amplifier's input impedance is critical; it must be high enough to enable the weak input signal to develop a sufficient voltage. Otherwise, the amplifier's input will overload the transducer, severely attenuating whatever signal may be present.

Noninverting op-amp circuits present the highest input impedance to a signal, because the feedback resistor network is connected to the negative input, leaving the input signal connected only to the positive terminal. The LM741's typical input resistance is 2 MΩ with an I_{BIAS} of 500 nA. These are acceptable input parameters for many applications. However, it might otherwise make more sense to use an inverting configuration for a high-gain amplifier in which nonideal characteristics such as I_{BIAS} can be compensated for as discussed previously. Figure 14.18 shows an example that uses two op-amp stages to achieve high input impedance with a unity-gain noninverting circuit followed by a high-gain inverting circuit that is compensated for I_{BIAS}.

Newer CMOS op-amps have much higher input impedance specifications than older bipolar devices, enabling them to buffer extremely weak transducers. As one example, the Texas Instruments/Burr-Brown OPA336 is specified with a maximum I_{BIAS} of 60 pA and an input resistance of 10^{13} Ω.* A photodiode is a weak transducer that is used in many optical communications applications ranging from IR or UV remote control devices to laser communications systems and fiber optic transceivers. Such applications are usually digital and therefore require a saturated on/off output rather than linear amplification. Because of their weak output (nanoamps to microamps), these transducers are best used as current sources to develop a usable voltage across a high resistance rather than attempting to directly measure a voltage across their terminals. Figure 14.19 shows several circuits that use high R_{IN} and low I_{BIAS} op-amps to amplify transducer currents in the nanoamp range. Essentially all of the transducer current, i_{TRANS}, is passed through the resistors because of the op-amps' low I_{BIAS}. For every microamp passed through a 1-MΩ resistor, 1 V is developed across that resistor.

Circuit (a) utilizes the noninverting configuration to amplify an input voltage of several hundred millivolts (corresponding to i_{TRANS} of several hundred nanoamps) by approximately 1,000. Circuit (b) is simpler, because i_{TRANS} is used to directly establish the output voltage of the op-amp. Circuit (c) is an improvement that increases the gain by raising the voltage at each op-amp input in addition to causing a voltage drop across the feedback resistor. If 200 nA is conducted by the transducer, v_+, and hence v_-, rise to 0.2 V. At the same time, 0.2 V is developed across the feedback resistor, resulting in a total output voltage of 0.4 V. Even thought these last two circuits use the negative op-amp input, they are not inverting circuits, because analysis shows current being drawn from the output node by the transducer through the feedback resistor, causing a positive voltage drop with respect to ground.

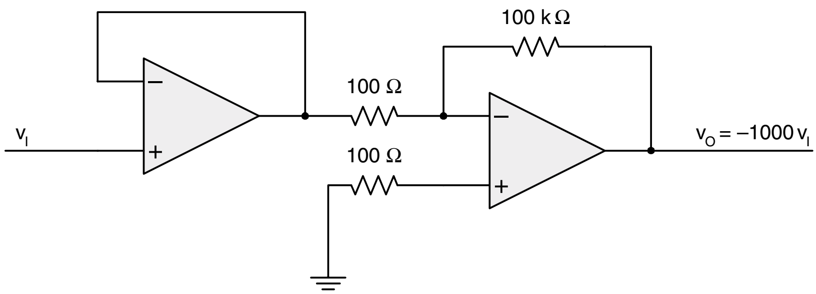

FIGURE 14.18 Two-stage low-input-impedance/high-gain amplifier.

* OPA336, Texas Instruments Incorporated, 2000, p.2.

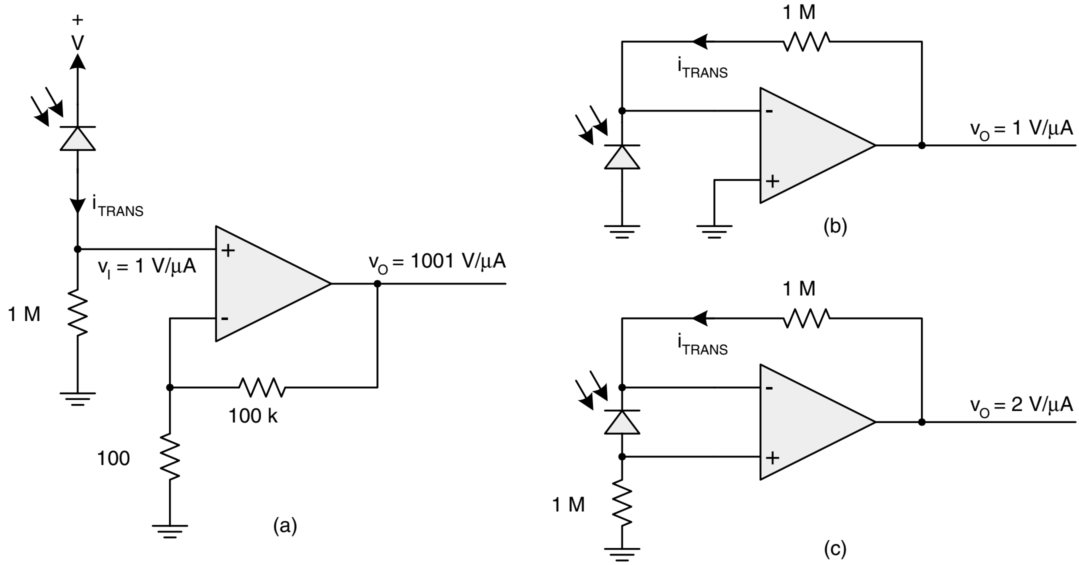

FIGURE 14.19 Amplification of very weak transducer signals.

A signal applied to a noninverting circuit directly drives the op-amp's positive input and, in doing so, establishes a voltage at both the positive and negative inputs due to the virtual short. Likewise, an inverting circuit's op-amp input voltages are established by the bias applied to the positive terminal. Referring back to the standard inverting circuit in Fig. 14.5, a voltage drop is developed across the input resistor, R1, that sets the input current: $i_{IN} = (v_{IN} - v_{\_}) \div R1 = v_{IN} \div R1$. Therefore, the input resistance seen by the signal is equal to this series input resistor. This basic circuit places a practical ceiling on the input resistance, because the circuit's gain is inversely proportional to that input resistor. If this ceiling is reached, and still higher input resistance is necessary, the basic inverting circuit can be augmented as shown in Fig. 14.20 with a "tee" topology in the feedback path.

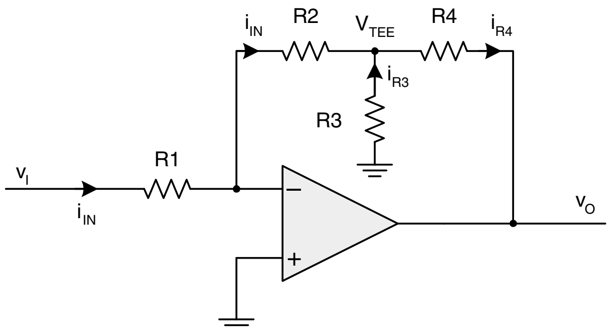

FIGURE 14.20 Inverting circuit with higher input resistance using tee feedback topology.