Precision Full-wave Rectifier Using Current Conveyors and Two Diodes

Jaroslav Koton, Norbert Herencsar, Kamil Vrba
Dept. of Telecommunications
Brno University of Technology
Purkynova 118, 612 00 Brno, Czech Republic
{koton, herencsn, vrbak}@feec.vutbr.cz

***Abstract*—In this paper, precision full-wave rectifier employing two current conveyors and only two diodes is presented. The proposed structure operates in mixed- or voltage-mode. To compare the behavior of the proposed structure, the frequency dependent RMS error and DC transient value for different values of input voltage amplitudes are evaluated.**

***Keywords*-Precision full-wave rectifier; current conveyor; voltage conveyor; measurements.**

I. INTRODUCTION

In applications such as ac voltmeters and ammeters, signal-polarity detectors, averaging circuits, peak-value detector rectification function is of great importance [1]. Because of the threshold voltage of the diodes, simple passive rectifiers operate inaccurately, if low-voltage signals are analyzed. Therefore, precision rectifiers employing active elements have to be used.

Probably, the most known precision rectifiers are based on operational amplifiers (opamps) [1]. However, because of the finite slew-rate and effects caused by diode commutation, these circuits operate well only at low frequencies [2], [3]. This problem can be overcome by the use of current conveyors (CCs), where the diodes are connected to the high-impedance current outputs of the active elements. In [4]–[7] the same precision full-wave rectifier is analyzed (Fig. 2b). It uses two second-generation CCs and four diodes. To further extend the frequency range the voltage [4], [7] or current [6], [7] biasing scheme can be used. Another precision full-wave rectifier is presented in [8] that is based on the standard opamp rectifier shown in Fig. 2a. Here, the OPA_1 is replaced by the operational conveyor and later by second-generation CC [3]. A full-wave rectifiers using second-generation and dual-X CCs are presented in [9] and [10], respectively, where the required diodes are suitably replaced by NMOS transistors. The use of fully differential operational transconductance amplifiers (BOTA) operating in weak inversion region for the design of precision full-wave rectifiers is presented in [11], which is based on the idea discussed in [12], where simple transconductance amplifiers (OTA) are used. Here, the transconductance of OTA is controlled by the current derived from the input signal to be rectified. In another group of precision rectifiers, a transistor connected to the current output of an active element operates as a switch. For this purpose the current conveyor [13] or transconductance amplifiers [14]–[16] are used.

In this paper, precision full-wave rectifier employing two second-generation CCs and two diodes is presented. It is of minimal configuration and operates in the voltage- or mixed-mode. Voltage or current biasing scheme can be also used to extend the frequency operation range. The behavior of the circuit is compared to the known conveyor based solution presented in [4]–[7]. Simulation results are given that show the feasibility of the newly designed circuit to rectify signals up to 1 MHz and beyond with no or little distortion.

II. CURRENT CONVEYORS

In 1968, the current conveyors were presented for the first time [22], however they did not found any significant usage since the operational amplifiers were more attractive at that time. Current conveyors received considerable attention after the second (CCII) [23] and later third (CCIII) [24] generation current conveyors were designed. These elements are now advantageously used in applications, where the wide bandwidth or current output response is necessary. Nowadays, different types of current conveyors are described that mostly base on the CCII, e.g., CCCII [25], DVCC [26], or ECCII [27]. The behavior of a four-terminal CCII (Fig. 1) is described by following equations:

$$v_{\mathrm{X}} = v_{\mathrm{Y}}, \quad i_{\mathrm{Y}} = 0, \quad i_{\mathrm{Z+}} = i_{\mathrm{X}}, \quad i_{\mathrm{Z-}} = -i_{\mathrm{X}}. \qquad (1)$$

III. NEW PRECISION FULL-WAVE RECTIFIER

The standard op amp based circuit from Fig. 2a [1] is a connection of an inverting half-wave rectifier (OPA_1) and summing amplifier (OPA_2). For desired full-wave rectification following conditions have to be fulfilled:

$$R_1 = R_2, \quad R_4 = 2R_3, \qquad (2a)$$

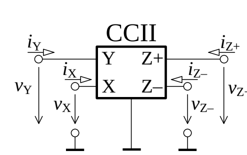

Figure 1. Circuit symbol of the four-terminal CCII

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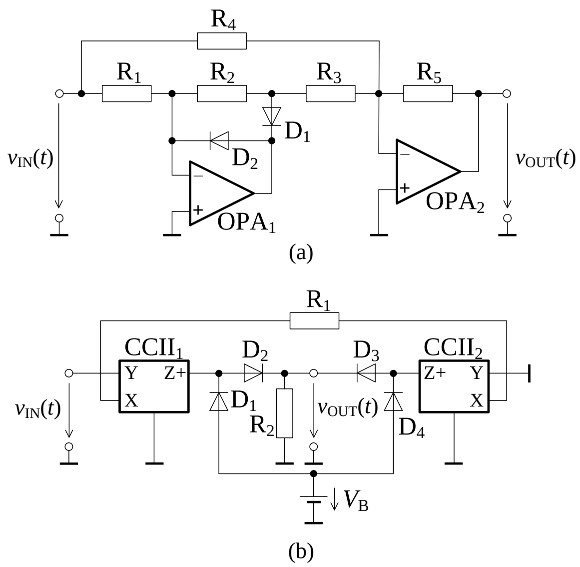

Figure 2. Voltage-mode (a) standard op amp based [1], (b) known conveyor based full-wave rectifier from [4]-[7]

or

$$R_2 = 2R_1, \quad R_3 = R_4, \tag{2b}$$

which generally means that the half-wave rectified signal must be amplified two times higher than the original input signal, either more commonly by the summing amplifier (according to (2a)) or by the half-wave rectifier (according to (2b)).

A well known circuit topology of the full-wave rectifier using two second-generation current conveyors and four diodes is shown in Fig. 2b [4]-[7]. Both CCIIs form a differential voltage-to-current converter. During the positive and negative input cycle the output currents make only the diodes D_2, D_4 and D_1, D_3 active, respectively. On the resistor R_2 the output current is converted back to voltage.

The newly proposed structure of the full-wave rectifier is shown in Fig. 3. Basically, it uses only one current conveyor ($CCII_1$) and two diodes. The second current conveyor operates as a current follower, where the resistors R_2 and R_3 connected to the Z-terminals convert the current back to voltage. Therefore, this full-wave rectifier can operate in the voltage- or mixed-mode.

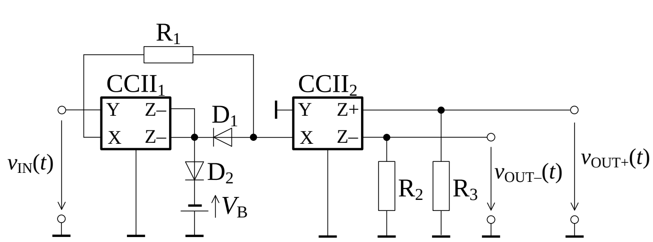

Figure 3. Proposed voltage-mode precision full-wave rectifier

The output voltages of the rectifier from Fig. 3 can be expressed as:

$$v_{\mathrm{OUT+}}(t) = \frac{R_3}{R_1}|v_{\mathrm{IN}}(t)|, \quad v_{\mathrm{OUT-}}(t) = -\frac{R_2}{R_1}|v_{\mathrm{IN}}(t)|, \tag{3}$$

Since the input voltage $v_{\mathrm{IN}}(t)$ is directly connected to the Y-terminal of the $CCII_1$, the input impedance of the rectifier is infinitely high in theory. Operated in mixed-mode, the current response is directly sensed at the Z-terminal having in theory infinitely high output impedance.

IV. DC and RMS Error Analyses

To evaluate and compare the accuracy of the voltage-mode full-wave rectifiers from Fig. 2 and Fig. 3, the DC value transfer p_{DC} and RMS error p_{RMS} have been analyzed [28]:

$$p_{\mathrm{DC}} = \frac{\int\limits_T y_{\mathrm{R}}(t)\,\mathrm{d}t}{\int\limits_T y_{\mathrm{ID}}(t)\,\mathrm{d}t}, \tag{4a}$$

$$p_{\mathrm{RMS}} = \sqrt{\frac{\int\limits_T \left[y_{\mathrm{R}}(t) - y_{\mathrm{ID}}(t)\right]^2\,\mathrm{d}t}{\int\limits_T y_{\mathrm{ID}}^2(t)\,\mathrm{d}t}}. \tag{4b}$$

where the $y_{\mathrm{R}}(t)$ and $y_{\mathrm{ID}}(t)$ represent the actual and ideally rectified signal and T is the period of the input signal. The ideal behavior of the rectifier is characterized by the values $p_{\mathrm{RMS}} = 0$ and $p_{\mathrm{DC}} = 1$.

V. Simulation Results

The behavior of the proposed voltage-mode full-wave rectifier has been compared with the circuit solutions from Fig. 2. As active elements the universal current conveyor UCC-N1B have been used. The current and voltage transfer bandwidths of the UCC are about 35 MHz [29]. Therefore, in the standard op amp based rectifier the AD8656 has been used [30]. The diodes are general purpose 1N4148 and all

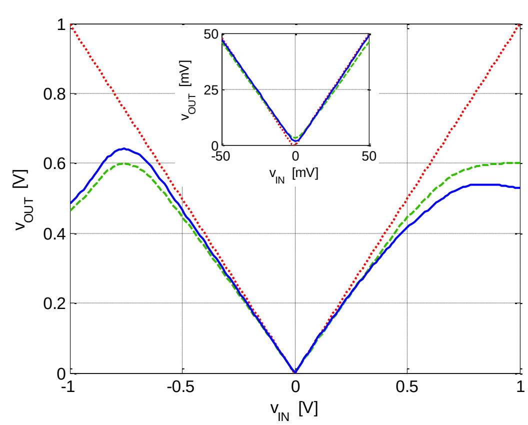

Figure 4. DC transfer of the full-wave rectifiers from Fig. 2a (dotted line), Fig. 2b (dashed line), and Fig. 3 (solid line)

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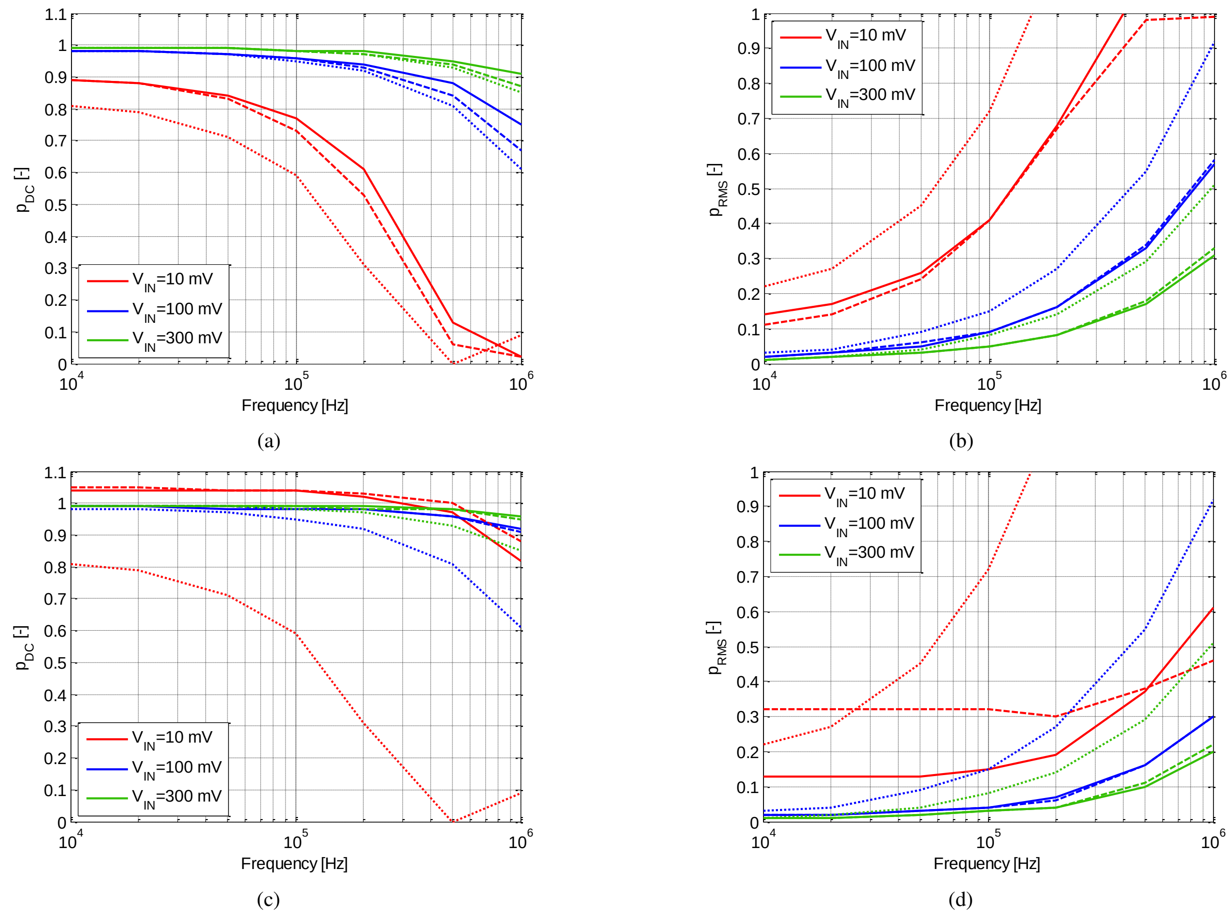

Figure 5. (a), (c) DC value transfer for $V_{\mathrm{B}} = 0$ V and $V_{\mathrm{B}} = 0.65$ V, (b), (d) RMS error for $V_{\mathrm{B}} = 0$ V and $V_{\mathrm{B}} = 0.65$ V of the rectifiers from Fig. 2a (dotted line), Fig. 2b (dashed line), and Fig. 3 (solid line), for input voltage amplitudes 10 mV, 100 mV, and 300 mV

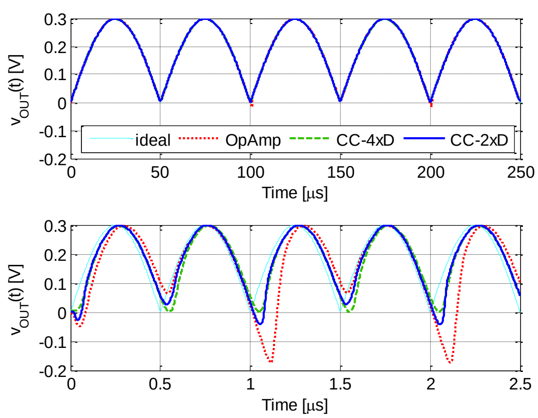

Figure 6. Transient simulation results of the full-wave rectifiers from Fig. 2a (dotted line), Fig. 2b (dashed line), and Fig. 3 (solid line) for frequencies 10 kHz and 1 MHz

resistors are 1 kΩ (in Fig. 2a $R_3 = 500$ Ω). In Fig. 4, the DC transfer characteristics are shown. Due to high voltage gain of the op amps, the DC error of the circuit from Fig. 2a is minimized and the DC transfer is almost ideal (in Fig. 4 dotted line). The non-unity voltage and current transfers of the current conveyors cause higher DC error of the conveyor based full-wave rectifiers (solid and dashed line).

Using (4) the behavior of the proposed rectifier has been analyzed in frequency domain and compared to the circuit solution from Fig. 2. The simulation results of the frequency dependent RMS error and DC value transfer for chosen values of amplitudes v_{IN} are shown in Fig. 5a and Fig. 5b, where the dotted, dashed, and solid lines stand for the circuits from Fig. 2a, Fig. 2b, and Fig. 3, respectively. If the frequency increases and/or amplitude decreases distortions occur and the p_{DC} decreases below one and p_{RMS} increases. From Fig. 5a, it is evident that the best results are achieved with the new minimal configuration rectifier. For an appropriate value of the bias voltage (here $V_{\mathrm{B}} = 0.65$ V), the conveyor based precision rectifiers can operate at higher frequencies (Fig. 5c, Fig. 5d).

The complete the simulations, for frequencies 10 kHz and 1 MHz and input amplitude $V_{\mathrm{IN}} = 300$ mV the time-domain performance of the analyzed rectifiers is shown in Fig. 6 ($V_{\mathrm{B}} = 0.65$ V). Also, one can observe, that at low

 ISBN: 978-1-61208-183-0

frequencies the behavior of the rectifiers is nearly the same. Once the frequency of the processed signal rises deviations occur.

VI. Conclusion

In this paper, the performance of conveyor based precision full-wave rectifier has been analyzed and compared to the standard opamp based topology. A new minimal configuration conveyor based rectifier has been presented, that employs current conveyors and two diodes. The rectifier can work in the voltage- or mixed-mode. Simulation were performed that prove the feasibility of the proposed conveyor based full-wave rectifier.

Acknowledgment

The paper has been supported by projects: GACR 102/10/P561, GACR 102/09/1681, MSM0021630513, and FEKT–S–11–15.

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