A NEW TEMPERATURE COMPENSATED CURRENT CONTROLLED CONVEYOR

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Key words: Conveyor, Temperature Compensation, Circuit, SPice Simulation

Abstract: A simple and effective temperature compensation scheme which generates approximately temperature-independent output current for a current controlled conveyor and its application to a current-mode oscillator is designed and introduced. The temperature sensitivity of the current controlled conveyor's parasitic resistance is reduced by this new design. This proposed circuit includes two current conveyors and a translinear circuit. The circuits' theoretical analysis was carried out, and the performance of the block circuit was confirmed through PSpice simulation results. From the simulation results for applications of proposed circuit, we found that the circuit's temperature-dependence was reduced.

Novo temperaturno kompenzirano vezje CCCII

Kjučne besede: CCCII, temperaturna kompenzacija, vezje, SPice simulacija

Izvleček: V članku opišemo enostaven in učinkovit pristop k izvedbi tokovno krmiljenega in temperaturno kompenziranega vezja CCCII, kakor tudi njegovo uporabo pri izvedbi tokovno krmiljenega oscilatorja. Z novim pristopom znižamo temperaturno občutljivost parazitnih uporov CCCII. Opravili smo teoretično analizo vezja in potrdili funkcionalnost posameznih blokov s pomočjo PSpive simulacije. Iz rezultatov sklepamo, da smo vezju za to uporabo močno zmanjšali temperaturno odvisnost.

1. Introduction

Until recently, a current-mode circuit has been used as the main building block in circuit design. The fact that the gain-bandwidth product is fixed in voltage mode circuits and the slew rate is bounded are disadvantages in many electronic circuit applications. Because current-mode circuits have a number of positive characteristics, such as large bandwidth, high slew rate, wide dynamic range, low power consumption, basic circuit structure and wide linearity, they are used widely in electronic circuit design, especially for oscillator and filter circuits /1-4/.

Current conveyors and related current-mode circuits have begun to emerge as an important class of circuits with properties that enable them to surpass their voltage-mode counterparts in a wide range of applications. A current-mode approach is not just restricted to current processing, but it offers important advantages when interfaced to voltage-mode circuits. The Current Controlled Conveyor (CCCII) which is electronically controllable by a biasing current has been employed in many applications /5,6/. CCCII has been used as a part of filters, oscillators, multipliers and many current-mode applications that require temperature compensation /6-8/. Parasitic resistance is essentially a disadvantage in electronic circuits. But it is used to advantage in current controlled conveyor circuits because it can be easily controlled by biasing current. Output current is negatively affected by the temperature dependence of this resistance /9/. This resistance is directly proportional to thermal voltage for bipolar technology /10/ and surface mobility (μ) for CMOS technology /11/. This means that the characteristics of the current controlled current conveyor-based circuits will depend strongly on the absolute temperature. Also the MOS transconductance parameter is affected by a strong dependence on temperature /12/. Therefore, a technique for temperature compensation is required. In a previous study /16/, a temperature compensated scheme for a translinear current conveyor-based circuit was investigated. This scheme had a disadvantage because it includes a resistor as a passive component. Also the temperature coefficient of the resistor was neglected in that work /16/. Until now, it is not shown that temperature compensated CCCII is used some where else.

In this study, a new circuit building block which consists of two CCCIIs and a translinear circuit block was designed for temperature compensation. The new building block, called the temperature compensated current controlled conveyor (TC-CCCII) has no passive component. Parasitic resistance's temperature dependence is eliminated, so that temperature compensation can be provided for the output current of the current conveyor. To demonstrate the proposed circuit's easy applicability it was used in a CCCII-based oscillator. The circuits' theoretical analysis was carried out, and the simulation process was realized using a PSpice electronic circuit simulation program. Simulation results verify the theoretical considerations.

2. Current controlled conveyor

A conventional current controlled conveyor is given in Fig. 1. Port characteristics of the current controlled conveyor are given in (1) /14/.

$$\begin{pmatrix} I_y \\ V_y \\ I_z \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 0 & 1 & 0 \end{pmatrix} . \begin{pmatrix} V_x \\ I_x \\ V_z \end{pmatrix} \tag{1}$$

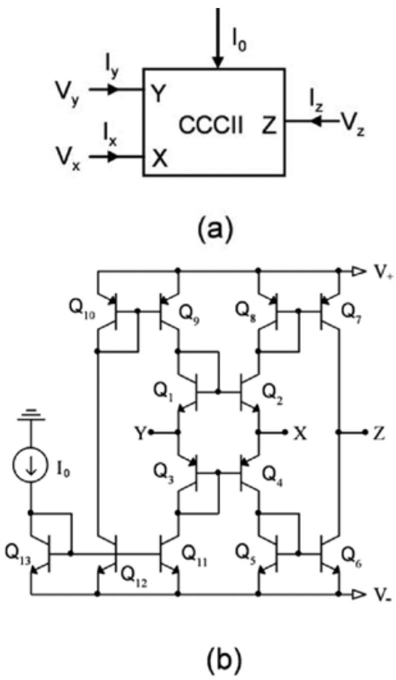

Fig. 1. Conventional CCCII; (a) Symbol, (b) Circuit diagram

When port *Y* of the CCCII is grounded and port *X* constitutes the input of the circuit (Fig. 1), the input current is then given by

$$I_X = 2I_0.\sinh(V_x/V_T) \tag{2}$$

In CCCII based circuits, realization methods take advantage of the parasitic resistance R_x that appears at port X of the conveyor. Hence, the resistance R_x, which can be varied by means of an external bias current. From (2), if $V_x << V_T$ is assumed, then the function sinh (V_x/V_T) is approximately equal to V_x/V_T. The expression for this equivalent resistance is

$$R_x = \frac{V_x}{I_x} = \frac{V_T}{2I_0} \tag{3}$$

where V_T is the thermal voltage given by *kT/q* and I_0 is an external bias current /9/. This means that the characteristic of the current conveyor based circuits will depend strongly on temperature. Therefore, some form of temperature compensation is required. The relation between ports *X* and *Y* can be modeled as shown in Fig. 2.

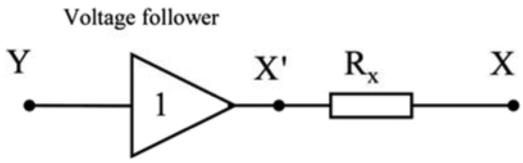

Fig. 2. Equivalent circuit between ports Y and X

3. Proposed circuit topology

Fig. 3 shows symbol and schematic diagram for the proposed temperature compensated current controlled conveyor (TC-CCCII).

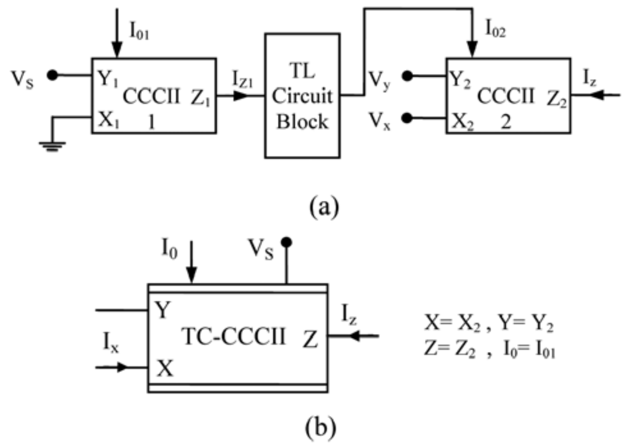

Fig. 3. Proposed TC-CCCII; (a) Schematic diagram, (b) Symbol

The temperature compensated current controlled conveyor was designed using two current conveyors and a translinear (TL) circuit block based on translinear principle.

Currents I_{01}, and I_{02} denote bias currents for the first and second current conveyors, respectively, and V_S is an external voltage. Fig. 4 shows the circuit structure of the TC-CCCII.

When port *X* of the first CCCII (X_1) is grounded and port *Y* of the first current conveyor (Y_1) constitutes the input of the proposed circuit, the output current of the first current conveyor (I_{Z1}), which is equal to current that exists at port *X* of the first current conveyor, can be expressed as

$$I_{Z1} = 2I_{01}\frac{V_S}{V_T} \tag{4}$$

It is shown that output current I_{Z1} of the first current conveyor depends on the voltage V_S applied to port Y_1 and the bias current of the first current conveyor (I_{01}) in (4).

A translinear circuit is used as a current divider circuit to generate bias current for CCCII. This circuit is almost temperature-independent. This circuit is presented in Fig. 5.

The relations among the currents in this circuit are given in (5).

$$I_{02} = \frac{I_1 I_2}{I_{Z1}} \tag{5}$$

where I_{02} is the bias current of the second current conveyor aiming at providing temperature compensation. As shown in Fig. 4, I_1 and I_2 are the collector currents of the Q_B and Q_C transistors respectively. The current of the second current conveyor's port *X* can be expressed as

$$I_x = 2I_{02}\frac{V_x}{V_T} \tag{6}$$

In this case, the current of the second current conveyor's port *X* will be

$$I_x = \frac{I_1 I_2 V_x}{I_{01} V_S} \tag{7}$$

Current mirrors which are obtained by Q_{10}, Q_{12} and Q_B, Q_C transistors allow the biasing current (I_{01}) to flow through the Q_{13} transistor at the collector of the Q_B and Q_C transistors. So I_1 and I_2 currents are equal to current I_{01}. From (7), we can see that the parasitic resistance of the second current conveyor can be expressed as,

$$R_x = \frac{V_S}{I_{01}} \tag{8}$$

The parasitic resistance R_x input current I_x and output current I_z of the whole circuit can be independent from V_T by adjusting the suitable configuration of the circuit blocks.

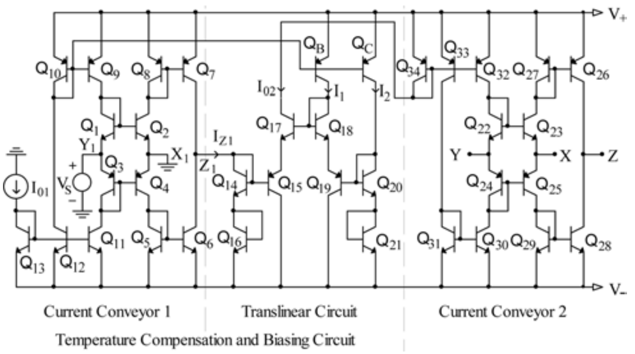

Fig. 4. Realization of the TC-CCCII circuit

4. Simulation results

To verify the validity of the theory, the circuits in Fig. 1 and Fig. 4 were simulated using models for the transistors of type NR100N and PR100N whose parameters are detailed in /15/. The biasing current I_0 = 85 μA , that is, R_x=150 Ω was used for the conventional current conveyor. The circuit parameters were chosen as I_{01}=100 μA and V_S = 15 mV for the temperature compensated current conveyor, and the power supply was ± 2.5 V.

First, a simulation of the conventional current conveyor shown in Fig.1 was realized using a PSpice simulation program. Port Y of the CCCII is grounded and port X constituted the input of the circuit. The I-V characteristic at port X for different temperature values are shown in Fig. 6.

From (1), I_Z is equal to I_X. Thus, from Fig. 6 it is concluded that I_Z is affected by temperature change.

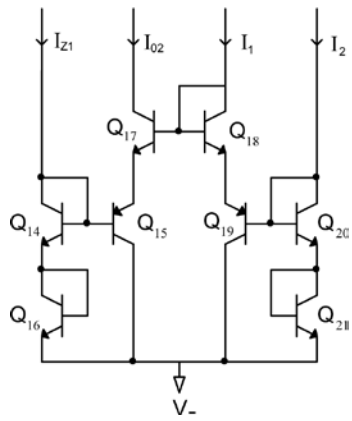

Fig. 5. Translinear circuit

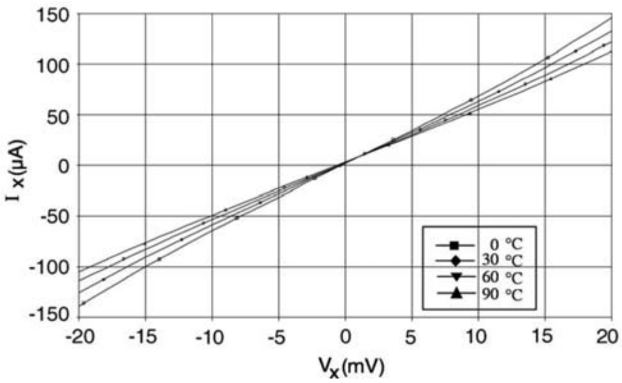

Fig. 6. Current-voltage characteristics of the CCCII without temperature compensation

Next, a simulation of the temperature compensated current conveyor was realized using a PSpice simulation program. Port Y of the second CCCII was grounded and port X of the second CCCII constituted the input of the circuit. The I-V characteristic at port X for different temperature values are shown in Fig. 7.

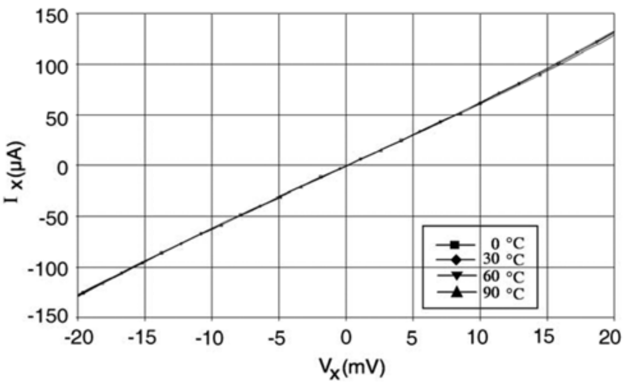

Fig. 7. Current-voltage characteristics of the TC-CCCII

In Fig. 7, it is clear that the output current for different temperature values changes in regard to nanoampers. These values are almost negligible. In addition, when Fig. 7 is taken into consideration, it does not show a characteristic deviation in the origin, on the contrary in Fig. 6. Characteristic deviation in the origin is caused by a mismatch between the transistors. This situation clearly denotes that the proposed circuit is more stable.

Fig. 8 depicts changing output current versus temperature for both the conventional and the temperature compensated CCCII's output current.

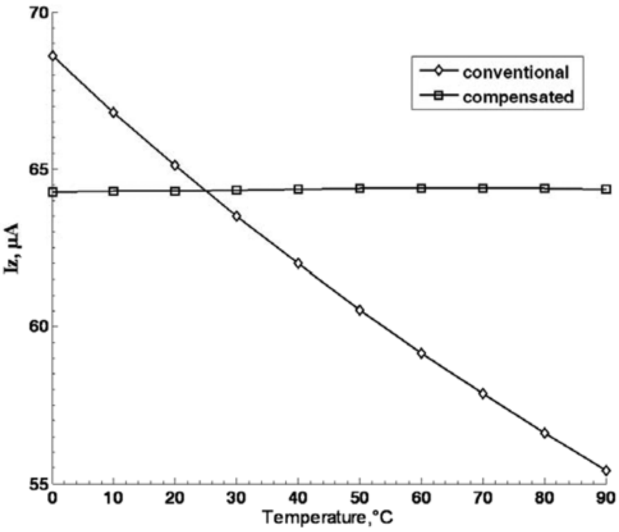

Fig. 8. Variation of the output currents versus temperature for CCCIIs

When the current curve of the conventional CCCII in Fig. 8 is considered, it can be seen that the characteristic is not exactly linear. This result is an obvious consequence of the hyperbolic function in (2). In previous studies /14/, this hyperbolic function was approximately linearized. Thus, the characteristic of CCCII output was obtained in linear form.

5. Current controlled oscillator based on cccii

The oscillator was designed using a current amplifier (current mirror) and two TC-CCCIIs as shown in Fig. 9.

The current loop gain or the return ratio *T(s)* of the circuit at port *X* is characterised by

$$T(s) = \frac{\alpha R_x C_1 S}{1 + 2R_x C_2 S + 2R_x C_1 C_2 S^2} \quad (9)$$

CCCII has a finite input resistance R_X at the X terminal, which is controllable by the bias current I_0 /16/. R_X is considerably affected by temperature. Sinusoidal oscillation frequency is shown in the following equation

$$f_0 = \frac{1}{2\pi R_x \sqrt{C_1 C_2}} \quad (10)$$

where the oscillation condition is α = 2 /16/. Oscillation frequency can be tuned by varying the R_x. The current mirror in Fig. 9 is independent from temperature, so oscillation frequency is not affected under this condition. Table 1 depicts a theoretical changing R_X and oscillation frequency versus temperature for the conventional CCCII.

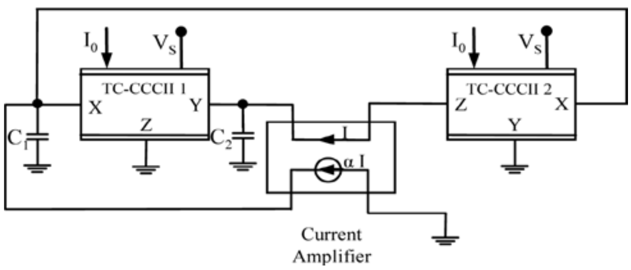

Fig. 9. Proposed current controlled oscillator schematic diagram

In Table 1, it is clear that R_x and oscillation frequency for different temperature values change. Biasing currents were chosen as I_0 = 250 µA for conventional CCCIIs.

Table 1. Theoretical changing R_X and oscillation frequency versus temperature for the conventional CCCII.

Temperature (°C)	R_X (Ω)	Frequency (KHz)
0	46.94	335.06
30	52.12	305.38
60	57.28	277.87
90	62.44	254.91

To demonstrate the applicability of the new temperature compensated CCCII, it was used in place of a conventional CCCII to realize temperature compensation in the current controlled oscillator.

To evaluate the performance of the circuit in Fig. 9, several PSpice simulations have been performed using the typical parameters of the bipolar transistor NR100N and PR100N whose parameters are detailed in /15/. A biasing current I_0 = 250 µA, that is, R_x = 50 Ω was used for the conventional current conveyor.

Circuit parameters were chosen as I_{01} = 75 µA and V_S = 15 mV for the temperature compensated current conveyor in Fig.4 and the power supply was ± 2.5 V. C_1 and C_2 were 0.01 µF for all simulations.

Simulation results are shown in Fig. 10, which displays current amplitude against frequency for a number of temperatures for the current controlled oscillator based on a conventional CCCII. This graph was obtained from an oscillator circuit using conventional CCCII.

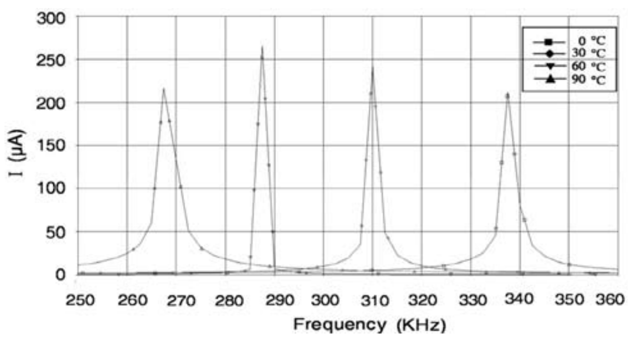

Fig. 10. Unstable oscillation frequency at different temperatures for oscillator based on conventional CCCII.

In Fig. 10, it is clear that, the oscillator's oscillation frequency is strongly affected by temperature change. The oscillation frequency of the circuit changes between 265 KHz – 340 KHz.

Fig. 11 shows stable oscillator frequency at different temperature values for the current controlled oscillator based on the temperature compensated CCCII. This graph was obtained from an oscillator circuit using the TC-CCCII.

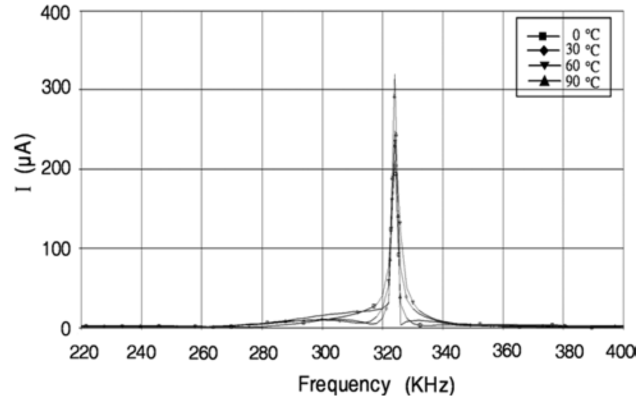

Fig. 11. Stable oscillation frequency at different temperatures for oscillator based on TC-CCCII.

It is clear that the temperature performance of the compensation circuit is much better than that of the conventional circuit. In addition, it can also be seen that the compensated circuit results in a much lower temperature sensitivity.

6. Conclusion

In this study, a temperature compensated circuit for conventional CCCIIs was designed, and its application to a current-mode oscillator was tested. The temperature sensitivity of the current controlled conveyor's parasitic resistance was reduced in this new design. The proposed circuit was simulated using a PSpice simulation program, and its simulation results were compared with the simulation results of a conventional CCCII. The compensated circuit was less temperature sensitive than conventional circuits. However, the proposed circuit was found to be suitable for implementing in integrated circuits due to its having no passive element. To demonstrate the applicability of the new temperature compensated CCCII, it was used in place of a conventional CCCII to realize temperature compensation in a current controlled oscillator. Finally, the proposed circuit which is controllable by biasing current was used as a part of many sensitive current-mode applications that especially require temperature compensation.

7. References

/1./ Palmisano G, Palumbo G, Pennisi, S. *CMOS Current Amplifiers*. Kluwer Academic Publishers: Boston (MA), 1999;1-9.

/2./ Schmid H. Approximating The Universal Active Element. *IEEE Transaction on Circuit Systems-II:Analog and Digital Signal Processing* 2000; **47**(11) : 1160 - 1169.

/3./ Siripruchyanun JM, Jaikla W. Current controlled current conveyor transconductance amplifier (CCCCTA): a building block for analog signal processing, *Electrical Engineering (Archiv fur Elektrotechnik), Electrical Engineering, Springer* 2008; **90**(6) : 443-453.

/4./ Cam U. A New Transadmittance Type First-Order Allpass Filter Employing Single Third Generation Current Conveyor. *Analog integrated circuits and signal processing* 2005; **43** : 97-99.

/5./ Yuce HE, Minaei S, Cicekoglu O. Resistorless floating immittance function simulators employing current controlled conveyors and a grounded capacitor. *Electrical Engineering (Archiv fur Elektrotechnik)* 2006; **88**(6) : 519-525.

/6./ Kiranon W, Kesorn J, Sangpisit W, Kamprasert N. Electronically tunable multifunctional translinear-c filter and oscillator. *Electronics Letters* 1997; **33** (7) : 573-574.

/7./ Minaei S, Turkoz S. New current-mode current-controlled universal filter implemented from single-output current controlled conveyors. *Frequenz* 2000; **54 (**5) : 138-140.

/8./ Cicekoglu O, Kuntman H, Berk S. Allpass filters using a single current conveyor. *International Journal of Electronics* 1999; **86** (8) : 947-955.

/9./ Fabre A, Saaid O, Wiest F, Boucheron C. High frequency applications based on a new current controlled conveyor. *IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications* 1996; **43** (2) : 82-91.

/10./ Fabre A. Bidirectional current controlled PTAT current source, *IEEE CASI* 1994; **41** : 922-925.

/11./ Adachi T, Izumiya S. A MOS temperature compensation function generator for TCXO using differential MOS multipliers. *IEEE International Frequency Control Symposium Joint with the 22nd European Frequency and Time Forum* 2009; 990-993.

/12./ Mahmoud, S. A low voltage CMOS floating resistor. *IEEE International Conference on Electrical, Electronic and Computer Engineering* 2004; 453-456.

/13./ Surakampontorn W, Riewruja V, Kumwachara K, Fongsamut C. Temperature compensation of translinear current conveyor and OTA. *Electronics Letters* 1998; **34** (8) : 707-709.

/14./ Fabre A, Alami M. Universal current mode biquad implemented from two second generation current conveyors. *IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications* 1995; **42** (7) : 383-385.

/15./ Frey DR. Log-domain filtering: an approach to current-mode filtering. *IEE Proceedings G, Circuits, Devices and Systems* 1993; **140**(6):406–416.

/16./ Kiranon W, Kesorn J, Wardkein P. Current controlled oscillator based on translinear conveyor. *Electronics Letters* 1996; **32** (15) : 1330-1331.

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