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OTA-based precision full-wave rectifier

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Abstract

An operational transconductance amplifier (OTA) based precision full-wave rectifier circuit is presented in this article. The proposed circuit has a very sharp corner in the DC transfer characteristic and simple configuration comprised three OTAs and one current mirror. The temperature dependence of the OTA transconductance is reduced. Experimental results demonstrating the characteristic of the circuit are included.

1. Introduction

A precision rectifier of low-level signal is one of important circuit building block used in analog signal processing and conditioning systems. For example, it can be used to implement demodulators, RMS to DC converters and peak detectors. The traditional approaches to realize a precision rectifier are based on the use of operational amplifiers (op-amps) and diodes [1] or transistors operating in class B [2], [3]. These approaches exhibit the output distortion evident during the zero-crossing of the low-level input signal due to the delay caused by the switching between "on" and "off" state of diodes or transistors. Alternatively, an approach based on the use of operational-amplifier supply-current sensing technique has been shown to realize a precision rectifier [4]. This approach requires the signal current much greater than the op-amp bias current to avoid nonlinearity error due to the op-amp characteristic [5]. In addition, two approaches to improve the nonideal precision rectifier performance based on current mode technique, which is demonstrated the use of current conveyors and diodes as the active elements, have been reported in literature [6], [7]. These approaches used the diodes biased to the edge of conduction to reduce the delay and improve high frequency performance. The purpose of this article is to propose an OTA based precision rectifier. The circuit consists of commercially available OTAs and a current mirror to produce rectification without the use of diode in signal path. The new circuit technique results in very sharp corner in the DC transfer characteristic and wide dynamic range. Experimental results exhibit very low distortion over the entire dynamic range.

2. Circuit Description

The simple configuration of the proposed circuit is shown in Fig. 1. Transistors Q_1 - Q_3 form a Wilson current mirror, CM_1, which has the current transfer ratio equal to 2. From the circuit, the transconductance gain of the OTAs A_1 and A_2 are equal. If v_{in} is an input signal voltage, therefore the current i_1 and i_2 are obtained as $g_m v_{in}$, where $g_m = I_B/2V_T$ denotes the transconductance gain of the OTA, I_B and V_T are OTA bias current and thermal voltage, respectively. The operation of the circuit can be explained as follows. For $v_{in} > 0$, the current mirror CM_1 forces the current $i_3 = 2i_1 = 2g_m v_{in}$. Then the output current I_{out} can be written as

$$i_{out} = i_2 - i_3 = -g_m v_{in} \qquad \text{for } v_{in} > 0 \qquad (1)$$

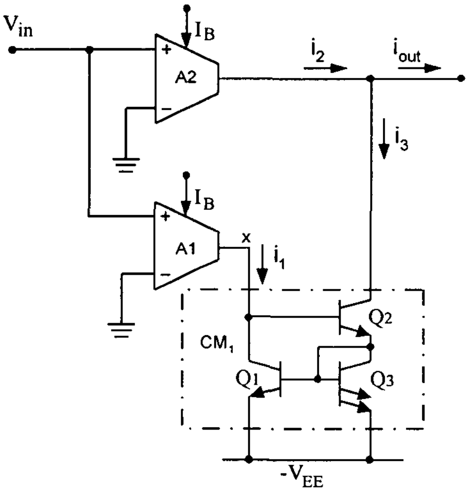

Figure 1. Principle Configuration of Full-wave Rectifier

For the case of $v_{in} < 0$, the current i_1 and i_2 are negative. Since the input stage of the current mirror CM_1 allows only positive current to flow through it, therefore the current mirror CM_1 forces the output stage of the OTA A_1 to be saturated. The voltage at node x, V_x, becomes $V_{EE}+V_{S1}$, where V_{S1} denotes the saturation voltage of internal transistors at the output stage of the OTA A_1 and V_{EE} denotes a negative power-supply. The voltage V_x provides the voltage drop across the input of the current mirror CM_1 and brings the current mirror CM_1 to operate in class AB. Then the current i_1 and i_3 are now become very low quiescent current and negligibly small. Therefore, the output current i_{out} can be obtained as

$$i_{out} = i_2 = g_m V_{in} \quad \text{for } v_{in} < 0 \tag{2}$$

Form Eq. (1) and (2), the output current i_{out} can be stated as

$$i_{out} = -g_m|V_{in}| = -\frac{I_B}{2V_T}|V_{in}| \tag{3}$$

As a result the output current i_{out} becomes a full-wave rectification of the input signal voltage v_{in}, with the transconductance gain equal to g_m. It should be noted that output current I_{out} is inversely proportional to temperature. This causes the characteristic of the circuit in Fig. 1 to be strongly dependent on the temperature, which is undesirable.

The proposed temperature compensated OTA-based precision full-wave rectifier is shown in Fig. 2. The OTAs A_1, A_2 and current mirror CM_1, function as a full-wave rectifier which is shown in Fig. 1. The OTA A_2 and resistor R function as a voltage to current converter. Then, from routine circuit analysis of Fig. 2, the voltage at node A, V_A, can be expressed as

$$V_A = \frac{g_{m3}R}{1+g_{m3}R}V_{in} \tag{4}$$

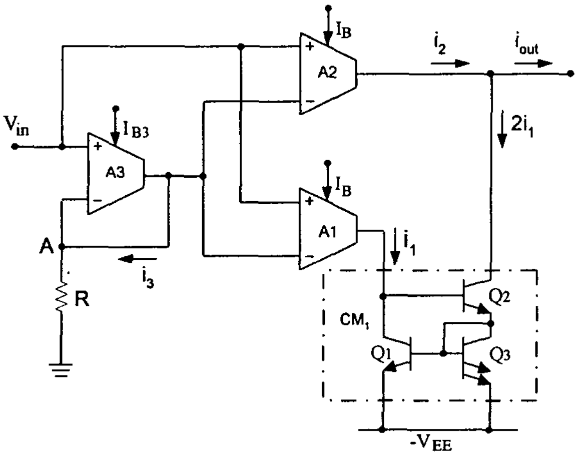

Figure 2. The proposed circuit

and the current i_1 and i_2 can be stated as

$$i_1 = i_2 = g_m(V_{in} - V_A) \tag{5}$$

From Eq. (4) and (5), the current i_1 and i_2 become

$$i_1 = i_2 = \frac{g_m}{g_{m3}R+1}V_{in} \tag{6}$$

If $g_{m3}R >> 1$, then the current i_1 and i_2 can be approximated to

$$i_1 = i_2 = \frac{g_m}{g_{m3}R}V_{in} = \frac{I_B}{I_{B3}R}V_{in} \tag{7}$$

It is clearly seen that the temperature dependence of the transconductance gain $g_m = I_B/2V_T$ is compensated. Then, the output current i_{out} becomes

$$i_{out} = -\frac{I_B}{I_{B3}R}|V_{in}| \tag{8}$$

Eq. (8) shows that the temperature dependence of the transconductance gain g_m and g_{m3} are compensated.

3. Experimental Results

To demonstrate the circuit performance, the circuit in Fig. 2 was implemented using commercially available OTAs CA3080 and current mirror TL012. The OTA bias current $I_{B1} = I_{B2}$ and I_{B3} were set to 2mA and 0.5mA, respectively, for $g_{m1} = g_{m2} = 0.04$A/V and $g_{m3} = 0.01$A/V. The power supply was set to ± 10V. For the resistor R = 10kΩ, the output current waveform for a 1kHz sine wave input waveform of peak to peak amplitude 2V is shown in Fig. 3. The linearity and low-level signal distortion of the proposed circuit can be illustrated by the use of triangular wave input signal of the peak to peak amplitude 100mV and the resistor R = 1kΩ that shows in Fig. 4. It is apparent that the circuit exhibits very low distortion for an input signal as low as 100mV peak to peak.

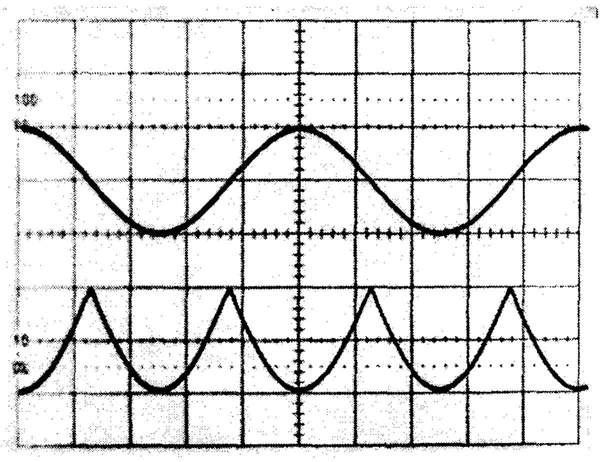

Figure 3. Experimental result for 1kHz sine wave input voltage (upper trace input: 1V/div, lower trace output: 200μA/div)

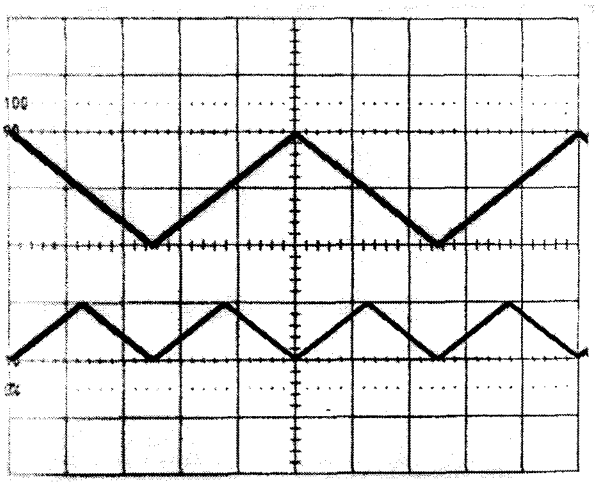

Figure 4. Measured result for 1 kHz triangular wave input signal voltage (upper trace input: 50mV/div, lower trace output: 200μA/div)

4. Conclusion

A new OTA-based precision rectifier circuit has been introduced. The circuit comprises commercial three OTAs and one current mirror resulting is suitable for implementing in monolithic integrated circuits. The temperature dependence of the OTA transconductance gain has been reduced. The proposed circuit results in very sharp corner in the DC transfer characteristic and wide dynamic range.

5. Acknowledgments

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