Rectifying wide-range signals with precision, variable gain

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Millivolt-level signals cannot be rectified directly because they are smaller than the typical 0.7-volt drop across a forward-biased diode. An operational amplifier can reduce this loss to around 10 microvolts. But such circuits have a fixed gain when designed straightforwardly, whereas variable gain is needed for range control in many applications—amplitude detection in ac voltmeters, for example.

Varying the gain has usually required either the adjustment of more than one resistor or, in very complex circuits, the use of a separate input amplifier. With the precision rectifier shown in the diagram, however, variable gain is achieved without a gain-control amplifier.

Gain is controlled by a single variable resistor, which can be a potentiometer or a multiple-tap resistor. In addition, this circuit has a high input impedance without an input buffer and requires only one resistance match. It has a gain range from unity to several thousand, for signals from 1 millivolt to 10 V.

Rectification results when the feedback diodes are switched by a reversal of the signal polarity, which in turn reverses the circuit gain polarity. With the diodes in one orientation, the signal path to the output is a noninverting amplifier; when they switch, it becomes a voltage follower and an inverting amplifier.

An input of positive signals produces a positive current i_1 that turns diodes D_2 and D_3 on and D_1 and D_4 off. This connects the noninverting amplifier A_1 to the output with a gain of $1/x$, where x is a fraction representing the potentiometer setting. In this mode A_2 is merely a ground return for the resistance xR_1; its output is disconnected from the circuit output by the reverse-biased diode D_4. Thus the circuit output, controlled by A_1 alone, is $e_o = e_i/x$.

When the input signal swings negative, so does the current i_1. It switches off D_2 and D_3 and turns on D_1 and D_4. Now the output of A_2 is connected to the circuit output, and A_1 merely maintains a signal equal to e_i at its own inverting input. In doing so it also develops this signal across the resistance xR_1. That resistance acts as the input resistor to A_2, connected as an inverting amplifier. With a gain of $-1/x$, this inverting amplifier develops $e_o = -e_i/x$, the negative of that produced by positive signals. Since the polarity of the gain switches with that of the input signals, the output signal is always positive, and $e_o = |e_i/x|$.

Gain can be varied from unity to several thousand to accommodate a wide range of signal levels. To insure continually equal gain for positive and negative signals, it is only necessary to match the resistor R_2 to the total potentiometer resistance R_1. Op amp gain error directly affects circuit gain, but identically for both positive and negative signals.

Otherwise, circuit accuracy depends upon the noises, dc errors, and ac responses of the op amps. Noise isn't generally a major source of error in the practical signal range of 1 mV to 10 V, as long as the resistance levels are low enough to limit the effects of noise currents at the amplifier inputs.

Ideally, the diodes would switch just as the input signal crosses zero, but the op amps' dc offset voltages—the input levels below which the amplifiers produce no outputs, as a result of mismatched transistors in the amplifiers—cause the circuit to depart from this ideal. The error currents are:

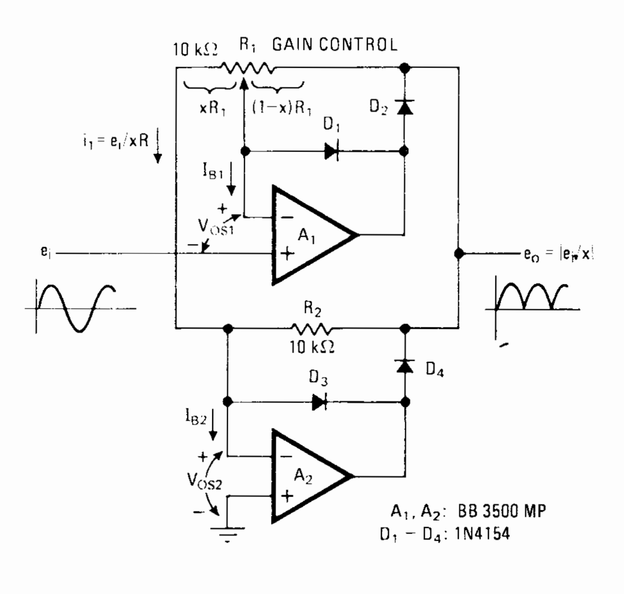
$$(V_{os1} - V_{os2})/xR_1 + I_{B1}$$

and

$$(V_{os1} - V_{os2})/xR_2 - I_{B2}$$

This switching-point offset limits the circuit's operation with very small signals. To extend it, the amplifiers are chosen for low bias currents, and the op-amp offset voltages are nulled. Matched op amps insure low initial dc errors and thermal drifts.

Another output offset is produced by input currents flowing through the feedback resistances. This offset cannot be removed by the op-amp null controls without again offsetting the diode switching, but it is minimized



Precision rectifier. Variable gain is achieved without a separate gain-control amplifier, since the control potentiometer varies the gains of both amplifiers identically. Circuit gain ranges from unity to several thousand. Forward or reverse biasing of diodes make the circuit either an inverting or noninverting amplifier.

by the choice of suitable op amps and resistances.

High-frequency performance is limited by the speed with which the op-amp outputs can turn off one rectifying diode and turn on the other. While the first diode is being turned off, the signal with the wrong polarity passes, and while the second diode is turning on, no signal passes. Ideally, this transition should be instantaneous, but in practice it always takes a finite time, limited by the operational amplifiers' slewing rates and their bandwidths, which are expressed by the speed with which the amplifiers can swing their outputs through two diode voltage drops, $2V_f$.

If the input signal is small, the rate of change of the amplifier output voltages equals the rate of change of the input signal multiplied by the open-loop gain of the amplifier at the signal frequency, $A(f_i)$, and therefore the transition time is the time required for the input signal to change by $2V_f/A(f_i)$. For larger signals the rate of change of the amplifier output voltage can be no more than its slewing rate limit S_r, so that the transition time is $2V_f/S_r$. These considerations limit the usable bandwidth of the precision rectifier to about 1 kilohertz. □