Universal Voltage Conveyor and Current Conveyor in Fast Full-Wave Rectifier

Josef Burian, Jaroslav Koton, and Norbert Herencsar

***Abstract*—This paper deals with the design of a fast voltage-mode full-wave rectifier, where universal voltage conveyor and second-generation current conveyor are used as active elements. Thanks to the active elements, in theory the input and output impedance of the non-linear circuit is infinitely high respectively zero. For the rectification only two diodes and three resistors are required as passive elements. The performance of the circuit is shown on experimental measurement results showing the dynamic range, time response, frequency dependent DC transient value and RMS error for different values of input voltage amplitudes.**

***Keywords*—Universal voltage conveyor, current conveyor, fast full-wave rectifier.**

I. Introduction

In instrumentation and measurement, precision rectifiers serve as very important blocks. They are used in applications such as ac voltmeters and ammeters, signal-polarity detectors, averaging circuits, peak-value detector rectification function is of great importance [1]. The threshold voltage of the diodes does not enable to use simple rectifiers if low-voltage signals are to be analyzed. Therefore precision rectifiers employing active elements have to be used.

As the nowadays systems operate at higher frequency bands, also the single functional blocks, analog or digital, have to be able to process the higher frequency signals. In area of precision full-wave rectifiers, the solutions using standard operational amplifiers are probably the most known [2]. However, such structures are able to operate well only at frequencies much bellow the transient frequency of the active element, mainly because of the finite slew-rate [3], [4]. To design non-linear structures, i.e. also rectifiers, operating at higher frequencies it is suitable to drive the diodes by current, which actually means to connect them to high-impedance current outputs of an active element. For this purpose, the second generation current conveyor (CCII) is used in the full-wave rectifier discussed in [5]. The same structure from [5] using two active elements and four diodes is also analyzed in [6]-[8]. As two diodes are grounded, the voltage- [5], [8] or current- [7], [8] biasing scheme can be used to further extend the operational region. Another precision full-wave rectifier based on operational amplifier structure is given in [9], where the original operational amplifier is replaced by the operational conveyor and latter by second generation current conveyor [4]. Once the diodes in the structure are replaced by NMOS transistors the MOS only rectifiers using CCII and dual-X current conveyors were presented in [10] and [11], respectively.

The operational transconductance amplifiers (OTA) feature with the high-impedance current output and hence are also suitable for the design of fast non-linear circuits [12]. In [13] or [14] transistors operating as switches are connected to the output of the OTA subsequently providing full-wave rectification. Operating the OTAs in weak inversion region the transconductance of the active element is controlled by the current derived from the input signal to be rectified. Such idea is presented in [15] and [16].

In this paper we present a new circuit solution of a voltage-mode full-wave rectifier using one universal voltage conveyor and one second generation current conveyor as active elements. The only two diodes used in the structure are suitably driven by current to enable the high-frequency signal processing. Thanks to the active elements used, the input impedance of the non-linear circuit is infinitely high in theory. The rectifier provides both inverting and non-inverting voltage responses that are taken at the output of voltage buffers having zero impedance in theory. Therefore, the structure is very suitable to be connected into the signal path without any additional circuitry. To show and make it possible to compare the performance of the new rectifier, the frequency dependent RMS error and DC transient value for different amplitudes of the input signal are evaluated. Measurement results of the DC and transient analyses are also given that show the feasibility to rectify the signals of frequency 2MHz and beyond.

II. Current and Voltage Conveyor

The current conveyors have been presented in 1968 for the very first time [17], however, they did not found any significant usage as the operational amplifiers were more attractive at that time. Current conveyors received considerable attention after the second (CCII) [18] and later third (CCIII) [19] generation current conveyors were designed. These elements are now advantageously used in applications, where the wide bandwidth or current output response is necessary. Mainly the CCII is used as basic active element from which other types of active elements can be derived, such as the current controlled CC (CCCII) [20], differential voltage CC (DVCC) [21], or electronically tunable CC (ECCII) [22]. The behavior of a three-terminal positive CCII (Fig. 1(a)) is described by following equations:

$$v_X = v_Y, \quad i_Y = 0, \quad i_Z = i_X. \tag{1}$$

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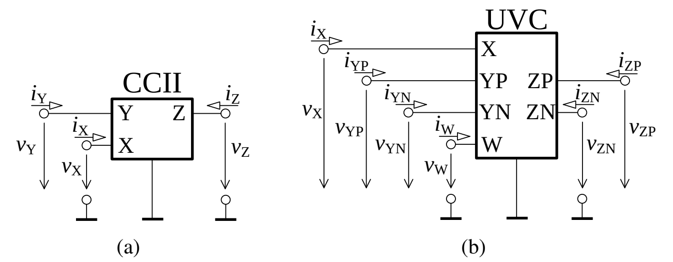

Fig. 1. Circuit symbol of (a) the three-terminal CCII, (b) the universal voltage conveyor UVC

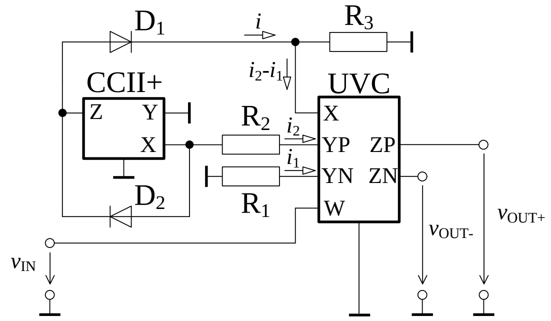

Fig. 2. Proposed fast full-wave rectifier

Another flexible building block for active circuit synthesis is the voltage conveyor (VC) that has been presented in [23]. Based on the duality principle to current conveyors, also first-, second-, and third-generation voltage conveyors can be described [24]. The current differencing buffered amplifier (CDBA) [25] can be identified as the differential current voltage conveyor (DCVC+) [26]. In [27], [28] the universal voltage conveyor (UVC) has been described (Fig. 1(b)). It is a 6-port active element that has one voltage input X, two current differencing inputs YP and YN, and two mutually inverse voltage outputs ZP and ZN. Connecting the auxiliary voltage input W either to ZP, common node (ground), or ZN the three generations of voltage conveyors can be designed [28]. The relation between the terminal currents and voltages is described by following set of equations:

$$i_{\mathrm{X}} = i_{\mathrm{YP}} - i_{\mathrm{YN}}, \quad v_{\mathrm{YP}} = v_{\mathrm{YN}} = v_{\mathrm{W}}, \tag{2}$$

$$v_{\mathrm{ZP}} = v_{\mathrm{X}}, \quad v_{\mathrm{ZN}} = -v_{\mathrm{X}}. \tag{3}$$

III. Proposed Full-wave Rectifier

As already given in the text above, the terminal W of the universal voltage conveyor is used to determine the generation of the voltage conveyor. However, it can be also used as an independent voltage input of a functional block featuring with infinitely high input impedance in theory. This fact is with advantage used for the design of the precision full-wave rectifier shown in Fig. 2.

For positive input voltage v_{IN} the diode D_2 is open and the current i through D_1 is therefore zero. Hence, the current flowing through the resistor R_3 is equal to the difference of i_2 and i_1 currents. The output voltages of this functional block can subsequently be derived as:

$$v_{\mathrm{OUT+}} = -v_{\mathrm{OUT-}} = \left(\frac{1}{R_2} - \frac{1}{R_1}\right) R_3 v_{\mathrm{IN}}, \quad v_{\mathrm{IN}} > 0. \tag{4}$$

If the input voltage is negative, the diode D_1 is open, the current i equals to the current flowing through the resistor R_2 and the output voltage can be determined as follows:

$$v_{\mathrm{OUT+}} = -v_{\mathrm{OUT-}} = -\frac{R_3}{R_1} v_{\mathrm{IN}}, \quad v_{\mathrm{IN}} < 0. \tag{5}$$

Comparing (4) and (5), if the circuit from Fig. 2 should really perform the operation of full-wave rectification, following condition needs to be fulfilled:

$$\frac{1}{R_2} - \frac{1}{R_1} = \frac{1}{R_1}, \tag{6}$$

which for the values of the resistors R_1 and R_2 means: $R_1 = 2R_2$. The required voltage gain can be then adjusted by the ratio of the resistors R_3 and R_1.

IV. Evaluated Parameters Description

Except the common measurements as are the DC transfer showing proper operation area of the functional block and time responses of the output signal, to compare current circuit solution to other rectifiers, it is suitable to also evaluate the frequency dependent DC value transfer p_{DC} and RMS error p_{RMS} [29]:

$$p_{\mathrm{DC}} = \frac{\int_T y_{\mathrm{R}}(t)\,\mathrm{d}t}{\int_T y_{\mathrm{ID}}(t)\,\mathrm{d}t}\ , \tag{7}$$

$$p_{\mathrm{RMS}} = \sqrt{\frac{\int_T \left[y_{\mathrm{R}}(t) - y_{\mathrm{ID}}(t)\right]^2\,\mathrm{d}t}{\int_T y_{\mathrm{ID}}^2(t)\,\mathrm{d}t}}\ , \tag{8}$$

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 rectified signal. The ideal behavior of the rectifier is characterized by the values $p_{\mathrm{DC}} = 1$ and $p_{\mathrm{RMS}} = 0$. Increasing the frequency and decreasing the magnitude of the input signal, compared to ideally rectified signal deviations of the actual output voltage $v_{\mathrm{OUT}}(t)$ occur and p_{DC} decreases below one and p_{RMS} increases.

Another possibility, how to evaluate proper behavior of the rectifier is to analyze the harmonic components of the output signal [4]. When a sinusoidal signal of frequency ω is applied to full-wave rectifier, the steady-state response at the output ideally consists of even harmonic components at frequencies of 2ω, 4ω, 6ω, etc., the odd harmonic components are zero. Using the Fourier series analysis the coefficients, i.e. the magnitudes of harmonic components of the output signal can be found as:

$$V_{2(2n)} = \frac{4V_{\mathrm{INmax}}}{\pi} \frac{1}{4n^2 - 1}, \tag{9}$$

where V_{INmax} is the amplitude of the input signal to be rectified, and $n = 1, 2, 3, \ldots$ defines the the $2n$-th harmonic component of the output signal.

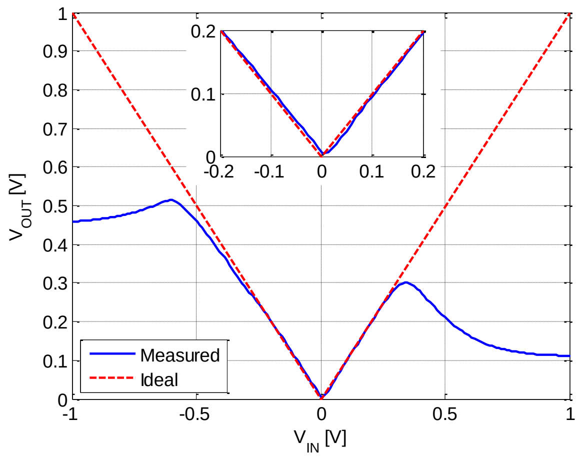

Fig. 3. DC transfer of the proposed full-wave rectifier

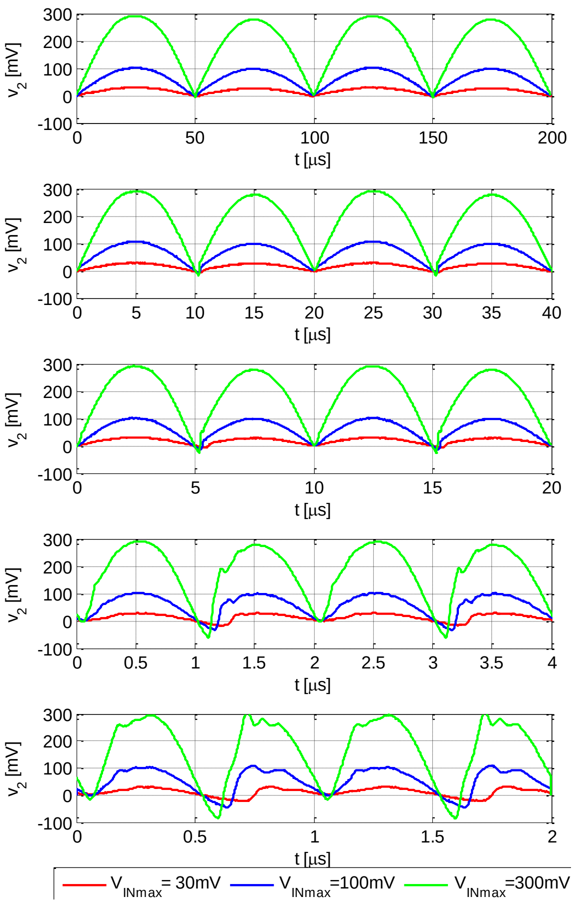

Fig. 4. Measured transient responses for $V_{\mathrm{INmax}} = \{30; 100; 300\}$ mV and frequencies 10 kHz, 50 kHz, 100 kHz, 500 kHz, and 1 MHz

V. Measurement Results

The proposed fast full-wave rectifier has been further analyzed by experimental measurements. As active elements the universal current conveyor UCC-N1B [30] and universal voltage conveyor UVC-N1C [31] have been used. The values of the resistors are $R_1 = R_3 = 1$ kΩ, $R_2 = 500$ Ω, and the diodes are all-purpose 1N4148 [32].

The measured DC transfer characteristic is shown in Fig. 3.

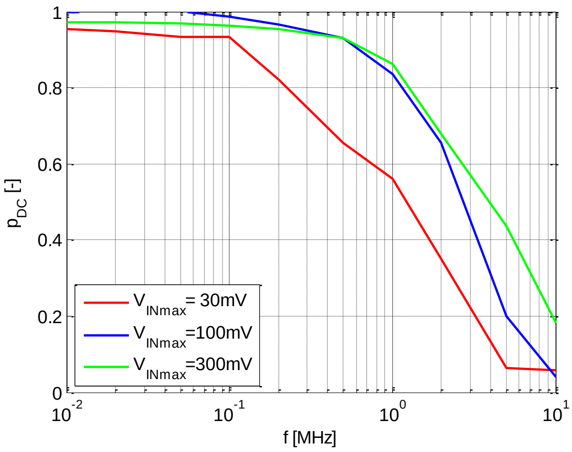

Fig. 5. The DC value transfer for different input signal magnitudes

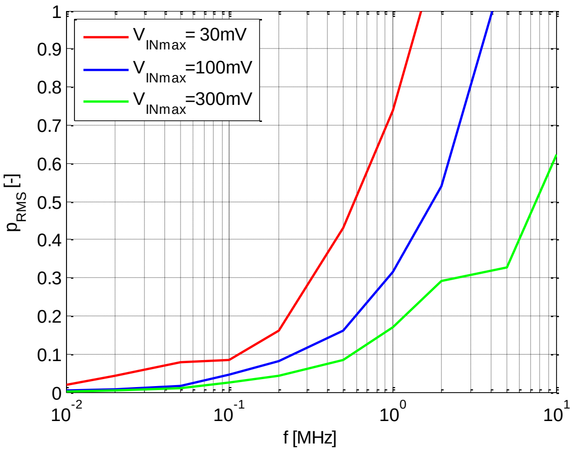

Fig. 6. The RMS error for different input signal magnitudes

In practice, the active elements use ±1.65 V supply voltage. From the parameters in [30] and [31], linear behavior of the UCC and UVC is defined for terminal voltages and currents up to ±0.7 V and ±0.7 μA . Therefore, to prevent the active elements to operate in their saturation region, the processed input signals should be of maximal magnitude 300 mV. The transient responses of the rectifier for input signal magnitudes $V_{\mathrm{INmax}} = \{30; 100; 300\}$ mV and frequencies 10 kHz, 50 kHz, 100 kHz, 500 kHz and 1 MHz are shown in Fig. 4. From the measurement results it can be seen that for input signal frequencies from 10 kHz to 100 kHz there are no or minor distortions of the output signal. First for the frequency 500 kHz more visible deviations in zero-cross area can be observed. Anyway, even if the transient responses do not fully agree to the ideally rectified signal, the deviations are not that significant as we are mainly interested in the DC component of the output signal.

Using (7) and (8), from transient measurements the frequency dependent DC value transfer p_{DC} and RMS error p_{RMS} for input signal magnitudes 30 mV, 100 mV, and 300 mV were evaluated and are shown in Fig. 5 and Fig. 6, respectively. As it can be seen from the graphs, at low frequencies the higher the magnitude of the input signal the closer are the values of p_{DC}

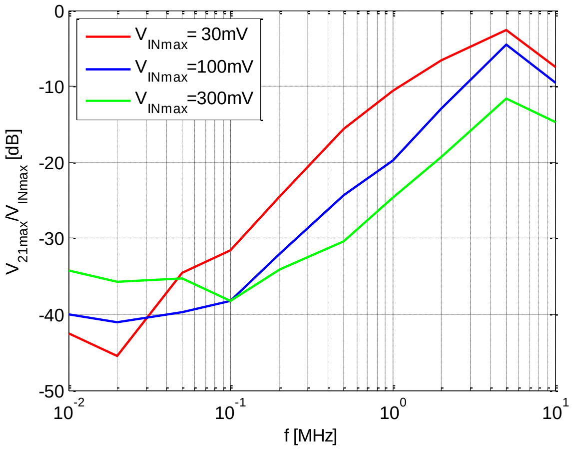

Fig. 7. Variation of the fundamental component magnitude of the output signal for different input signal magnitudes

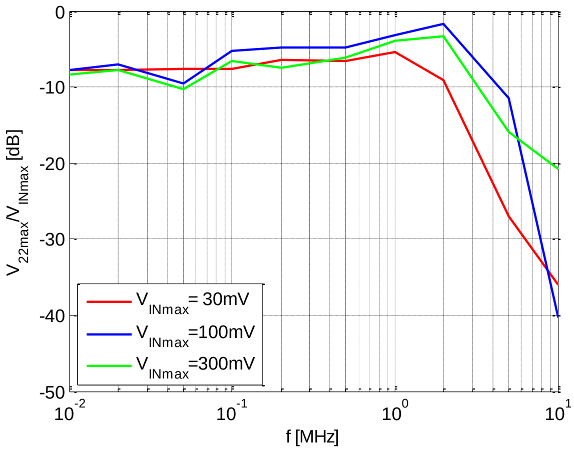

Fig. 8. Variation of the second-harmonic (2ω) component magnitude of the output signal for different input signal magnitudes

and p_{RMS} parameters to the ideal ones. Once the frequency increases the p_{DC} drops below unity and for the magnitude of 300 mV the rectifier can be used to process signals up to 2 MHz ($p_{\mathrm{DC-3dB}}$).

The harmonic components of the output signal have also been analyzed. According to the theory, the odd harmonic components of the fundamental frequency ω are zero, i.e. $-\infty$dB. However, based on the measurements, it is in the range of -40 dB at low frequencies, see Fig. 7. As the frequency of the input signal increases, also the magnitude of fundamental component at the output increases. The drop of magnitude at frequencies higher than 5 MHz is caused by the active elements, as they start to attenuate the input signal. The magnitude of second-harmonic component is shown in Fig. 8. As it could be expected from (9), the magnitude of the second-harmonic component is close to -7.44 dB for all magnitudes of the input signal. Increasing the frequency, the magnitude drops down as the circuit looses its feature to rectify the signal.

VI. Conclusion

In this paper a new realization of the voltage-mode full-wave rectifier has been presented. The structure uses one universal voltage conveyor and one second-generation current conveyor (CCII). The two diodes are directly connected and driven by the current terminal of the CCII, which enables high frequency operation of the functional block. The behavior of the proposed rectifier has been verified by experimental measurements, where except of the DC transfer and time responses, the frequency dependent DC value transfer p_{DC} and RMS error p_{RMS} have also been evaluated.

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