Minimal Configuration Versatile Precision Full-Wave Rectifier Using Current Conveyors

Jaroslav Koton, Norbert Herencsar, and Kamil Vrba

Abstract—In this paper a precision full-wave rectifier of minimal configuration is presented. The main structure employs only single second-generation current conveyor and two diodes. It enables to process both low-voltage and low-current signals. The proposed circuit is able to rectify signals up to 500 kHz and beyond with no or small distortion. If the voltage or current biasing scheme is used the frequency range can be further extended. Using the CMOS structure of the current conveyor, the behavior of proposed full-wave rectifier has been verified by SPICE simulations. Furthermore, using the universal current conveyor UCC-N1B 0520 experimental measurements are also presented.

Keywords—analog processing circuits, CMOS, current conveyors, instrumentation, precision full-wave rectifier.

I. INTRODUCTION

In instrumentation and measurements the precise rectification function is of great importance since it is utilized in applications such as ac volt- and ampere-meters, signal-polarity detectors, peak value measurement, or averaging circuits [1]. Because of the threshold voltage of the diodes, simple passive rectifiers operate inaccurately with small signals. Therefore, precision rectifiers containing active elements have to be used.

Conventional precision rectifiers based on voltage feedback amplifiers (op amps) suffer from the finite slew rate and effects caused by the diode commutation [1]. These circuits operate well only at low frequencies and cause considerable waveform distortions already above 1 kHz [2], [3]. Significant improvement in high frequency signal rectification has been achieved by using active elements with high-impedance current outputs, to which the diodes are connected. In [4]–[7] the same voltage-mode full-wave rectifier using second-generation current conveyors and four diodes is presented, which can be used to process signals at frequencies up to 100 kHz. The frequency range can be further extended using the voltage [4], [7] or current [6], [7] biasing scheme. In [8] and [9] full-wave rectifiers are proposed that employ second-generation current conveyor, bipolar current mirrors and three or two resistors. Here, neither voltage nor current biasing scheme can be used and therefore the rectified signals can be at frequencies up to 100 kHz. A voltage-mode full-wave rectifier using dual-X current conveyor is presented in [10], where the required diodes are suitably replaced by NMOS transistors. Another precise full-wave rectifier is presented in [11]. The structure uses the standard op amp bases rectifier (Fig. 2a), where the OPA1 is replaced by operational conveyor and later by second-generation current conveyor [3].

In this paper new current conveyor based precision full-wave rectifier is presented. If it operates in current-mode, only single active element and two diodes are to be used. For voltage-mode operation additional resistors are connected that represent simple voltage-to-current and current-to-voltage convertors. The behavior of the proposed precise full-wave rectifier has been verified both by SPICE simulations and by experimental measurements.

II. CURRENT CONVEYOR

A current conveyor is generally a three- (or four-)- terminal active device. It has one low-impedance current input X, one high-impedance voltage input Y and one or more high-impedance current outputs Z. The current conveyor was introduced in 1968 for the first time [12] and labeled as first-generation current conveyor CCI. Later, the second- (CCII) [13] and third-generation current conveyors [14] (CCIII) were presented. These active elements receive considerable attention and are used in applications where the wide frequency bandwidth or output current response is necessary. Even if different generations are described nowadays, the most often used one is the CCII and other types from it derived, e.g. electronically tunable CC [15], current controlled CC [16], differential difference CC [17], differential voltage CC [18], universal CC [19] can be mentioned as examples. The relation between the currents and voltages of a four-terminal CCII (Fig. 1) is described by following set of equations:

\[ v_X = v_Y , \quad i_Y = 0 , \quad i_Z = i_X , \quad i_Z = -i_X \, . \]  


Fig. 1 Circuit symbol of four-terminal CCII
III. PROPOSED RECTIFIER CIRCUITS

The voltage feedback operational amplifier based circuit from Fig. 2a [1] is a connection of an inverting half-wave rectifier and summing amplifier. The output voltage can be described as follows:

\[
v_{\text{OUT}}(t) = \begin{cases} 
\frac{R_2}{R_1} - \frac{R_2}{R_4} v_{\text{IN}}(t), & v_{\text{IN}}(t) \geq 0 \\
\frac{R_1}{R_4} v_{\text{IN}}(t), & v_{\text{IN}}(t) \leq 0 
\end{cases}
\]

For desired characteristic of a full-wave rectifier following condition must be fulfilled:

\[
\frac{R_2}{R_1} = -\frac{R_2}{R_4},
\]

that means, the amplitude of the half-wave rectified signal must be two times higher than the amplitude of the original input signal \(v_{\text{IN}}(t)\). Based on this fact, new current conveyor based full-wave rectifiers have been designed. The new current-mode rectifier is shown in Fig. 2b. The main structure consists of only single second-generation current conveyor CCII, and two diodes. Another advantage of the proposed circuits is that the input impedance is zero in theory.

The current conveyor CCII operates as a current follower that is used to achieve high-impedance current outputs. The voltage-mode rectifier (Fig. 2c) is obtained by adding resistors \(R_1, R_2, \) and \(R_3\) that represent simple voltage-to-current and current-to-voltage converters. Since the input voltage \(v_{\text{IN}}(t)\) is directly connected to the Y-terminal of the CCII, the input impedance is infinitely high in theory.

Routine analysis of the proposed current- and voltage-mode precision full-wave rectifiers leads to following expressions of the output currents and voltages:

\[
\begin{align*}
i_{\text{OUT}1}(t) &= \frac{1}{R_1} |v_{\text{IN}}(t)|, \\
i_{\text{OUT}2}(t) &= \frac{R_2}{R_4} |v_{\text{IN}}(t)|, \\
v_{\text{OUT}1}(t) &= -\frac{R_1}{R_4} v_{\text{IN}}(t), \\
v_{\text{OUT}2}(t) &= \frac{R_1}{R_4} v_{\text{IN}}(t).
\end{align*}
\]

The gain of the voltage-mode rectifier can be adjusted by choosing proper values of the resistors. The gain of the current-mode rectifier can also be adjusted, if the CCII or CCII conveyor is replaced by the electronically tunable current conveyor (ECCII) [15], [20].

IV. SIMULATION RESULTS

To verify the feasibility of the proposed circuit the current-mode precision full-wave rectifier was simulated in SPICE. The CCII is simulated using the schematic implementation shown in Fig. 3 with DC power supply voltages ±1.5 V and bias voltages \(V_{\text{B1}} = V_{\text{B2}} = 0.6 \text{ V}\). The MOS transistors are simulated using TSMC 0.35 \(\mu\text{m}\) CMOS process model parameters (\(V_{\text{TH}} = 0.54 \text{ V}, \mu_N = 436 \text{ cm}^2/(\text{V·s}), \quad V_{\text{THP}} = -0.71 \text{ V}, \quad \mu_P = 212 \text{ cm}^2/(\text{V·s}), \quad T_{\text{OX}} = 7.9 \text{ nm}\)). The dimensions of the transistors are listed in Table I. The main parameters of the CCII in Fig. 3 are summarized in Table II.

### TABLE I

<table>
<thead>
<tr>
<th>Transistor</th>
<th>W/L ((\mu\text{m}))</th>
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</thead>
<tbody>
<tr>
<td>M1-M3</td>
<td>1.2/0.8</td>
</tr>
<tr>
<td>M4-M10</td>
<td>66/0.8</td>
</tr>
<tr>
<td>M11-M15</td>
<td>28/0.8</td>
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</tbody>
</table>

### TABLE II

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parasitic elements at X terminal: (R_X, L_X)</td>
<td>12.5 (\Omega), 10.5 (\mu\text{H})</td>
</tr>
<tr>
<td>Parasitic elements at Y terminal: (R_Y, C_Y)</td>
<td>(\times 10^4), 0.48 (\Omega)</td>
</tr>
<tr>
<td>Parasitic elements at Z+ terminal: (R_{Z+}, C_{Z+})</td>
<td>204.2 (\Omega), 279 (\Omega)</td>
</tr>
<tr>
<td>Parasitic elements at Z- terminal: (R_{Z-}, C_{Z-})</td>
<td>205.1 (\Omega), 16.4 (\Omega)</td>
</tr>
<tr>
<td>Voltage gain (v_Y \rightarrow v_X)</td>
<td>0.999</td>
</tr>
<tr>
<td>Current gain (i_X \rightarrow i_{Z+}), (i_X \rightarrow i_{Z-})</td>
<td>0.999, 0.983</td>
</tr>
<tr>
<td>Bandwidth (v_Y \rightarrow v_X)</td>
<td>118.3 MHz</td>
</tr>
<tr>
<td>Current gain (i_X \rightarrow i_{Z+}), (i_X \rightarrow i_{Z-})</td>
<td>134.6 MHz, 127.5 MHz</td>
</tr>
<tr>
<td>Voltage slew-rate (v_Y \rightarrow v_X)</td>
<td>413.6 (\text{mV/ns})</td>
</tr>
<tr>
<td>Current slew-rate (i_X \rightarrow i_{Z+}), (i_X \rightarrow i_{Z-})</td>
<td>37.9 (\mu\text{A/ns}), 37.5 (\mu\text{A/ns})</td>
</tr>
</tbody>
</table>
The diodes used are general-purpose 1N4148 diodes. The
time-domain performance of the proposed current-mode
rectifier was tested by applying 100 µA peak sinusoidal
current at frequencies 100 kHz, 500 kHz, 1 MHz and 5 MHz.
Simulation results are shown in Fig. 4, where the behavior of
the circuit without (dashed line) and with (solid line) voltage
biasing scheme are compared with ideally rectified signal
(dotted line). The bias voltage is $V_B = -0.75$ V.

From the simulation results, it is evident that for a 100 kHz
input frequency (Fig. 4a) the two waveforms are almost
identical. However, as the input frequency increases
differences are clearly apparent. If the voltage biasing scheme
is used no significant waveform distortions can be seen for an
input frequency 1 MHz (Fig. 4c). Further increasing the input
frequency (Fig. 4d), rectification of the circuit without voltage
biasing scheme can be considered as absent, but can be still
observed of the rectifier using the voltage biasing scheme.

![Fig. 3 Internal structure of the CCII](image)

![Fig. 4 SPICE simulation results of the current-mode full-wave rectifier for frequencies (a) 100 kHz, (b) 500 kHz, (c) 1 MHz, (d) 5 MHz for $V_B = 0$ V (dashed line), $V_B = -0.75$ V (solid line), ideal (dotted line).](image)
V. EXPERIMENTAL MEASUREMENTS

Using the universal current conveyor UCC-N1B that has been produced as laboratory samples by AMI Semiconductor Czech, Ltd. (now ON Semiconductor Czech Republic, Ltd.) [21], [22], the behavior of the voltage-mode precision full-wave rectifier of Fig. 2c has also been verified by experimental measurements. The values of all the resistors are 1 kΩ, and the type of diodes used is 1N4148.

In Fig. 5 the measurement results for 150 mV peak input sinusoidal voltage at frequency 1 MHz are shown as example. From Fig. 5a it can be seen that without using the voltage biasing scheme (\( V_{\text{B}} = 0 \text{ V} \)) significant waveform distortions occur. Setting appropriate bias voltage causes bandwidth extension of the full-wave rectifier (Fig. 5b).

VI. CONCLUSION

In his paper new minimal configuration versatile precision full-wave rectifier has been presented. The main structure consists only of single second-generation current conveyor and two diodes. With advantage it can be used for current-, voltage-, or mixed-mode operations. Since the diodes are directly connected to the high-impedance current-outputs of the active element the rectifier can be used to process signals at frequencies 500 kHz without causing significant waveform distortions. Using voltage or current biasing scheme the frequency range can be further extended.

To prove the feasibility of the proposed circuit it has been simulated using a CMOS implementation of the active elements, and furthermore experimental measurements have been performed and presented.

REFERENCES