Improved Class AB Full-Wave Rectifier

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Abstract

The CMOS class AB full-wave rectifier is improved to reduce an error in the output signal in low voltage range. The improved rectifier uses a current input signal to substitute for the voltage input signal. This current input signal is produced by changing a voltage input signal using a CMOS voltage to current converter (V-I) based on class AB circuit. The theory of this improvement is described and simulated results obtained from PSPICE program are used to verify the theoretical prediction. The simulated results have shown that the improved rectifier has an error in low output voltage range much lower than that of rectifier.

1. Introduction

Rectifier circuits are extensively used in wattmeters, AC voltmeters, RF demodulators, piecewise linear function generators, and various nonlinear analog signal-processing circuits. The operation of diode rectifiers is limited by the threshold voltages, approximately 0.3 V for germanium diode and 0.7 V for silicon diode so they are used only in some applications of which the precision in range of threshold voltage is insignificant, such as radio frequency demodulators and DC voltage supply rectifiers. Nevertheless, for the applications requiring high accuracy, the diode rectifiers cannot be used for the purpose. This problem can be corrected using MOS or bipolar transistor integrated rectifiers instead.

Recently, integrated rectifiers have been reported. The full-wave rectifiers studied are, for instance: the rectifier with OTAs by Mead [1] which uses two OTAs and two current mirrors; the rectifier built using current-feedback opamps (CFOAs) by Khan *et al.* [2] which uses four diodes, two resistors, and two CFOAs; the rectifier with current conveyors (CCIIs) by Toumazou *et al.* [3] which uses four diodes, two resistors, one bias voltage source, and two high frequency CCIIs; the rectifier with CMOS class AB amplifier by Surakampontorn and Riewruja [4] which uses eight MOSs, two resistors, and two constant current sources; and the rectifier with CCIIs and opamps by Wilson and Mannama [5] which uses two opamps, two resistors, two CCIIs, two constant current sources, and two diode bridge rectifiers. As for the half-wave rectifiers studied they are, for instance: the rectifier with CMOS diode by Ramirez-Angulo [6] which uses four MOSs, one resistor, and two constant current sources; and the rectifier with CMOS transconductor circuit by Jun and Kim [7] which uses six MOSs and one constant voltage source. In the above literature review, the rectifiers use opamps, OTAs, and CCIIs employing many bipolar or MOS transistor devices. The full-wave rectifier [4] is a good CMOS rectifier, namely having a simple circuit and using few devices, yet it has an error in the low output voltage range. In this paper, the author modifies it to reduce this drawback.

2. Circuit description

2.1 CMOS class AB amplifier

The CMOS class AB amplifier as shown in Fig.1a consists of two NMOSs, two PMOSs, and two constant current sources. Assuming that the MOSFETs, M_1 and M_2 as well as M_3 and M_4, have the same characteristics and they operate in saturation region, including two constant current sources $I_1=I_2=I_B$. The current and voltage in the circuit [8] are given by

$$V_X = V_Y \qquad (1)$$

the equivalent circuit of class AB amplifier for this voltage buffer operation is shown in Fig.1b. Moreover

$$I_{DN} = \frac{(4I_B - I_{in})^2}{16I_B} \quad \text{for } -4I_B \le I_{in} \le 4I_B \tag{2}$$

$$I_{DP} = \frac{(4I_B + I_{in})^2}{16I_B} \quad \text{for } -4I_B \le I_{in} \le 4I_B \tag{3}$$

$$I_{DN} = I_{in}; I_{DP} = 0 \quad \text{for } I_{in} < -4I_B \tag{4}$$

$$I_{DP} = I_{in}; I_{DN} = 0 \quad \text{for } I_{in} > 4I_B \tag{5}$$

2.2 Class AB full-wave rectifier [4]

The class AB full-wave rectifier [4] is shown in Fig.2. It is composed of one class AB amplifier, two resisters, and two current mirrors. Using the equation (1), the input current of this circuit can be written as

$$I_{in} = \frac{V_{in}}{R_I} \tag{6}$$

In the circuit, the drain current of M_2 is reflected through M_5 and M_6, respectively, while the drain current of M_4 is reflected through M_7, M_8, M_5, and M_6, respectively. Using the equation (4) and the equation (5), the drain current of M_6 that is the output current, can be obtained as

$$I_{out} = |I_{in}| \tag{7}$$

By choosing R_I=R_O, the output voltage can be obtained as

$$V_{out} = |V_{in}| \tag{8}$$

In this case, the circuit operates as a full-wave rectifier.

As the operation of this class AB full-wave rectifier is explained, it is evident that the output voltage has an error in the range of $-4I_B \le I_{in} \le 4I_B$ following the equation (2) and the equation (3). It is seen that one can easily reduce this error range by using the very low values of the constant current sources, I_1=I_2=I_B. But in fact, it is not possible to use this approach because if the values of I_1 and I_2 are reduced at very low value; the equation (1) will be not true in the case when R_I is connected at node Y, since the output impedance Z_{out} (see Fig.1b) of the class AB amplifier is increased [9] and as a result the voltage at node Y is decreased. This effect is the cause of the error of output voltage and the reduction of output operating voltage range.

2.3 Improved class AB full-wave rectifier

From the problem mentioned in 2.2, the error of the full-wave rectifier can be reduced by using the improved rectifier as shown in Fig. 4 instead. In the improved rectifier, the added part is a class AB V-I converter as shown in Fig. 3 that is composed of M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, I_1, I_2, and R_I. The output current of the V-I converter is the I_{in} that is reflected through two current mirrors, M_5 and M_6 as well as M_7 and M_8, reaching the output of V-I converter. Using the equation (1), the output current of V-I converter can be expressed as

$$I_{out(V-I)} = \frac{V_{in}}{R_I} \tag{9}$$

This output current is fed into node Y_2, a current input node, of the full-wave rectifier. In this case, the input of the rectifier is the current thus the values of two constant current sources, I_3 and I_4, can be reduced at very low values in order to reduce the range of the error as appearing in the equation (2) and the equation (3), this reduction has no affect on the operation of the rectifier.

3. Simulated results

To verify the theoretical improvement analysis, the improved rectifier in Fig.4 was simulated by the PSPICE program. The used parameters in the simulation are as same as the parameters of the rectifier [4] that is K=33.78μ AV^{-2}, V_T=1.2V, and W/L=20, where K is the transconductance parameter, V_T is the threshold voltage, W is the channel width, and L is the channel length. Two employed voltage supplies are V_{DD}=5V and V_{SS}=-5V. Four employed constant current sources are I_1=I_2=10μA and

$I_3=I_4=0.1\mu A$. Two resisters are $R_I=R_O=10k\Omega$. The simulated DC characteristics of the rectifier [4] and the improved rectifier are compared and shown in Fig.5. The relations between the input (sine wave 100kHz, $2V_{P-P}$) and the output signals of the rectifier [4] and of the improved rectifier are shown in Fig.6 and Fig.7, respectively. From the simulated results as shown in Fig.5 to Fig.7, It is evident that the improved rectifier has an error in low output voltage range much lower than that of the rectifier [4].

4. Conclusions

It is possible to reduce the error in low output voltage range of the class AB full-wave rectifier [4] by using the current input signal in place of the voltage input signal which is carried out by combining the class AB V-I converter with the rectifier [4].

5. Acknowledgement

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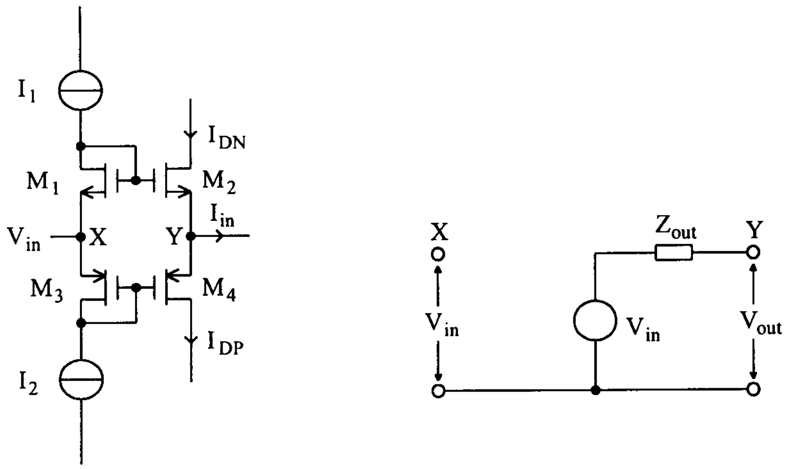

(a) (b)

Fig. 1 The CMOS class AB amplifier: (a) circuit and (b) equivalent circuit for voltage buffer operation.

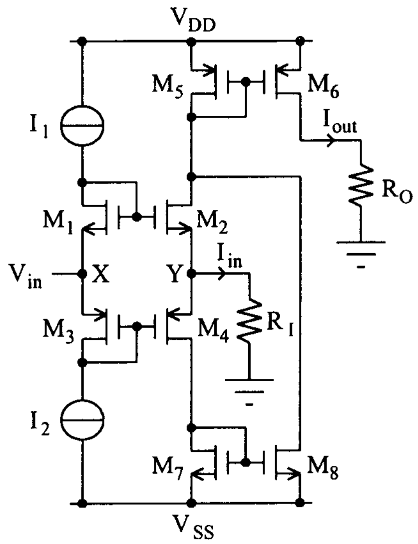

Fig. 2 The CMOS full-wave rectifier circuit proposed by Surakampontorn and Riewruja [4].

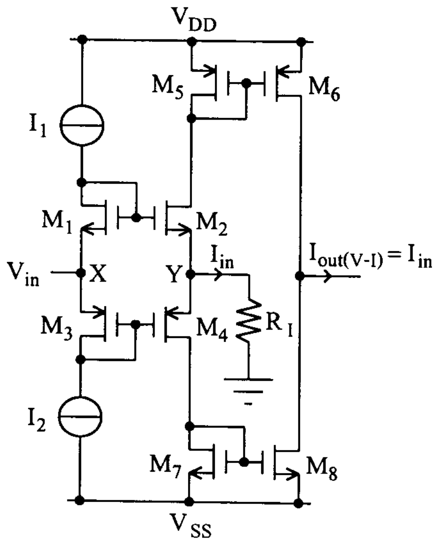

Fig. 3 The V-I converter circuit based on class AB amplifier.

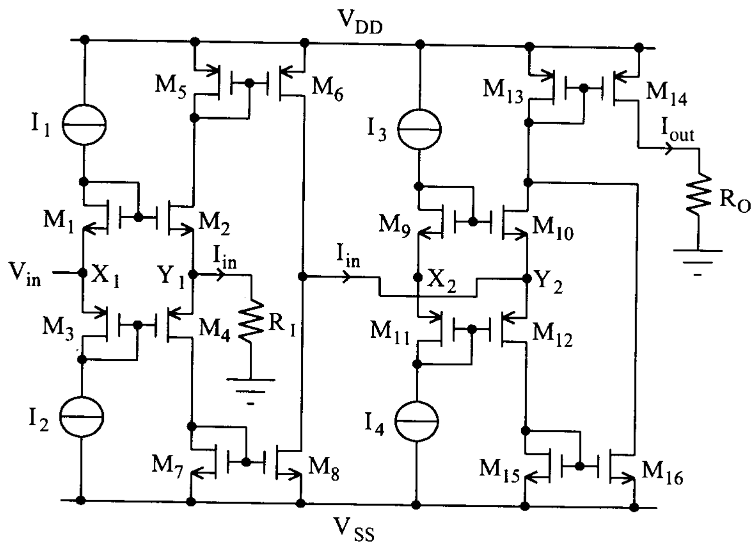

Fig. 4 The Improved full-wave rectifier circuit that is a combination of the rectifier [4] and the V-I converter.

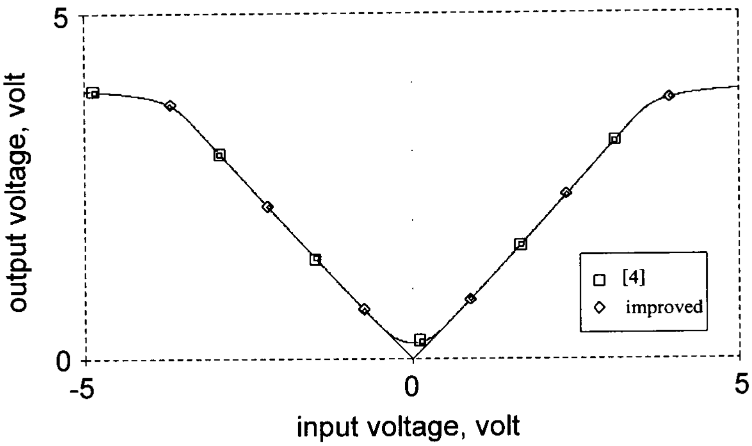

Fig. 5 The DC transfer characteristics of the rectifier [4] and the improved rectifier.

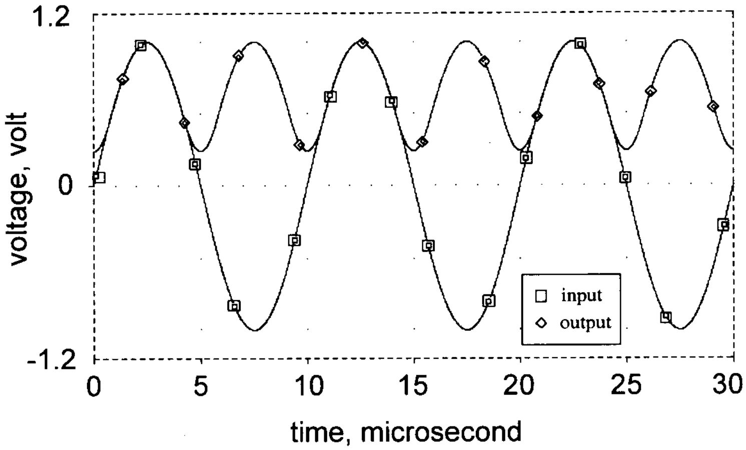

Fig. 6 The simulated input and output signals of the rectifier [4].

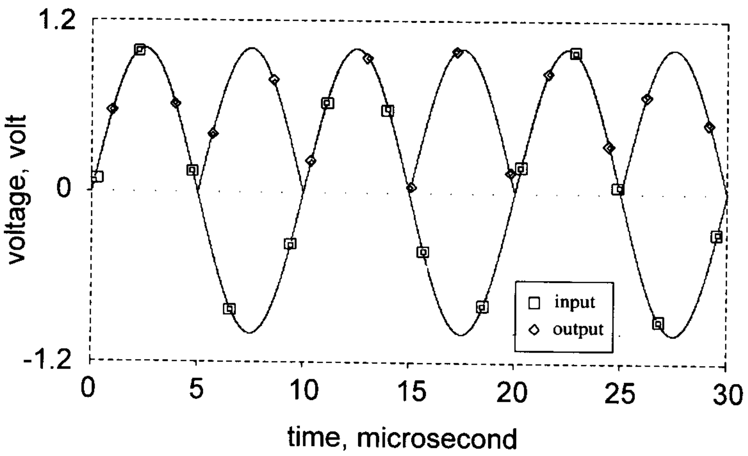

Fig. 7 The simulated input and output signals of the improved rectifier.

6. References

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