Minimal configuration precision full-wave rectifier using current and voltage conveyors

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Abstract: In this paper, new minimal configuration precision full-wave rectifier is presented. The structure employs one current and one voltage conveyor and only two diodes. It enables to process both low-voltage and low-current signals. Compared to the op amp based circuit, the proposed circuit is able to rectify signals up to 500 kHz and beyond with no or small distortion. Experimental measurements are performed that show the feasibility of the new precision full-wave rectifier.

Keywords: analog processing circuits, current conveyor, instrumentation and measurements, precision full-wave rectifier, voltage conveyor

Classification: Electronic instrumentation and control

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1 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. 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, 5, 6, 7] the same voltage-mode full-wave rectifier using two second-generation current conveyors and four diodes is presented that 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 A voltage-mode full-wave rectifier using dual-X current conveyor is presented in [8], where the required diodes are suitably replaced by NMOS transistors. Another precise full-wave rectifier is presented in [9]. The structure uses the standard op amp bases rectifier (Fig. 2c), where the OPA1 is replaced by operational conveyor and later by second-generation current conveyor [3].

Here, we present new versatile full-wave rectifier that employs single current and voltage conveyor, and two diodes. The proposed circuit can be used to process both current and voltage signals.

2 Current and voltage 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 [10] and labeled as first-generation current conveyor CCI. Later, the second- (CCII) [11] and third-generation current conveyors [12] (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 [13], current controlled CC [14], differential difference CC [15], differential voltage CC [16], universal CC [17] can be mentioned as examples. The relation between the currents and voltages of a three-terminal CCII (Fig. 1a) is described by following set of equations:

$$v_X = v_Y, \quad i_Y = 0, \quad i_Z = i_X. \quad (1)$$

The recent research also focuses on voltage conveyors (VCs) that have been defined as dual active elements to the current conveyors [18]. As in the theory of current conveyors, also here first-, second- and third-generation

Fig. 1. Circuit symbol of a) CCII, b) UVC

VC can be described [19]. The best known VC is the differential current voltage conveyor (DCVC+) [20] that is more often called the current differencing buffered amplifier (CDBA) [21]. In [22, 23, 24], the universal voltage conveyor (UVC) is presented that is advantageously used for the design of minimal configuration full-wave rectifier. The UVC is a 6-port active element (Fig. 1b), which has one voltage input X, two current differencing inputs YP and YN, and two mutually inverse voltage outputs ZP and ZN. The auxiliary voltage input W is used to determine the generation of the voltage conveyor [24]. The UVC is described by following set of equations:

$$i_X = i_{YP} - i_{YN}, \quad v_{YP} = v_{YN} = v_W, \quad v_{ZP} = v_X, \quad v_{ZN} = -v_X. \quad (2)$$

3 Proposed full-wave rectifier

The proposed current- and voltage-mode full-wave rectifiers are shown in Fig. 2a and Fig. 2b, respectively. To enable signal processing at higher frequencies than it is currently allowed by standard op amp based solution (Fig. 2c), the diodes are directly connected to the high impedance terminal Z of the current conveyor CCII as in [4, 5, 6, 7]. Subsequently, the differential current inputs of the universal voltage conveyor are used with advantage and

Fig. 2. Proposed minimal configuration conveyor based full-wave rectifier working in the a) current-, b) voltage-mode, c) standard voltage feedback amplifier based full-wave rectifier [1]

therefore only two diodes need to be used. Routine analysis of the current- and voltage-mode full-wave rectifier leads to following expressions:

$$i_{\text{OUT}}(t) = -|i_{\text{IN}}(t)|, \quad (3)$$

$$v_{\text{OUT1}}(t) = -\frac{R_2}{R_1}|v_{\text{IN}}(t)|, \quad v_{\text{OUT2}}(t) = \frac{R_2}{R_1}|v_{\text{IN}}(t)|. \quad (4)$$

The resistors R_1 and R_2 generally represent simple voltage-to-current and current-to-voltage convertors. Choosing proper values, the voltage gain of the rectifier can be easily adjusted. The further advantage of the rectifier is that working in the current-mode the input impedance is generally zero at ground potential and the output impedance is infinitely high in theory. Similarly, if the rectifier works in the voltage-mode the input impedance is infinitely high and the output impedance is zero.

4 Experimental measurements

To support the theoretical analyses, the behavior of the proposed voltage-mode full-wave rectifier from Fig. 2b has been verified by experimental measurements and compared to the standard op amp based rectifier from Fig. 2c. As active elements the universal current UCC-N1B and universal voltage conveyors UVC-N1C have been used, both produced as laboratory samples by AMI Semiconductor Ltd. (now ON Semiconductor Ltd.) [25, 27]. The current and voltage transfer bandwidth of the CCII and UVC is about 35 MHz [27], hence as op amps the AD825 [28] have been used. The diodes are general-purpose 1N4148 diodes.

The transient measurement results of the precision full-wave rectifiers for different frequencies and amplitudes of the input voltage are shown in Fig. 3 and compared. Here, it can be observed that the behavior of the designed conveyor based rectifier is very satisfactory. As shown in Fig. 3a, b at a 10 kHz input frequency significant distortions of the standard rectifier already occur. At higher frequencies (Fig. 3b, c, d, e) the full-wave rectification is already absent of the op amp based circuit. However, the proposed conveyor based rectifier can be used to process signals at frequencies 100 kHz without causing any major distortions and even at higher frequencies the full-wave rectification can be still observed (Fig. 3d, e).

5 Conclusion

In this paper new minimal configuration full-wave rectifier using current and voltage conveyors has been presented. Since the diodes are directly connected to the high-impedance current-output terminal the rectifier can be used to process signals at frequencies up to 500 kHz and beyond with no or small distortions. Even at higher frequencies the full-wave rectification is still preserved.

Further advantage is in the use of only two diodes and the possibility of working in the voltage-, current- and mixed-mode. Experimental measurements were performed that proved the feasibility of the proposed circuit.

Fig. 3. Transient responses of the minimal configuration full-wave rectifier from Fig. 2b (solid line) and of the standard rectifier from Fig. 2c (dashed line) for signal frequencies and amplitudes: a) $f = 10$ kHz, $V_{IN} = 100$ mV_{pp}, b) $f = 10$ kHz, $V_{IN} = 500$ mV_{pp}, c) $f = 100$ kHz, $V_{IN} = 100$ mV_{pp}, d) $f = 100$ kHz, $V_{IN} = 500$ mV_{pp}, e) $f = 500$ kHz, $V_{IN} = 100$ mV_{pp}, f) $f = 500$ kHz, $V_{IN} = 500$ mV_{pp}

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