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沒有負載效應的精密全波整流器電路
Precision Full-wave Rectifier without Loading Effect

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摘要

本文提出一個用運算放大器架構之沒有負載效應的精密全波整流器電路。此電路由兩個運算放大器、兩個二極體及少數被動元件組成。本電路所需之元件數目少，且具有輸入阻抗高、輸出阻抗低以及將輸出波形放大等特性。HSPICE 模擬和電路實做結果也證實其理論與分析。
關鍵詞：全波整流，運算放大器

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].

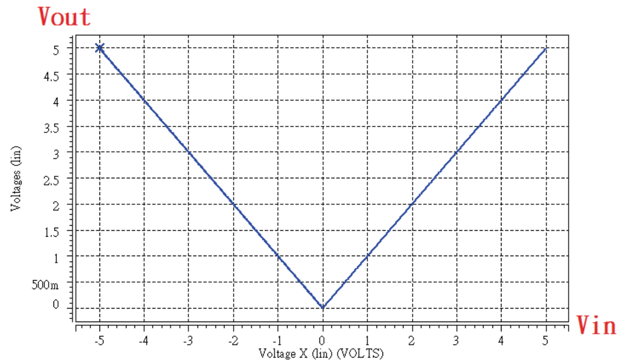

Fig. 1 V_{out} versus V_{in} transfer characteristic of full-wave rectifier

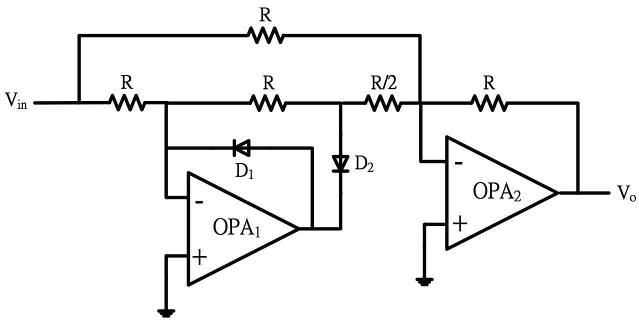

Fig. 2 Simple precision full-wave rectifier for low-frequency operation

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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 intented 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.

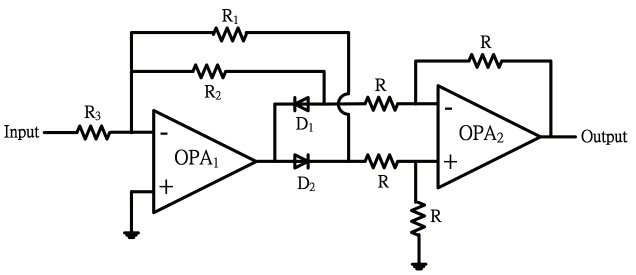


Fig. 3 Precision full-wave rectifier made from a difference amplifier

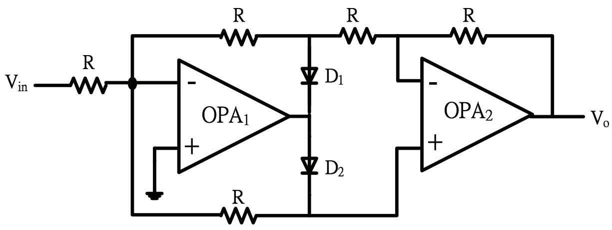


Fig. 4 Another precision full-wave rectifier

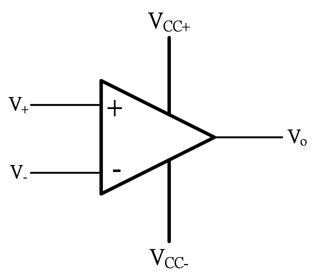


Fig. 5 Symbol of OPA

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 V_{in} is positive. Then D_1 is off and D_2 is on, as indicated in Fig. 7(b). As the operational amplifier is ideal, we let the inverting and non-inverting input of A_2 to be $V+V_{in}$. Since the input terminals of A_1 are at the same potential, the currents coming to the terminals of A_1 are as indicated in the figure.

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

$$\frac{V}{2R}+\frac{V}{R}=\frac{V_{in}}{R_1} \tag{1}$$

then

$$V=\frac{2R}{3R_1}V_{in} \tag{2}$$

The output voltage is

$$V_o=iR_5+V+V_{in} \tag{3}$$

where current i equals V/2R. Hence,

$$V_o=\frac{2R+R_5+3R_1}{3R_1}V_{in} \tag{4}$$

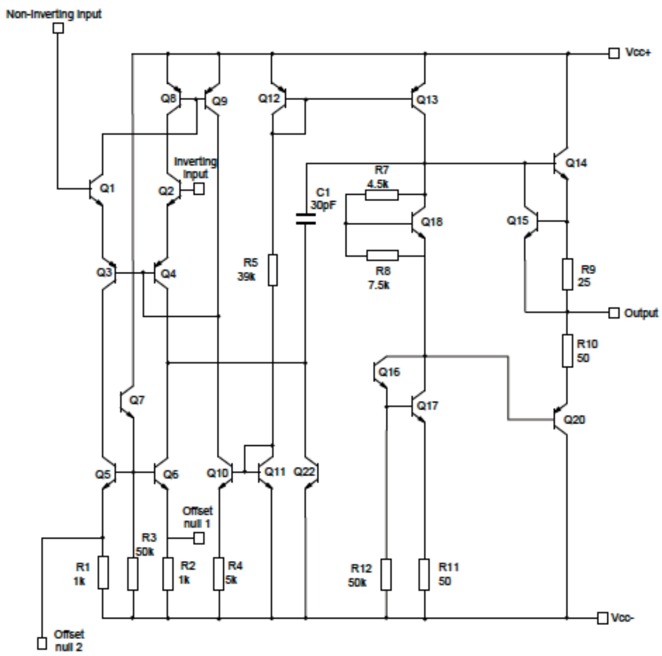


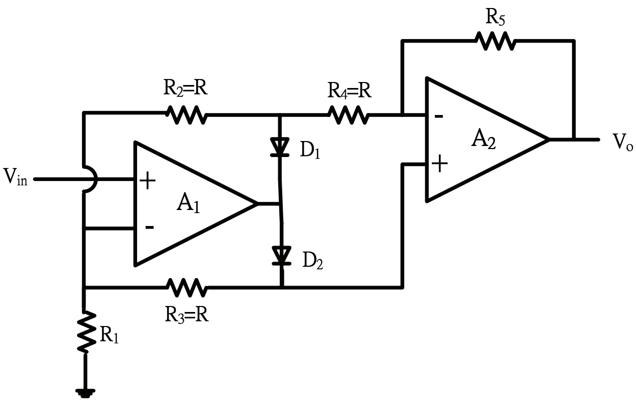
Fig. 6 Detailed schematic of μA741

For $V_{in} > 0$, the gain of this half cycle is

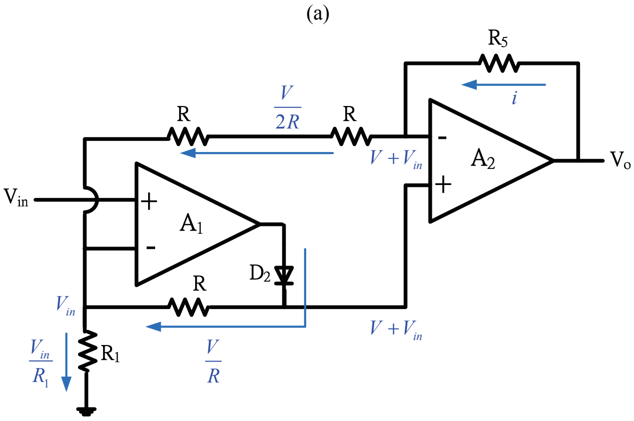
$$A_{V_+} = \frac{V_o}{V_{in}} = \frac{2R + R_5 + 3R_1}{3R_1} \tag{5}$$

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_t to ground, Kirchhoff's voltage law (KVL) gives the equation as

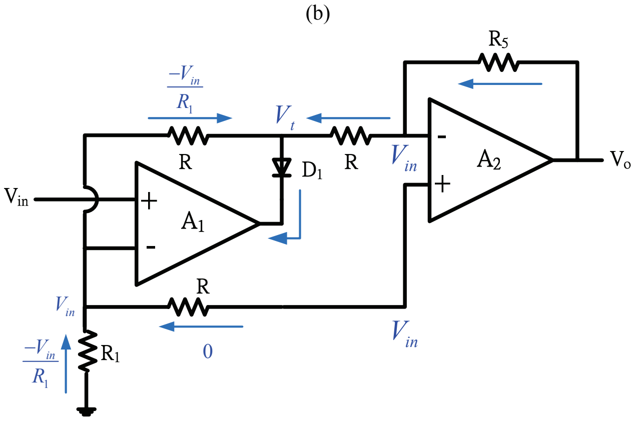
$$V_t + (R + R_1)(\frac{-V_{in}}{R_1}) = 0 \tag{6}$$



(a)



(b)



(c)

Fig. 7 (a) The proposed full-wave precision rectifier circuit, (b) Equivalent circuit for $V_{in} > 0$, (c) Equivalent circuit for $V_{in} < 0$

where

$$V_t = \frac{V_{in}}{R_1}(R + R_1) \tag{7}$$

The output voltage is

$$V_o = \frac{R_5}{R}(V_{in} - V_t) + V_{in} = V_{in}(1 - \frac{R_5}{R_1}) \tag{8}$$

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

$$A_{V_-} = \frac{V_o}{V_{in}} = \frac{R_1 - R_5}{R_1} \tag{9}$$

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].

$$\left|A_{V_+}\right| = \left|A_{V_-}\right| \tag{10}$$

i.e.

$$\frac{2R + R_5 + 3R_1}{3R_1} = \frac{R_5 - R_1}{R_1} \tag{11}$$

thus

$$3R_1 + R - R_5 = 0 \tag{12}$$

From Eq. (12), we found that the gain of this circuit must satisfy the conditions: $A_V \geq 3$, 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 μA741 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.

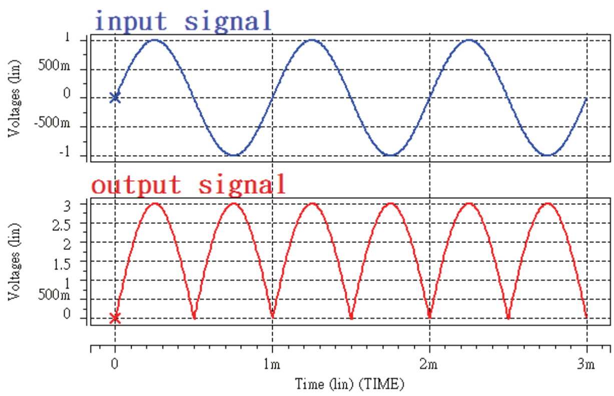


Fig. 8 Simulation results of proposed circuit

Table 1 Simulation results of power dissipation

Precision full-wave rectifier circuit	Power dissipation (watts)
Fig. 2	99.7037558 m
Fig. 3	99.7037555 m
Fig. 4	99.7037551 m
Fig. 7	99.7037551 m

Fig. 9 and Fig. 10 are the experiment implement and the waveforms of the experiment results from bread board implementation using the oscilloscope Tektronix TDS 1002B, respectively. The elements we used are μA741 OPAs, IN4007 diodes, and the resistances R_1=R_2=R_3=R_4 =1 kΩ, R_5=4 kΩ.

As shown in Fig. 11 at a 10 kHz input frequency, the full-wave rectification can be observed, but as the input frequency increases to 30 kHz and beyond, the output waveforms are distorted. At an input frequency of 500 kHz, full-wave rectification is almost absent.

Table 1 are the power dissipations compared with the circuits of Fig. 2, Fig. 3, Fig. 4 and Fig. 7 using HSPICE simulations. The results show that the power dissipations of these circuits are almost the same.

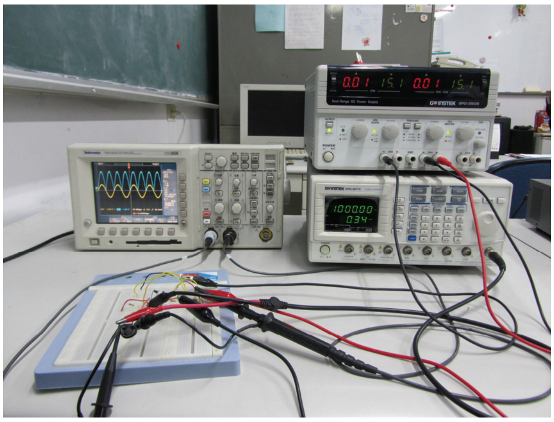


Fig. 9 Experiment implement of Fig. 7

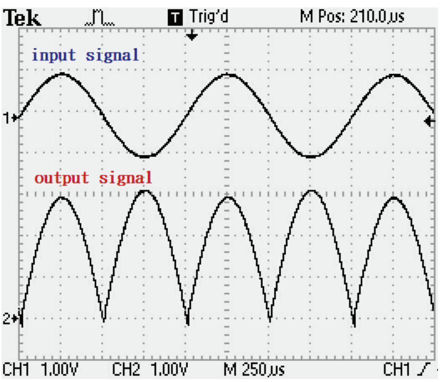


Fig. 10 Waveforms of the experiment results

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.

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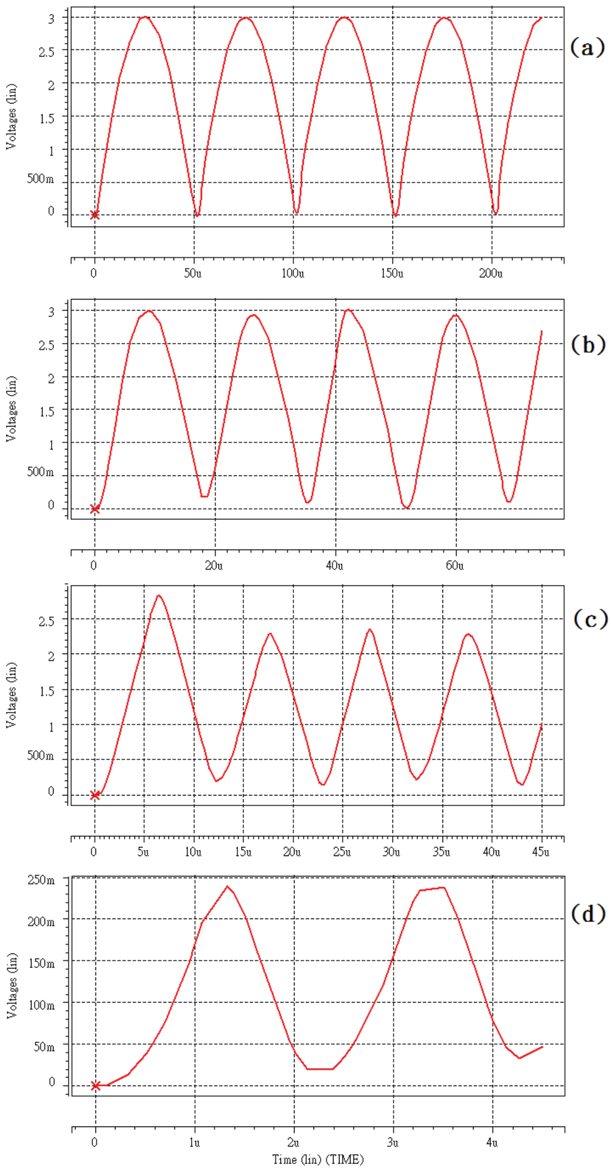

Fig. 11 Output waveforms for the circuit of Fig. 7 to input frequencies (a) 10, (b) 30, (c) 50, (d) 500 kHz

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