A primer on precision rectifier circuits

Designing absolute value amplifiers

by Dr. I. H. IBRAHIM

Absolute value amplifiers are commonly used in precision rectifier circuits. This article explains how they work.

Absolute value amplifiers have many useful applications especially in measurement and control systems but very little attention has been given to the design and analysis of these circuits. Although most basic circuit blocks such as inverting and non-inverting amplifiers, precision half wave rectifiers, comparators and active filters have well known circuits, there is no established or well known circuit for absolute value amplifiers. This article introduces a simple, accurate and low cost circuit using a single operational amplifier.

Basic circuit

Fig. 1 shows a general amplifier configuration with resistors R2 and R5 and diodes D1 and D2 making up the feedback path. To simplify the circuit analysis, we shall assume that the operational amplifier is ideal and so are the two diodes.

The effects of the finite gain of the amplifier and the non-linearity of the diodes will be given later in this article.

Now the voltage at the non-inverting (+) input of the operational amplifier is equal to:

$$V+ = Vin \frac{R3}{R4 + R3} \qquad (1)$$

by normal voltage divider action. If Vin is positive, then diode D1 at the op amp output will be reverse biased and no current will flow through R1 (because the op amp acts to set the voltages at its inputs so they are equal).

The output voltage V_{01} is then equal to V+, as in equation one.

On the other hand if Vin is a negative voltage $-V_2$ then the output V_{01} becomes:

$$Vo1 = -V2 \frac{R1R3 - R2R4}{R1(R4 + R3)} \qquad (2)$$

This means that the voltage amplification of the circuit V_{01}/Vin will be:

(a) for positive signals

$$A+ = \frac{R3}{R3 + R4} \qquad (3)$$

(b) for negative signals

$$A- = \frac{R1R3 - R2R4}{R1(R4 + R3)} \qquad (4)$$

For an absolute value amplifier we need A+ = −A− or

$$\frac{R3}{R4 + R3} = \frac{R2R4 - R1R3}{R1(R4 + R3)}$$

which yields:

$$2R1R3 = R2R4 \qquad (5)$$

A similar argument applies for the output V_{02} which yields

$$2R1R3 = R5R4 \qquad (6)$$

From equations 5 and 6 we can see that for balanced outputs V_{01} and V_{02} the resistors R_2 and R_5 should be equal. On the other hand if the negative output V_{02} is not required then R_5 may be replaced by a short circuit.

Output impedance

The output impedance of the circuit is not constant but it depends on the polarity of the input signal. For example, consider the positive output V_{01}. When the input signal is positive, D_1 will be off and the output current is supplied via R_2, resulting in an output impedance equal to R_2. But when the input signal is negative, D_1 will be conducting and the output voltage will be dependent upon the output current "within the amplifier output current limitation". That is, equivalent to zero output impedance. This means, in practice, that if the circuit satisfies conditions 5 and 6 then it will perform absolute value amplification only if the output is connected to a very high load impedance.

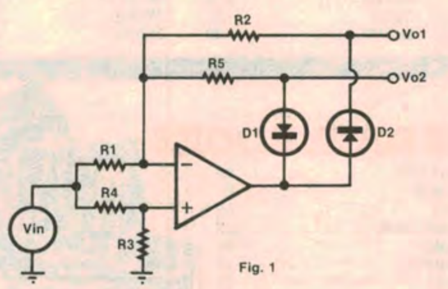


Fig. 1

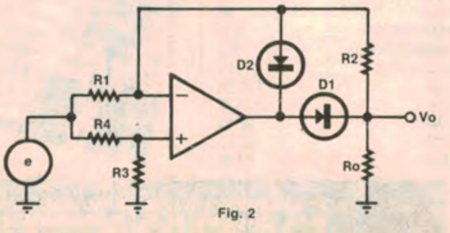


Fig. 2

In spite of the fact that the output impedance is not fixed, it is always possible to design an absolute value amplifier according to a given load impedance. For example, consider the circuit of Fig. 2.

Here the output is connected to a "matched" load resistance R_0. The circuit will have amplification factors of:

$$A+ = \frac{R3}{R4 + R3} \cdot \frac{Ro}{R2 + Ro} \qquad (7)$$

if the input is positive and

$$A- = \frac{R1R3 - R2R4}{R1(R4 + R3)} \qquad (8)$$

if the input is negative.

Equating A+ and −A yields the general condition:

$$R1R3\left(\frac{2Ro + R2}{Ro + R2}\right) = R2R4 \qquad (9)$$

The source impedance has no effect on the balance condition given by equation 9. But the voltage amplification of the current will drop by a factor

$$B = 1 + \frac{Rs(R1 + R4)}{R1(R3 + R4)} \qquad (10)$$

where Rs is the source resistance. Even when the circuit is supplied from an ideal signal current source with infinite internal resistance the balance condition will not be affected.

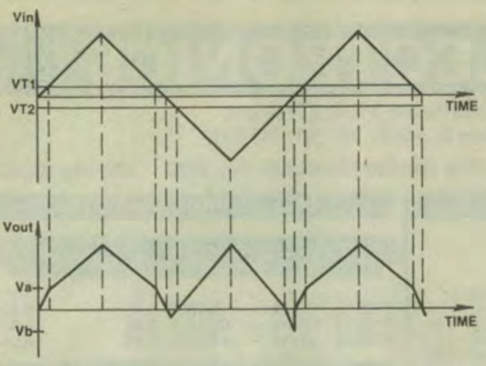


Fig. 3

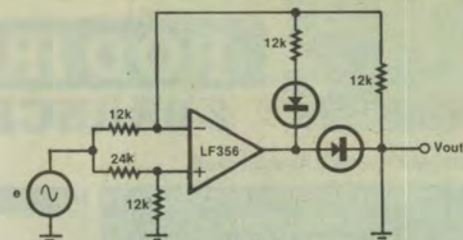


Fig. 4

The circuit above is a realisation of Fig. 2 while the waveforms at left demonstrate the response of the circuit when the input signal amplitude is small.

In this case, the output voltage will be given by:

$$V_o = |I_{in}| \frac{R1R3}{R1 + R4} \qquad (11)$$

Dynamic performance

The dynamic performance of the circuit of Fig. 2 is better explained by assuming a triangular waveform is applied to the input. We also assume that the diodes have voltage of V_T and that the amplifier has a DC voltage amplification of V_0 and a 3dB point of f_0 Hz. Therefore the open loop voltage amplification of the operational amplifier varies with frequency according to:

$$A = A_o\left(\frac{1}{1 + \frac{f}{f_o}}\right) \qquad (12)$$

and at frequencies much higher than f_0 we get:

$$|A| = A_o \frac{f_o}{f} \qquad (13)$$

Fig. 3 shows the input and output waveforms. Due to the finite gain of the amplifier there will exist a certain minimum input signal level V_{T1} and V_{T2} at which the output of the op-amp is less than the conduction voltage of the diodes. In that case the output voltage of the absolute value amplifier does not follow the value given by the above equations but will show some sharp spikey waveform in the output voltage range V_a to V_b. That voltage range can be easily shown to be dependent upon the inverse of the amplifier gain as well as input and output offset voltages of the operational amplifier.

The most important thing to notice is that as the frequency of the input signal increases, the open loop gain of the op-amp decreases and thus V_{T1} and V_{T2} increases yielding an increase in the undefined voltage range V_a-V_b.

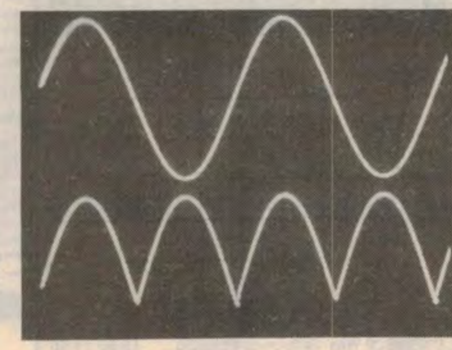
A practical example

The circuit of Fig. 4 was used as an experimental circuit and the input supplied with a sinusoidal signal. The circuit has a voltage amplification of 0.33.

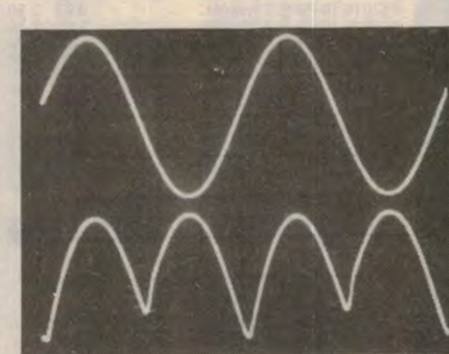
Fig. 5 and Fig. 6 show the oscilloscope traces with an input signal frequency of 200Hz and 20kHz respectively. The upper trace in each photo shows the input signal while the lower trace shows the output. In both cases, negative spikes are present in the output signal but they have a higher magnitude at the higher frequency.

As such, the circuit of Fig. 4 is suitable for many absolute value amplifier applications such as full-wave rectification, AC/DC measurement circuits, control systems, frequency doublers, and AM detectors.

The distortion of the output waveform at high frequencies is typical of all rectifier circuits that employ operational amplifiers. However that distortion does not limit the usability of the circuit for most applications.



This photo shows the response of the practical circuit to a 200Hz sinewave signal: Upper trace, input, 2V/div; Lower trace, output, 0.5V/div.



This photo shows the response of the practical circuit to a 20kHz sinewave signal. Vertical scales are the same as for photo at left.