A Full-Wave Rectifier Using a Current Conveyor and Current Mirrors with Improved Efficiency

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Abstract

A full-wave rectifier using a current conveyor and current mirrors proposed by Monpapassorn *et al.* (2001) is improved. The improved rectifier uses two voltage sources in place of two transistor-diodes and three constant current sources of the original rectifier. The improvement yields better performance in view of device number, power consumption and operation frequency. Simulation results that agree with theory are included.

Keywords: full-wave rectifier, current conveyor, current mirrors, improved efficiency, operation frequency

1. Introduction

Recently, many current conveyor full-wave rectifiers have been reported (LTP Electronics Ltd. [1], Toumazou *et al.* [2], Hayatleh *et al.* [3], Khan *et al.* [4], Monpapassorn *et al.* [5]). These rectifiers rectify a signal in current mode with an advantage in view of the operation frequency. Rectifiers proposed by LTP Electronics Ltd. [1], Toumazou *et al.* [2], Hayatleh *et al.* [3] and Khan *et al.* [4] use two current conveyors, one ungrounded resistor, one grounded resistor and four diodes as devices. Monpapassorn *et al.* [5] presented a full-wave rectifier using a current conveyor, two grounded resistors and four current mirrors as main devices, shown in figure 1, with a feature of simplicity for IC fabrication. Namely, the rectifier can be built by using all MOS or bipolar structure, applying MOS or bipolar resistors in place of passive resistors. In addition, it is easy to make all grounded resistors of the rectifier in an IC process, compared with the realization of the ungrounded resistor. In this paper, the authors present an improved version of the rectifier presented by Monpapassorn *et al.* [5], which yields better performance as follows.

1) The improved rectifier uses two voltage sources substituting two transistor-diodes and three constant current sources of the original rectifier. Thus, the improved rectifier uses fewer devices than the original rectifier.
2) In the original rectifier, to reduce the error at zero crossing of an output, three constant current sources are used. Two constant current sources create an offset current that is compensated by a constant current source. These constant current sources cause the current to flow through the circuit all the time. The improved rectifier uses the voltage sources in place of the constant current sources, which makes the current in the circuit, all the time, to be lower. This leads to lower power consumption.
3) Although the original rectifier uses two transistor-diodes and three constant current sources to reduce the problem of on/off transition at zero crossing, this problem still exists. Using two voltage sources instead of transistor-diodes and constant current sources can completely avoid the on/off transition problem.

2. Improved rectifier

To be simple for readers, the authors will explain the operation of the original rectifier displayed in figure 1. A second generation current conveyor CCII+ (Sedra and Smith [6]) shown in figure 2 is used as one component of the voltage to current converter in the original rectifier. The relations between the currents and voltages at nodes (X, Y, and Z) of this current conveyor are given by:

$$\left.\begin{aligned} i_y &= 0 \\ v_x &= v_y \\ i_z &= i_x \end{aligned}\right\} \quad (1)$$

From (1), an output current of CCII+ (i_z) of the original rectifier in figure 1 can be written as:

$$i_z = \frac{V_{in}}{R_I} \quad (2)$$

This current is fed into the input of a current mode full-wave rectifier. In the original rectifier, the current mode full-wave rectifier consists of four Wilson bipolar current mirrors (CM1 (Q1 to Q4), CM2 (Q5 to Q8), CM3 (Q9 to Q12), and CM4 (Q13 to Q16)); two transistor-diodes (Q17 and Q18); and three constant current sources (I_1, I_2, and I_3). The Q17 and Q18 operate as diodes to protect from short circuit between I_1 and I_2. The constant current sources, $I_1 = I_2 = I$, mean that the transistors in CM1 to CM4 are turned-on all the time, reducing the problem during the non-conduction/conduction transition of these transistors. Both I_1 and I_2 create an offset current (2I) through R_O. To eliminate this offset current at R_O, we exploit I_3 = 2I at the output of the original rectifier.

The operation of the current mode full-wave rectifier is as follows: When $i_z > 0$, it is fed through Q17 and then is mirrored by CM1 to the collector of Q4 as $-i_z$. This $-i_z$ is again mirrored by CM3 to the collector of Q12 as $+i_z$. In addition, when $i_z < 0$, it is fed through Q18 and then, is mirrored by CM2 to the collector of Q8 as $-i_z$. This $-i_z$ is second mirrored by CM4 to the collector of Q16 as $+i_z$, and this $+i_z$ is third mirrored by CM3 to the collector of Q12 as $-i_z$. From the operation of the current mode full-wave rectifier the relations between the input current (i_z) and the output current at the collector of Q12$\left(I_{C(Q12)}\right)$ can be expressed as:

$$\left.\begin{aligned} i_z > 0;\ I_{C(Q12)} &= +i_z + 2I \\ i_z < 0;\ I_{C(Q12)} &= -i_z + 2I \end{aligned}\right\} \quad (3)$$

The offset, $2I$, in (3) is compensated by using I_3. Thus we can write the relations between i_z and the output current (I_{R_O}) as:

$$\left.\begin{aligned} i_z > 0;\ I_{R_O} &= +i_z \\ i_z < 0;\ I_{R_O} &= -i_z \end{aligned}\right\} \quad (4)$$

Using (2) and $R_O = R_I$, we get the relations between the input and output voltages of the original rectifier as:

$$\left.\begin{aligned} V_{in} > 0;\ V_{out} &= +V_{in} \\ V_{in} < 0;\ V_{out} &= -V_{in} \end{aligned}\right\} \quad (5)$$

This means that the original rectifier operates as a full-wave rectifier.

From the above operation, to solve the on/off transition problem, the original rectifier uses I_1 to make the transistors in CM1 turn on all the time and also uses I_2 for the transistors in CM2. The use of I_1 and I_2 leads to the use of transistor-diodes, Q17 and Q18, to protect from no flow through CM1 and CM2 of I_1 and I_2. Additionally, the use of I_1 and I_2 results in the offset current 2I at the output, which is subtracted by using I_3. Although the on/off transition problem of CM1 and CM2 is cleared, the fewer on/off transition problems of Q17 and Q18 is a new problem.

An improved rectifier is shown in figure 3. It uses two voltage sources, V_A and V_B, to make the transistors in CM1 and CM2 turn on all the time, in place of using I_1, I_2, I_3, Q17 and Q18 of the original rectifier. Both V_A and V_B have to be adjusted to the minimum voltage (approximately $2V_{BE}$) that can make the transistors in CM1 and CM2 turn on all the time. Namely, if V_A and V_B are lower than $2V_{BE}$, it is the cause of the on/off transition problem. Inversely, if V_A and V_B are higher than $2V_{BE}$, it is the cause of the offset at the output. Note from the operation of the improved rectifier, with suitable V_A and V_B, that there is no on/off transition problem. Of course, owing to no on/off transition problem, the improved rectifier yields a higher operation frequency than the original rectifier. Besides, because V_A and A_B must be set to the minimum voltage that can make the transistors in CM1 and CM2 turn on all the time, the offset current in the improved rectifier is lower than in the original rectifier.

Note that for the improved rectifier, the V_A, V_B, and the input sections of CM1 and CM2 are connected in series, causing quiescent current. The quiescent current of the improved rectifier can be determined by the voltages (V_A and V_B) and the input impedance of CM1 and CM2 by Ohm' law. Namely, if the voltages of V_A and V_B are high, the quiescent current will be high, and if the input impedance of CM1 and CM2 is high, the quiescent current will be low. This quiescent current results in the offset current at the output, leading to the output offset voltage as:

$$V_{out(offset)} \approx 2R_O\left(\frac{V_A + V_B - |4V_T|}{R_{in(CM1)} + R_{in(CM2)}}\right) \quad (6)$$

where V_T is the threshold voltage of the transistors in CM1 and CM2 (V_{BE} of an operating transistor) approximately 0.6V for the silicon transistor, $R_{in(CM1)}$ and $R_{in(CM2)}$ are the input impedance of Wilson current mirrors CM1 and CM2 [8].

This offset may be compensated by using I_3 as the original rectifier. To consume low power, the quiescent current should be as low as possible.

3. Simulation results

The authors simulated an original rectifier to compare with an improved rectifier to verify the theoretical improvement by using the PSPICE program. A current conveyor CCII+ in a current feedback opamp, AD844, (Svoboda *et al.* [7]) as well as NPN and PNP transistors, 2N3904 and 2N3906, are used. These device models are obtained from their data sheets. The supply voltage is ± 10 V. Constant current sources are $I_1 = I_2 = 100$ μA and $I_3 = 200$ μA for the original rectifier. These current sources are built by using only one current source to supply the current through the unity and double gain current mirrors. Voltage sources, $V_A = V_B = 1.2$ V, are set. Resistors $R_I = R_O = 100\ \Omega$ are chosen.

One applies a sine wave signal (100 mV_{peak}) at inputs of the original rectifier and of the improved rectifier. Using the frequency of 100 kHz, the upper output signal of the original rectifier and the lower output signal of the improved rectifier, are shown in figure 4. Figure 7 also shows the output signals at the frequency of 1 MHz. For the frequency of 100 kHz, figure 5 and figure 6 show the outputs of the improved rectifier using $V_A = V_B = 1.3$ V and $V_A = V_B = 1.1$ V. The amplitude of output signals is not 100 mV_{peak}, the theoretical voltage, because the resistance at node X of the current conveyor in AD844 is 50 Ω (Svoboda *et al.* [7]). Figure 4 to figure 7 show the results to correspond to the theory. The zero crossings of output signals of the improved rectifier are not 0 V in figure 4 and figure 7, since $V_A = V_B = 1.2$ V are not the minimum voltage that can make the transistors in CM1 and CM2 turn on all the time. The voltage of V_A and V_B can be decreased. Although, for the improved rectifier, it is hard to get the theoretical minimum voltage with simulation adjustment, the error at zero crossing of the improved rectifier is much lower than that of the original rectifier. The power consumption of both rectifiers is simulated at the frequency of 100 kHz in the case of $V_A = V_B = 1.2$ V. The power consumption of the original rectifier is higher than that of the improved rectifier by about 6 mW.

4. Conclusions

A full-wave rectifier using a current conveyor and current mirrors with improved efficiency has been described in the paper. It shows that it is possible to improve the original rectifier in view of device number, power consumption and operation frequency, by using two voltage sources in place of two transistor-diodes and three constant current sources.

5. References

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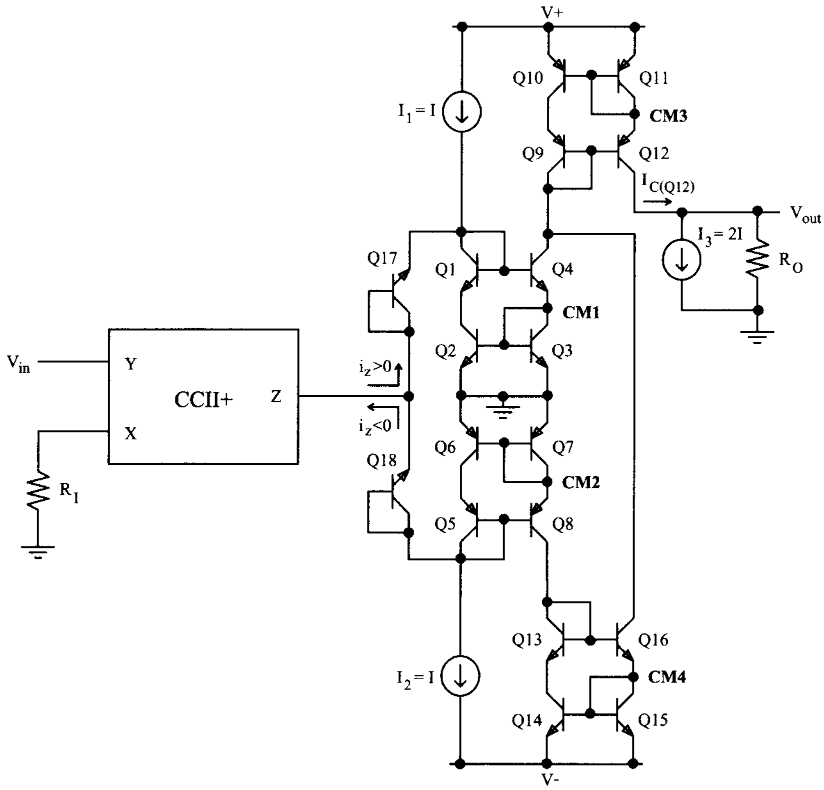

Figure 1. Original full-wave rectifier using a current conveyor and current mirrors.

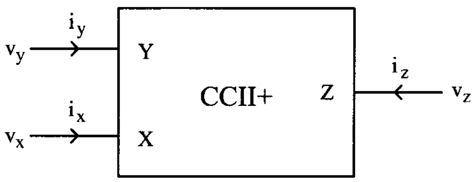

Figure 2. Current conveyor CCII+.

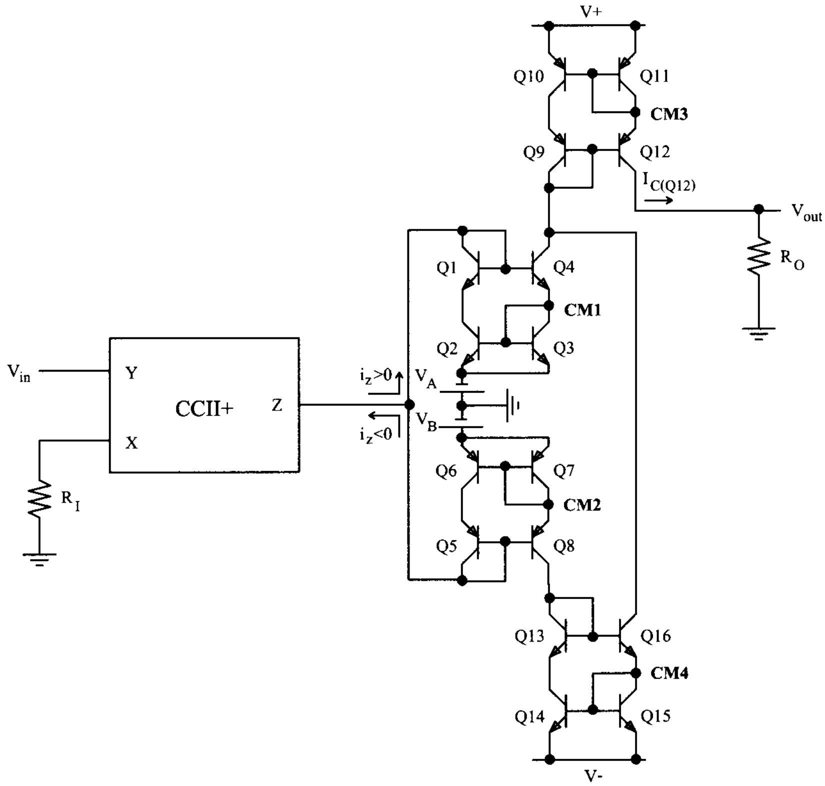

Figure 3. Improved full-wave rectifier.

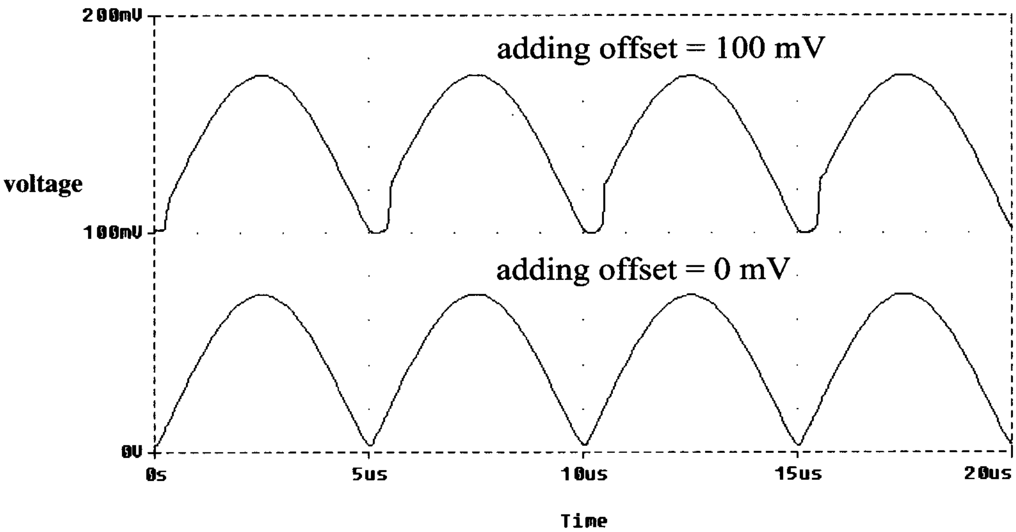

Figure 4. Outputs at the frequency of 100 kHz of the original rectifier (top) and the improved rectifier (bottom).

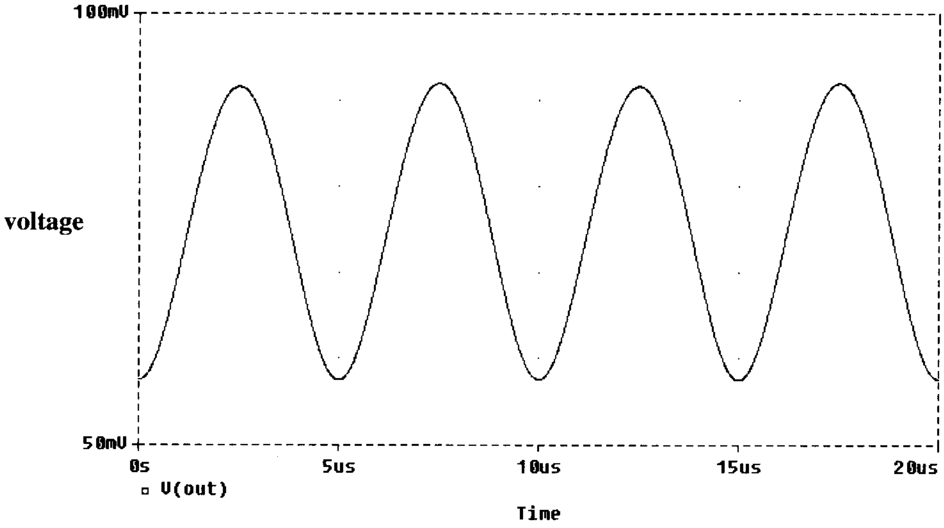

Figure 5. Output at the frequency of 100 kHz of the improved rectifier with $V_A = V_B = 1.3$ V.

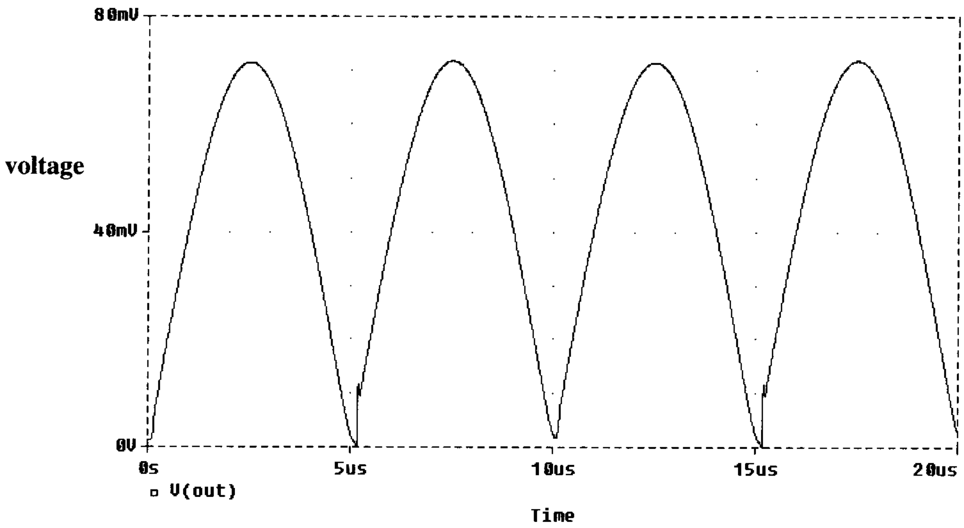

Figure 6. Output at the frequency of 100 kHz of the improved rectifier with $V_A = V_B = 1.1$ V.

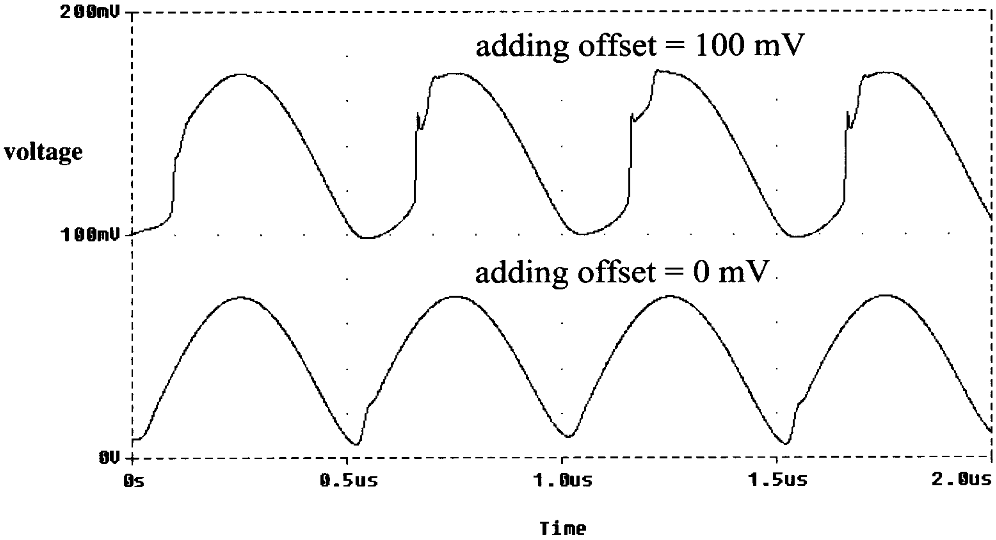

Figure 7. Outputs at the frequency of 1 MHz of the original rectifier (top) and the improved rectifier (bottom).