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Temperature Independent Current Conveyor Precision Full-Wave Rectifier for Low-Level Signal

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Abstract: A circuit that provides precision rectification low-level input signal with low temperature sensitivity is presented in this paper. It utilizes an improved second type current conveyor based around current-steering output stage and voltage biased silicon diodes, rather than more usual current mirrors. Proposed design of the precision rectifier ensures good current transfer linearity in the range that satisfy class A of the amplifier and good voltage transfer characteristic for low level signals. Distortion during the zero crossing of the input signal is practically eliminated. Design of the proposed rectifier is realized with usual components that can be bought in the market.

Keywords: : Current conveyor, rectifying circuits, PSpice program, full-wave rectifier.

1 Introduction

PRECISION RECTIFIERS are important building blocks for signal processing, conditioning and instrumentation of low level signals. Voltage operational amplifiers (voltage operational amplifier), with their high open-loop gain, have been effectively used in this application and provide accurate precision rectification. But the classical problem with conventional precision rectifiers based on diodes and voltage operational amplifiers is that during the non-conduction/conduction transition of the diodes the voltage operational amplifiers have to recover with a finite small-signal dV/dt resulting in significant distortion during the zero crossing of the input signal. Operational amplifiers with high slew-rate can not solve this fundamental drawback because it is a small-signal transition problem [1,2]. To overcome diode resistance problem we have to drive diodes from a high-impedance sources

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such the case with the submitted current conveyor. The high impedance of the current conveyor ensues that defined current flow through the diodes into output, independently of the diode resistance. At the first time, design of the current conveyors was based on employing the power supply rails of the voltage operational amplifiers as the current rectification path, but the first problem encountered with such schemes is that signal levels need to be significantly higher than the supply bias to guarantee precision rectification, and second problem is zero crossing signal when we lose rectification. Finally, it is known that the PSpice program [3] cannot track the current in positive and negative input power-supply leads of voltage operational amplifiers, because this program operates with functional and not physical model, and on that way it can not be used for testing. Proposed current conveyor overcomes all enumerated problems.

2 Current Conveyor Based Around Current- Steering Output Stage

A second generation current conveyor (CCII) can be represented as a three-terminal device in which a voltage applied to high-impedance terminal Y is buffered with unity gain to terminal X, from which any current that flows is mirrored to terminal Z, as shown in Figure 1 [4].

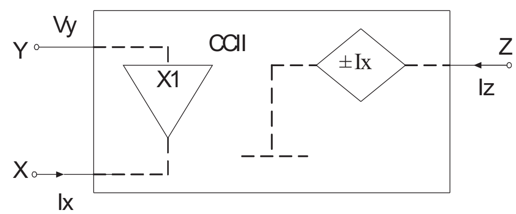

Fig. 1. Second generation CCII current conveyor.

Mathematically, second generation current conveyor can be described by the following matrix equation:

$$\begin{bmatrix} V_x \\ I_y \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ \pm 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix} \tag{1}$$

or by three linear equations:

$$V_x = V_y \tag{2}$$

$$I_y = 0 \tag{3}$$

$$I_z = \pm I_x \tag{4}$$

The sign of current I_z in (4) determines the positive (CCII+) or negative (CCII-) type of CCII.

Figure 2 shows the improved current conveyor formulation based on current steering output stage (CCIICS) [4].

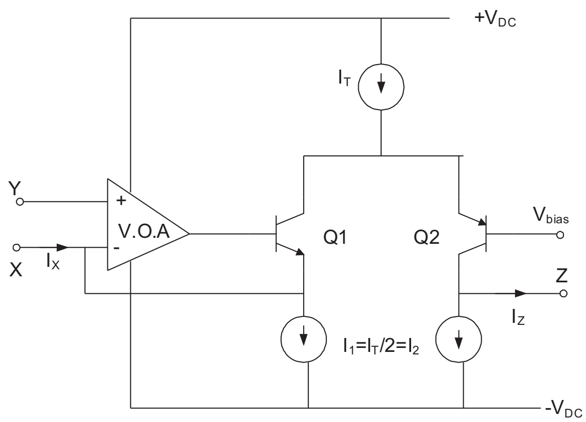

Fig. 2. Improved current conveyor based on current-steering output stage.

Good voltage transfer accuracy between Y and X terminal is ensured by the use of negative feedback around voltage operational amplifier and transistor Q_1. If we chose value of current source I_T sufficiently large to keep the emitter resistance of Q_1 very small compared to the output resistance of the current source, voltage transfer error will remain very small. A conveyor input current I_x results in an identical decrease of current through Q_1 and identical increase of current through Q_2, causing an output current of I_x to flow from node Z by subtraction from the source providing collector bias current for Q_2. Transistor Q_1 and Q_2 should be high devices to ensure close equivalence of collector and emitter currents in both cases. Current transfer accuracy from X to Z terminal no longer depends on device matching within current mirrors, but is controlled by Kirchhoff's current low (summation equation). Current offset, as a result of any variation DC biasing sources and device parameters, can be eliminated externally. It must be noted that the value of the current sources I_1 and I_2 is one half of the I_T.

3 Precision Full-Wave Rectifier For Low Level Signals

A full-wave precision rectifier for low level signals can be configured using two CCIICS and four diodes as shown in Figure 3 [5].

The operation of the circuit shown in the Figure 3 is as follows: both of the

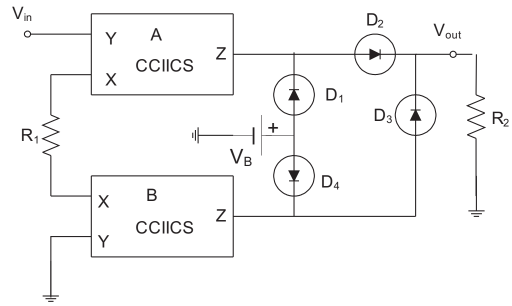

Fig. 3. Configuration of the precision rectifier for low level signal.

CCIICSs form a differential voltage-current converter such that during the positive input cycle the output currents of value Vin/R1 flow out of the Z node of the CCIICS-A and into the *Z* node of CCIICS-B, thus making only diodes D_4 and R_2 active (ON state). Because R_2 is active, the current from the *Z* node of CCIICS-A flows into the output resistance R2 making:

$$V_{out} = \frac{R_2}{R_1} V_{in} \tag{5}$$

During the negative input cycle, diodes D_3 and D_1 are active, so the output current of the CCIICS-B is going into resistance R2 making again output signal same as equation 5. In that way we proved that circuit shown in the Figure 3 work as full-wave rectifier.

The voltage at the anode of diodes D_1 and D_4 is biased by a low impedance voltage source VB ($\simeq$1.2 V) allowing forward bias for each silicon diode [6]. When D_1 and D_4 conduct the voltage at the subsequent *Z* terminal is approximately $+0.6$ V and the output voltage is zero. This condition ensures that the load impedance presented to the *Z* terminal is kept low at all times, especially as the diode pairs D_1/D_3 and R_2/D_4 swap condition roles. Note that all the diodes are on the edge of conduction during the zero crossing input signal.

4 Circuit Implementation

In order to explore the potential performance of the new rectifier topology, first we realize CCIICS as it shown in the Figure 4.

Analysis of CCIICS and full-wave precision rectifier was made with PSpice program [5]. For testing purposes, the conveyor has been configured as a voltage amplifier, this time by feeding the voltage signal to terminal *X* via resistor R_{in}, connecting R_L between output terminal *Z* and ground and connecting terminal *Y*

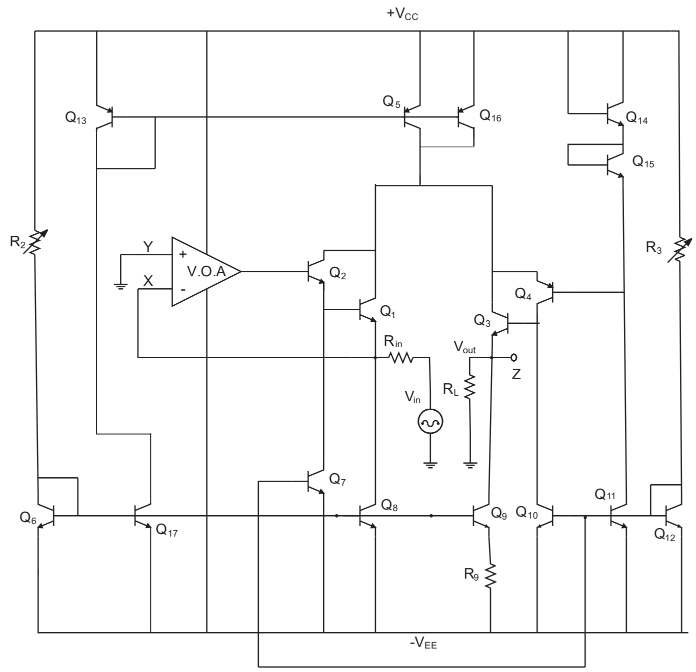

Fig. 4. Topology of the CCIICS.

to ground. The circuit of Figure 4 operates from $\pm$ 10 V. We used the next couple values for resistor R_2 and R_3 to define current source I_T without offset voltage at the output of the current conveyor: $R_2 = 9.7$ kΩ and $R_3 = 118$ kΩ, $I_T = 4$ mA and $I_1 = I_2 = I_T/2 = 2$ mA. Current offset can be nulled with resistor $R_9 = 18\Omega$. All npn transistors in the circuit are 2N2369 and pnp 2N995 with $\beta = 80$. Operational amplifier TL082 that uses FET transistors at differential entry points and has small DC bias currents is applied in the circuit. Resistors $R_{in} = 15\Omega$ and $R_L = 16\,\Omega$ ensures maximal current range for class A amplifier. Nominally these two resistors should be equal for unity voltage gain, but this small difference in value is due to the adjustment of the unitary ratio on the rectifier voltage transfer characteristic (Figure 7). Current transfer linearity of the proposed CCIICS is shown on Figure 5. It can be concluded that current range $-1.5\,\text{mA} \div 1.5\,\text{mA}$ satisfying relation (4).

Figure 6 shows frequency response of the proposed CCIICS for unity voltage gain ($R_L = R_{in}$) and for gain=10 ($R_L = 10R_{in}$). From that figure one can conclude that frequency range of that circuit is about 1 MHz.

Precision full-wave rectifier for low level signal is realized with two CCIICS and four fast diodes (1N4148) as it shown on Figure 3 and his transfer characteristic, $V_{out} = f(V_{in})$, is presented on the Figure 7. From the Figure 7 we can make two

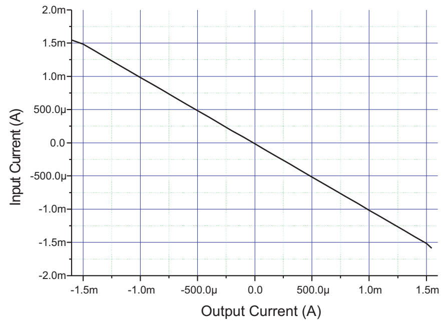

Fig. 5. Current transfer linearity of the proposed CCIICS.

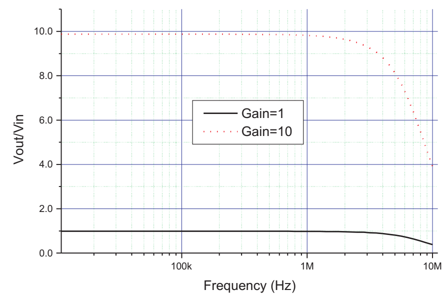

Fig. 6. Frequency response of the proposed CCIICS.

conclusions: first, there is distortion during the zero crossing input signals but in this case it is very small (in the range $-1\,\text{mV}\div 1\,\text{mV}$), and second, transfer characteristic of the proposed rectifier is little temperature dependent. The improvement of temperature independency of the proposed rectifier was described in the reference [7].

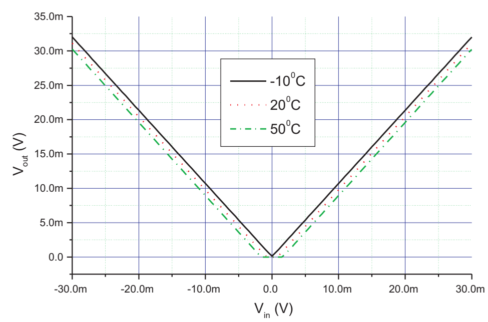

Fig. 7. Temperature dependence of the transfer characteristic proposed rectifier.

Figure 8 show output waveform of the proposed rectifier for the sinusoidal input signal amplitude 30 mV, frequency 10 kHz and with gain =1, Figure 8(a), with gain=10, Figure 8(b).

5 Conclusion

In this paper it is presented design of a temperature independent precision full-wave rectifier circuit based on improved current conveyor with current-steering output stage and voltage biased output diodes. Proposed rectifier have good voltage transfer characteristic for low level signal, good current transfer linearity in the

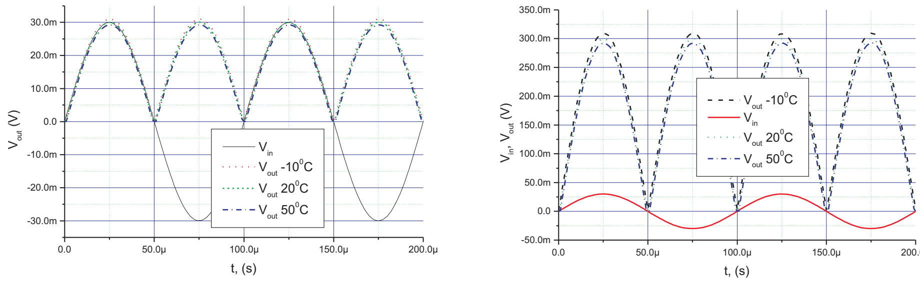

Fig. 8. Output waveform of the proposed rectifier for the sinusoidal input signal amplitude 30mV.

range that satisfy class A of the amplifier and at the same time it can be amplified input signal very precise. Design of the rectifier is realized with components that can be bought in the market.

References

[1] F. J. Lidgey, K. Hayatleh, and C. Toumazou, "New current- mode precision rectifiers," in *Proc IEEE Int. Symp. Circuits and Systems Chicago*, 1993, pp. 1322–1325.

[2] S. Đukić, "The analysis of full-wave wide-band precision rectifier with modified second type current conveyor," *Facta Univ. Ser.: Elec. Energ.*, vol. 20, no. 2, pp. 215–221, Aug. 2007. [Online]. Available: http://factaee.elfak.ni.ac.rs/7djukic.pdf

[3] *PSpice Circuit Analysis*, MicroSim Corporation, Jan. 1991, version 4.05.

[4] B. Wilson, M. Al-Gahtani, J. Vosper, and R. Deloughry, "High-precision current conveyor implementation employing a current-steering output stage," *International Journal of Electronics*, vol. 93, no. 10, pp. 653–662, Oct. 2006.

[5] A. Khan, M. El-Ela, and M. A. Al-Turaigi, "Curent-mode precision rectification," *International Journal of Electronics*, vol. 79, pp. 853–859, 1995.

[6] F. J. Toumazou, C.and Lidgey and S. Chattong, "High frequency current conveyor precision full-wave rectifier," *Electronic letters*, vol. 30, no. 10, pp. 745–746, May12 1994.

[7] K. Hayatleh, S. Porta, and F. J. Lidgey, "Temperature independent current conveyor precision rectifier," *Electronic Letters*, vol. 30, no. 25, pp. 2091–2093, Dec. 1994.