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A New Polyphase Current-Mode Filter Using Digitally-Programmable CCCII

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***ABSTRACT* — A novel polyphase current-mode filter suitable for CMOS integrated circuit implementation is presented. The circuit uses two digitally-programmable current-controlled current-conveyors, MOSFETs, and two grounded capacitors. The proposed circuit can be operated from a low power supply voltage (±1.5V) and its parameters enjoy low active- and passive-sensitivity. Simulation results using CMOS CCCII are included.**

***Key-Words:* —Current-mode, Polyphase filter**

I. INTRODUCTION

Polyphase filters [1], also known as complex analog filters [2] are widely used for the generation of quadrature signals and image rejection in the analog front-end of the radio frequency integrated wireless transceivers [3]-[6]. Although, passive polyphase filters, using only resistors and capacitors, have been widely used; see for example [3],[4], their higher-order passive filters design is considered complicated due to the absence of the cascading concept to avoid loading effects [5]. Active polyphase filters have, therefore, emerged using operational amplifiers [7]-[9], operational transconductance amplifiers [10]-[13], current mirrors [14], second-generation current-conveyors [15] and current-feedback operational amplifiers [16], [17].

The performances of current-conveyor based circuits, in terms of bandwidth, linearity, and dynamic range, are better than the operational amplifier and the operational transconductance based circuits. Moreover, errors in the transfer functions of current-conveyor based circuits, resulting from the conveyor nonidealities, can be easily compensated than those resulting from amplifier nonidealities in operational amplifier based circuits [15].

Despite the expected advantages in using current-conveyors or current-feedback operational amplifiers for designing polyphase filters, only few realizations are reported [15]-[17]. The current-conveyor and current-feedback amplifier based realizations reported in [15] and [16] have some drawbacks such as large number of active components used, three or more, and no electronic tuning options. Moreover, polyphase filter in [16] uses floating capacitors which limits signal frequency operation.

Recently, a current-controlled current-conveyor based realization is presented in [18] which exhibit electronic tuning for filter's parameters. However, available tuning range and linearity are limited due to their main dependency on the transistor's transconductance. The major intention of this paper is, therefore, to present a new current-mode realization for a first-order polyphase filter which exhibits wide digitally-tuning range. The proposed circuit uses two digitally-programmable current-controlled current-conveyors, MOFETs and two grounded capacitors. The proposed circuit can be easily cascaded to obtain higher-order filters.

II. PROPOSED CIRCUIT

Fig. 1 shows the circuit diagram of current-controlled current-conveyors which is the core building block for the proposed polyphase filter. The negative feedback loop formed by transistors M_1, M_2 and M_7 forced voltage at M_2 gate to track the voltage at M_1 gate with good accuracy. Moreover, the matched transistors M_1 and M_2 are biased with equal dc current, I_A, which results in zero dc offset voltage between M_1 and M_2 gate voltages. To complete the CCCII realization a resistor R is inserted between gate of M_2 and terminal X which results in a voltage difference V_{xy} described by:

$$V_{xy} = i_x \times R \qquad (1)$$

Thus CCCII characteristic can be modeled as:

$$i_y = 0, v_x = v_y + i_x R_x, \qquad i_{z1} = i_x = -i_{z2}$$

Figure 2(a) shows the symbol of the current-controlled current conveyor and the proposed polyphase filter circuit is shown in Fig. 2(b). Assuming ideal current-controlled current-conveyor, routine analysis of the circuit of Fig. 2 yields the following current transfer functions

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$$\frac{I_{o1}}{I_1}=\frac{\frac{R_1}{R_{x1}}}{1+j(\omega C_1R_1-\frac{R_1}{R_{x1}})} \qquad (2)$$

$$\frac{I_{o2}}{I_2}=\frac{\frac{R_2}{R_{x2}}}{1+j(\omega C_2R_2-\frac{R_2}{R_{x2}})} \qquad (3)$$

In deriving equations (2) and (3) it is assumed that the output currents are in quadrature that is $I_{o1}=jI_{o2}$ [3]. With $R_{x1}=R_{x2}=R_x$, $C_1=C_2=C$ and $R_1=R_2=R$, equations (1) and (2) can be rewritten as

$$\frac{I_{o1(2)}}{I_{1(2)}}=\frac{\frac{R}{R_x}}{1+j(\frac{\omega-\omega_c}{\omega_o})} \qquad (4)$$

where

$$\omega_c=\frac{1}{R_xC} \qquad (5)$$

and

$$\omega_o=\frac{1}{RC} \qquad (6)$$

Equations (4) is the transfer functions of a current-mode bandpass filter with symmetrical characteristics centered around ω_c and asymmetrical transfer function around the zero frequency. Therefore, transfer function of a complex filter is a bandpass filter that can be used for image rejection and sequence discrimination [2].

Resistors used in the CCCII circuit and the proposed filter structure are linear-programmable resistors which are based on two parallel triode transistors (NMOS and PMOS), Fig. 3. A simple analysis shows that with matched transistors, the nonlinearity of each transistor will be canceled by its counter part. As a result a linear resistor is obtained and given by:

$$R=\frac{(V_1-V_2)}{I_R}=\frac{1}{K(V_n-V_p-V_{tn}+V_{tp})} \qquad (7)$$

Equations (7) show that R is linear resistor and its value can be controlled through transistor sizes, V_n and V_p. A digitally-controlled resistor is implemented using array of parallel transistors with different sizes as shown in Fig. 4. Resistor value is adjusted through four bits digital word which results in sixteen different values.

In Fig. 5, current i_z –voltage V_y relation is plotted for different digital words to test the functionality of the proposed CCCII. The results shows good linearity and wide tuning range, more than one decade.

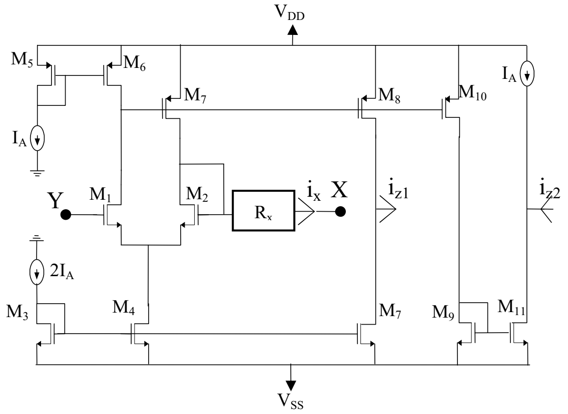
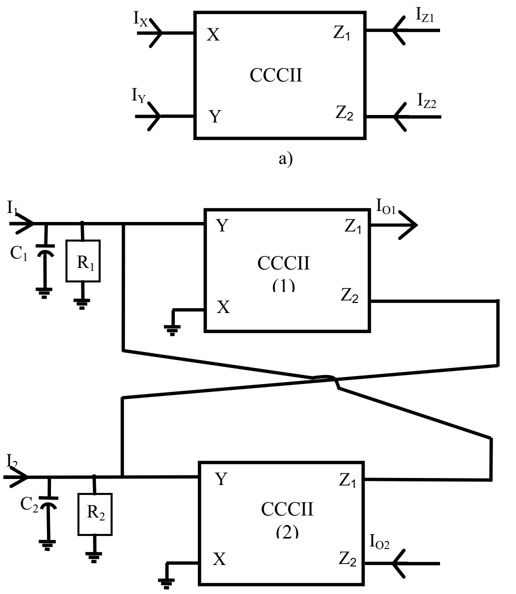


Figure 1: Circuit Configuration of the proposed CCCII ±.



a)

b)

Figure2: a) Block Diagram of the CCCII
b) Proposed Polyphase Current-Mode Bandpass Filter

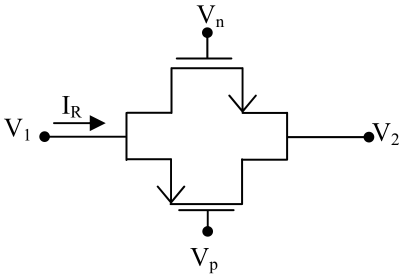


Figure 3: Linear programmable resistor

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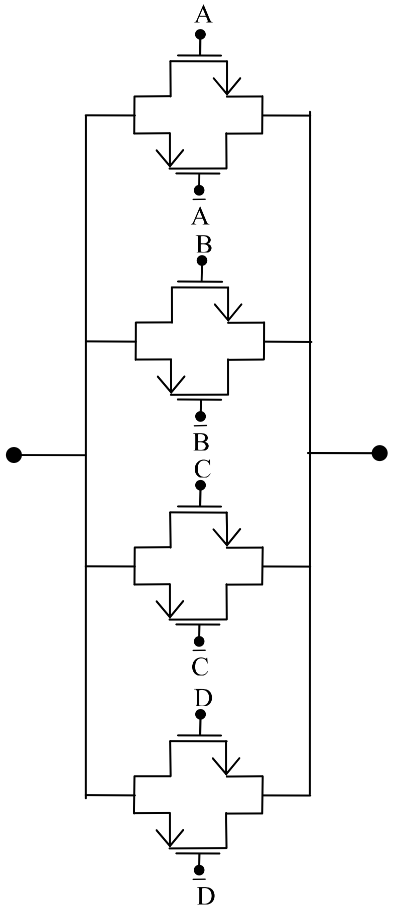

Figure 4: Digitally-programmable resistor

A. Nonideal Analysis

Current-controlled current-conveyors are nonideal devices suffering from current- and voltage tracking errors. Therefore, the effect of its nonidealities on the performance of the proposed filter must be studied. As mentioned in CCCII circuit description, negative feedback is employed between x and y terminals. Hence voltage tracking error is expected to be minimal as opposed to the traditional open loop CCCII realizations. Assuming that the CCCIIs are identical with nonideal characteristics expressed by $i_z = \pm \alpha i_x$ where $\alpha = 1 - \varepsilon_i, |\varepsilon_i| << 1$ represents the current-tracking error, reanalysis yields the following transfer function

$$\frac{I_{o1(2)}}{I_{1(2)}} = \frac{\frac{R}{\alpha R_x}}{1 + j\left(\frac{\omega - \frac{\omega_c}{\alpha}}{\omega_o}\right)} \qquad (8)$$

Comparison between equations (4) and (8) clearly shows that the effect of the CCCII current tracking errors can be easily compensated.

Parasitic capacitor at y terminal can be easily compensated by the external capacitor $C_{1(2)}$ respectively. Moreover, with x terminal grounded in this structure, its parasitic capacitance effects is eliminated.

III. SIMULATION RESULTS

To confirm the operability of the proposed circuit, shown in Fig. 2, as an image rejection filter, the circuit was simulated with HSPICE using the CMOS CCCII given in Fig. 1. The CMOS transistors were modeled by the 0.5μm BSIM3V3 CMOS models made available through MOSIS. The current-mode polyphase bandpass filter with a bandwidth of 18kHz and shifting frequency of 45KHz, 90KHz, and 135KHz at digital words of (0101), (1010) and (1111) respectively using two 1nF capacitors is realized. The simulation results of the bandpass filter shown in Fig. 6 agree quite well with the theoretical analysis. Figure 6 also shows that the proposed filter has a good attenuation response to the image signal.

IV. Conclusion

In this paper, a new polyphase current-mode bandpass filter is presented. The circuit comprises two programmable CCCII, MOSFETs and two grounded capacitors. It can be easily cascaded to obtain higher-order current-mode filters. Furthermore, proposed filter enjoys low sensitivity to parasitic, electronically tuning for its bandwidth and center frequency, and low power supply (±1.5V) which makes it suitable for circuit integration. Finally simulation results, which confirm the theoretical analysis, are given.

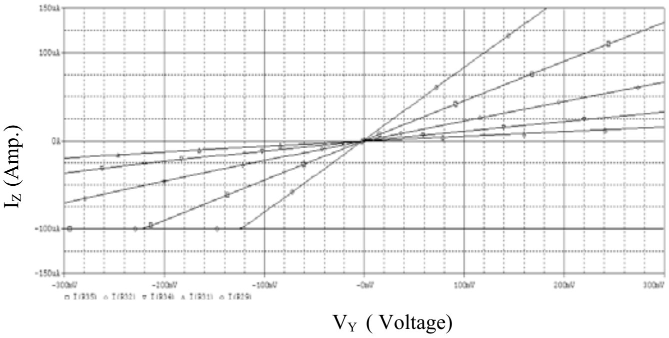

Fig. 5 Proposed CCCII current i_z as a function of voltage V_y, x terminal grounded, for different digital words

Top

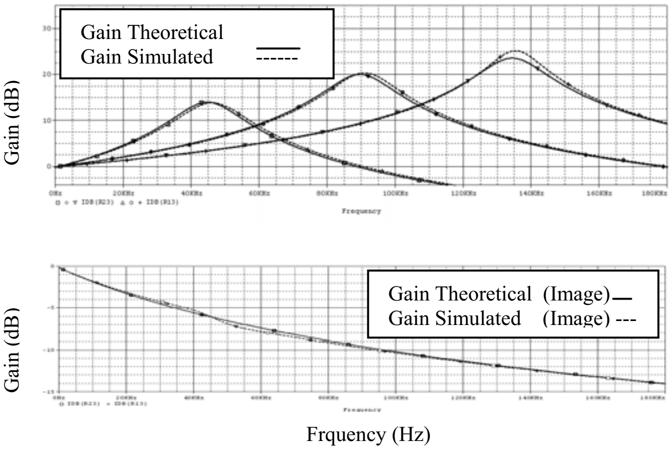

Fig. 6 Theoretical and Simulated Response of the Proposed Polyphase Current-Mode Bandpass Filter

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