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A Grounded Capacitor Differentiator Using Current Feedback Amplifier

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ABSTRACT

A new non-inverting RC active differentiator network base on a current feedback amplifier and using a grounded capacitor is described. Small time constant can be achieved by adjusting a single grounded resistor. Because the output impedance of the CFA is very low, the output terminal of the proposed circuit can be directly connected to the next stage. Experimental results that confirm theoretical analysis are presented.

Keywords: Active Differentiator; Current-Feedback Amplifier; Current Conveyor; Analog Signal Processing

1. Introduction

Active RC differentiator networks are useful for a number of applications in the areas of electronic signal processing or signal conditioning [1-10]. Several RC differentiator networks based on conventional operational amplifiers (Op Amps) were proposed [1-5]. However, the finite gain bandwidth product of these Op Amps will limit the accuracy and the operating frequency range. Current feedback amplifiers (CFAs) can provide not only constant bandwidth independent of closed-loop gain but also high slew-rate capability [11]. Thus, it is beneficial to use the current-feedback amplifier as a basic building block to realize analogue signal processing circuits [12-19]. Note that, the CFA is equivalent to second-generation current conveyor (CCII) with a voltage buffer [11]. On the other hand, circuits that employ only grounded capacitors are beneficial from the point of view of integrated circuit implementation [20].

Patranabis and Ghosh [6] proposed a generic configuration for realizing integrators and differentiators by using one CCII, one grounded capacitor and some resistors. Liu and Hwang [7] proposed five generic configurations for realizing dual-input differentiators using two CCIIs. However, the time constants of the differentiators presented in **Figure 1** of [6] cannot be independently adjusted by grounded resistor. Moreover, because the output impedances of these circuits [6,7] are not small, other buffering devices are needed while cascade these circuits to the next stage. Lee and Liu [8] proposed another
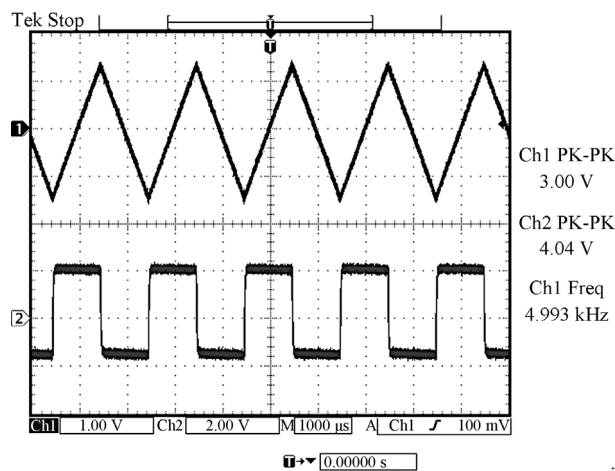

Figure 1. Input and output waveforms of the proposed differentiator.

dual-input differentiator circuit by using one plus-type CFA, one minus-type CFA, five resistors and one floating capacitor. In 2001, Lee and Liu [9] proposed a differentiator circuit by using one minus-type CFA, five resistors and one floating capacitor. In 2003, Nagaria *et al.* [10] proposed a differentiator circuit by using one plus-type CFA, one multiplier, two resistors and one floating capacitor. However, because the differentiator networks in [7-10] employ floating capacitors, these circuits are not ideal for integrated circuit implementation. Furthermore, the differentiators in [8,9] employ minus-type CFAs, since the minus-type CFAs are not comercially

available, one minus-type CFA must be implemented by two plus-type CFAs in practical realizations.

In this paper, a new differentiator network by using one plus-type CFA, five resistors and one grounded capacitor is presented. By adjusting the single grounded resistor, small time constant can be achieved. With respect to the CCII based circuits in [6,7], the proposed circuit has the advantage of low output impedance. With respect to the CFA based circuits in [8-10], the proposed circuit uses only grounded capacitor. Moreover, the proposed circuit uses only one plus-type CFA that is simpler than the minus-type CFAs in [8,9].

2. Circuit Description

The circuit symbol of a plus-type CFA is shown in **Figure 2**. This circuit is equivalent to a plus-type CCII with a voltage buffer [11]. Its characteristic can be modeled as

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \text{ and } v_o = v_z \quad (1)$$

The proposed differentiator network comprises only one plus-type CFA, five resistors and one grounded capacitor is shown in **Figure 3**. The use of grounded capacitor is beneficial for integrated circuit implementation [20]. Circuit analysis yields the output voltage as
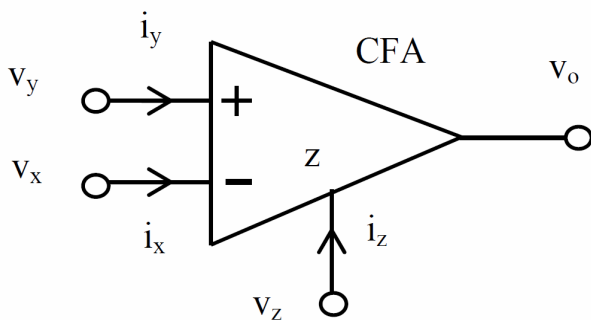
Figure 2. Circuit symbol of current-feedback amplifier.
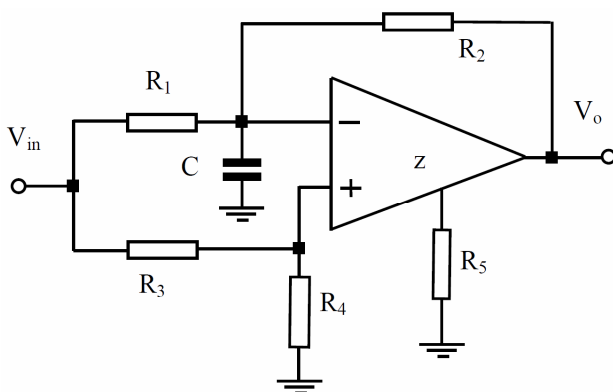
Figure 3. The proposed active RC differentiator circuit.

$$V_o = \left[\frac{R_1 R_4 - R_2 R_3}{R_1 R_2 (R_3 + R_4)} + sC \frac{R_4}{R_3 + R_4} \right] \frac{R_2 R_5}{R_2 + R_5} V_{in} \quad (2)$$

Thus, the condition for an ideal non-inverting differentiation function realization is

$$R_1 R_4 = R_2 R_3 \quad (3)$$

Under the condition of Equation (3), Equation (2) can be rewritten as

$$V_o = sC \frac{R_4}{R_3 + R_4} \frac{R_2 R_5}{R_2 + R_5} V_{in} = s\tau V_{in} \quad (4)$$

where $\quad \tau = C \dfrac{R_4}{R_3 + R_4} \dfrac{R_2 R_5}{R_2 + R_5} \quad$ (5)

The grounded resistor R_5 can independently control the time constant of this differentiator. Small time constant can be achieved by choosing small R_5. Because the output impedance of the CFA (terminal v_o) is very small, the output terminal of the differentiator can be directly connected to the next stage.

3. Non-Ideal Effects

Taking into account the non-ideal CFA, namely $i_z = \alpha(s) i_x$, $v_x = \beta(s) v_y$ and $v_o = \gamma(s) v_z$, where $\alpha(s)$ is the current transfers from i_x terminal to i_z terminal, $\beta(s)$ is the voltage transfers from v_y terminal to v_x terminal, and $\gamma(s)$ is the voltage transfers from v_z terminal to v_o terminal. The $\alpha(s)$, $\beta(s)$ and $\gamma(s)$ can be approximated by first-order lowpass functions, which can be considered to have a unity value for frequency much less than their corner frequencies. By assuming the circuit is working at frequencies much less than the corner frequencies of $\alpha(s)$, $\beta(s)$ and $\gamma(s)$, namely, $\alpha(s) = \alpha = 1 - \varepsilon_1$ and $\varepsilon_1 (|\varepsilon_1| \ll 1)$ denotes the current tracking error of a CFA, $\beta(s) = \beta = 1 - \varepsilon_2$ and $\varepsilon_2 (|\varepsilon_2| \ll 1)$ is the input voltage tracking error, and $\gamma(s) = \gamma = 1 - \varepsilon_3$ and $\varepsilon_3 (|\varepsilon_3| \ll 1)$ is the output voltage tracking error. The output voltage V_o becomes

$$V_o = \left[\frac{R_1 R_4 \alpha\beta\gamma + R_2 R_4 \alpha\beta\gamma - R_2 R_4 \alpha\gamma - R_2 R_3 \alpha\gamma}{R_1 R_2 (R_3 + R_4)} \right.$$
$$\left. + sC \frac{R_4 \alpha\beta\gamma}{R_3 + R_4} \right] \frac{R_2 R_5}{R_2 + R_5 \alpha\gamma} V_{in} \quad (6)$$

Thus, the condition for the non-inverting differentiator can be rewritten as

$$R_1 R_4 \beta + R_2 R_4 \beta = R_2 R_3 + R_2 R_4 \quad (7)$$

Under the condition of Equation (7), Equation (6) can be rewritten as

$$V_o = sC \frac{R_4 \alpha\beta\gamma}{R_3 + R_4} \frac{R_2 R_5}{R_2 + R_5 \alpha\gamma} V_{in} = s\tau V_{in} \quad (8)$$

where $\quad \tau = C \dfrac{R_4 \alpha \beta \gamma}{R_3 + R_4} \dfrac{R_2 R_5}{R_2 + R_5 \alpha \gamma}$ (9)

From Equations (6)-(9), the tracking errors slightly change the realization condition and time constant of the differentiator. However, the realization condition of the proposed differentiator can still be independently tuned by the resistor R_1 and the time constant can also be independently controllable by another resistor R_5.

4. Experimental Results

Experiments were made to verify the feasibility of the proposed circuit. The plus-type CFA was implemented using one AD844. The proposed differentiator was built with $C = 20$ nF, $R_1 = R_2 = R_3 = R_4 = 19.97$ kΩ and $R_5 = 10.03$ kΩ. The triangular waveform with 3 V peak-to-peak and 4.993 kHz was applied to V_{in} (channel 1). The output waveform is shown in **Figure 1** (channel 2). Its operating frequency range is from 500 Hz to 35 kHz with a phase error $< 10°$. The phase error may be due to the ignored non-idealities of the CFA.

5. Conclusion

An active RC differentiator network with independently tunable small time constant has been presented. The proposed circuit employs only one plus-type CFA, five resistors and one grounded capacitor. The use of only grounded capacitor is ideal for integrated circuit implementation. Because the output impedance of the CFA is very small, the differentiator can be directly connected to the next stage. Experimental results were shown to demonstrate the feasibility of the proposed circuit.

6. Acknowledgements

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