

DESIGNING WITH LINEAR IC'S

A look at two lesser known but still powerful devices—the logarithmic and isolation amplifiers.

JOSEPH J. CARR

Part 6 THIS MONTH, WE WILL look at two lesser-known linear devices: logarithmic and isolation amplifiers. Let's start with the logarithmic amplifier.

A logarithmic amplifier produces an output voltage that is proportional to the log of the input voltage. We can build a logarithmic amplifier by combining an ordinary op-amp and an NPN silicon transistor, as shown in Fig. 1. Transistor Q1 is connected in the negative feedback loop such that the op-amp output voltage, V_O , is also the transistor's base-emitter voltage, V_{BE} , and the transistor's collector current, I_C , is also the feedback current applied to the summing junction. From the above discussion and basic transistor theory we know the following:

$$V_{BE} = \frac{KT}{Q} \ln \left(\frac{I_C}{I_S} \right) \quad (1)$$

$$V_O = V_{BE} \quad (2)$$

From basic op-amp theory we also know:

$$I_C = -I_1 \quad (3)$$

and

$$I_1 = V_I/R_1 \quad (4)$$

so we are justified in writing Equation 1 as:

$$V_O = \frac{KT}{Q} \ln \left(\frac{V_I/R_1}{I_S} \right) \quad (5)$$

where: K is Boltzmann's constant, Q is

the electronic charge, T is the temperature in degrees Kelvin, V_I is the input voltage, R_1 is the input resistor, and I_S is the transistor's reverse-saturation current. The terms K, Q, R_1 , and I_S are constants, and T can be made constant. In essence, therefore, Equation 5 tells us that output voltage V_O is a function of input voltage V_I and some constants. We are justified, therefore, in calling the circuit shown in Fig. 1 a logarithmic amplifier.

There is still a problem, however, which makes Fig. 1 a little too simple for practical application: temperature, T. It is not likely that the temperature of Q1 will remain constant, so the output signal will contain a variable term that is independent of the input voltage, V_I ; in other words, there is an error associated with temperature.

Eliminating the temperature error requires the use of thermistors or PN junctions connected so that the effects of temperature are counteracted. For many circuit designers the best solution to that hassle is to buy an IC or hybrid logarithmic-amplifier device.

So what use is the log amp? Rarely will some instrument need to take the logarithm of the input signal, but there are cases where that is desirable, for instance for input-data compression. Many instruments will see analog signals that have an extremely wide dynamic range. Yet we find that amplifier gains that give us adequate low-level resolution will cause saturation on high-level signals. But if the gain is low enough to prevent saturation, then we lose the ability to resolve changes in low-level signals. The solution to that problem is to use a logarithmic amplifier

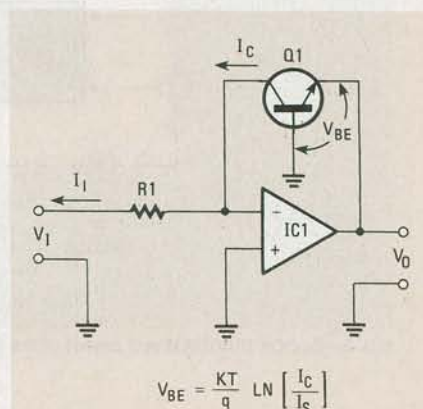


FIG. 1—A LOGARITHMIC AMPLIFIER can be formed by combining an ordinary op-amp with an NPN transistor.

that has a different gain at different input-signal levels.

If we want to decompress the analog data, or take the antilog of an analog signal for any other reason, then we may want to use an antilog amplifier (see Fig. 2). To make that type of amplifier is simple: We merely reverse the positions of R_1 and Q1 in the log amp. The antilog amplifier of Fig. 2 also requires temperature

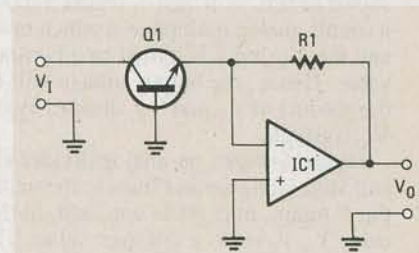


FIG. 2—AN ANTI-LOG AMPLIFIER circuit resembles the log-amp circuit. Only the circuit positions of Q1 and R_1 have been swapped.

compensation.

Figure 3 shows the block diagram for the Burr-Brown 4301 and 4302 hybrid amplifiers. Those two devices are essentially the same except for package style (plastic-vs-metal) and temperature range. The 4301/02 contains logarithmic amplifiers and a summing network. The device accepts three input voltages (V_X , V_Y and V_Z) that produces an output voltage according to the transfer function:

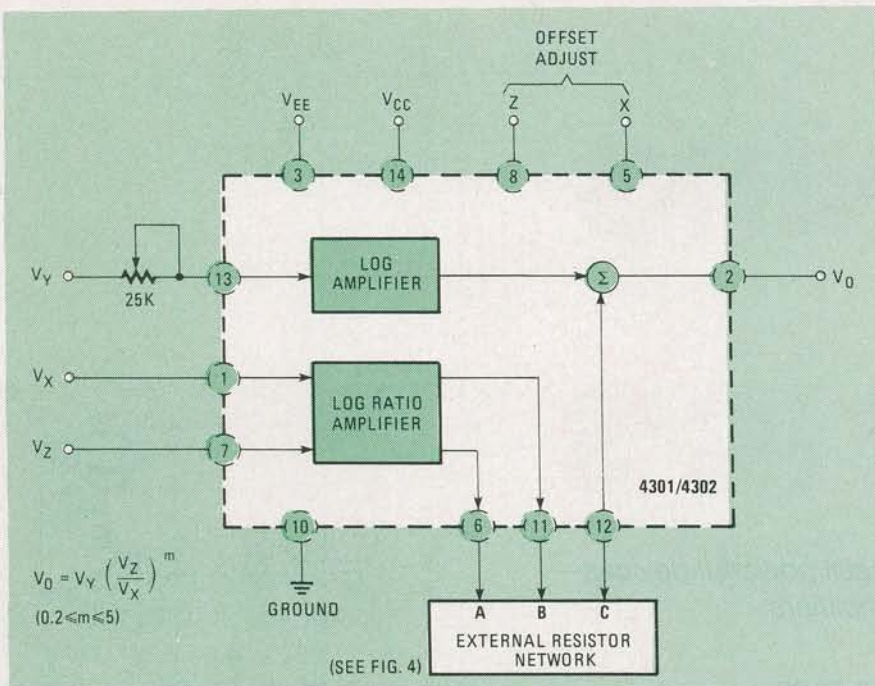


FIG. 3—BLOCK DIAGRAM and pinout of the Burr-Brown 4301/4302 hybrid logarithmic amplifiers.

$$V_O = V_Y \left(\frac{V_Z}{V_X} \right)^m \quad (6)$$

where V_O is the output voltage; V_X , V_Y , and V_Z are input voltages, and m has a value between 0.2 and 5.0. The value of m is set by a simple resistor network. Because of that, the 4301/02 allows us to create transfer functions that would otherwise be difficult to achieve with simple circuitry. Figures 4-a through 4-c show the resistor networks for three cases: $m=1$, $m<1$, and $m>1$, respectively.

Typical applications for the 4301/02 are shown in Figs. 5, 6, and 7. Figure 5 shows a simple analog multiplier in which $m=1$ and the V_X input is biased to a constant value. Hence, the output voltage will be the product of V_Y and V_Z , divided by the V_X constant.

Figure 6 shows an analog-divider circuit built along similar lines to the multiplier. Again, m is set to one, and, in this case, V_Y is set to a constant value. The result is an output voltage $V_O = 10V_Z/V_X$.

Figure 7 shows a circuit that might be called an exponentiator, and has a transfer function of $V_O = 10(V_Z)^m$, where m is set by R_4 , as shown in Fig. 7-b and Fig. 7-c. Of course, each potentiometer can be replaced with a pair of resistors selected according to the equations shown in Figs. 4-b and 4-c.

Isolation amplifiers

There are certain cases where it is desirable to maintain a very high degree of isolation between the inputs and outputs of an amplifier. If there is some factor in one environment that is dangerous to the

other, then the use of an isolation amplifier is justified. Biomedical instruments are a case in point. It is believed that the maximum safe exposure to 60-Hz AC for certain patients is about 10 microamperes. Normal leakage currents can exceed that value by a couple orders of magnitude, so medical equipment designers usually specify an isolated input amplifier stage. For medical applications it is common to find the degree of isolation expressed as 10^{12} ohms between inputs and the power terminals of the nonisolated side of the circuit.

Previously, isolation amplifiers were built from discrete components. Today, however, we can buy hybrid isolation amplifiers from several sources. At least two methods are now being used to achieve isolation: transformer coupling and optical coupling.

Figure 8 shows the transformer-coupling method in block-diagram form. A high-frequency (50 to 500 kHz) signal is generated in a power oscillator on the nonisolated side of the circuit. The use of such high frequencies allows the construction of transformers (T1 and T2) that easily pass the signal but severely attenuate the low-frequency 60-Hz AC leakage.

The oscillator output signal (200 kHz in this example) is coupled to the isolated side of the circuit via transformer T1. The oscillator signal is used for two purposes. Those are to provide 200-kHz AC to the rectifier/filter isolated DC power-supply, and to provide a 200-kHz carrier to the modulator stage.

The purpose of the isolated DC power-supply is to completely divorce the power for the isolation amplifier from the power

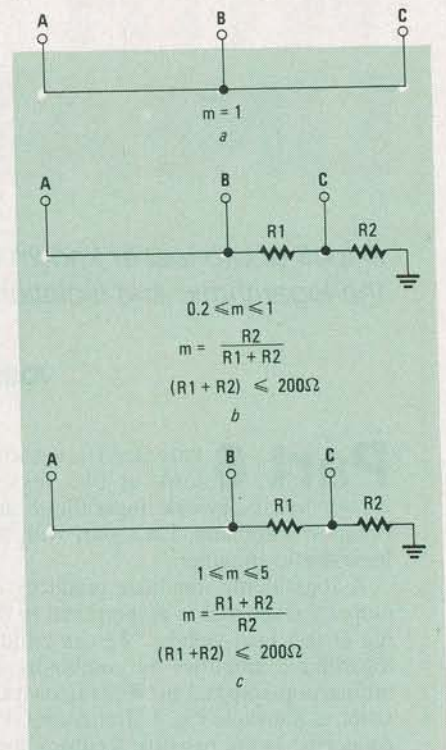


FIG. 4—THESE SIMPLE RESISTOR NETWORKS are used to set the value of m . The one in a is for the $m=1$ case, the one in b is for the $m<1$ case, and the one in c is for the $m>1$ case.

for the nonisolated "outside world." Since the current level is very low, the rectifiers used in that circuit are often ordinary signal diodes rather than rectifier diodes. Also, the high frequency of the AC, 200 kHz, allows use of very low-value filter capacitors in the isolated DC-supply; we don't need large, high-value electrolytic capacitors.

Amplifier IC1 is connected to the signal source (a patient in biomedical applications, for instance). That stage usually has a medium level-gain that is a healthy fraction of the total gain. The signal from the output of IC1 is fed to the input of a modulator stage. The modulator output is an AM signal with a carrier frequency of 200 kHz. The AM signal is coupled to the nonisolated side of the circuit via transformer T2.

The original signal (V_1) is recovered by demodulating the AM signal. While some designs use simple envelope detectors (as in AM radios), others use a phase-sensitive detector (also called a synchronous

detector) for the demodulator stage. That type of AM detector requires a sample of the carrier, so a 200-kHz signal is provided by the power oscillator.

Following the demodulator will be an output buffer-amplifier (IC2). That stage may or may not provide variable gain, depending on design.

Optically-coupled isolation amplifiers (see Fig. 9), as their name would imply, use light to carry the signal from isolated to nonisolated sides of the circuit. Most isolation amplifiers are of the optoisolator variety. That device should be familiar to most **Radio-Electronics** readers. It con-

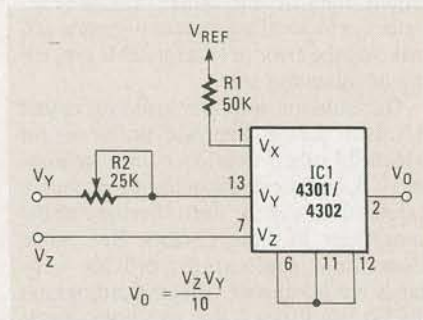


FIG. 5—IN THIS APPLICATION, an analog multiplier, the output is the product of V_Y and V_Z , multiplied by V_X .

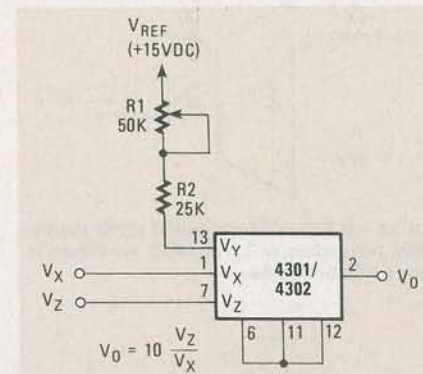


FIG. 6—IN THIS ANALOG DIVIDER, the output is equal to $10V_Z$ divided by V_X .

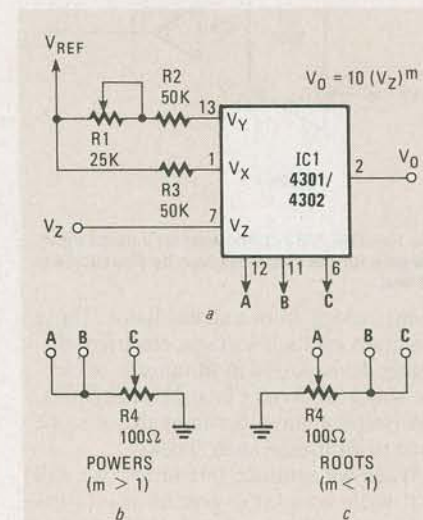


FIG. 7—IN THE CIRCUIT SHOWN IN *a*, the value of m is set by R_4 as shown in *b* and *c*.

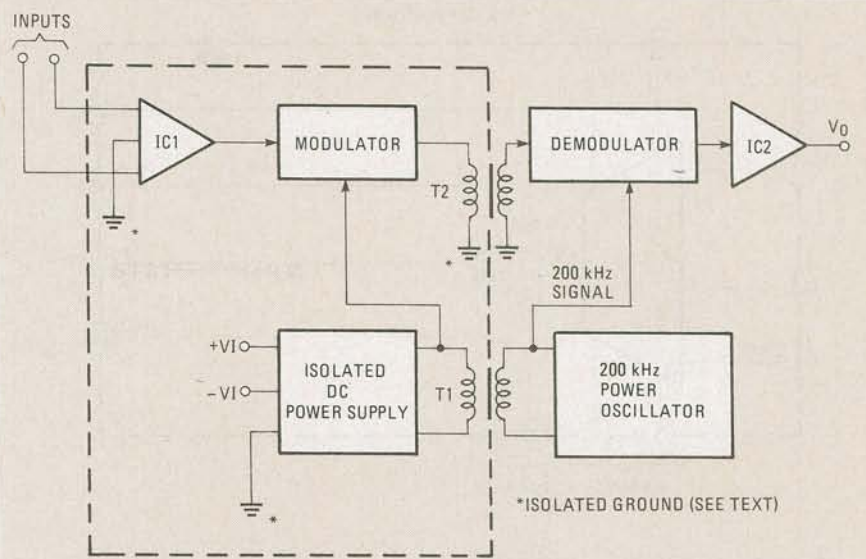


FIG. 8—BLOCK DIAGRAM of a transformer-coupled isolation amplifier. The transformers used are designed to pass the high-frequency signals but sharply attenuate any 60-Hz leakage current.

sists of a light-emitting diode (LED) and a phototransistor housed in an IC package. Although many people are aware of the digital applications of the optoisolator, it is also possible to use that device in linear applications. For instance, if we modulate the LED light, the pattern of modulation is reproduced at the transistor output.

Note in Fig. 9 the use of an isolated ground for the input stage. If isolation is to be achieved, the input-stage ground must be kept separate from the ground used by the balance of the circuit.

Figure 10 shows the pinouts and block diagram for the Burr-Brown 3650 and 3652 isolation amplifiers. The two devices differ from each other in that the 3650 is a current-input amplifier and the 3652 can be configured for either a current or voltage input. Both the 3650 and 3652 are optically coupled and use a unique Burr-Brown circuit that tends to cancel the drift problems seen on certain other optically-coupled designs.

The 3650/52 devices do not contain a built-in isolated power supply. The $+V$ and $-V$ voltages to the nonisolated side can be supplied from the regular DC supply used in the rest of the circuit. The voltages for the isolated stages must come from a source that is isolated from the AC power lines. That requirement usually means batteries (not while connected to the charging circuit!) or an external, isolated power-supply. Burr-Brown makes several suitable DC-to-DC converters including single-port (710), dual-port (722) and quad-port (724) versions. The dual and quad-port versions will supply power for two or four isolation amplifiers, respectively.

Figure 11 shows a 3650 with differential current-source inputs (I_1 and I_2). The gain of the isolation amplifier is 10^6 volts per ampere, so the output voltage is given by:

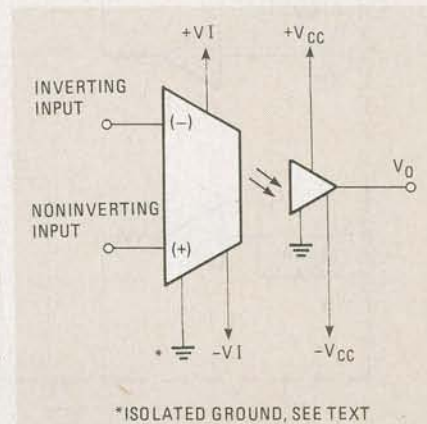


FIG. 9—OPTICALLY COUPLED isolation amplifiers require the use of a separate, isolated ground for the input stage.

$$V_O = (I_1 - I_2) (10^6 \text{ V/A}) \quad (7)$$

where: I_1 and I_2 are the input currents in amperes.

A voltage-input configuration for the 3650 is shown in Fig. 12. In that circuit, two input resistors (R_{G1} and R_{G2}) are in series with the input terminals of the 3650. The gain is given by:

$$V_O = \frac{10^6}{R_{G1} + R_{G2} + R_{IN} + R_9} (V_1 - V_2) \quad (8)$$

where: R_{G1} and R_{G2} are the external resistors shown in Fig. 12, R_{IN} is the nominal input resistance of the 3650, and R_O is the output resistance of the driving signal source. In many practical cases we find it possible to lump R_{IN} and R_O together into one term of approximately 115 ohms. That action makes the gain dependent solely upon R_{G1} and R_{G2} . The resultant simplification will break down only when using a signal source with an excessive output resistance.

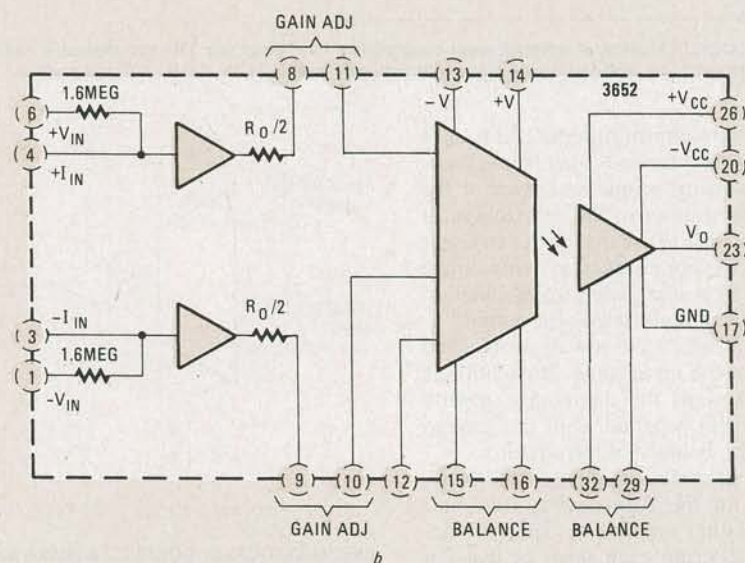
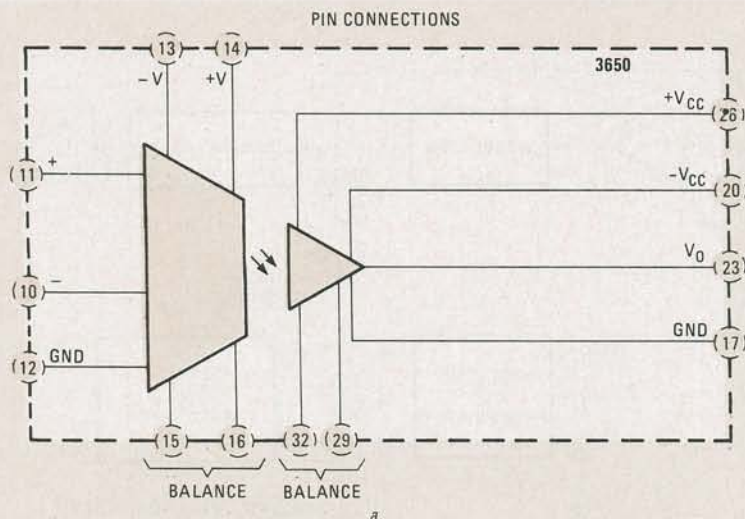


FIG. 10—BLOCK DIAGRAM and pinout of the Burr-Brown 3650 is shown in a; the block diagram and pinout of the Burr-Brown 3652 is shown in b.

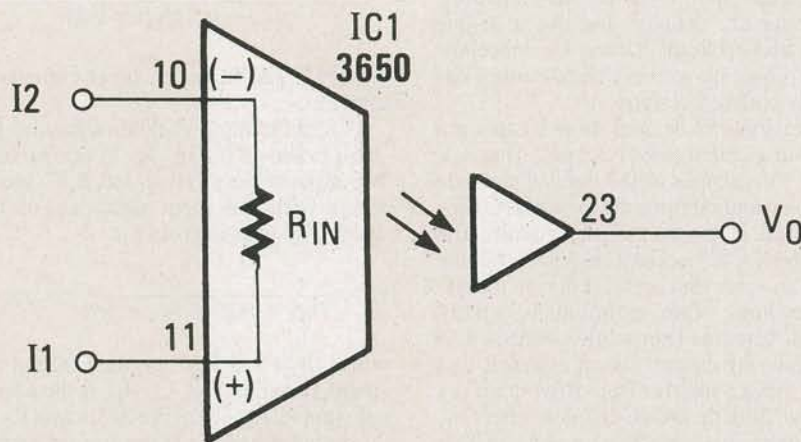


FIG. 11—HERE, THE 3650 is configured with differential current-inputs.

The configuration for the voltage-input 3652 is shown in Fig. 13. As in the previous case, the gain is set by Eq. 8 with $R_O + R_{IN}$ lumped together as 115 ohms. Let's rewrite Eq. 8 in simplified form to solve for R_{G1} and R_{G2} when the gain is

known. As a basic assumption $R_{G1} = R_{G2} = R_{G1}$, so Eq. 8 becomes:

$$R_G = \frac{1}{2} \left(\frac{10^6}{A_V} - 115 \right) \quad (9)$$

Let's look at an example: Calculate R_{G1} and R_{G2} for an amplifier with a gain (A_V) of 1000 (10^3). Assume a 3652 isolation amplifier and $R_{G1} = R_{G2}$. Then:

$$\begin{aligned} R_G &= \frac{1}{2} \left(\frac{10^6}{10^3} - 115 \right) \\ &= \frac{1}{2} (1000 - 115) \\ &= 442.5 \text{ ohms} \end{aligned}$$

In a practical case we would accept a tiny gain error by using $R_G = 440$ ohms (a standard value). If precise gain is required, then we may either trim those resistors or factor the gain into two parts and make up the error in an adjustable preceding or following stage.

The isolation amplifier is unique in that it solves certain interface problems for which no other solution is even reasonable. Biomedical applications probably require their use the most, because of the importance of patient safety. But, some biomedical applications provide very harsh environments. Electrocardiograph (ECG) amplifiers, for example, must sometimes withstand a 2000–3000 volt,

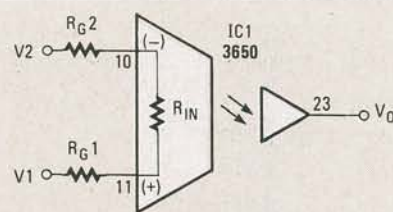


FIG. 12—IN THE VOLTAGE-INPUT CONFIGURATION, two resistors, R_{G1} and R_{G2} , are placed in series with the inputs.

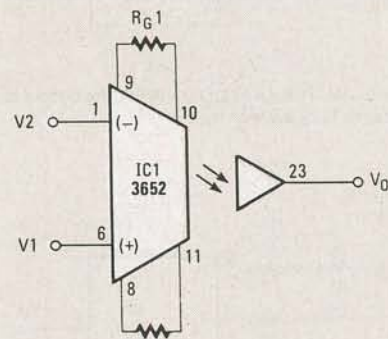


FIG. 13—THE 3652 configured for voltage input. The gain for the circuit is given by Equation 8 in the text.

10-ms, shock from a defibrillator. Those machines are high-voltage, electrical-discharge devices used to administer an electric shock to correct fatal heart rhythms. The isolation amplifier must therefore be rated to withstand such shocks.

When we continue this series, we will deal with waveform-generator circuits that are based on operational amplifiers. We will include sinewave, squarewave, and pulse generators, and more! **R-E**