Ideal rectifier uses equal-value resistors

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Operational amplifiers can be combined with diodes and resistors to perform nearly ideal rectification, satisfying $e_o = |e_i|$. The diodes are situated within the feedback loop, so that the diode forward voltage drop is reduced at the output by the feedback factor. Figure 1a shows a commonly used full-wave rectifying circuit which gives a positive output, e_o, for bipolar input at e_i. This circuit has the following disadvantages:

- Output e_o due to plus input at e_i is obtained by bucking out the plus current from R5 with the negative (rectified) current through R3. The tolerance of this difference voltage can be three times resistor tolerance, since it is obtained by subtraction.
- Non-zero input impedance. If a summing junction is required at the input node, another operational amplifier is required.
- Increased drive requirements. The input at e_i drives two amplifiers in parallel.
- Unequal resistor values. R3 is half of R5.

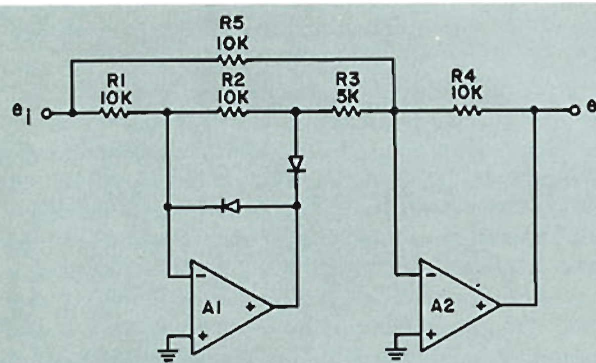

FIGURE 1a.

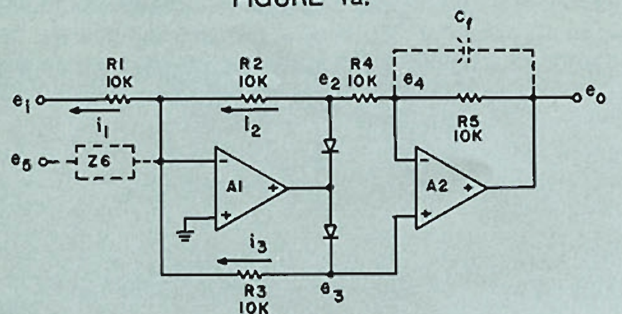

FIGURE 1b.

An improved 'ideal' full-wave rectifier (b) is achieved by modifying a standard circuit (a).

Figure 1b shows an "ideal" rectifier configuration which has the following advantages:

- All resistors are of the same (arbitrary) value.
- Output voltage tolerance is an additive function of resistor tolerance. Equal-value resistors are easy to select for high accuracy.
- Zero input impedance. The single summing junction at n allows extra isolated inputs to be connected, as shown dotted for e_5 and Z6.

It may be necessary to connect a small capacitor, C_f, in parallel with R5 in order to prevent high-frequency oscillations. Rectified voltages e_2 and e_3 are unequal in this circuit.

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It turns out that the equal-resistor version is a special case and that, in general, the resistors can be unequal as long as they satisfy Eq. 3 below, which is derived in the following manner. The voltage gain for plus input is:

$$G(+) = e_o/e_i = (R2/R1)(R5/R4). \qquad (1)$$

This is the gain of two tandem-connected inverting operational amplifiers.

For minus input there are two feedback paths to the summing junction of A1, one from each amplifier out (Figure 1b). Mathematically this is expressed as:

$$i_1 = i_2 + i_3$$

or

$$e_i/R1 = e_o/(R2+R4+R5) + e_3/R3;$$

since:

$$e_3 = e_4 = e_o(R2+R4)/(R2+R4+R5),$$

then:

$$\begin{aligned} 1/G(-) &= e_i/e_o \\ &= R1[1/(R2+R4+R5) \\ &\quad + (R2+R..)/R3 \\ &\quad \times (R2+R4+R5)]. \qquad (2) \end{aligned}$$

This is equated with $1/G(+) = [(R1/R2)(R4/R5)]$ to ensure equal output for plus and minus inputs. The resulting identity is solved for R2/R3:

$$R2/R3 = (R4/R5) + [(1 - R2/R4)/(1 + R2/R4)]. \qquad (3)$$

Inspection of Eq. 3 shows that if R2 = R4 the second term drops out and R3 = R5. Furthermore, for unity gain, R2 = R3 and R2 = R3 = R4 = R5; the result is the circuit shown in Figure 1b. If current gain is required from A1, R2/R4 >1 and Eq. 3 is used to calculate R3 after R2, R4, and R5 have been selected. If the calculated value of R3 is negative, R5 is reduced and R3 is recalculated.

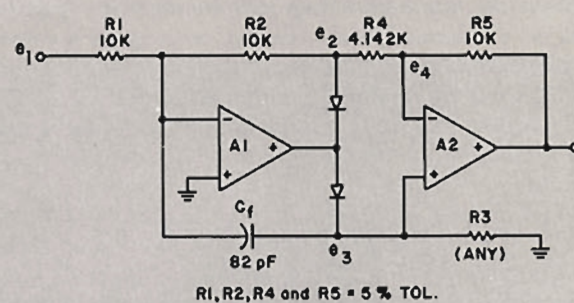

FIGURE 2. Degenerate form of ideal rectifier uses only four precision resistors.

A new circuit results if R3 is allowed to go to infinity and the noninverting input of A2 is returned to ground through a resistor of arbitrary value (Figure 2). This is an ideal rectifier circuit that requires only *three* precision resistors (four, if R1 is counted in). If a further constraint that three of these resistors must be equal is imposed, the resistor ratios are:

$$R1 = R2 = R5 = R;$$
$$R4 = (2^{1/2} - 1)R;$$
$$|G| = 2^{1/2} + 1.$$

(continued on next page)

In general:

$$R2 > R4;$$
$$R4/R5 = (R2/R4 - 1)/(R2/R4 + 1);$$
$$|G| = (R2/R1)(R5/R4)$$
$$= (R2 + R4 + R5)/R1.$$

The gain is fixed at $1 + 2\frac{1}{2}$ for both plus and minus inputs. One difficulty with the circuit of Figure 2 is that the forward path for negative inputs consists of the full open-loop gain of A1 and A2 in tandem. A value for C_f of 82pF was sufficient to stabilize an operating breadboard made with low-cost commercial units.

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