沒有負載效應的精密全波整流器電路

Precision Full-wave Rectifier without Loading Effect

侯俊禮* 陳暐鈞 洪君維
Chun-Li Hou*, Wei-Chun Chen, Jiun-Wei Horng

Abstract

This paper presents an OPA-based precision full-wave rectifier without loading effect. The circuit consists of two operational amplifiers, two diodes and few passive elements. This circuit is used few elements, and is capable of giving amplified output and has high input impedance and low output impedance. HSPICE simulation and the experiment results are in good agreement with the theoretical analysis.

Keywords: full-wave rectifier, operational amplifier

I. INTRODUCTION

If the output and the input waveforms are not related by a linear equation, the circuit is said to be operating in a nonlinear fashion. A precision rectifier is one of important nonlinear circuits extensively used in analog signal processing systems. When a diode is used in half- and full-wave rectifiers, its nonlinear characteristics tend to distort the output waveform at low signal levels. Since a silicon diode must be forward biased to about 0.7 V before condition begins, device is not suitable for the rectification of small signal levels below several volts. The use of operational amplifiers (OPAs) can improve the performance of the voltage drop that occurs in an ordinary semiconductor rectifier and give precision rectification [1-4].

A precision full-wave rectifier circuit is also known as an absolute value circuit. This means the circuit gives an output signal in proportion to the magnitude of its input signal, regardless of the input polarity [5]. Fig. 1 shows that the output equals the absolute value of the input.

There are three conventional OPA-based precision full-wave rectifier circuits in Fig. 2, Fig. 3 and Fig. 4.

Fig. 2 is composed of a precision half-wave rectifier followed by a two-input summing amplifier. This circuit performs general well at low frequencies but products moderate to severe waveform distortion at frequencies above 1 kHz [6].

Fig. 1  V_{out} versus V_{in} transfer characteristic of full-wave rectifier

Fig. 2  Simple precision full-wave rectifier for low-frequency operation
The first half of the circuit in Fig. 3 produces two complimentary half-wave outputs and the second half is a difference amplifier [3]. This circuit uses more resistors than Fig. 2. In Fig. 4, equal value resistors are used throughout the circuit [5]. This circuit has higher input resistance than the circuit of Fig. 2, although less than the circuit we proposed. The proposed circuit has the advantage of high input impedance over the mentioned circuits [3, 5-6].

II. CIRCUIT DESCRIPTION

1. Operational amplifier

The operational amplifier (OPA) is used in our circuit design. The OPA we used is μA741, which is a high performance monolithic operational amplifier constructed on a single silicon chip. It is intended for a wide range of analog applications, such as summing amplifier, voltage follower, integrator, active filter, and function generator [7]. The circuit symbol and its detailed schematic are given in Fig. 5 and Fig. 6, respectively.

2. Precision full-wave rectifier

The proposed circuit is shown in Fig. 7(a). The input signal is connected directly to the non-inverting terminal of the OPA to obtain high input impedance. This circuit requires resistors that are precisely proportioned but not all equal. The input impedance of the proposed circuit is approaching infinity and the output impedance is extremely low, that means the loading effect of this circuit can be ignored.

In the following analysis the operational amplifiers and diodes are assumed to be ideal. The arrows in Fig. 7(b) and Fig. 7(c) are the real directions of the current flowing.

Consider the half cycle where Vin is positive. Then D1 is off and D2 is on, as indicated in Fig. 7(b). As the operational amplifier is ideal, we let the inverting and non-inverting input of A2 to be \( V^+ + V_{in} \). Since the input terminals of A1 are at the same potential, the currents coming to the terminals of A1 are as indicated in the figure.

From Kirchhoff’s current law (KCL) at this node, we obtain

\[
\frac{V}{2R} + \frac{V}{R} = \frac{V_{in}}{R}
\]

then

\[
V = \frac{2R}{3R_1} V_{in}
\]

The output voltage is

\[
V_o = iR_3 + V + V_{in}
\]

where current \( i \) equals \( V/2R \). Hence,

\[
V_o = \frac{2R + R_3 + 3R_1}{3R_1} V_{in}
\]
For $V_{in} > 0$, the gain of this half cycle is

$$A_{v+} = \frac{V_i}{V_{in}} = \frac{2R + R_i + 3R}{3R_i}$$

(5)

Then consider the half cycle where $V_{in}$ is negative, $D_1$ is on and $D_2$ is off, as indicated in Fig. 7(c). According to the loop from $V_i$ to ground, Kirchhoff’s voltage law (KVL) gives the equation as

$$V_i + (R + R_i)(\frac{-V_{in}}{R_i}) = 0$$

(6)

where

$$V_i = \frac{V_{in}(R + R_i)}{R_i}$$

(7)

The output voltage is

$$V_o = \frac{R_s}{R}(V_{in} - V_i) + V_{in} = V_{in}(1 - \frac{R_s}{R_i})$$

(8)

From equations (6)-(8), for $V_{in} < 0$, the gain of this half cycle is

$$A_{v-} = \frac{V_i}{V_{in}} = \frac{R_s - R}{R_i}$$

(9)

If both halves of the input waves are to be amplified by the same gain, i.e. the outputs for the two half cycles are identical, thus verifying that the circuit performs full-wave rectification [8].

$$A_{v+} = |A_{v-}|$$

(10)

i.e.

$$2R + R_s + 3R = \frac{R_s - R_i}{R_i}$$

(11)

thus

$$3R_i + R - R_s = 0$$

(12)

From Eq. (12), we found that the gain of this circuit must satisfy the conditions: $A \geq 3$, and we may choose the proper values of $R_1$, $R$, and $R_5$ to obtain the given gain.

III. SIMULATION AND EXPERIMENTAL RESULTS

To verify the theoretical prediction, the circuit in Fig. 7 was simulated using HSPICE with $\mu$A741 OPA models. The supply voltages are $V_{CC} = V_{EE} = 15$ V. The resistances were $R_1 = R_2 = R_3 = R_4 = 1$ kΩ, and $R_5 = 4$ kΩ. The input sine wave magnitude is 1 V and the frequency is 1 kHz. Fig. 8 shows the simulation results of the proposed precision full-wave rectifier.
IV. CONCLUSIONS

A precision full-wave rectifier without loading effect has been proposed. It has high input impedance and low output impedance. The analysis of the transfer characteristics of the full-wave rectifier for $V_{in} > 0$ and for $V_{in} < 0$ are shown. The HSPICE simulation results and the experiments are also given to demonstrate the theoretical expectation.

REFERENCES


