A New Polyphase Current-Mode Filter Using Programmable-Gain Current-Controlled Current-Conveyor

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Abstract: - A novel polyphase current-mode filter suitable for CMOS integrated circuit implementation is presented. The circuit uses two programmable-gain current-controlled current-conveyors and two grounded capacitors. The proposed circuit can be operated from a low power supply voltage (±1.25V) and its parameters enjoy low active- and passive-sensitivity. Simulation results using CMOS programmable gain CCCII are included.

1 Introduction

Polyphase filters [1] , also known as complex analog filters [2], vector filters [3] and sequence discriminators [4], are widely used for generation of quadrature signals and image rejection in the analog front-end of radio frequency integrated wireless transceivers [5]-[8]. They can also be used for generation and detection of single sideband signals [9]-[11] and frequency division multiplex-communication systems [4].

Passive polyphase filters, using only resistors and capacitors, are widely used; see for example [5],[6] and [12]-[14]. However, cascading of identical passive polyphase filters, in order to obtain higher-order filters, results in loading effects and substantially complicates the synthesis process [7]. While it is possible to obtain analytical expressions for second-, third and probably higher-order filters [15], these expressions are very complicated and complicate the design of higher-order passive polyphase filters. Alternatively, additional buffers must be inserted among stages to overcome these effects [14]. Active polyphase filters have, therefore, emerged using operational amplifiers [16]-[18], operational transconductance amplifiers [19]-[22], current mirrors [23], second-generation current-conveyors [24] and current-feedback operational amplifiers [25].

While the selection of an appropriate implementation technique for the active polyphase filters depends on the specifications imposed by the intended application [26], some general observations can be made. Operational amplifiers have finite values for the gain-bandwidth product. This will limit the signal frequencies [23] and will result in errors in the polyphase filter transfer function [17] and [27]. Operational transconductance amplifier based realizations either require a large number of transconductance elements [19]-[22] or suffer from the excessive dispersion in the values of the passive components [18] and/or transistor mismatches [16]. Current-mirror based realizations suffer from the parasitic capacitances [23] and the current-mirror errors. 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 [24]. Current-feedback operational amplifiers are no more than a plus-type second-generation current conveyor plus a voltage buffer. Therefore, while current-feedback operational amplifier based realizations are expected to enjoy the same attractive advantages of the current-conveyor based realizations, they have the additional advantage of providing a low impedance output voltage. This makes easy the cascading of similar filter sections to achieve higher-order filters.

Despite the expected advantages in using current-conveyors or current-feedback operational amplifiers for designing polyphase filters, only two realizations are reported [24] and [25]. The current-conveyor based realization reported in [24] is a current-mode realization with current-input and current-output. It uses three plus-type and one minus-type second-generation current conveyors. A minus-type current conveyor is not commercially available and can be realized using two of the commercially available plus-type second-generation current-conveyors. Therefore the practical implementation of the circuit proposed in [24] requires five plus-type second-generation current-conveyors. The current-feedback operational amplifier based realization reported in [25] is a voltage-mode realization with voltage-input and voltage-output. It uses three current-feedback operational amplifiers and requires four floating capacitors. Obviously, this will limit its signal frequency operation.

Recently, a programmable-gain current-controlled current-conveyor, shown in Fig.1, has been presented [28]. Compared to the traditional second-generation current-conveyor, the programmable-gain current-controlled current-conveyor has two additional high-impedance output currents. Moreover, while in the traditional current-conveyor the current-gain is unity; in the programmable current-conveyor these two additional output currents have a programmable current gain. The major intention of this paper is, therefore, to present a new current-mode realization for a first-order polyphase filter using the programmable current-controlled current-conveyor. The proposed circuit uses two programmable-gain current-controlled current-conveyors and two grounded capacitors. The proposed circuit also enjoys a low input impedance node and a high output impedance node. Thus, it can be easily cascaded to obtain higher-order filters.

2 Proposed Circuit

Figure 2(a) shows the symbol of the programmable-gain current-controlled current conveyor and the proposed polyphase filter circuit is shown in Fig. 2(b). Assuming that an ideal programmable-gain current-controlled current-conveyor with characteristic can be characterized by

$$i_y = 0, v_x = v_y + i_x R_x, i_{z1} = i_x \text{ and } i_{z3} = -i_{z2} = K i_x$$

where, $K = \sqrt{I_B / I_A}$ is the current gain, routine analysis of the circuit of Fig. 1 yields the following current transfer functions

$$\frac{I_{o1}}{I_1} = \frac{1}{1 + j(wC_1R_{x1} - K_1)} \quad (1)$$

$$\frac{I_{o2}}{I_2} = \frac{1}{1 + j(wC_2R_{x2} - K_2)} \quad (2)$$

In deriving equations (1) and (2) it is assumed that the output currents are in quadrature that is $I_{o1} = jI_{o2}$ [5] and [18]. With $R_{x1} = R_{x2} = R, C_1 = C_2 = C$ and $K_1 = K_2 = K$, equations (1) and (2) can be rewritten as

$$\frac{I_{o1(2)}}{I_{1(2)}} = \frac{1}{1 + j(\frac{w - w_c}{w_o})} \quad (3)$$

When outputs are obtained from terminals Z_2 and Z_3, equation (3) becomes

$$\frac{I_{o1(2)}}{I_{1(2)}} = \frac{K}{1 + j(\frac{w - w_c}{w_o})} \quad (4)$$

where

$$w_c = \frac{K}{R_x C} \quad (5)$$

and

$$w_o = \frac{1}{R_x C} \quad (6)$$

Equations (3) and (4) are the transfer functions of a current-mode bandpass filter with a symmetrical characteristics centered around w_c and asymmetrical transfer function around the zero frequency. Equations (3) and (4), therefore, represents the transfer function of a complex analog bandpass filter that can be used for image rejection and sequence discrimination [2].

2.1 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. Assuming that the CCCIIs are identical with nonideal characteristics expressed by $i_z = \pm a\, i_x$ where $a = 1 - e_i, |e_i| << 1$ represents the current-tracking error, reanalysis yields the following transfer function

$$\frac{I_{o1(2)}}{I_{1(2)}} = \frac{a}{1 + j(\frac{w - aw_c}{w_o})} \quad (7)$$

Comparison between equations (4) and (7) clearly shows that the effect of the CCCII current- and voltage tracking errors can be easily compensated.

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

3 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 [28]. The CMOS transistors were modeled by the .5µm BSIM3V3 CMOS models made available through MOSIS. The current-mode polyphase bandpass filter with a bandwidth of 20KHz and shifting frequency of 30KHz, 40KHz, and 50KHz at current gain K of 3, 4, and 5 respectively using two 4nF capacitors is realized. The simulation results of the bandpass filter shown in Fig. 3 agree quite well with the theoretical analysis. Figure 3 also shows that the proposed filter has a good attenuation response to the image signal.

4 Conclusion

In this paper, a new polyphase current-mode bandpass filter is presented. The circuit comprises two programmable gain CCCII 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 (±1.25V) which makes it suitable for circuit integration. Finally simulation results, which confirm the theoretical analysis, are given.

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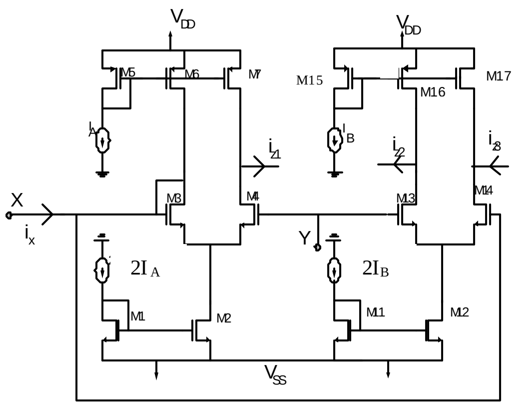
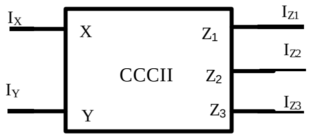
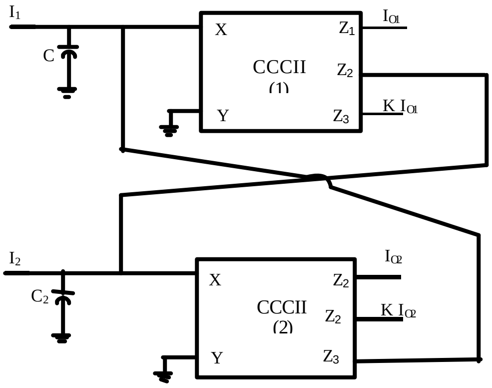


Fig. 1. Circuit Configuration of the Variable Current Gain CCCII± [28]



a)



b)

Figure1: a) Block Diagram of the Programmable Gain CCCII
b) Proposed Polyphase Current-Mode Bandpass Filter

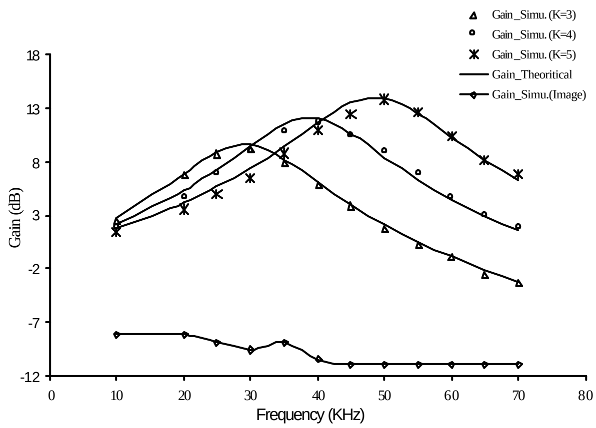


Fig. 3 Theoretical and Simulated Response of the Proposed Polyphase Current-Mode Bandpass Filter

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