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A Novel Current-Mode Temperature-Insensitive APF using a Single CCCII+2 with Grounded Capacitor

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***Abstract*— A novel first-order all-pass filter (APF) using a single positive second-generation current conveyor of current gain equal to 2 (named as CCII+2), one grounded capacitor and one resistor is proposed. From the proposed CCII+2 based filter, by replacing the CCII+2 and the resistor with a positive second-generation current-controlled conveyor of current gain equal to 2 (named as CCCII+2), a new filter which requires only a single CCCII+2 and one grounded capacitor is achieved. In order to operate in current-mode with temperature insensitive, a temperature compensation technique for the CCCII is also proposed. The experimental and PSPICE simulation results found in a good agreement with theoretical analysis are included.**

***Index Terms*— all pass filter; current mode; CCII; CCCII**

I. Introduction

An all-pass filter (APF) is a circuit element that widely used in analog signal processing to shift the phase of an electrical signal while keeping the amplitude of the signal constant over the frequency range of interest. Traditionally, the APF can be constructed using op-amps as basic building blocks [1]-[2]. However, the main problems facing op-amp-based circuits are that they use large numbers of passive elements and their performances are limited by the bandwidth of the op-amps. Current conveyors have also received considerable attention in technical literature to realize first-order APF [3]-[6]. However, most of them employ large numbers of active and passive components as well as with complex component matching constrains.

First-order APFs using only a single current controlled conveyor with less passive elements have been reported recently [7] - [10]. However, all of them require floating capacitors and the circuit performances are temperature dependent. Noting that, for the ease of monolithic IC implementation, it is advantageous for APF to employ grounded capacitors.

The purpose of this paper is to introduces a novel current-mode APF using a single positive second-generation current-controlled conveyor of current gain equal to 2 (CCCII+2).

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For passive circuit elements, it requires only one grounded capacitor and no external resistor. A temperature compensation scheme for the CCCII+2 is also introduced. Thus, the filter phase shift can be electronically tuned with a temperature insensitive. The circuit with a single conveyor gives a canonical structure and the use of grounded capacitor is beneficial to IC implementation. Characteristics of the proposed circuit are verified using experimental and PSPICE simulation results.

II. Circuit Description

A. APFs using grounded capacitor

Usually, the CCII-based circuits are designed by using the current conveyors that the current gain is restricted to the case of equal to 1. The usefulness of the current conveyor can be extended if the current conveyor current gain can be different from 1.

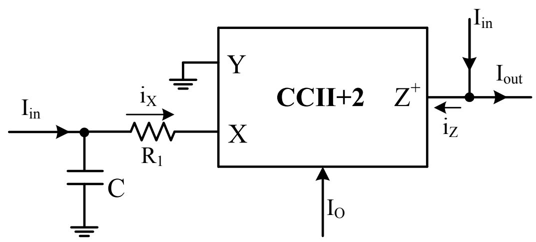

Fig. 1. APF using a single CCII+2 .

Fig. 1 shows the proposed current-mode APF using a single CCII+2, one grounded capacitor and one resistor. Using standard notation, the port relationship of the CCII ± 2 can be characterized by $i_Y = 0$, $v_X = v_Y$ and $i_Z = \pm 2 i_X$. By straightforward analysis, the current transfer function of the circuit can be expressed as

$$\frac{I_{out}}{I_{in}} = -\left(\frac{1 - sCR_1}{1 + sCR_1}\right) \tag{1}$$

The equation (1) clearly indicates that the circuit of Fig.1 is a first-order all-pass filter. The circuit gives a canonical structure and the use of grounded capacitor is particularly attractive for integrated circuit implementation.

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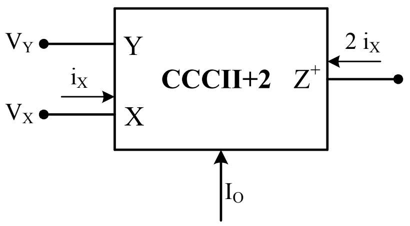

Fig. 2. CCCII+2 symbol.

Consider the block diagram of the proposed CCCII+2 of Fig. 2, its characteristic can be defined by the following matrix equation

$$\begin{bmatrix} i_Y \\ V_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_X & 0 \\ 0 & m & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ i_X \\ V_Z \end{bmatrix} \tag{2}$$

where m is the current conveyor current gain that equal to 2. A bipolar-based circuit to realize the CCCII+2 is shown in Fig. 3, where an additional current mirror is added at the port Z in order to provide $i_Z = 2i_X$. From the circuit of Fig. 3, the intrinsic resistance R_X at the port X can be expressed as

$$R_X = \frac{V_T}{2I_O} \tag{3}$$

where V_T is the thermal voltage given by kT/q and I_O is the bias current of the conveyor. It should be noted that the intrinsic resistance R_X of the CCCII+2 can be varied by the bias current I_O.

The proposed current mode CCCII+2 based all pass filter is shown in Fig.4. The circuit is realized by replacing the CCII+2 and the resistor R1 of Fig.1 by the CCCII+2. Therefore, from (1), if we set $R_1 = R_X$, the current transfer function of the CCCII-based APF can be expressed as

$$\frac{I_{out}}{I_{in}} = -\left(\frac{1-sCR_X}{1+sCR_X}\right) = -\left(\frac{1-sCV_T/2I_o}{1+sCV_T/2I_o}\right) \tag{4}$$

From this equation, we can found that the circuit of Fig. 4 can be realized as a first-order current-mode APF, that using only a single CCCII+2 and one grounded capacitor. Note from (4) the minus sign has defined the phase of 180°. Particularly, the use of grounded capacitor is attractive for integrated circuit implementation. Furthermore, the phase response of the filter can be expressed as

$$\phi(\omega) = 180° - 2\tan^{-1}(\pi fCV_T / I_O) \tag{5}$$

It is clearly indicated that the filter phase shift can be adjusted by an external bias current I_O. This means that the circuit can provide the phase shift with electronically tunable property. However, from (4) and (5), one major disadvantage of the APF is that the filter phase response is strong temperature dependent. Therefore, in the next section, a temperature compensation scheme will be introduced.

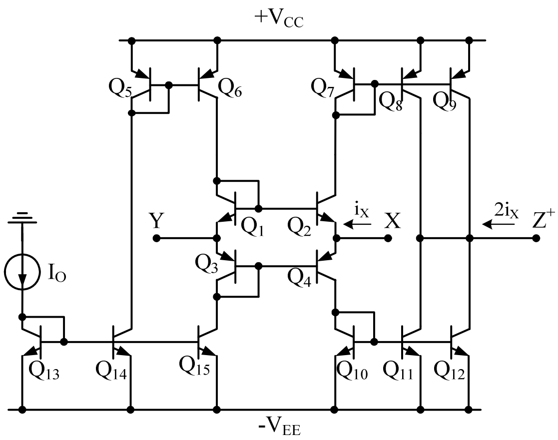

Fig. 3. Schematic implementation of CCCII+2.

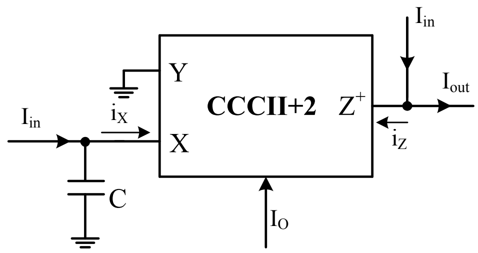

Fig. 4. APF using a single CCCII+2.

B. *Temperature-insensitive APF using a single CCCII+2 with grounded capacitor*

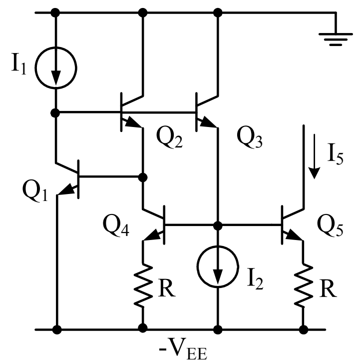

Fig. 5. A temperature dependent constant current source.

Fig. 5 shows a low-voltage current-mode logarithmic function generator circuit that proposed by [11]. This circuit can be modified to function as a temperature dependent current source if the two resistors are selected to be equal.

Assuming that the dimensions of all transistors are the same, then by straightforward analysis the current I_5 can be expressed as

$$I_5 = \frac{V_T}{R}\ln\frac{I_1}{I_2} = \frac{V_T}{R}K \tag{6}$$

where $K = lnI_1/I_2$ and V_T is the usual thermal voltage, I_1 and I_2 are dc constant bias currents. If we designed such that K=1 and I_1>I_2 with I_1/I_2 = 2.72 for simplicity, from (6) we can write

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$$I_5 = \frac{V_T}{R} \quad (7)$$

From (7), we can see that the current I_5 is directly proportional to the temperature. In order that the current can also be electronically tuned, as shown in Fig. 6, a translinear circuit cell formed by transistors Q_6 to Q_9 is added. From the figure, the output current I_9 can be given by

$$I_9 = \frac{I_6 I_{O1}}{I_{O2}} \quad (8)$$

Substituting (7) into (8), where $I_5 = I_6$, we obtain

$$I_9 = \frac{I_{O1}}{I_{O2}}\left(\frac{V_T}{R}\right) \quad (9)$$

Now, we can see that the current I_9 is directly proportional to the temperature and can also be electronically varied.

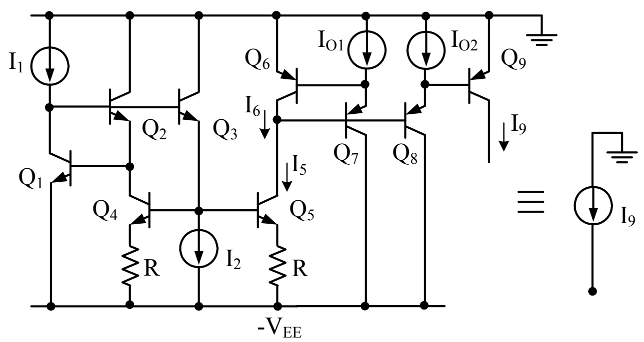

Fig. 6. A tunable temperature dependent constant current source.

As shown in the Fig. 7, by applying the temperature dependent current source I_9 to the circuit of Fig. 4, a temperature-insensitive CCCII+2-based APF named as TICCCII+2, using a single CCCII+2 and grounded capacitor is achieved. By substituting the current I_9 of (9) by the current I_O from (5), we get

$$\phi(\omega) = 180° - 2\tan^{-1}(\pi fCRI_{O2} / I_{O1}) \quad (10)$$

Now, the filter phase response $\phi(\omega)$ can also be linearity tuned by external bias currents ratio I_{O2}/I_{O1} with temperature-insensitive.

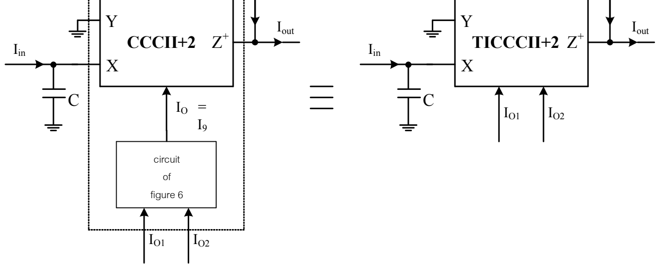

Fig. 7. A temperature-insensitive current-mode APF using a single CCCII+2.

C. Effect of non-ideal of current conveyor and sensitivity analysis

For the non-idealities, the port relationship of the current conveyor with the current gain equal to 2 can be given by

$$V_X = \beta V_Y \quad i_Z = 2\alpha i_X \quad and \quad i_Y = 0 \quad (11)$$

where $\beta = 1 - \varepsilon_v$ and $\alpha = 1 - \varepsilon_i$. The ε_v represents the voltage transfer error while ε_i is the current transfer error. The non-ideal current transfer function for the circuit of Fig. 4 can be expressed as

$$\frac{I_{out}}{I_{in}} = \frac{s - (2\alpha - 1)/R_X C}{s + 1/R_X C} \quad (12)$$

Noting that, the voltage transfer error has no error, no effect on the current transfer function. As the transfer error ε_i is quite small in comparison with α, the filter performance is affected negligibly due to the current transfer error.

In addition, the pole sensitivity of the APF can be analyzed and found to be

$$S^{\omega_o}_{R_X,C} = -1, \quad S^{\omega_o}_{\alpha,\beta} = 0 \quad (13)$$

It is evident from (13) that the pole-ω_o sensitivities due to passive components are within unity in magnitude. Thus, APF enjoys attractive sensitivity performance.

III. Experimental and Simulation Results

In order to verify the theoretical design and to confirm the circuit characteristics, the performance of the proposed a current-mode APF is studied through the use of the experimental result from the bread boarding circuit. The CCCII+2 is realized by using the schematic implementation diagram shown in Fig. 3 with a dc supply voltage of ±3V. The bipolar transistors of the 2N3904 and 2N3906 were used for the NPN and PNP transistors, respectively.

Fig. 8 shows the experimental result of the circuit in Fig.4 that were designed for a phase shift of 145° at 50kHz, 115° at 100kHz and 77° at 200kHz with C = 0.001μF and I_O =500μA, respectively. We found that the maximum error of about 3% was achieved. Due to the stray capacitances in the bread boarding circuit, the high-frequency capability was not measured directly. Therefore, the high-frequency performance was studied by using PSPICE. The BJT model parameters of the NR100N and PR100N were used in the simulation.

The simulated frequency responses, both amplitude and phase responses of the circuit in Fig. 7 were shown in Fig. 9. For the case that the APF in Fig. 7 was designed to provide a phase shift of 90° at the frequency of 100 kHz. The design values were C = 0.01μF, R = 1kΩ, I_1/I_2 = 2.72, I_{O1} = 100μA and I_{O2} = 32μA for the circuit in Fig. 7 and I_O = 500μA for the circuit in Fig. 4. It should be noted that the simulated phase value is deviated from the designed value (90^o at 100 kHz) by less than 1 %.

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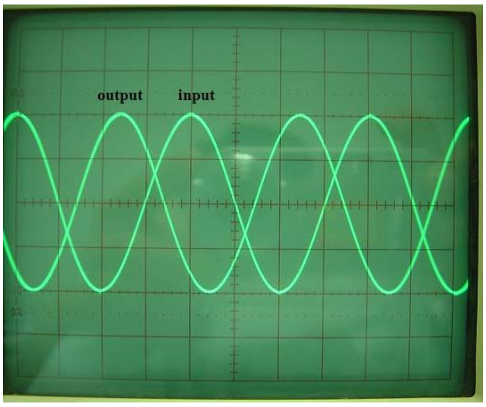
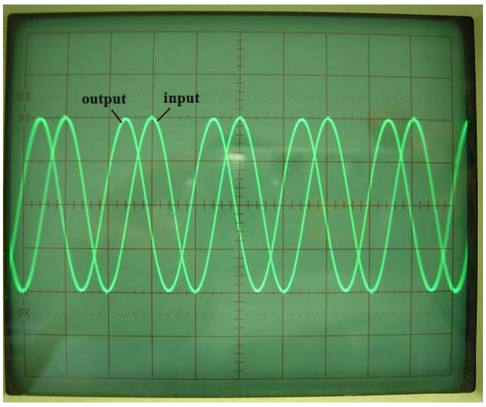
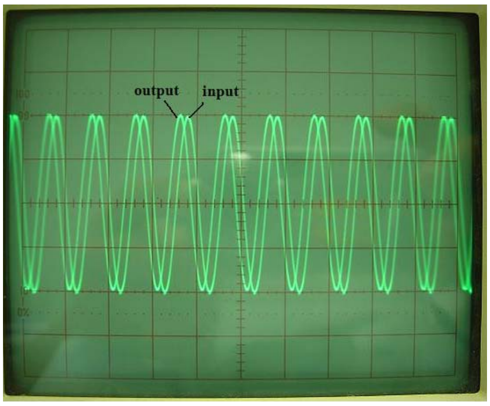


(a)



(b)



(c)

Fig. 8. The experimental results for phase shift circuit in Fig.4: (a) $\phi = 145^\circ$ at 50 kHz (b) $\phi = 115^\circ$ at 100 kHz and (c) $\phi = 77^\circ$ at 200 kHz .

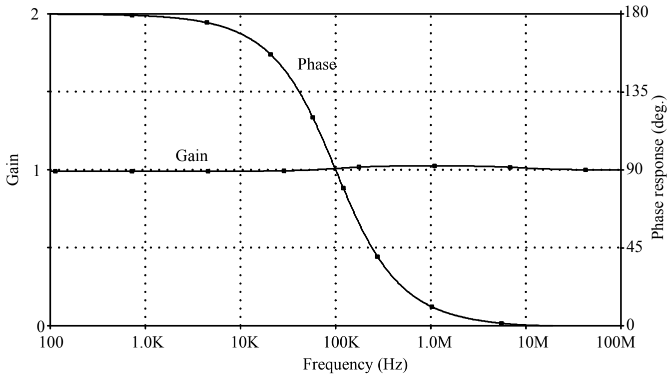


Fig. 9. The frequency response of the APF.

The simulated results in Fig. 10 shows the phase shift (ϕ) against temperature, where the temperature is varied from -40°C to 100°C. We can clearly see that the temperature performance of compensated circuit is much better than the uncompensated circuit over a wide temperature range. The phase shift is constant and approximately equal to 90° degrees for the temperature compensated circuit.

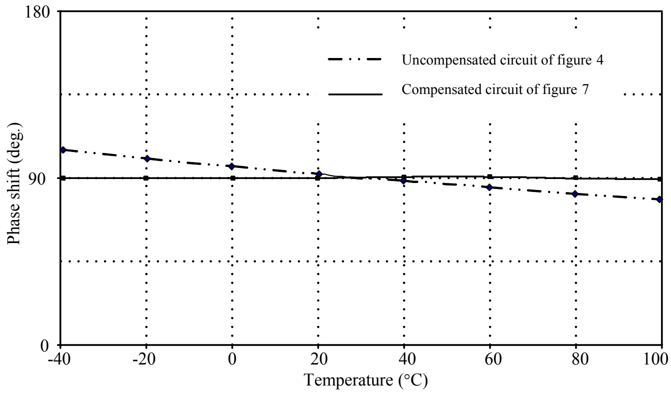


Fig. 10. The variation of the phase shifts ϕ against the temperatures.

IV. Conclusion

A novel current-mode APF using a single CCCII+2 is presented. The proposed circuit requires only a single CCCII+2 and grounded capacitor. The circuit with a single conveyor gives a canonical structure and the use of grounded capacitor is particularly attractive for integrated circuit implementation. The special features of the circuit enjoy low component count, attractive sensitivity performance, stability and the phase shift (ϕ) is insensitive of temperature. The performances of the proposed are confirmed from the experimental results and PSPICE simulation results.

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