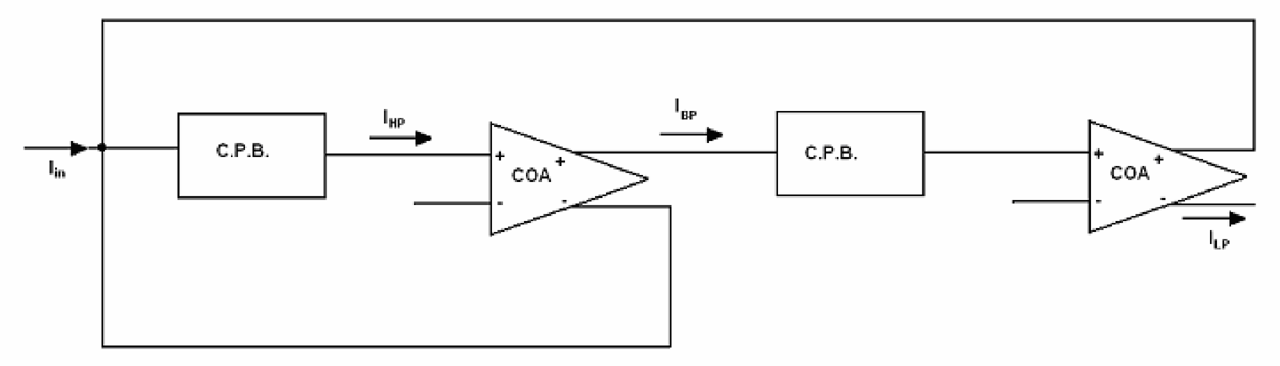

Figure 7. Block diagram of a current-mode multifunction filter

As it is seen from Figure 6, COA shows integrator characteristic in the shaded area which is in the frequency range from 90Hz to 100MHz. In other words, the COA can be used in active-only filters in this frequency range. This is a result of the low impedance nodes in the COA structure. The parasitic poles formed by these low-impedance nodes are at high frequency.

III. CURRENT-MODE MULTIFUNCTION FILTER STRUCTURE

A simple current-mode multifunction structure is shown in Figure 7. In Figure 7, C.P.B. is the Current Proportional Block used for tuning filter parameters electronically. Current proportional block can be realized by the OTA-DO-OTA structure of Figure 8. For the circuit of Figure 8,

$$\frac{I_2}{I_1} = -\frac{I_3}{\imath_1} = \frac{gm_2}{gm_1} = \sqrt{\frac{I_{b2}}{I_{b1}}} \tag{3}$$

if CMOS OTA and DO-OTA are under consideration.

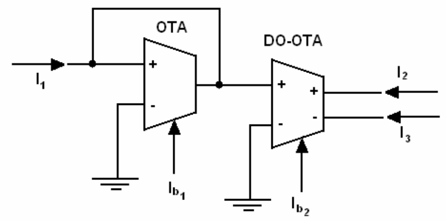

Figure 8. Current proportional block using OTA and DO-OTA

The proposed current-mode filter is shown in Figure 9. In Figure 9, DO-OTA is used to take highpass and bandpass responses from high impedance nodes. Note that lowpass response is also taken from high-impedance node which is the output of COA_2.

IV. DESIGN EQUATIONS OF THE PROPOSED FILTER

If open-loop gains of COA_1 and COA_2 are of the form $\frac{K_1}{s}$ and $\frac{K_2}{s}$, respectively and the C.P.B.'s have the small signal current gains A_1 and A_2, respectively, then highpass, bandpass and lowpass characteristics can be written as

$$\frac{I_{hp}(s)}{I_{in}(s)} = \frac{s^2 A_1}{s^2 + sK_1A_1 + K_1K_2A_1A_2} \tag{4a}$$

$$\frac{I_{bp}(s)}{I_{in}(s)} = \frac{sK_1A_1A_2}{s^2 + sK_1A_1 + K_1K_2A_1A_2} \tag{4b}$$

$$\frac{I_{lp}(s)}{I_{in}(s)} = \frac{K_1K_2A_1A_2}{s^2 + sK_1A_1 + K_1K_2A_1A_2} \tag{4c}$$

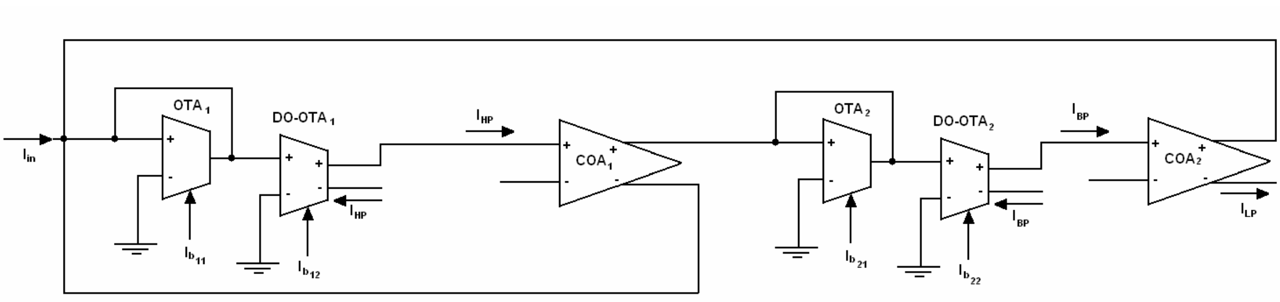

Figure 9. The proposed current-mode active-only multifunction filter

Thus, pole angular frequency and quality factor of the filter can be expressed as,

$$\omega_0 = \sqrt{K_1 K_2 A_1 A_2} \tag{5a}$$

$$Q_0 = \sqrt{\frac{K_2 A_2}{K_1 A_1}} \tag{5b}$$

The sensitivities of the filter are

$$S_{K_1}^{\omega_0} = S_{K_2}^{\omega_0} = S_{A_1}^{\omega_0} = S_{A_2}^{\omega_0} = \frac{1}{2} \tag{6a}$$

$$S_{K_2}^{Q_0} = S_{A_2}^{Q_0} = -S_{K_1}^{Q_0} = -S_{A_1}^{Q_0} = \frac{1}{2} \tag{6b}$$

all of which are low.

V. SIMULATION RESULTS

The proposed filter is simulated using SPICE. The parameters of 0.5μm MIETEC process are used. The COA structure of Figure 5, OTA structure given in [9] and DO-OTA structure of [17] are used in simulations. I_{b12} and I_{b22} are taken as 2μA and 4μA, respectively. Supply voltages are chosen as ±2.5V. Biasing voltage V_{BB} is selected as −1.67V. The compensation capacitors of COAs are 0.6pF. Filter is simulated for different biasing currents of OTAs to verify electronically tunability. Lowpass, bandpass and highpass filter responses are shown in Figures 10 and 11 for $I_{b11}=I_{b21}=7\mu A$, 15μA, respectively.

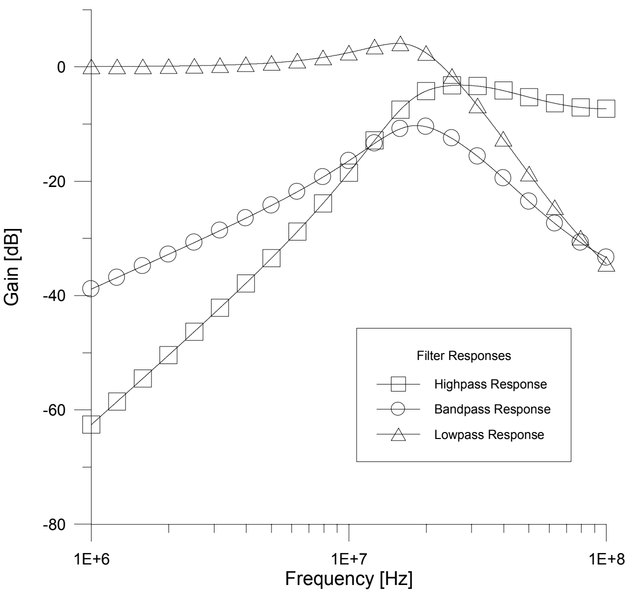

Figure 10. Filter’s lowpass, highpass and bandpass frequency responses for $I_{b11}=I_{b21}=7\mu A$ (pole frequency is 23.068MHz)

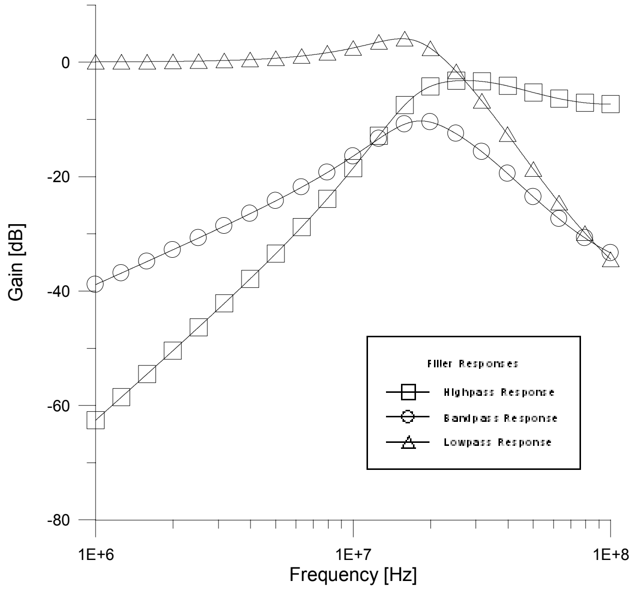

Figure 11. Filter’s lowpass, highpass and bandpass frequency responses for $I_{b11}=I_{b21}=15\mu A$ (pole frequency is 18.281MHz)

As it is seen from Figures 10 and 11, the proposed filter realizes lowpass, bandpass and highpass characteristics. The variation of pole frequency of the filter with biasing currents of OTAs’ is plotted in Figure 12 according to the SPICE simulation results. Figure 12 shows that the pole frequency of the filter can be electronically tuned via biasing currents of OTAs.

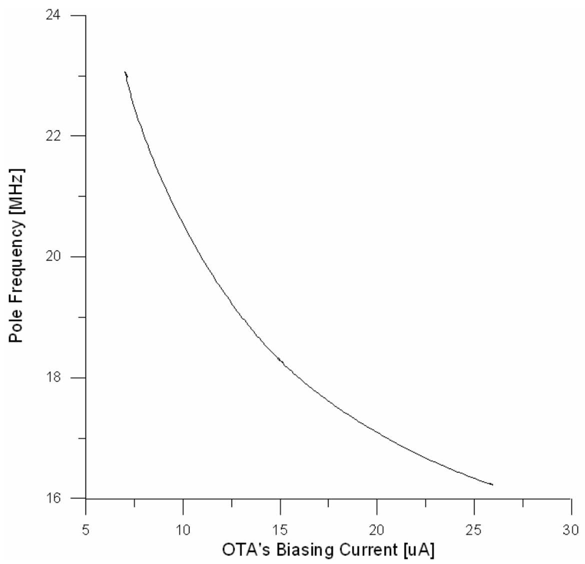

Figure 12. Filter’s pole frequency versus OTAs’ biasing currents $I_{b11}=I_{b21}$

In order to determine the linearity of the circuit, Fourier analysis is performed using SPICE. Total harmonic distortion (THD) is plotted versus input current amplitude at 3MHz in Figure 13.

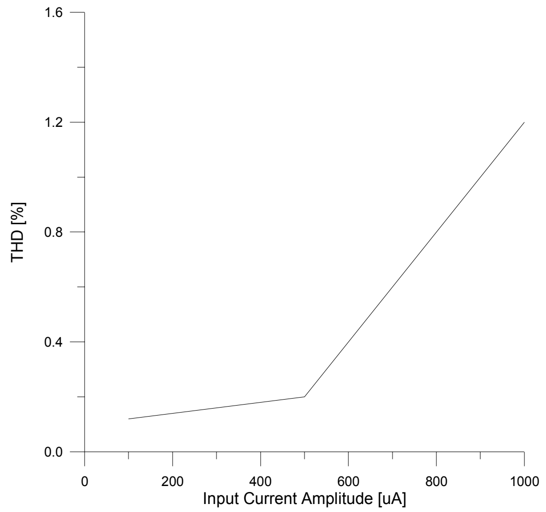

Figure 13. Total harmonic distortion introduced by the filter @ 3MHz

VI. CONCLUSIONS AND FUTURE WORK

In this paper, a novel electronically tunable current-mode active-only multifunction filter is proposed. The novelty of the paper is that current operational amplifiers are used as integrator structures. By using COAs instead of VOAs, true current-mode operation is achieved which brings higher frequency operation range according to previously proposed structures [1-11]. SPICE simulation results of the filter are given. Simulation results show that the proposed filter can be used from 90Hz to a 100MHz as a result of using COAs as current mode integrators instead of using VOAs which can operate typically only up to a 10MHz. The pole frequency of the filter is plotted as a function of control current to verify electronically tunability. Another advantage of the filter is that sensitivities of filter parameters are low. Future work includes the design of active-only filters and active-only immittance simulators using COAs operating at high frequency.

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