PRECISION FULL-WAVE RECTIFIER USING UNIVERSAL CURRENT CONVEYOR AND SIX DIODES

Lukas Langhammer

Doctoral Degree Programme (1), FEEC BUT

E-mail: xlangh01@stud.feec.vutbr.cz

Supervised by: Jan Jerabek

E-mail: jerabekj@feec.vutbr.cz

Abstract: The main aim of this paper is to find a circuit solution of the precision full-wave rectifier with an effort to decrease the negative effect of the diode reverse recovery time and obtain more accurate rectification of low-level signals. This article introduces the precision full-wave rectifier with the universal current conveyor and six diodes. Furthermore, results of simulations are given and a comparison of proposed circuit of precision full-wave rectifier and its known variant is presented.

Keywords: precision full-wave rectifier, conveyor, universal current conveyor (UCC), diode reverse recovery time

1. INTRODUCTION

Precision rectifiers are crucially important for analog signal processing function and instrumentation [1, 2]. Applications of rectifiers can be found in peak-value detectors, AC voltmeters and ammeters, amplitude-modulated signal detectors, RMS to DC convertors, signal-polarity detectors etc [3, 4].

Conventional voltage-mode rectifiers based on diodes and operational amplifiers have a serious drawback . It's due to the fact that these circuits have to overcome the threshold voltage of the diodes. This problem prevents the rectification of signals below a voltage of about 0.6 V [5, 6]. During transition of the diodes from their non-conduction state to their conduction state the operational amplifiers have to recover with a finite small signal, which leads to the significant distortion during the zero crossing of the input signal [3]. We can obtain wider bandwidth, improve the signal to noise ratio, achieve higher precision of the output rectified signal and decrease energy consumption by using current active elements such as current conveyors (CC) [1-8], operational transconductance amplifiers (OTA) [9], current followers (CF) [10] etc.

Another negative effect which prevents obtaining the accurate rectification is the diode reverse recovery time. It's the one of the major factor limiting the use of the diodes for high-frequency signals. Basically, it's the time of the transition of the diode from open to the closed state. When the polarity of the input current is changing the diode stays for a short time in the conductive state even during the opposite polarity results in a overshoot of the diode current to the reverse polarity. This happens because the semiconductor diode is a nonideal component. Duration of this period depends on the physical parameters of the diodes respectively on material from which the diode is made and on its technological performance. Each P or N type of semiconductor contains not only majority carriers, but also minority carriers of the opposite polarity. P-N junction remains for these minority carries open during the reverse polarity, therefore, the diode still conducts current until the exhaustion of the minority carriers and then the reverse current decreases to a minimum value. Diode reverse recovery time can be described by periods t_s and t_d. During the period t_s minority carriers are discharged from P-N junction and on the diode remains almost constant voltage, which is slightly smaller than the forward voltage. In time t_d, the parasitic capacitance of diodes is charging. After this time voltage on the diode remains at the value of the reverse voltage. Time t_s can be reduced by increasing the reverse current flowing through the diode, but it results in greater overshoot when the polarity is changing. Shorter time t_d can be obtained by using a voltage or current source to set the diodes near to their open state (as can be seen in Fig. 1 b), for example). This modification set the diodes during the zero crossing of the input current near to their conductive state, thereby, it reduces the changes of the voltage at the input node when the input current changes. Rising frequency increases the negative effect of the diode reverse recovery time and this leads to an increasing distortion of rectified signal [11, 12].

2. UNIVERSAL PRECISION FULL-WAVE RECTIFIERS

2.1. DESCRIPTION OF THE BASIC CIRCUIT OF THE UNIVERSAL PRECISION FULL-WAVE RECTIFIER

Basic universal precision full-wave rectifier based on two diodes and two operational amplifiers can be seen in Fig. 1a) [2]. The circuit consists of a half-wave rectifier based around the first operational amplifier and a summing amplifier which is created by the second amplifier. Half-wave rectified current flows through D_2 on a negative half cycle of the input signal v_{IN}. This signal is feeded into the summing amplifier and summed with the input signal. Signals have relative weights set according to the values of resistors R_4 = R/2 and R_1=R_2=R_3=R_5=R resulting in the full-wave rectified signal on the output of the rectifier. Circuits of this type process low-frequency signals without problems, but provide a significant waveform distortion at frequencies higher than 1 kHz. It's caused by the transition point of the input signal, the diodes are closed and the operation amplifier operates in an open-loop configuration. As the input signal frequency increases, limited slew rate prevents more the OA from switch diodes rapidly which leads to the distortion of the output signals.

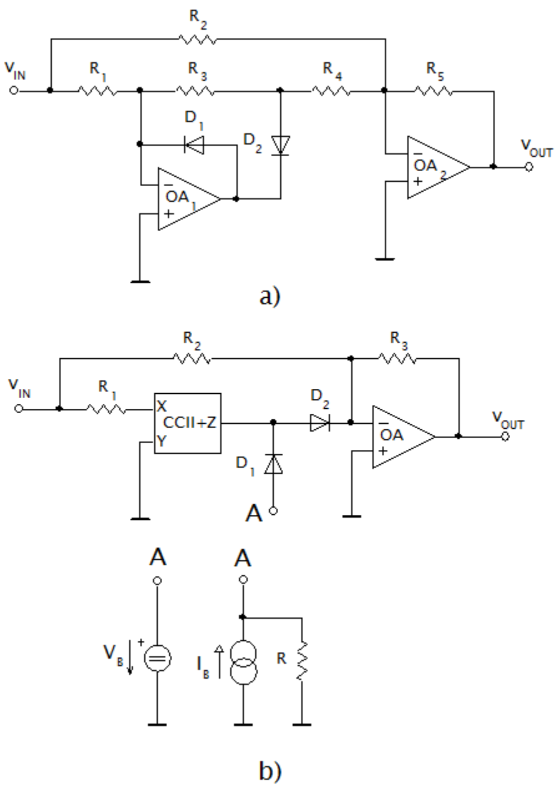

Fig 1. Universal precision full-wave rectifier a) based on operational amplifiers, b) based on current conveyor employing a voltage or current source for bias.

This problem solves a circuit solution shown in Fig. 1 b). Where the half-wave rectifier formed around the operational amplifier is replaced by one with a current conveyor [2]. A precision full-wave rectifier using current conveyors offers inherent speed improvement because the diodes are no longer a part of a negative feedback. The high output impedance of the current conveyor helps overcome the turn-ON resistance of the diodes and the circuit operates precisely even at higher frequencies. As it is shown in Fig. 1 b) a voltage or current source is used to set the diodes near to their open state and helps to decrease distortions of the output signal.

2.2. PROPOSAL OF THE PRECISION FULL-WAVE RECTIFIER WITH UCC AND SIX DIODES

Fig. 2) shows modified version of the universal precision full-wave rectifier shown in Fig. 1 b). The main purpose was to decrease the negative effect of the diode reverse recovery time and obtain better results for the rectification of low-level signals. It contains the universal current conveyor [13, 14], three operational amplifiers and six diodes. The modification consists of an addition of 4 diodes and one summing amplifier. Second generation current conveyor is replaced by the universal current conveyor, because this circuit uses one positive and one negative output of the current conveyor. Similarly to the circuit shown in Fig. 1 b) half-wave rectified current flows through D_2 on a negative half cycle of the input signal v_{IN} and is summed in the summing amplifier which is created by OA_1 with the input signal. Weights of these signals are set according to the values of resistors $R_1 = R/2$ and $R_2 = R_3 = R$ resulting in the full-wave rectified signal on the output of the OA_1. However this full-wave rectified signal is affected by the influence of the diode reverse recovery time results in overshoots to the opposite polarity. The input signal taken from output Z_{1-} is feeded into the new branch where the current flowing through D_4 and D_6 results in a signal which is consisted only from overshoots caused by the diode reverse recovery time. This signal is summed in the summing amplifier created around OA_2 with the full-wave rectified signal from the output of OA_1. Due to the fact this signal has the opposite polarity than signal on the output of OA1 overshoots caused by the diode reverse recovery time are supposed to cancel each other. However, the signal on the output of OA_1 contains only one overshoot per the signal period, but the signal flows through D_4 and D_6 contains two for both cases when the diode current changes its polarity. This second overshoot is added to the full wave rectified signal creates a small distortion of the output waveform. This circuit must be complemented with the circuit of all-pass filter created around OA_3 to compensate different delays of each branch to achieve appropriate summation of these signals. Each diode pair is supplemented with a voltage source to set diodes close to the open state and obtain accurate rectified signal.

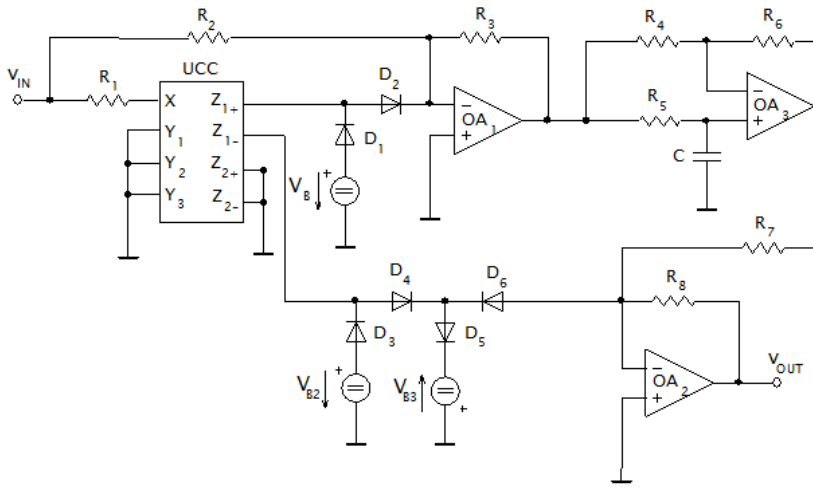

Fig. 2. Proposed circuit of the precision full-wave rectifier using UCC and six diodes

Simulations of proposed circuit were carried out to verify its function. In Fig. 3 can be seen a comparison of the output waveforms of the basic circuit of the universal precision full-wave rectifier shown in Fig. 1 b) and proposed circuit Fig. 2 when the input frequency was 1 MHz and amplitude of the input signal 0.1 V. From the output waveforms it can be seen that the proposed circuit achieves significantly better results for signals with smaller amplitude than the basic circuit where the negative effect of the diode reverse recovery time already distorts output signal and decreases accurate rectification. Circuits were simulated with components of value $R_1 = 510\ \Omega$, $R_2 = R_3 = R_6 = R_7 = R_8 = 1.1\ \mathrm{k\Omega}$, $R_4 = 10\ \mathrm{k\Omega}$, $R_5 = 4.5\ \mathrm{k\Omega}$, $C = 5$ pF. For both circuits the voltage sources of value $V_B = 0.6$ V are used to bias the diodes. Comparison of DC transfer functions of simulated circuits is also given and it's shown in Fig. 4.

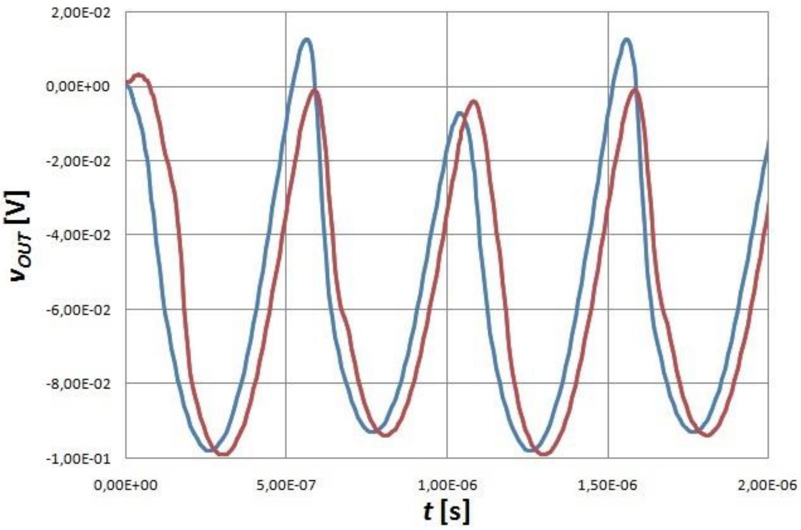

Fig. 3. Simulated output waveforms of basic circuit from Fig. 1 b) (blue line) and proposed circuit (red line) when the input signal frequency was 1 MHz and amplitude 0.1 V

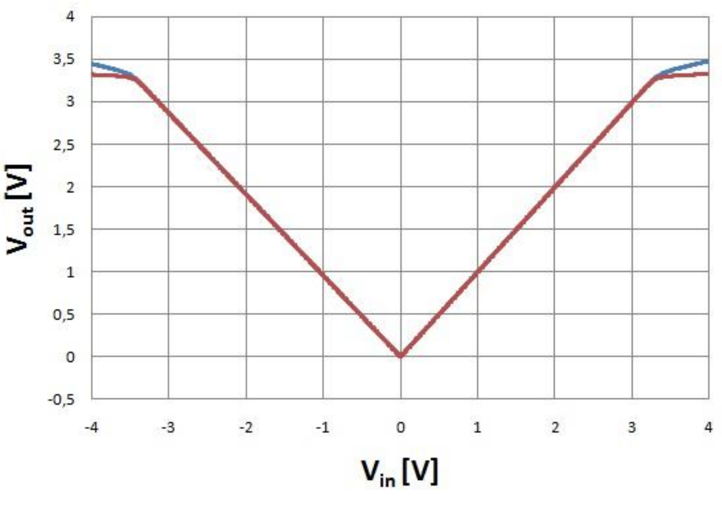

Fig. 4. Simulated DC transfer functions, basic circuit from Fig. 1 b) (blue line), proposed circuit (red line)

3. CONCLUSION

A new circuit solution of the universal precision full-wave rectifier with an effort to decrease the negative effect of the diode reverse recovery time is presented. Better results for the rectification of small signals were achieved. Proposed circuit provides good results up to frequency of 1 MHz All simulations were performed using simulation models of the universal current conveyor as the current active element, THS4052C [15] as an operational amplifier and diodes of 1N4148 type. Comparisons of the rectified output waveforms and transfer functions of the basic circuit of the universal precision full-wave rectifier from Fig. 1 b) and its new proposed version are presented. Furthermore is planned implementation and experimental measurements of proposed circuit to verify its function.

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