A New Polyphase Mixed-Mode Bandpass Filter Section Using Current-Feedback Operational Amplifiers

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***Abstract*-A new polyphase mixed-mode filter using commercially available integrated circuits is presented. The circuit uses two current-feedback operational amplifiers, four grounded resistors and two grounded capacitors. The proposed circuit enjoys independent grounded-resistance control of its parameters. Simulation results using are included.**

I. 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.

The major intention of this paper is, therefore, to present a new current-feedback operational amplifier based realization for a first-order polyphase filter. The proposed circuit is a mixed-mode with current-input and voltage-output. It uses two grounded capacitors and four grounded resistors and can be easily converted into voltage-mode or current mode by adding two additional second-generation current-conveyors. The proposed circuit also enjoys a low output impedance node and a low input impedance node. Thus, it can be easily cascaded to obtain higher-order filters.

II. Proposed Circuit

The proposed circuit is shown in Fig. 1. Assuming ideal current-feedback operational amplifiers with $i_y = 0, i_z = \pm i_x, v_y = v_x$ and $v_w = v_z$, routine analysis yields the following transfer functions

$$\frac{v_{o1}}{i_1} = \frac{1}{G_1 + j(\omega C_1 - G_{m1})} \qquad (1)$$

$$\frac{v_{o2}}{i_2} = \frac{1}{G_2 + j(\omega C_2 - G_{m2})} \qquad (2)$$

In deriving equations (1) and (2) it is assumed that the output voltages are in quadrature that is $v_{o1} = jv_{o2}$ [5] and [18]. With $G_1 = G_2 = 1/R, C_1 = C_2 = C$ and $G_{m1} = G_{m2} = 1/R_m$, equations (1) and (2) can be rewritten as

$$\frac{v_{o1(2)}}{i_{1(2)}} = \frac{R}{1 + j(\frac{\omega - \omega_c}{\omega_o})} \qquad (3)$$

where $\omega_c = \frac{1}{R_m C}$ and $\omega_o = \frac{1}{RC}$.

Equation (3) is the transfer function of a mixed-mode bandpass filter with a symmetrical transfer centered around ω_c and asymmetrical transfer function around the zero frequency. Equation (3), therefore, represents the transfer function of a complex analog bandpass filter that can be used for image rejection and sequence discrimination [2].

III. Nonideal Analysis

Current-feedback operational amplifiers are nonideal devices suffering from current- and voltage-tracking errors. Therefore, the effect of the amplifier nonidealities on the performance of the proposed filter must be studied. Assuming that the amplifiers are identical with nonideal characteristics expressed by $i_z = \pm \alpha i_x, v_y = \beta v_x$ and $v_w = \gamma v_z$, where $\alpha = 1 - \varepsilon_i, |\varepsilon_i| << 1$ represents the current-tracking error, $\beta = 1 - \varepsilon_v, |\varepsilon_v| << 1$ represents the input voltage tracking error and $\gamma = 1 - \sigma_v, |\sigma_v| << 1$ represents the output voltage tracking errors, reanalysis yields the following transfer function

$$\frac{v_{o1(2)}}{i_{1(2)}} = \frac{\beta\gamma R}{1 + j\left[\frac{\omega - \frac{\beta}{\alpha}\omega_c}{\omega_o}\right]} \qquad (4)$$

Comparison between equations (3) and (4) clearly shows that the effect of the current-feedback operational nonidealities can be easily compensated.

Current-feedback operational amplifiers also suffer from parasitic resistances and capacitances at terminals, x, y and z with r_x around few tens of ohms, r_y and r_z of the order of few mega ohms, and C_y and C_z of the order of few pico-farads. With R_{m1} and R_{m2} in parallel with the parasitic resistances and capacitances at terminals y and z, then proper selection of the values of these resistances can eliminate the effect of the parasitic components. To study the effect of the resistance r_x, the circuit of Fig. 1 was reanalyzed assuming $v_x = v_y + i_x r_x$ and identical current-feedback operational amplifiers. Equation (3) becomes

$$\frac{v_{o1(2)}}{i_{1(2)}} = \frac{\frac{R}{1 + \frac{\omega r_x CR}{R_m}}}{1 + j(\frac{\omega - \omega_{cn}}{\omega_{on}})} \qquad (5)$$

where $\omega_{cn} = \frac{R + r_x}{R_m RC}$ and $\omega_{on} = \frac{1 + \frac{\omega r_x CR}{R_m}}{RC}$. From equation (5), it appears that a proper selection of the components so that $\omega r_x CR / R_m << 1$ and $r_x << R$, then $\omega_{on} = \omega_n$ and $\omega_{cn} = \omega_c$. Thus, the effect of the finite value of the resistance r_x can be eliminated.

IV. Simulation Results

To confirm the operability of the proposed circuit of Fig. 1, the circuit was simulated as an image filter using HSPICE and its built-in model of the current-feedback operational amplifier AD844. The results obtained with $R_1 = R_2 = 1590\Omega, R_{m1} = R_{m2} = 159\Omega$ and $C_1 = C_2 = 10nF$ are shown in Fig. 2. From Fig. 2 it appears that an image rejection of 20 dB is feasible using the proposed circuit of Fig. 1.

V. Conclusion

In this paper, a new polyphase mixed-mode, with input current and output voltage, bandpass filter has been presented. The circuit uses two current-feedback operational amplifiers, four grounded resistors and two grounded capacitors. Using a simple voltage-to-current converter at its output, it can be easily cascaded to obtain higher-order mixed-mode filters. Furthermore, the proposed filter enjoys low sensitivity to parasitic, independent grounded-resistance control for its bandwidth and center frequency and uses off-the-shelf components.

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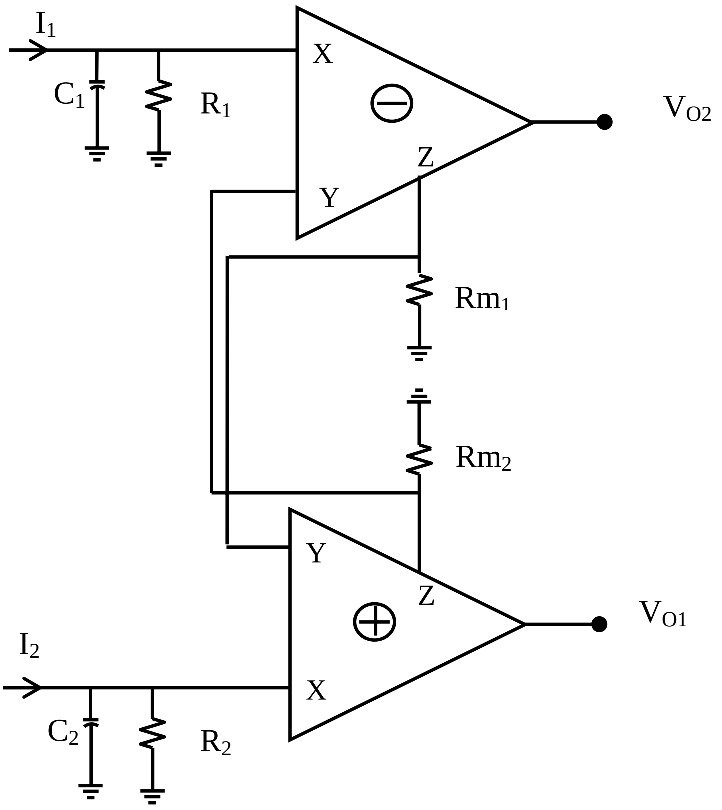

Figure1: Proposed Polyphase Mixed-Mode Bandpass Filter

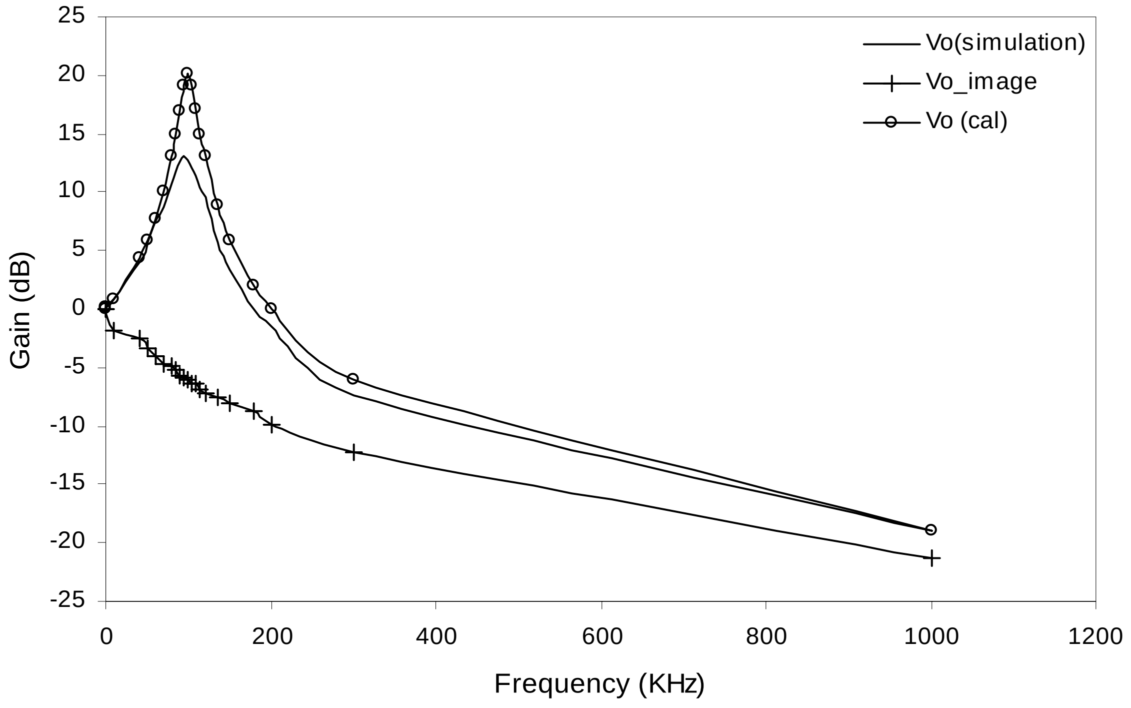

Fig. 2 Theoretical and Simulated Response of the Proposed Polyphase Mixed-Mode Bandpass Filter