

Full-Wave Current Conveyor Precision Rectifier

Slobodan R. Djukic¹

Abstract: A circuit that provides precision rectification of small signal with low temperature sensitivity for frequencies up to 100kHz without waveform distortion is presented. It utilizes an improved second type current conveyor based on current-steering output stage and biased silicon diodes. The use of a DC current source to bias the rectifying diodes provides higher temperature stability and lower DC offset level at the output. 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 standard components.

Keywords: Current conveyor, Rectifying circuits, Operational amplifiers, PSpice program.

1 Introduction

Precision rectifiers are important building blocks for signal processing, conditioning and instrumentation of small signals. Voltage operational amplifiers (VOA), 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 VOAs is that during the non-conduction/conduction transitions of the diodes the VOAs 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]. To overcome diode resistance problem we have to drive diodes from a high-impedance sources as is solved in proposed current conveyor. High impedance of the current conveyor ensures that defined current flows through diodes into output, regardless of the diode resistance. At the first time, design of the current conveyors was based on employing the power supply rails of the VOAs as the current rectification path, but the first problem encountered with such solutions is that signal levels need to be significantly higher than the supply bias to guarantee precision rectification. The second problem is zero crossing signal when rectification is lost. Finally, it is known

¹Technical Faculty Cacak, Svetog Save 65, 32000 Cacak, Serbia; E-mail: sdjukic@tfc.kg.ac.yu

that the PSpice program [2] cannot track the current in positive and negative input power-supply rails of VOAs, because this program operates with functional and not with physical model. Proposed current conveyor rectifier try to overcome above mentioned problems.

2 Current Conveyor Based on Current-Steering Output Stage

A second generation current conveyor (CCII) can be represented as a three-terminal device in which voltage applied to high-impedance terminal Y is buffered with unity gain to the terminal X. Current from terminal X is mirrored to terminal Z, as shown in Fig. 1 [3].

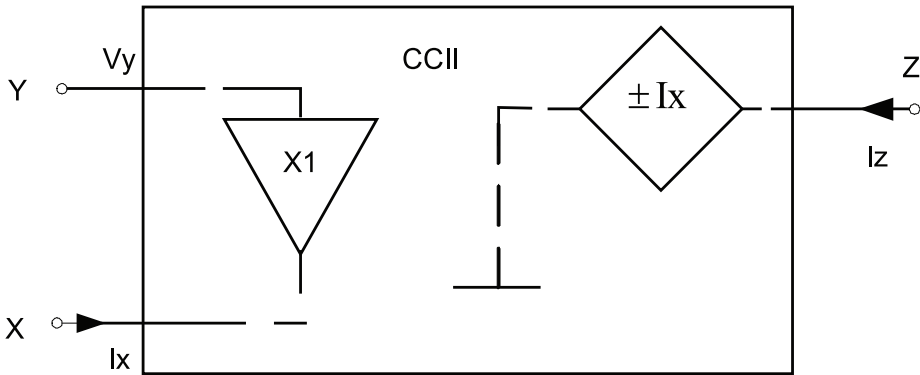


Fig. 1 – Second generation CCII current conveyor.

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

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

or by three linear equations:

$$V_x = V_y \quad (2)$$

$$I_y = 0 \quad (3)$$

$$I_z = \pm I_x \quad (4)$$

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

Fig. 2 shows the improved current conveyor based on current steering output stage (CCIICS) [3].

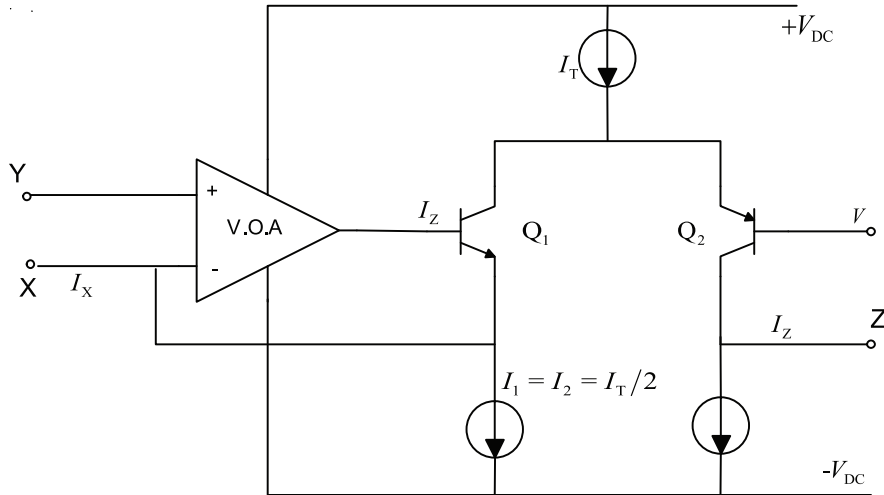


Fig. 2 – Improved current conveyor based on current-steering output stage.

Good voltage transfer accuracy between Y and X terminal is ensured by the use of negative feedback around VOA 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 increase results in an identical decrease of current through Q_1 and identical increase of current through Q_2 , causing an output current of $I_z = I_x$ to flow from node Z. Transistors Q_1 and Q_2 should be high β devices to ensure close equivalence of collector and emitter currents in both cases. Current transfer accuracy from X to Z node does not depend on matching of current mirrors, but is controlled by Kirchoff's current law (summation equation). It must be noted that the current I_T have to be exactly divided on two equal parts, $I_1 = I_2 = I_T/2$, for the correct functioning of the conveyor.

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 is shown in Fig. 3 [4].

Both of the CCIICSs form a differential voltage-current converter such that during the positive input cycle the output currents of value V_{in}/R_1 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 D_2 conducting. Because D_2 is active, the current from the Z node of CCIICS-A flows into the output resistance R_2 making:

$$V_{out} = \frac{R_2}{R_1} V_{in} \quad (5)$$

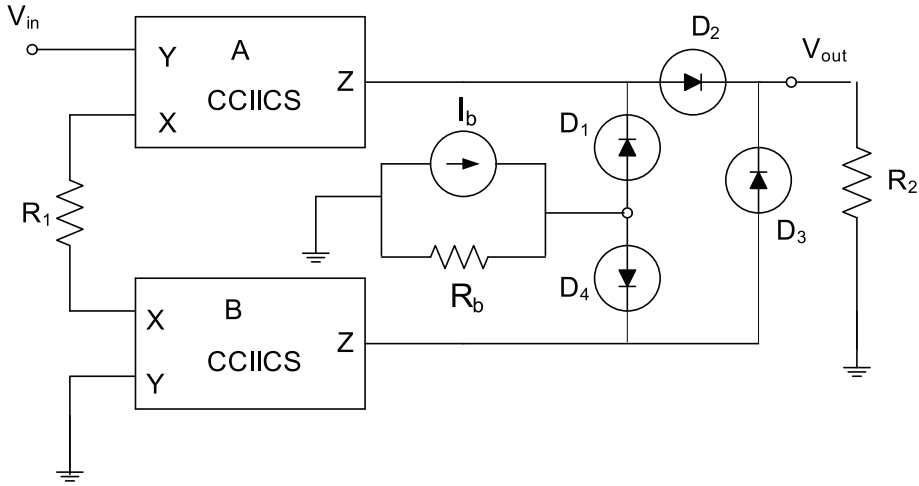


Fig. 3 – Configuration of the precision rectifier for low level signal.

During the negative input cycle, diodes D_3 and D_1 are conductive, so the output current of the CCIICS-B is going into resistance R_2 making again output signal same as is defined by equation (5). The circuit shown in the Fig. 3 works as full-wave rectifier.

To keep DC voltage offset at the output node on a minimum, the diode current should be reduced to the lowest value I_b^* that is able to ensure the proper biasing of the diodes. Resistance R_b is necessary to provide a path to earth for the signal current [6]. For a given value of direct current I_b such that the output offset current is I_b^* , it can be written following equation using Kirchoff's voltage law:

$$R_b (I_b - 2I_b^*) - 2V_T \ln \left(\frac{I_b^*}{I_s} \right) - R_2 2I_b^* = 0. \quad (6)$$

From the equation (6) R_b can be calculated as:

$$R_b = \frac{2}{I_b - 2I_b^*} \left[V_T \ln \left(\frac{I_b^*}{I_s} \right) + I_b^* R_2 \right], \quad (7)$$

where I_s is saturation current of the diodes, and V_T is thermal voltage.

In this way the switching delays around the zero crossing points are minimized because diodes are conducting continuously. The output offset level can be adjusted easily by choice of a resistor R_b .

4 Circuit Implementation

Realization of CCIICS is shown in the Fig. 4.

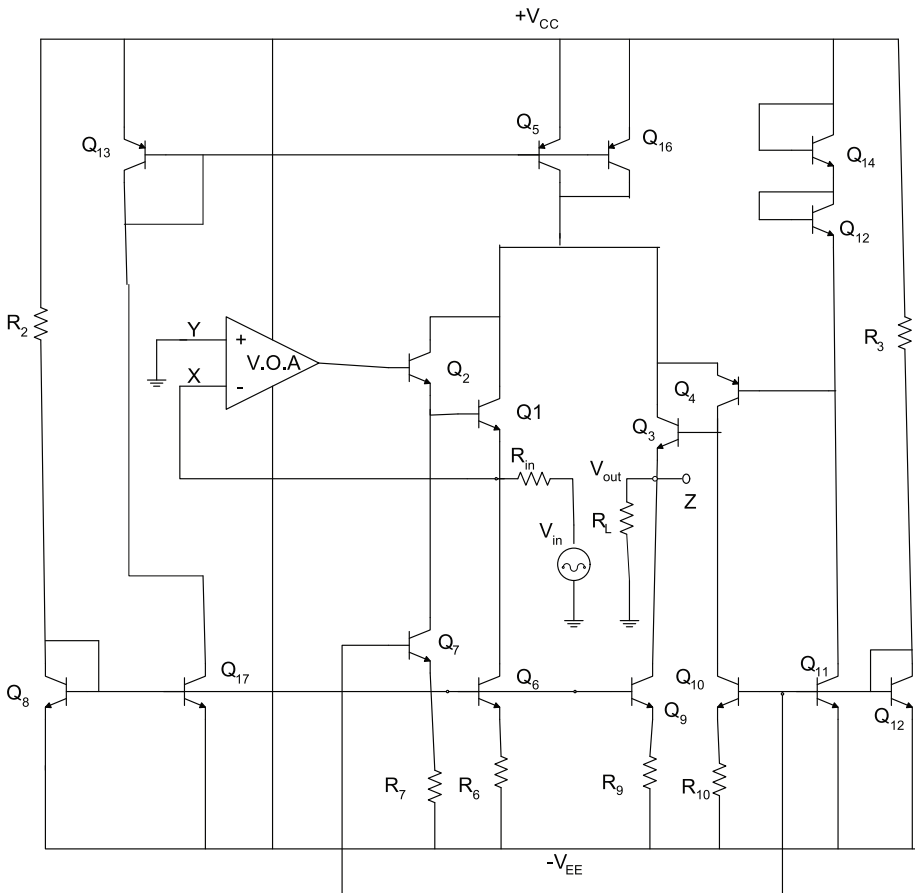


Fig. 4 – Realization of the CCIICS.

Analysis of CCIICS and full-wave precision rectifier was made with PSpice. The conveyor has been configured as a voltage amplifier. Voltage signal is applied to terminal X via resistor R_{in} . Load R_L is connected between output terminal Z and ground. Terminal Y is on ground. The circuit of Fig. 4 operates

with $R_2 = 9.4\text{k}\Omega$, $I_T = 4\text{mA}$ and $I_1 = I_2 = I_T/2 = 2\text{mA}$. Current offset can be nulled with resistor $R_7 = R_{10} = 20\Omega$ and $R_6 = R_9 = 1.4\Omega$. All npn transistors in the circuit are 2N2369 and pnp 2N995 with $\beta \approx 80$. Operational amplifier TL082 uses FET transistors at differential entry points and has small DC bias currents. Resistors $R_{in} = 100\Omega$ and $R_L = 101\Omega$ ensures maximal current range for class A amplifier. Nominally these two resistors should be equal for unity voltage gain, but this small difference is due to the adjustment of the unity ratio on the rectifier voltage transfer characteristic, Fig. 7. Current transfer linearity of the proposed CCIICS is shown in Fig. 5. It can be concluded that current range $-1.8\text{mA} \div 1.8\text{mA}$ satisfies relation (4).

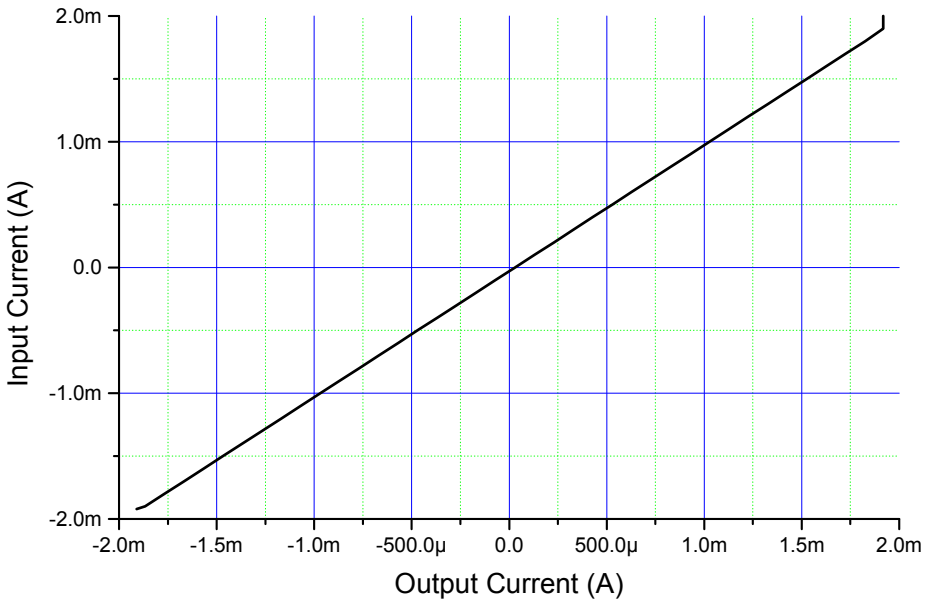


Fig. 5 – Current transfer linearity of the proposed CCIICS.

Fig. 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 Fig. follow that frequency range of circuit is about 1MHz.

Temperature independent wide-band precision full-wave rectifier for low level signal is realized with two CCIICS, four fast diodes (1N4148), DC current source $I_b = 3\text{mA}$, resistance $R_b = 340\Omega$. From Fig. 7 we can make two conclusions: first, there is distortion during the zero crossing input signals but in this case it is very small, and second, transfer characteristic of the proposed rectifier is little temperature dependent.

Full-Wave Current Conveyor Precision Rectifier

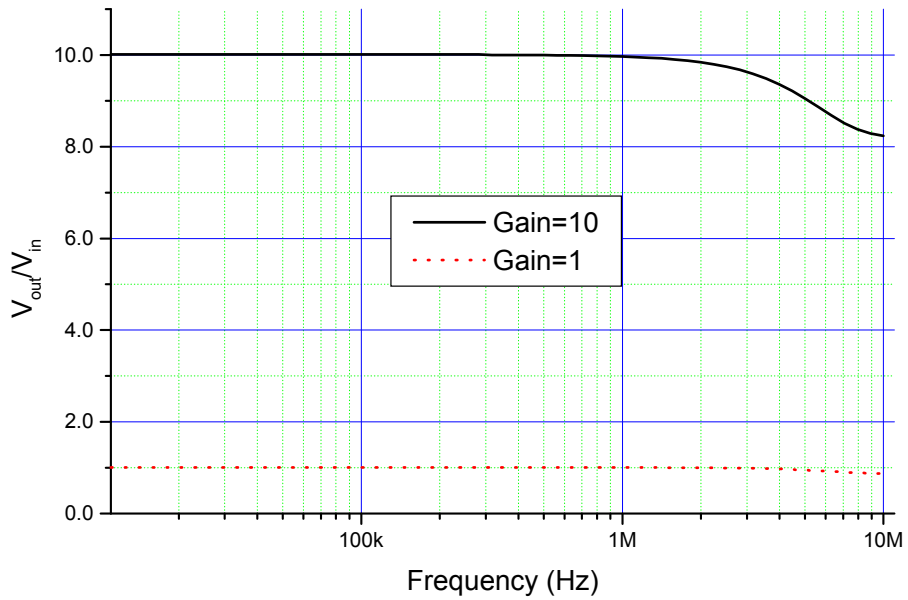


Fig. 6 – Frequency response of the proposed CCIICS.

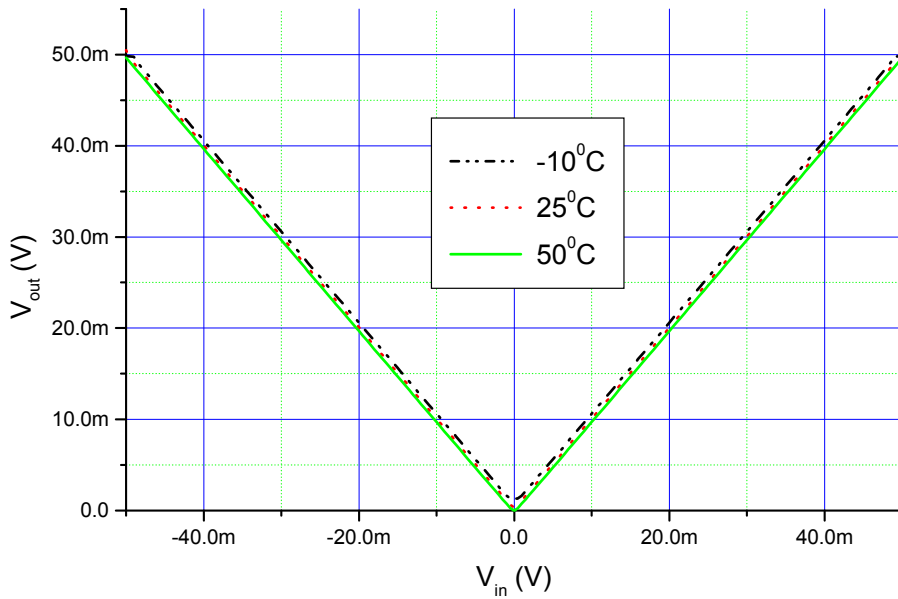
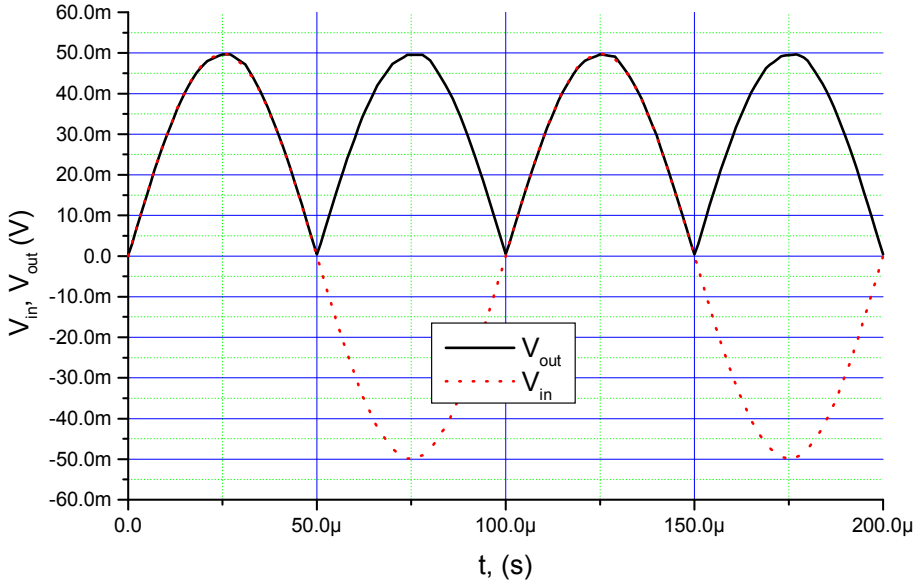
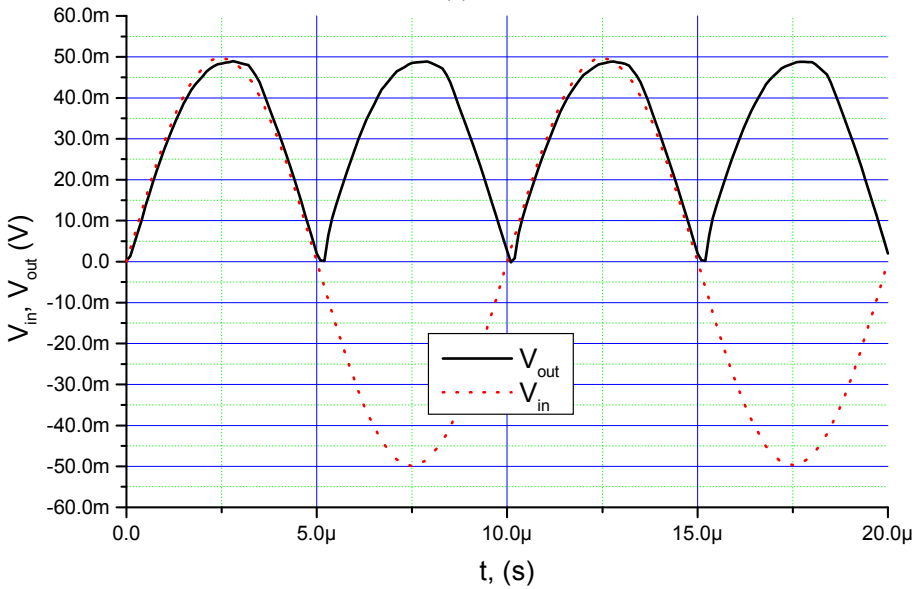


Fig. 7 – Temperature dependence of the transfer characteristic of proposed rectifier.

Fig. 8 shows output waveform of the proposed rectifier for the sinusoidal input signal with amplitude 50mV: (a) frequency 10kHz, (b) frequency 100kHz .



(a)



(b)

Fig. 8 – Output waveforms of the proposed rectifier for the sinusoidal input signal with amplitude 50mV: (a) 10 kHz, (b) 100 kHz (b).

5 Conclusion

This paper presents design of a wide-band full-wave temperature stable precision rectifier circuit based on improved current conveyor with current-steering output stage and current biased output diodes. Proposed rectifier have good voltage transfer characteristic for low level signal, good current transfer linearity in the range that satisfy class A of the amplifier. Design of the rectifier is realized with general purpose components.

6 References

- [1] F.J. Lidgey, K. Hayatleh, C. Toumazou: New Current-mode Precision Rectifiers, Proc IEEE Int. Symp. Circuits and Systems, Chicago, 1993, pp. 1322 – 1325.
- [2] PSpice Circuit Analysis, Version 4.05. MicroSim Corporation, Jan. 1991.
- [3] B. Wilson, M. Al-Gahtani, J. Vosper, R. Deloughry: High-precision Current Conveyor Implementation Employing a Current-steering Output Stage, International Journal of Electronics, Vol. 93, No. 10, 2006, pp 653 – 662.
- [4] A. Khan, M.A. El-Ela, M.A. Al-Turaigi: Current-mode Precision Rectification, International Journal of Electronics, Vol. 79, No. 6, Dec. 1995, pp 853 – 859.
- [5] C. Toumazou, F.J. Lidgey, S. Chattong: High Frequency Current Conveyor Precision Full-wave Rectifier, Electronic letters, Vol. 30, No. 10, May 1994, pp 745 – 746.
- [6] K. Hayatleh, S. Porta, F.J. Lidgey: Temperature Independent Current Conveyor Precision Rectifier, Electronic Letters, Vol. 30, No. 25, Dec 1994, pp 2091 – 2093.