A Current-Mode Dual-Input Dual-Output Multifunction Filter Based on ICCIIs

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***Abstract*— This paper presents a new current-mode (CM) multi-function filter with two inputs and two outputs. The filter uses only three dual-output inverting second generation current conveyors (DO-ICCIIs), two grounded capacitors and two MOS resistors. Without using any external passive elements, the proposed circuit can simultaneously realize lowpass and bandpass or bandpass and highpass responses without changing the circuit topology and without any matching or cancellation conditions, all at high impedance outputs. The parameters ω_o and Q, can be electronically tuned by adjusting the bias voltages of the MOS resistive circuits. The proposed circuit enjoys low sensitivities.**

***Keywords*— Current-Mode, Multifunction Filters, ICCII, MOS Resistor, Electronically Tuning**

I. Introduction

In electrical engineering applications, it is well known that an analog filter is an important block that is widely used for continuous-time signal processing. It can be found in many fields for instance, communication, measurement and instrumentation, and control systems. One of the most popular analog filters is the universal biquadratic filter as it can provide several functions [1]. Recently the research activities have trended to the development of current-mode (CM) filters since they offer several potential advantages such as wider bandwidth, better linearity, wider dynamic range and simplicity of signal operation compared with their voltage-mode (VM) counterparts [2]. Therefore, a number of multifunction CM filters based on CM active elements have been presented [3-17]. Multifunction filters are able to achieve more than one basic filter function simultaneously with the same topology. They therefore bring versatility, simplicity and cost reduction to the integrated circuit manufacturer. Second-generation current conveyors (CCIIs) have been found very useful in filtering applications. The presented topologies in the literature can be classified considering the number of active/passive elements (grounded or floating), the number of simultaneously realized functions, the possibility of a realization of other filter functions by a slight modification of the circuit, component matching constraints, an independent electronic adjustability of the resonant angular frequency and quality factor, active/passive sensitivities, component spread, and output impedance. A CM filter theoretically should exhibit high output impedance to enable easy cascadability and to enable additional filter responses by a simple connection of the outputs. Most of the circuits presented in the literature suffer from a lack of electronic tunability [3-10].

The CM multifunction filters may be divided into subcategories considering the input and output terminals. Some filters are single-input multiple-output (SIMO) type and others are multiple-input single-output (MISO) type. For both classes low input impedance and/or high output impedance is advantageous from cascadability point of view. For certain filters in which output signal is obtained on a passive element additional active elements will be needed to sense the output signal and to cascade [3-7]. For cascadability to obtain higher order filters the structure should exhibit high output resistance. For the cases where power consumption is an important parameter, the number of active elements employed will be important. The circuit in [8] employs five active elements with floating resistors. The CDTA-based filter in [9] realizes simultaneously two responses in which one of the two outputs flows through the grounded capacitor. The CFTA-based filter in [10] realizes lowpass (LP), bandpass (BP) and highpass (HP) responses in which the BP and HP outputs flow through the grounded capacitors.

On the other hand by using the second generation current controlled conveyor (CCCII) introduced by Fabre and others [11], current conveyor applications have been extended to the domain of electronically tunable functions [12-15]. However, only bipolar transistor realization of the CCCII can provide a wide range of tunability for the filters [16]. Although the electronically tunable CM filter in [12] seems to be the most attractive one among the given circuits since it employs only two multi-output second-generation current controlled conveyors (MO-CCCIIs) and two capacitors but it requires two identical input currents which means an additional active element is required. An electronically tunable CM universal biquad filter is proposed in [16]. The proposed filter employs three dual-X second-generation current conveyors (DXCCIIs), two grounded capacitors and four NMOS transistors acting as linear resistors. Another electronically tunable CM universal biquad filter is proposed in [17]. This filter is constructed with two DXCCIIs, one dual-output inverting second-generation current conveyor (DO-ICCII) [18], two grounded capacitors and two MOS transistors.

By using the inverting second generation current (ICCII) and a simple MOS transistor electronically tunable functions could be achieved since the voltage at terminal X is the inversion of the voltage at terminal Y of the ICCII a linear MOS resistor can be achieved [19] that makes the proposed filter electronically tunable by adjusting the gate voltage of the MOS transistors.

It is worth noting that circuits employing only grounded passive elements have some advantages in integrated circuit realization. Also, a circuit employing minimum number of active and passive elements is attractive from the very large scale integration (VLSI) point of view.

This paper presents a multifunction filter which has two inputs and two high-impedance outputs providing LP and BP or BP and HP responses simultaneously through changing the input terminals. It uses minimum number of capacitors (two capacitors), two MOS resistors which act as electronic resistors and three DO-ICCIIs. The high impedance outputs enable easy cascadability without the need of any supplementary buffer circuits The simulation results of the proposed filter configuration are given using SPICE to verify the theoretical analysis.

II. The Proposed Circuit

The ICCII is an active element with terminals namely Y, X and Z. The terminal voltage-current relationships of an ICCII can be expressed as:

$$I_Y = 0 \tag{1a}$$

$$V_X = -V_Y \tag{1b}$$

$$I_Z = \pm I_X \tag{1c}$$

The voltage at terminal X is the inversion of the voltage at terminal Y. The current at terminal Z follows the current at terminal X in magnitude. The plus and minus signs in (1c) indicate the plus and minus type of ICCII ($I_{Z+}=I_X$ or $I_{Z-}=-I_X$), respectively. The proposed CM dual-input dual-output filter using three DO-ICCIIs is illustrated in Fig. 1. The filter circuit employs two grounded capacitors with two MOS resistors and realizes LP and BP or BP and HP responses. It should be noted that the output current signals are taken from high output impedance nodes which is important for cascade connections. In addition, both of the capacitors used in the circuit are grounded, which is attractive in integrated circuit implementation point of view. In addition, since the voltage at terminal X is the inversion of the voltage at terminal Y of the ICCII a linear MOS resistor can be achieved [19] that makes the proposed filter electronically tunable by adjusting the gate voltage of the MOS transistors. The resistance of the MOS transistors is found as:

$$R_i = \frac{1}{K_{ni}(V_{Ci} - V_{th})}$$

where, V_{th} is the threshold voltage and $K_{ni}=\mu_n C_{ox}(W/L)i$ is the transconductance parameter of the i^{th} MOS transistor. Here μ_n is the surface mobility, C_{ox} is the gate capacitance per unit area and $(W/L)_i$ is the channel width/channel length of the i^{th} transistor. In addition V_{Ci} is the control voltage applied to the gate of the i^{th} transistor.

The corresponding transfer functions of the proposed dual-input dual-output filter are given below.

i) $I_{in}=I_{in1}$, $I_{in2}=0$,

$$\frac{I_{out1}}{I_{in1}} = \frac{I_{LP}}{I_{in1}} = \frac{\frac{2}{R_1R_2C_1C_2}}{s^2 + \frac{2}{R_2C_2}s + \frac{4}{R_1R_2C_1C_2}} \tag{2a}$$

$$\frac{I_{out2}}{I_{in1}} = \frac{I_{BP}}{I_{in1}} = -\frac{\frac{2}{R_1C_1}s}{s^2 + \frac{2}{R_2C_2}s + \frac{4}{R_1R_2C_1C_2}} \tag{2b}$$

ii) $I_{in}=I_{in2}$, $I_{in1}=0$,

$$\frac{I_{out1}}{I_{in2}} = \frac{I_{BP}}{I_{in2}} = -\frac{\frac{2}{R_2C_2}s}{s^2 + \frac{2}{R_2C_2}s + \frac{4}{R_1R_2C_1C_2}} \tag{3a}$$

$$\frac{I_{out2}}{I_{in2}} = \frac{I_{HP}}{I_{in2}} = \frac{s^2}{s^2 + \frac{2}{R_2C_2}s + \frac{4}{R_1R_2C_1C_2}} \tag{3b}$$

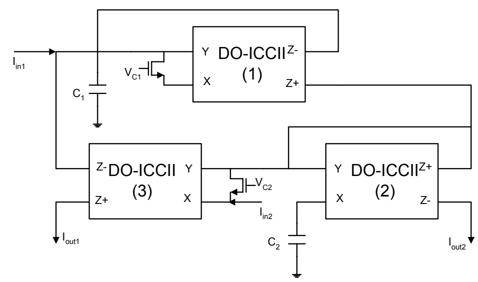


Fig. 1 The proposed dual-input dual-output CM filter

(2a) and (2b) represent the CM filter functions for LP and BP responses while (3a) and (3b) represent the CM filter functions for BP and HP responses. The natural frequency ω_o and the quality factor Q for the filter are given by:

$$\omega_o = \sqrt{\frac{4}{R_1R_2C_1C_2}}, \quad Q = \sqrt{\frac{R_2C_2}{R_1C_1}} \tag{4}$$

It is clear from (4) that ω_o and Q can be electronically tuned by adjusting the bias voltage of MOS transistors (changing R_1 and R_2). In addition, it can be seen that the parameters ω_o and Q are orthogonally controllable by adjusting the ratio R_2 to R_1, C_2 to C_1 or R_2C_2 to R_1C_1.

Sensitivity analysis of the filter parameters shows that

$$S_{R_1}^{\omega_o} = S_{R_2}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -S_{R_2}^{Q} = -S_{C_2}^{Q} = S_{R_1}^{Q} = S_{C_1}^{Q} = -\frac{1}{2}$$

which are low.

Finally, it should be mentioned that the proposed filter in this paper can be compared with the presented CM multifunction filters given in [16] and [17] such that all the three filters can be controlled electronically via bias voltages of MOS transisitors but the proposed filter structure in this paper has a superiority as it based on DO-ICCIIs [17] whose CMOS structure is simpler than DXCCII [16] on which the filters given in [16] and [17] based even though they can produce three filter functions simultaneously.

III. The Simulation Results

In order to confirm the theoretical validity of the proposed filter configuration given in Fig. 2 it is simulated with SPICE simulation program. To implement the DO-ICCIIs the CMOS structure given in Fig. 3 is used [17]. The aspect ratios of the MOS transistors are given in Table I. The device model parameters from TSMC 0.35μm CMOS process model parameters are used for the SPICE simulations and the supply voltages of V_{DD}=-V_{SS}=1.5 V and V_B=-V_C=0.1 V are selected.

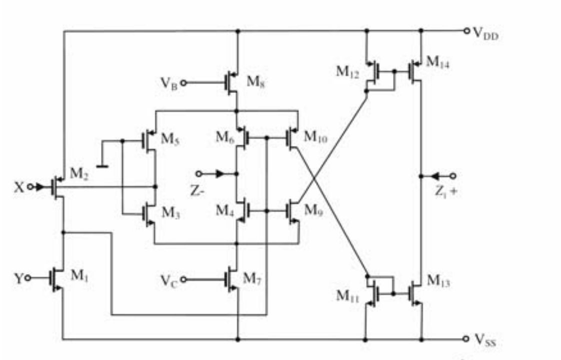


Fig. 2 The CMOS realization of DO-ICCII used for the simulations [17]

TABLE I

Transistor aspect ratios of the DO-ICCII circuit shown in Fig. 2

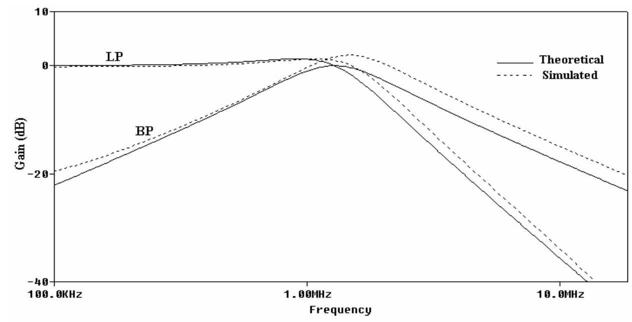
Transistor	W (μm)	L (μm)
M1-M4	1.4	0.7
M5-M6	5.6	0.7
M7, M8, M13, M14, M15	14	0.7
M9-M10	20.3	0.7
M11, M12, M16, M17, M18	58.1	0.7

Simulated magnitude and phase responses of the proposed filter circuit are given in Figs. 3 and 4, respectively. For this purpose, equal resistances of 1.3 kΩ and equal valued capacitances of 0.15 nF are chosen to simulate the filter at a natural frequency of f_o=1.63 MHz and a quality factor of Q=1. The W/L ratio for the equal MOS resistors is chosen as 4.2/0.7.

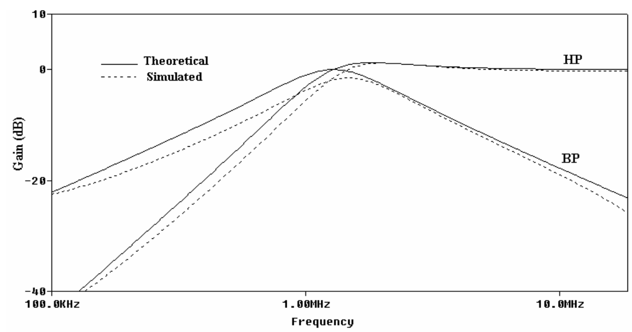
The results for the large-signal transient response of LP-BP and BP-HP are shown in Fig. 5, where the input current is a sinusoidal signal of 200 μA (peak to peak) with a 1.63 MHz frequency. The total harmonic distortion is not more than 3.2% in non of the responses. Maximum power consumption is about 0.26 mW.

To show the tunability of the proposed filter, different values of V_{C1} and V_{C2} as 0.9 V, 1.1 V and 1.3 V are selected to obtain resonance frequencies of 0.9 MHz, 1.31 MHz, and 1.74 MHz, respectively. The results are shown, as an example, for the BP response in Fig. 6.

It can be observed from Figs. 3–6 that the simulation results agree well with the theoretical ones. However, the differences between ideal (theoretical) and simulated responses mainly stem from the parasitic effects and non-ideal current and voltage gains of the DO-ICCIIs.

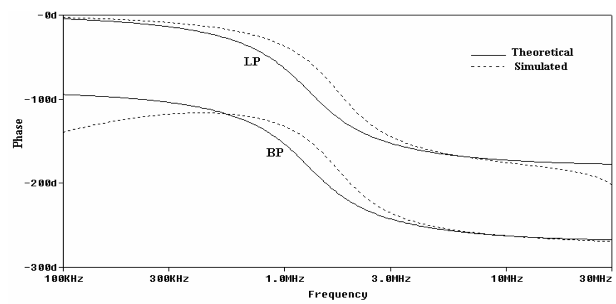


(a)

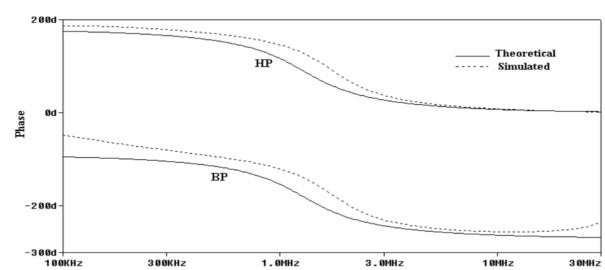


(b)

Fig. 3 Magnitude responses of the proposed filter for (a) I_{in}=I_{in1} (BP and LP responses) and (b) I_{in}=I_{in2} (HP and BP responses)

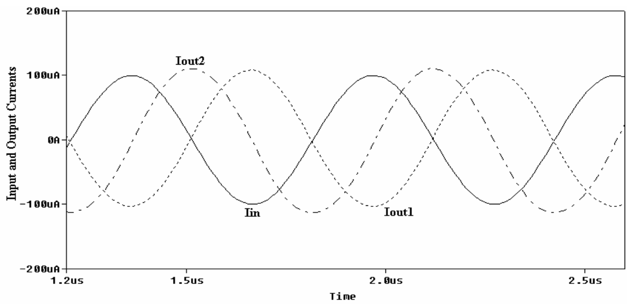


(a)

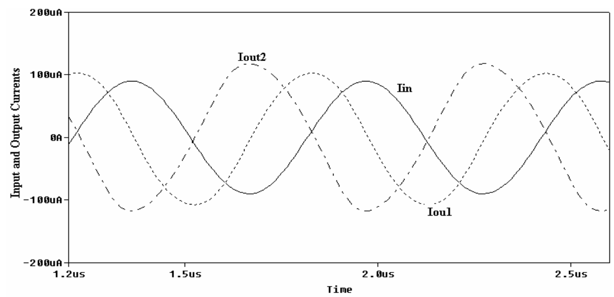


(b)

Fig. 4 Phase responses of the proposed filter for (a) I_{in}=I_{in1} (BP and LP responses) and (b) I_{in}=I_{in2} (HP and BP responses)



(a)



(b)

Fig. 5 The input and output waveforms of (a) BP-LP and (b) HP-BP filter responses for 200 μA (peak-to-peak) sinusoidal input current at 1.63 MHz.

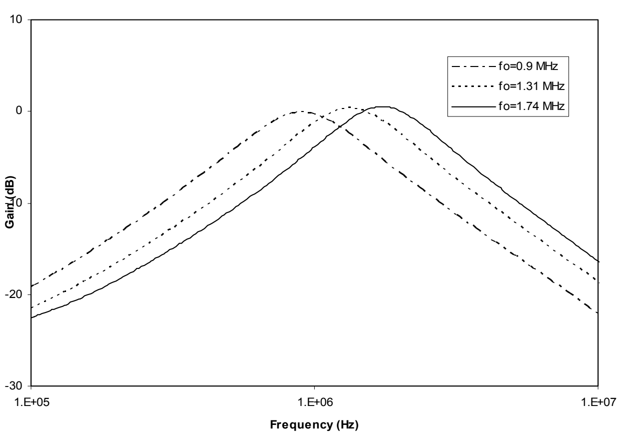


Fig. 6 Magnitude of the BP response for different control voltages

IV. Conclusion

A new CM dual-input dual-output multifunction filter using only three inverting current conveyors is proposed in this work. The validity of the proposed filter has been demonstrated through SPICE simulations. The proposed filter has the following advantages: (i) The configuration of the filter is simple due to the use of only three DO-ICCIIs and minimum number of passive components; (ii) Realization of the three basic filter functions: LP, HP and BP filter responses from the same configuration; (iii) Low sensitivities; (iv) Employing only grounded capacitors so it is easy to realize the proposed filter in IC process, (v) It is free from the critical active and passive component matching conditions and/or cancellation constraints, (vi) No need to employ inverting-type current input signal or double input current signal to realize all three basic filter functions, (vii) Capability of electronically adjusting of the parameters ω_o and Q, through adjusting the bias voltage of MOS resistors (viii) ω_o can be adjusted without disturbing Q.

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