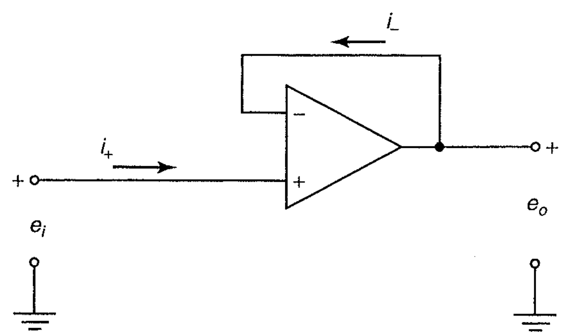
FROM MECHANICAL MEASUREMENTS, 6E
BY THOMAS BECKWITH

EXAMPLE 7.3

The *voltage follower*, or *impedance transformer*, has a feedback loop connecting the full output to the inverting input.



The feedback loop prevents saturation by holding $e_- \approx e_+$. Since $e_i = e_+$ and $e_o = e_- \approx e_+$, the output voltage is equal to (follows) the input voltage: $e_o = e_i$. The circuit gain is $G = 1$.

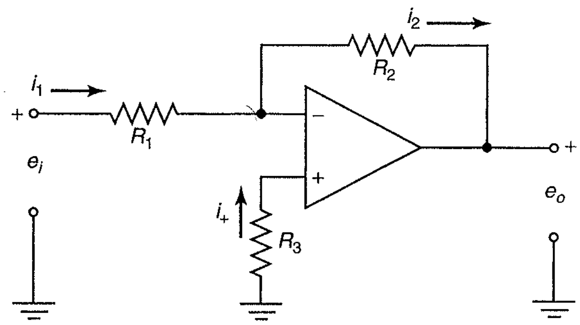
This circuit capitalizes on the high input impedance of the op amp: Since the input impedance is so large, the input current i_+ is in nanoamps (nA) or even picoamps (pA). Source loading is minimized and can often be entirely neglected ($i_+ \approx 0$). In contrast, the output terminal can deliver up to the maximum current of the op amp. This circuit acts as an impedance transformer in that the input impedance is in gigaohms, whereas the output impedance is a fraction of an ohm.

This example demonstrates two important rules of thumb that can be applied any op-amp circuit having negative feedback:

1. The input currents, i_+ and i_-, are essentially zero: $i_+, i_- \approx 0$.
2. The input voltages, e_+ and e_-, are held equal by the negative feedback: $e_+ \approx e_-$.

EXAMPLE 7.4

The *inverting amplifier* is one of the most used op-amp circuits. Feedback is provided through resistor R_2.



Since $i_+ \approx 0$, Ohm's law shows $e_+ = 0$. Because negative feedback is present, $e_- = e_+ = 0$. The inverting input also draws no current, so that $i_1 = i_2$. Thus we can apply Ohm's law to resistors R_1 and R_2 to find the relation between e_i and e_o:

$$i_1 = \frac{e_i - 0}{R_1} = \frac{e_i}{R_1}$$

$$i_2 = \frac{0 - e_o}{R_2} = -\frac{e_o}{R_2}$$

or

$$e_o = -\frac{R_2}{R_1} e_i$$

The output is opposite in sign from the input (inverted, or 180° out of phase), and the gain of the circuit is $G = -R_2/R_1$.

The resistor R_3 is commonly made approximately equal to the parallel value of R_1 and R_2, i.e., $R_3 \approx R_1 R_2/(R_1 + R_2)$. This choice provides nearly equal input impedances at the (−) and (+) terminals.

EXAMPLE 7.5

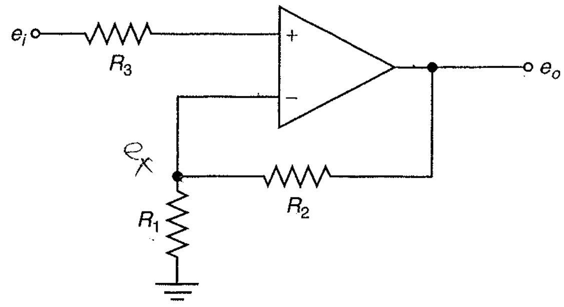
The *noninverting amplifier* is as shown at the top of the next page.

The input voltage is applied to the (+) terminal ($e_i = e_+$); because negative feedback is present, $e_- = e_+ = e_i$. The output voltage is related to the voltage at the inverting terminal by the voltage-divider relation:

$$e_- = \left(\frac{R_1}{R_1 + R_2}\right) e_o$$

Rearranging,

$$e_o = \left(\frac{R_1 + R_2}{R_1}\right) e_i$$

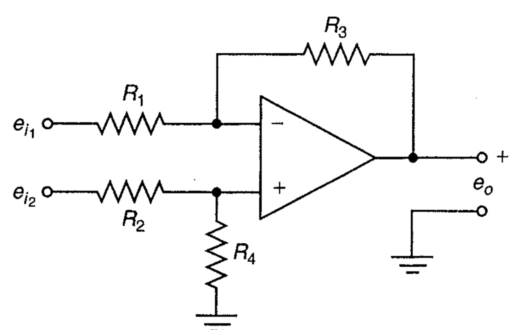


Thus, the output and the input are in phase and the circuit gain is $G = (R_1 + R_2)/R_1$. Resistor R_3 serves the same purpose as in the inverting amplifier.

EXAMPLE 7.6

In the *differential*, or *difference, amplifier*:

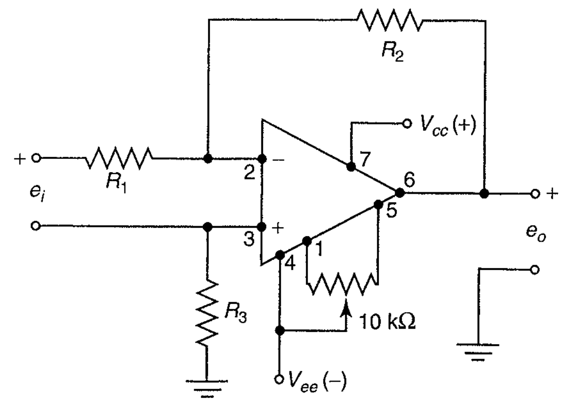
1. If $R_1 = R_2$ and $R_3 = R_4$, then $e_o = -(R_3/R_1)(e_{i_1} - e_{i_2})$ (see Problem 7.23).
2. The need for offset null adjustment (see Example 7.7) is minimized by making input resistances at (−) and (+) equal.
3. Precise resistor matching is necessary to achieve high CMRR.



EXAMPLE 7.7

An amplifier with offset null adjustment is exemplified by the accompanying diagram.

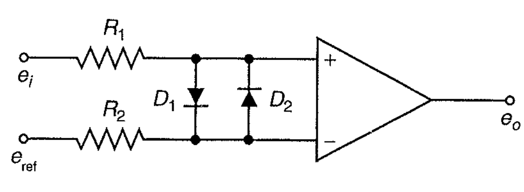
1. The circuit allows trimming to zero output with zero input.
2. Specific example shown illustrates pin numbering.



EXAMPLE 7.8

The *voltage comparator* has the following features:

1. A small voltage difference between e_i and e_{ref} swings output to limit permitted by power supplies; e_{ref} is set to desired reference voltage. No feedback is used.
2. When $e_i > e_{ref}$, output is positively saturated; when $e_i < e_{ref}$, output is negatively saturated. This provides output indication for the size of e_i relative to e_{ref}. For example, should e_i be gradually rising, when its value reaches e_{ref} the output polarity would reverse. This could be used to trigger external action. (See Section 8.11.2 for application to analog-to-digital conversion.)
3. Diodes serve to limit differential input.

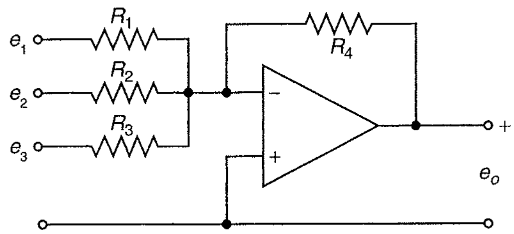


EXAMPLE 7.9

The *summing amplifier* shown at the top of the next page has the following characteristics:

1. $e_o = -[e_1(R_4/R_1) + e_2(R_4/R_2) + e_3(R_4/R_3)]$ (see Problem 7.24).
2. If $R_1 = R_2 = R_3 = R$, then $e_o = -(R_4/R)(e_1 + e_2 + e_3)$.

3. This circuit has application to digital-to-analog converters (Section 8.11.1). Also note the similarity to the inverting amplifier (Example 7.4).



7.15 SPECIAL AMPLIFIER CIRCUITS

7.15.1 Instrumentation Amplifiers

In practice, transducer signals are often small voltage differences that must be accurately amplified in the presence of large common-mode signals. Simultaneously, the current drawn from the transducer must remain small to avoid loading the transducer and degrading its signal. Standard op-amp circuits, such as the differential amplifier (Example 7.6), may not provide adequate input impedance or CMRR when high-accuracy measurements are needed.

The *instrumentation amplifier* uses three op amps to remedy these problems (Fig. 7.22). The instrumentation amp is essentially a differential amplifier with a voltage follower placed at each input (this is easily seen if R_1 is temporarily removed). The voltage followers increase the (+) and (−) input impedances to the op-amp impedances. The addition of R_1 between the two followers has the effect of raising CMRR. Resistor matching is less critical for this circuit than for a differential op-amp circuit alone.

Instrumentation amplifiers may be built from discrete components, or they may be purchased as single integrated circuits. The typical instrumentation amp may have CMRR reaching 130 dB, input impedance of $10^9\ \Omega$ or more, and circuit gain of up to 1000.

7.15.2 The Charge Amplifier (WE LIKELY WON'T USE THESE,

The *charge amplifier* is used with piezoelectric transducers (Sections 6.14, 13.6, 14.7.3, and 18.5.1). These transducers are composed of a high-impedance material that generates electric charge $Q(t)$ in response to a varying load. The charge amp produces an output proportional to the charge while avoiding the potential noise difficulties of a high-impedance source. The complete circuit is shown in Fig. 7.23.

The transducer, cable, and feedback capacitances are C_t, C_c, and C_f, respectively (see Sections 5.17–5.19 for a brief review of charge and capacitance). If the large feedback resistor R_f is ignored, the output of the circuit can be expressed as

$$e_o = \frac{-Q(t)}{C_f + (C_t + C_c + C_f)/G}$$

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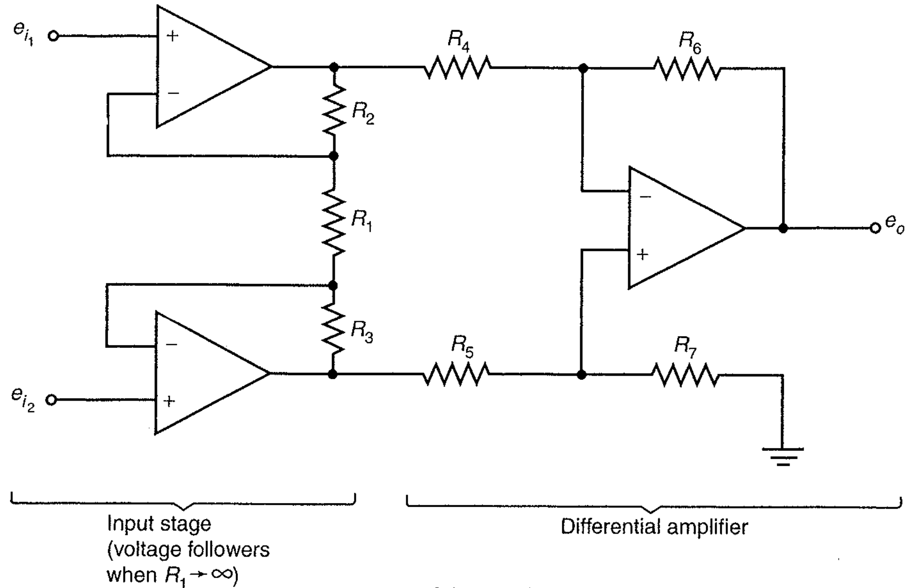

$$e_o = G(e_{i_1} - e_{i_2})$$

$$G = \left(1 + \frac{2R_2}{R_1}\right)\left(\frac{R_6}{R_4}\right)$$

$$R_2 = R_3$$
$$R_4 = R_5$$
$$R_6 = R_7$$

FIGURE 7.22: An instrumentation amplifier circuit.

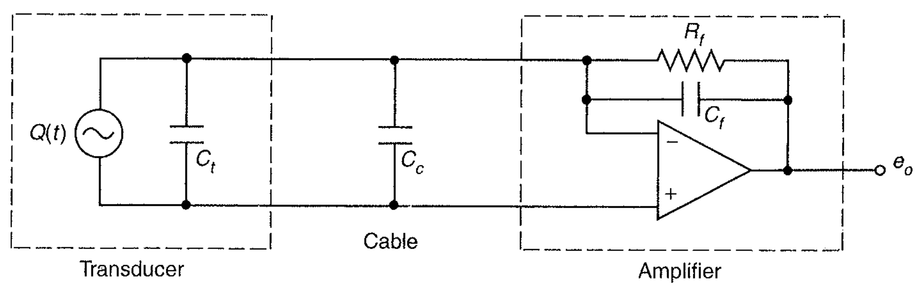

FIGURE 7.23: A charge amplifier circuit.