Current-Mode Active-Only Universal Bi-Quad Filter Employing CCIIs and OTAs

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***Abstract* – In this study, a new current-mode active-only multifunction filter is presented. The proposed circuit employs parasitic capacitances of CCIIs to realize the integrator part of characteristic. OTAs are also used in the circuit to provide electronically tuneability. The proposed circuit realizes lowpass, bandpass, highpass and bandstop responses simultaneously with high impedance outputs which require no element matching. Simulation of the circuit is performed using SPICE with 0.5µm MIETEC parameters.**

INTRODUCTION

Several continuous-time filter designs without using external passive elements are reported in the literature [1-11]. These circuits are referred to as active-only filters and use voltage operational amplifiers (VOAs) together with operational transconductance amplifiers (OTAs) and current conveyors (CCIIs). 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. However, parasitic capacitances of other elements than VOAs can also be utilized for designing active-only circuits. For example, the terminal impedances of CCIIs are also candidates.

On the other hand, there is an increasing interest in the current-mode active filter design due to advantages of current-mode operation such as higher bandwidth, lower consumption and using less elements, comparing to VM counterparts [8, 11, 12].

In this study, a new active-only filter is presented. It realizes lowpass, bandpass, highpass responses simultaneously. The filter utilizes two current conveyors whose terminal impedances are used as frequency-dependent parameter. Also, there are six OTAs to tune circuit characteristics and output currents from high-impedance nodes. In order to minimize power consumption, the circuit does not use any passive elements.

ACTIVE-ONLY CURRENT-MODE INTEGRATOR USING CCII

Current conveyors are utilized in various types of circuits due to their superior performance and properties such as wider bandwidth, lower power consumption and simple circuit structures, compared to voltage mode elements [13-14]. However, among only-active circuitry published up to now, there is not any usage of CCIIs as a frequency dependent element.

Considering the circuit of Fig. 1a, the macromodel of this circuit can be given as in Fig. 2.

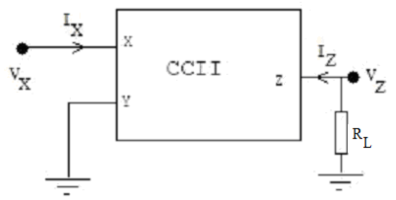

Fig. 1a CCII with a load resistor R_L and grounded Y terminal

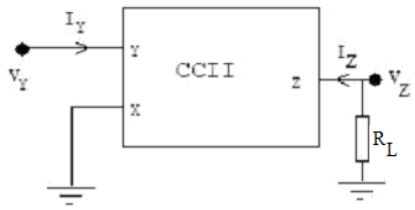

Fig. 1b CCII with a load resistor R_L and grounded X terminal

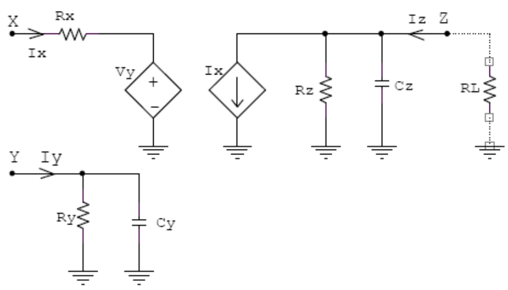

Fig. 2 CCII macromodel with a load resistor R_L

If the Y terminal of CCII is grounded, current transfer ratio is given as

$$\frac{i_z}{i_x} = \frac{1}{R_L C_Z}\left[\frac{1}{s+\omega_Z}\right] \tag{1}$$

If $\omega >> \omega_Z$, then

$$\frac{i_z}{i_x} = \frac{1}{R_L C_Z}\left[\frac{1}{s}\right] = \frac{K}{s} \tag{2}$$

where

$$K = \frac{1}{R_L C_Z} \tag{3}$$

As it can be seen from Eq. 3, a single CCII without any external capacitors can be utilized as a current-mode integrator. Similarly, in case of X terminal of CCII is grounded as shown in Fig. 1b, the macromodel can be drawn as given in Fig. 3 and the current transfer ratio is written as

$$\frac{I_Y}{I_Z} = \frac{K}{s} \tag{4}$$

where

$$K = \frac{1}{R_X C} \tag{5}$$

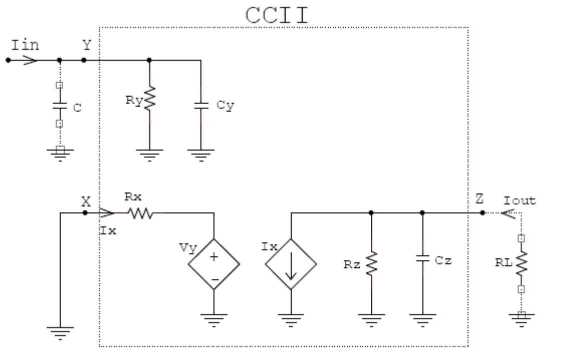

Fig. 3 CCII macromodel with load resistor R_L and parasitic input capacitance C

In Fig. 3, C shows the equivalent capacitance connected to Y terminal of CCII.

PROPOSED ACTIVE-ONLY FILTER CIRCUIT

The proposed filter circuit is shown in Fig. 4. In this circuit, parallel OTAs are used to obtain the lowpass, bandpass, highpass and bandstop responses from high impedance nodes. CCII-1 and CCII-2 are the active-only current-mode integrator blocks.

When the integrator constant of CCII-1 is labeled as K_1 and that of CCII-2 as K_2, then the lowpass, bandpass, highpass and bandstop current responses are given as

$$T_{LP}(s) = \frac{I_{LP}(s)}{I_{in}(s)} = \frac{g_{mb2}K_1K_2}{g_{ma0}s^2 + g_{ma1}K_1 s + g_{ma2}K_1K_2} \tag{6}$$

$$T_{BP}(s) = \frac{I_{BP}(s)}{I_{in}(s)} = \frac{g_{ma1}K_1 s}{g_{ma0}s^2 + g_{ma1}K_1 s + g_{ma2}K_1K_2} \tag{7}$$

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{g_{ma0}s^2}{g_{ma0}s^2 + g_{ma1}K_1 s + g_{ma2}K_1K_2} \tag{8}$$

$$T_{BS}(s) = \frac{I_{BS}(s)}{I_{in}(s)} = \frac{g_{ma0}s^2 + g_{ma2}K_1K_2}{g_{ma0}s^2 + g_{ma1}K_1 s + g_{ma2}K_1K_2} \tag{9}$$

Electronically tuneable pole angular frequency and the quality factor are written as

$$\omega_0 = \sqrt{\frac{g_{ma2}K_1K_1}{g_{ma0}}} \tag{10}$$

$$Q_0 = \frac{1}{g_{ma1}}\sqrt{\frac{g_{ma0}g_{ma2}K_2}{K_1}} \tag{11}$$

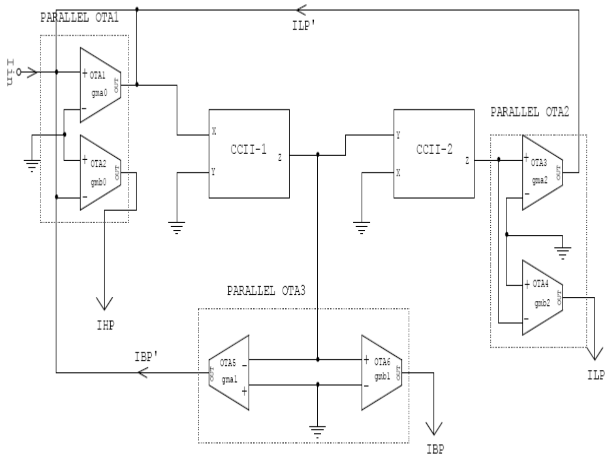

Fig. 4 Proposed current-mode active-only filter using CCIIs and OTAs

The CCII structure shown in Fig. 5 and OTA circuit given in Fig. 6 are used in simulations.

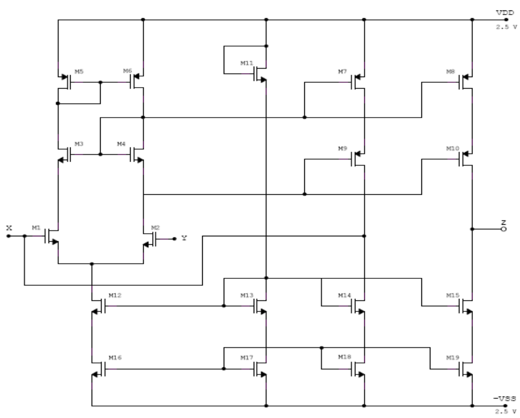

Fig. 5. CCII structure used in simulations

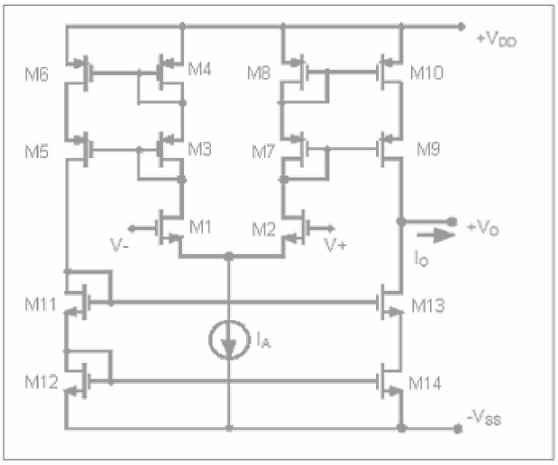

Fig. 6. OTA structure used in simulations

Transistor aspect ratios of CCII and OTA circuits are given in Table 1 and Table 2, respectively.

Table 1. CCII circuit MOS dimensions

Transistor	W(μm)	L(μm)
M1-M4	10	4
M5-M6	25	2
M7-M10	25	1
M11	85	1
M12-M19	55	1

Table 2. OTA circuit MOS dimensions

Transistor	W(μm)	L(μm)
M1-M2	5	1
M3-M10	15	1
M11-M14	10	1

Supply voltages are taken as ±2.5V. MIETEC 0.5 μm CMOS process parameters are used in SPICE simulations.

The obtained filter characteristics for different control currents (I_1 is the control current of OTAs with g_{m1}, I_2 is the control current of OTAs with g_{m2}) are shown in Figs. 7a, 7b and 7c.

Table 3. Pole frequencies of the filter for various control currents

I_0[μA]	I_1[μA]	I_2[μA]	f_0 (MHz)
50	50	50	5.3
100	100	100	5.87
150	150	150	6.2
200	200	200	6.35
250	250	250	6.47
300	300	300	6.58
350	350	350	6.74

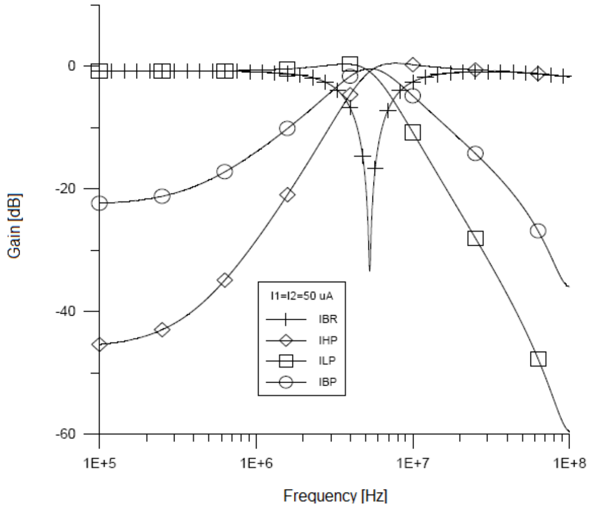

Fig. 7a. Filter characteristics for $I_1=I_2=50$ μA (5.3 MHz pole frequency is obtained from simulations)

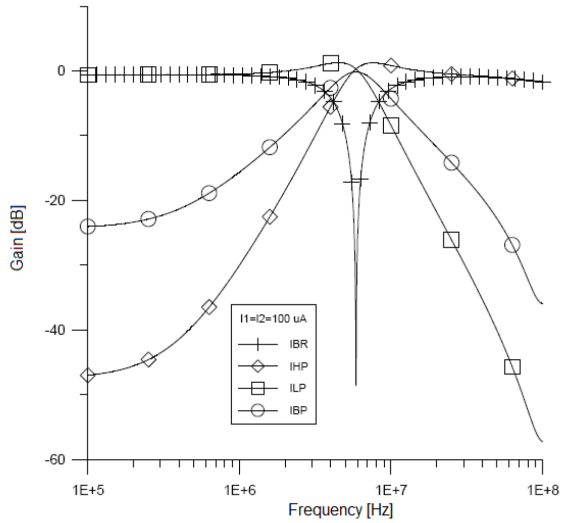

Fig. 7b. Filter characteristics for $I_1=I_2=100$ μA (5.87 MHz pole frequency is obtained from simulations)

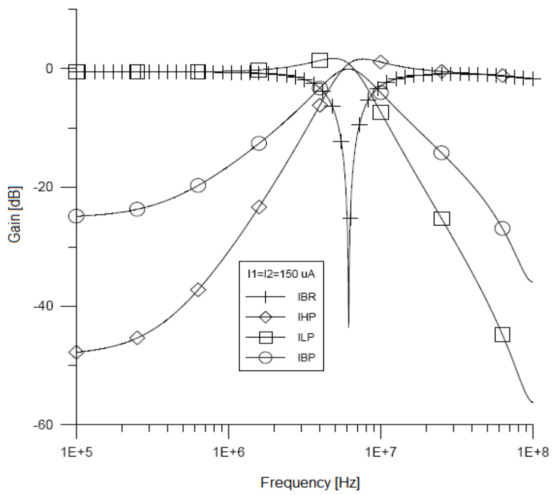

Fig. 7c Filter characteristics for $I_1=I_2=150$ μA (6.2 MHz pole frequency is obtained from simulations)

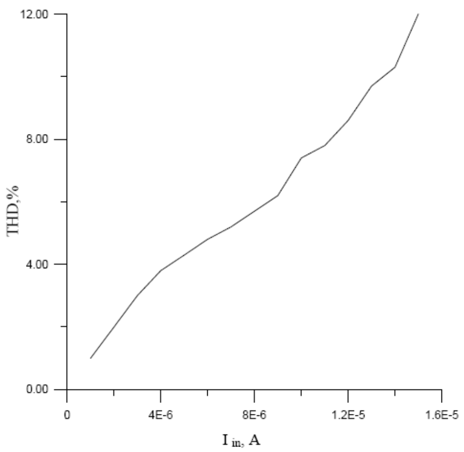

Fig. 8 THD introduced by the filter

The variation of the pole frequency by adjusting the biasing currents of OTAs is obtained and given in Table 3.

Total harmonic distortion (THD) introduced by the filter is plotted against input current amplitude in Fig. 8.

Generally, distortion is taken as THD into consideration in such circuits. It is possible to separate it into its harmonics, but as a result, THD is more important. For the proposed circuit, THD is rather large, especially in higher currents, because of using the FET structure of OTA and CCII. For the lower THD, the operating point must be shifted to lower currents; or BJT structures should be preferred.

CONCLUSIONS

A new active-only filter circuit is proposed. The filter employs open-loop current conveyors and its parasitic impedances as current mode integrators. The advantages of the circuit that it does not use passive elements. Moreover, it is not necessary to use a lot of divider that makes the circuit more complex such as in published counterpart. It gives four types of filter responses simultaneously without any matching condition, provides current outputs from the high impedance nodes and electronically tuneable pole angular frequency and the quailty factor.

From the SPICE simulations, it is found that the circuit provides electronic tuneability from 5.3 MHz to 6.74 MHz. Moreover, the band stop response provides more than 45 dB attenuation.

Future work includes the design of voltage-mode active only circuits using the parasitic impedances of current mode elements.

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