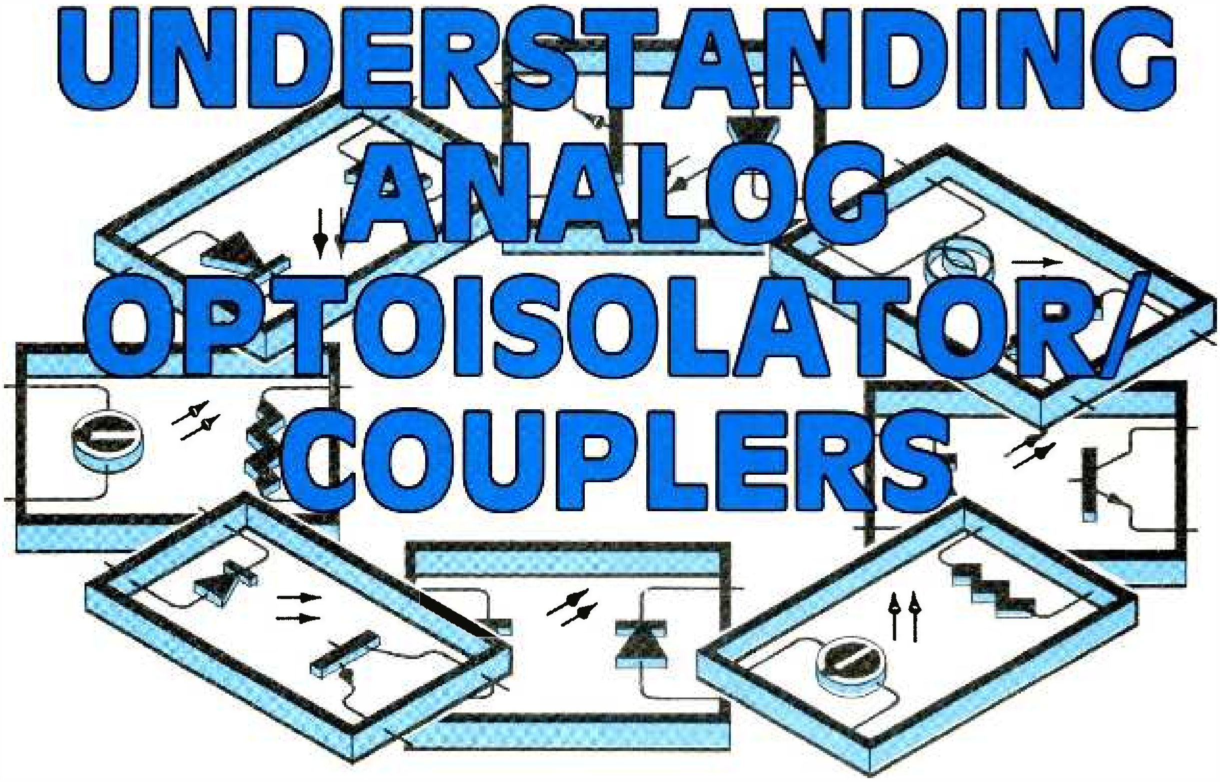
UNDERSTANDING ANALOG OPTOISOLATOR/ COUPLERS



In this article, we'll cover some of the basics of analog optoisolator/couplers, as we explore a few circuits that you can experiment with on your own or, perhaps, incorporate into your next project.

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Digital optoisolator/couplers are very common today, and most people involved in electronics are aware of their purpose and application. Optoisolator/couplers are used to provide a "visual" path (optical coupling) between two circuits or devices, while keeping them electrically separated (isolated) from each other. The optical path eliminates ground loops and electrical interface problems that can occur when two circuits are physically connected to one another. And in many situations optoisolator/couplers are used to satisfy safety concerns.

Analog optoisolator/couplers are not nearly as common as the digital type, but they provide the same advantages for analog circuits as digital units provide for digital circuits. Analog optoisolator/couplers eliminate ground loops and noise problems, provide an additional level of safety through electrical isolation, and, in addition, have characteristics that can be used to their best advantage in certain circuit configurations.

Analog optoisolator/couplers can also be used for switching operations in certain digital applications where they are better suited to a particular operation than digital types. Analog optoisolator/couplers, which are available in many different configurations, are inexpensive, reliable, and fairly readily available. In addition, they can also be fabricated by the hobbyist, allowing their characteristics to be tailored to specific applications.

What's An Analog Optoisolator/ Coupler? Analog optoisolator/couplers are comprised of a light source (input device) and a light detector (output device), which are housed in a light-tight package. There are several different light sources and several detectors that can be used in this application, one of which may be better suited to a specific application than the others.

Figure 1A is a schematic representation of a typical analog optoisolator/coupler that uses an incandescent lamp as the input device and a photocell as the output device. Although an incandescent lamp is used as the input device in that illustration, a neon lamp, light-emitting diode (LED), or any other light source could have easily been used. The light source has a great impact on the optoiso-

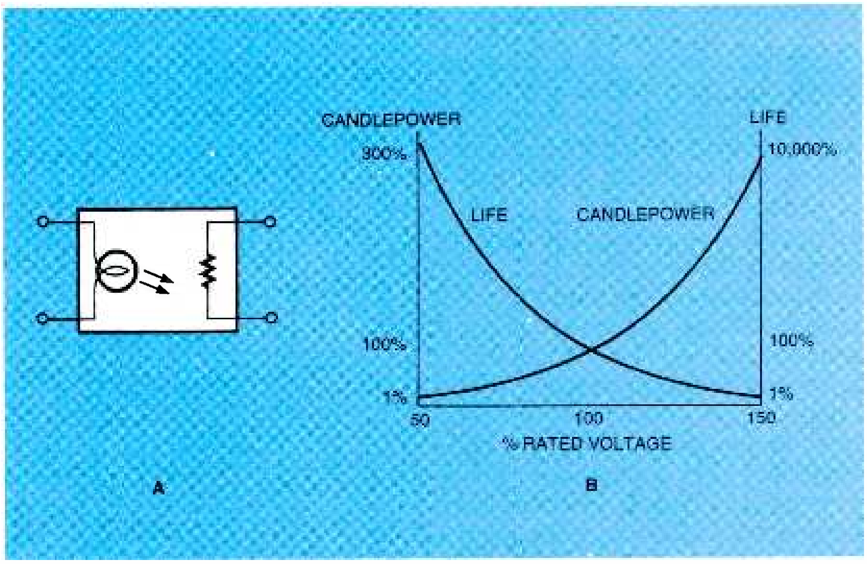

Fig. 1. Analog optoisolator/couplers are comprised of selected input device and output devices that are housed in light-tight packages, as shown in A. The relationship between lamp life and light output is illustrated in B.

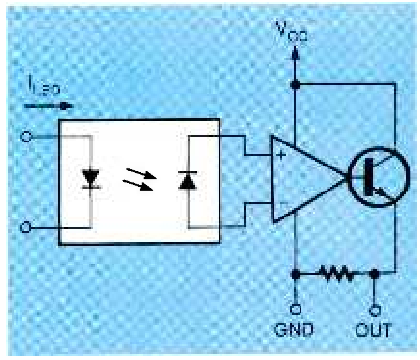

Fig. 2. Shown here is a schematic diagram for analog optoisolator/coupler with an LED input and a photodiode output. Signals applied to the device's LED input are transmitted via light radiation to the photodiode.

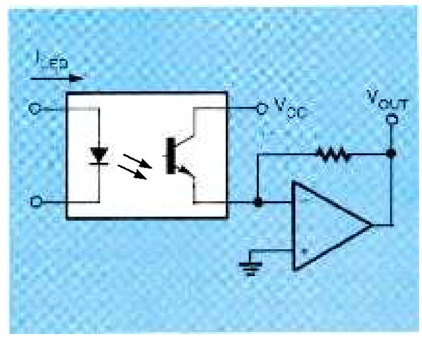

Fig. 3. A diode/transistor version of the analog optoisolator/coupler is shown here. The LED is optically coupled to a phototransistor, whose output is used to drive the inverting input of an amplifier.

lator/coupler's characteristics and must be selected to optimize the unit's desired traits.

Incandescent Lamp. Incandescent lamps may be operated from either AC or DC sources. The radiated light is proportional to the temperature of the filament. That thermal dependence makes an incandescent lamp a true rms (root mean squared) sensor. The response time for an incandescent lamp depends on the driving circuit and the mass of the filament. Small lamps can turn on in 20 milliseconds or less if the mass of the filament is low. The lamp's inrush current can be as much as 15 times the steady-state current of the device, so the driving circuit must be capable of providing a great deal of current if the fastest possible turn-on time is desired. The turn-off time for incandescent lamps can be as fast as 20 milliseconds. If the inrush current is limited, the turn-on time may increase by a second or more, but the turn-off time will be unaffected.

The life of an incandescent lamp depends on the operating temperature of the filament and the tungsten evaporation rate. Manufacturing variations in the cross-sectional area of the filament and anomalies in the tungsten composition can cause hot spots in the filament. Excessive evaporation in any of the hot spots, coupled with the tungsten recrystallization produced, reduces lamp life to below theoretical values. That phenomenon is exaggerated when the lamp is operated from a DC source. Since filament temperature is determined by the applied voltage, the lamp life and light output can be related to that voltage, as illustrated in Fisg. 1B .

Incandescent lamps are sensitive to shock and vibration. Mechanical impact can reduce lamp life significantly. The output of a analog optoisolator/coupler can be affected by motion of the lamp, and is most apparent when the input signal is low and the lamp is barely on.

Neon Lamp. Neon lamps are primarily used as the light source of an analog optoisolator/coupler that's intended for AC input voltage applications because of the lamp's bidirectional characteristics. Neon lamps may also be used for DC applications of either polarity, because the volt-amp characteristic is symmetrical. Neon lamps have a high standoff voltage with a very high input resistance prior to breakdown. After breakdown, they require a lower sustaining voltage and the series resistance of the lamp drops significantly. Breakdown voltage may be as low as 60 volts, but it is typically 90 to 110 volts. The sustaining voltage is typically 45 to 55 volts.

Ambient light is required to partially ionize the gas in a neon lamp so that it breaks down at a reasonable voltage level. Because analog optoisolator/couplers are housed in light-tight packages, a small amount of radioactive material is usually used to produce the slight ionization that is required for reliable breakdown. The turn-on voltage would be 300 volts or more without the radioactive material. All neon lamps require a series resistor to limit lamp current once the breakdown voltage has been exceeded.

LED. Light-emittisng diodes (LEDs) are the ideal light source for many analog optoisolator/coupler applications. LEDs require low drive current and voltage, and have a fast response time. In addition, they are rugged—they're unaffected by shock and vibration—and they are very reliable and inexpensive. LEDs conduct in one direction only, so they are best suited for DC applications. However, circuit modifications can be made so that they can be used relatively easily for AC applications as well. The LED must be protected from excessive current by a series-connected, current-limiting resistor.

Like the input device of an analog optoisolator/coupler, the output device (or detector) can be anyone of several different devices; for example, a photocell, photodiode, or phototransistor. The type of detector selected depends on the type of circuit to be driven by the optoisolator/coupler's output.

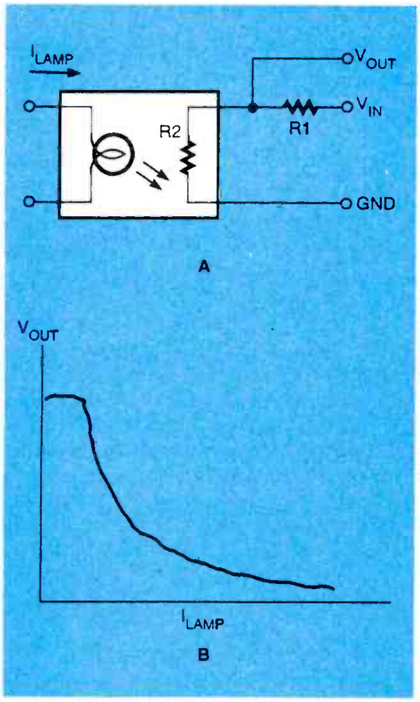

Fig. 4. The photocell type analog optoisolator/coupler is well suited to attenuation applications. In A, the unit's photocell output serves as a shunt resistor. The V_{OUT} vs. I_{LAMP} characteristics of this circuit is shown in B.

Photocell. By far the most common type of output (detector) device used in an analog optoisolator/coupler is the photocell. A photocell is a light-dependent resistor or LDR (also known as a photoresistor). The resistance of the photocell can be altered by varying the input current or voltage applied to the light source, and thus the intensity of the light produced by the input device. Aside from the obvious variable resistance applications—where the unit could be made to track the input signal in an analog fashion—the photocell can be made to switch between an on and off state, in a similar manner to a digital switch. Other attributes of the photocell are its very low harmonic distortion characteristic (making it an ideal candidate for controlling audio systems), in addition to being very rugged and extremely easy to use.

Photocells are usually composed of either cadmium sulfide or cadmium selenide. The photocell output of an analog optoisolator/coupler acts as an electrically variable resistor (potentiometer). Since the output device is essentially a resistor, the voltage applied to the output can be DC or AC. The amplitude of the applied voltage can be as low as zero or as high as the maximum voltage rating of the device. The light source and the photocell must be selected properly for the specific application, since there are many trade-offs to consider. Some of the parameters to consider are input voltage, input current, output voltage, output current, and response time.

Since the photocell is a resistor, it must be treated accordingly. The resistance of the photocell depends on the amount of light that strikes its light-sensitive area. Because the photocell is essentially a light-variable resistor, its output current depends on the intensity of the light that falls on the photocell, plus the voltse applied to it.

The dark resistance of a photocell (typically ranging from 500k ohms to 200 megohms) is its resistance with no illumination. The dark resistance is important because it produces leakage current, which can lead to false triggering in some applications.

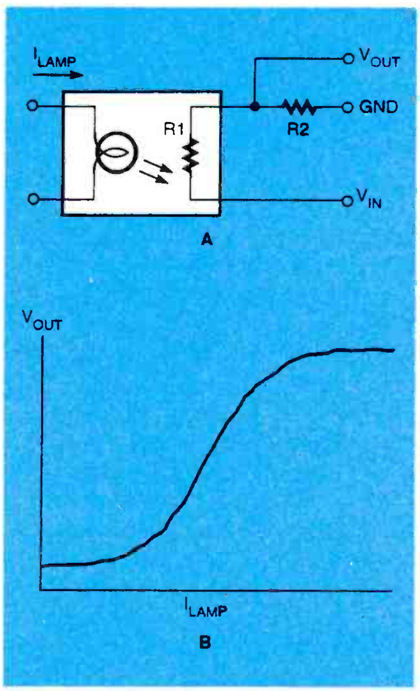

Fig. 5. Here is another optoisolator/coupler attenuator circuit. In A, the photocell is connected as the series resistor. The V_{OUT} vs. I_{LAMP} characteristics of this circuit is shown in B.

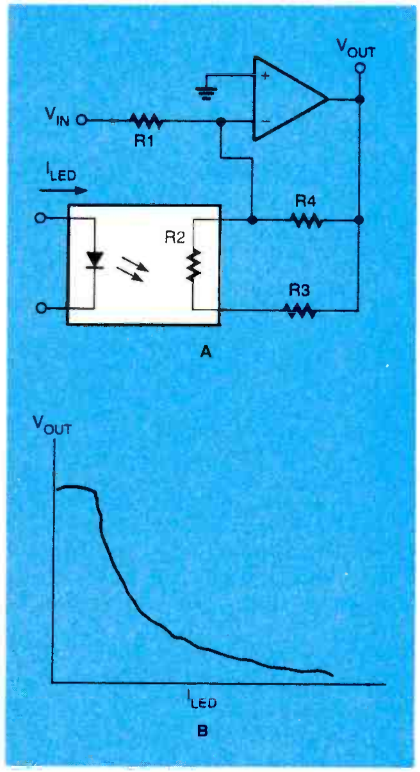

Fig. 6. Analog optoisolator/couplers can also be used as gain controls as shown in A. The gain of the op-amp is affected by changes in the resistance of the photocell caused by light radiation. The V_{OUT} vs. I_{LED} characteristics of this gain-control circuit is shown in B.

Photocells are affected, to some extent, by temperature. In order to minimize temperature-related variations, it is best to operate the photocells at the highest reasonable light level. Cadmium sulfide photocells are usually less affected by temperature and a bit slower than the cadmium selenide type. All photocells have a longer response time in cold environments.

Typically, the response time of a photocell ranges from 5 to 100 milliseconds, and can be even faster at higher light levels. A short response time can cause the photocell to exhibit light modulation when the analog optoisolator/coupler is operated from an AC source. However, higher current lamps can help to reduce the modulation.

Photocells also exhibit a light history effect; *e.g.*, they tend to remember their most recent storage condition and their instantaneous conductance is a function of its pre-

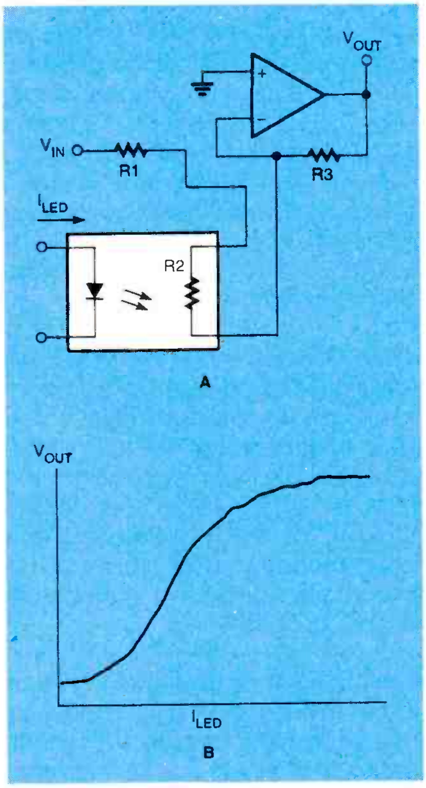

Fig. 7. In the gain-control circuit shown in A, the gain of the op-amp is affected by varying the magnitude of the input signal. The V_{OUT} vs. I_{LED} characteristics of the gain control circuit is shown in B.

vious condition. The magnitude of the light history effect depends on the new light level being sensed, the difference between the new and immediately previous light level, and the time spent at each light level. That effect is reversible. The magnitude of this effect is larger for cadmium selenide units than for cadmium selenide photocells, and can be minimized by keeping the photocell exposed to a constant low level of illumination rather than total darkness.

The photocell can be considered as a resistor in parallel with a small capacitance. The value of the capacitance is a function of the size of the photocell base. The capacitance is usually about 3 picofarads, which is negligible in most applications, but should be considered where high frequencies are involved.

The electrical noise generated in a photocell is the same as for any other type of resistor. One form of noise is *thermal noise*, which is caused by the random motion of free electrons within the photocell material. Thermal noise is independent of frequency, but increases with temperature and is greater in high-resistance photocells. Another form of noise is *shot noise*. Shot noise is caused by random variation in the cell due to photon absorption within the photocell material. A third form of noise is *flicker noise, which is caused by* the photocell material itself, and has the greatest effect at low frequencies. In most applications, the actual noise level of an analog optoisolator/coupler is irrelevant when the voltage level exceeds 80 volts.

Photodiode and Phototransistor. A schematic diagram for the typical photodiode-type analog optoisolator/coupler is shown in Fig. 2. It consists of an LED or other light source optically coupled to a photodiode, which is at the input of an amplifier. The amplifier converts the photodiode current variation to an output voltage variation. There are commercially available devices manufactured for this application.

To use digital optoisolator/couplers in linear applications, the LED must be forward biased to a suitable current level, typically 5 to 20 milliamps. Modulating signals can then be impressed on the DC bias. For good high-frequency performance, the phototransistor should be operated into a low-impedance input,

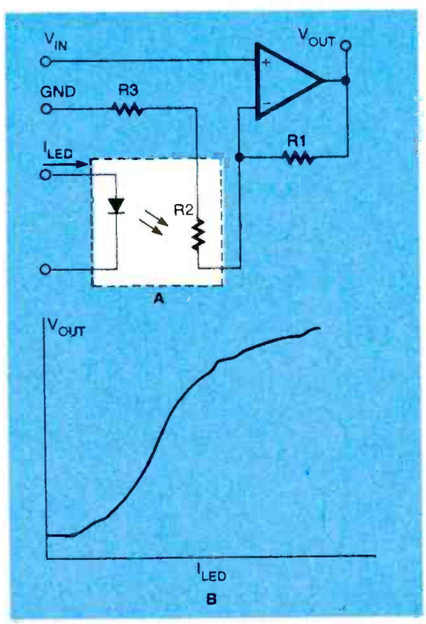

Fig. 8. A typical non-inverting amplifier circuit controlled by an analog optoisolator/coupler is shown in A, while its V_{OUT} vs. I_{LED} characteristics is illustrated in B.

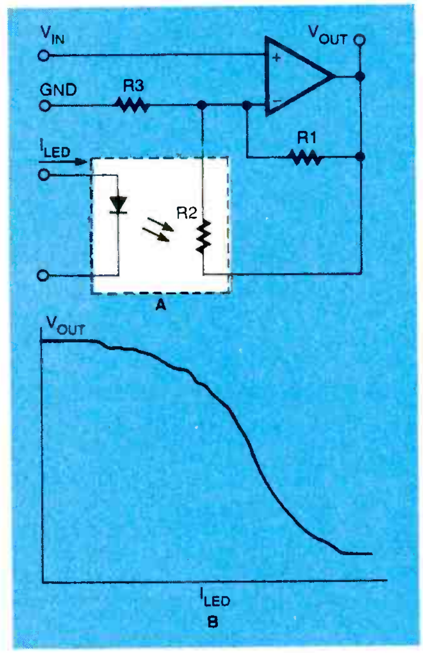

Fig. 9. A non-inverting amplifier with an analog optoisolator/couple connected in the feedback loop is shown in Fig. 9A, and its V_{OUT} vs. I_{LED} characteristics is illustrated in B.

current amplifier. A high-speed operational amplifier, as shown in Fig. 3, can be used with excellent results. The output of the optoisolator/coupler can be taken from either the collector or the emitter of the phototransistor, depending on the desired polarity. The operating speed is the same in either case.

Attenuators. Analog optoisolator/couplers are well suited to attenuation applications. But when the attenuator is located a great distance from an active circuit, it can pick up noise. Because of that, it is best to keep the attenuator as close as possible to the active circuit. A photocell type optoisolator/coupler is recommended for attenuator applications, particularly for use in audio circuits, because of its low harmonic distortion and insensitivity to polarity. Figure 4A shows an analog optoisolator/coupler configured as an attenuator, where the unit's photocell output serves as a shunt resistor. In this case $V_{out} = V_{in} \times R2/(R1 + R2)$. The characteristics of this circuit are shown in Fig. 4B.

Figure 5A shows an analog optoisolator/coupler configured as an attenuator with the optoisolator/coupler as the series resistor. In this case $v_{out} = v_{in} \times R2/(R1 + R2)$.

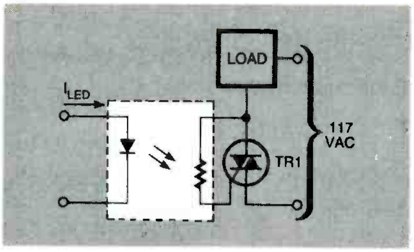

Fig. 10. Analog optoisolator/couplers can be used to control Triacs as shown here. The Triac turns on when the LED is illuminated and turns off when it extinguishes.

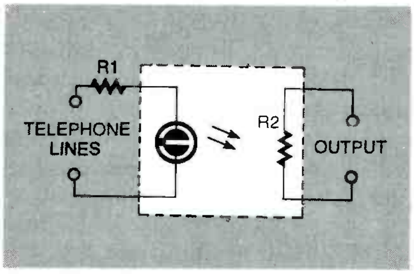

Fig. 11. In the telephone ring detector, an analog optoisolator/coupler serves as a sensor. Note that the input device in this coupler is a neon lamp, which is very compatible with the high voltage AC telephone line.

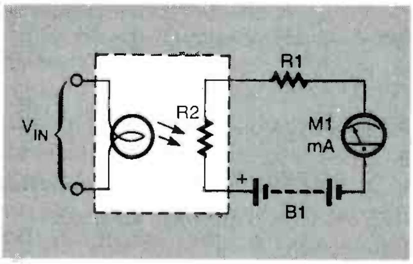

Fig. 12. A photocell type of analog optoisolator/coupler is ideal for true rms (root mean squared) measurement.

The characteristics of this circuit are shown in Fig. 5B.

Gain Control. An inverting operational amplifier can be controlled by an analog optoisolator/coupler as shown in Fig. 6A. For that circuit $V_{out} = -V_{in} \times \{(R4 \times (R2 + R3))/(R1 \times (R2 + R3 + R4))\}$. Resistor R4 sets the maximum gain of the amplifier and stabilizes the DC output voltage. Resistor R3 sets the minimum gain of the amplifier. The output characteristics are shown in Fig. 6B

An inverting operational amplifier can also be controlled with an analog optoisolator/coupler as shown in Fig. 7A. In that circuit, $V_{out} = -V_{in} \times R3/(R1 + R2)$. Resistor R2 limits the maximum gain of the amplifier. The characteristics of this circuit are shown in Fig. 7B.

Non-inverting amplifiers can also be controlled with analog optoisolator/couplers. Figure 8A shows a typical non-inverting amplifier circuit controlled by an analog optoisolator/coupler (Fig. 8A). For this circuit $V_{out} = V_{in} \times (1 + R1/(R2 + R3))$. The characteristics are shown in Fig. 8B.

A non-inverting amplifier can also be controlled as shown in Fig. 9A. In this case $V_{out} = V_{in} \times (1 + (R1 \times R2)/\{R3 \times (R1 + R2)\})$. The characteristics are shown in Fig. 9B.

Triac Control. An analog optoisolator/coupler can be used to control Triacs as shown in Fig. 10. The Triac turns on when the lamp is illuminated and turns off when the lamp is extinguished. Be certain that all of the components are rated properly as this circuit can be hazardous when used in high voltage applications.

Telephone Ring Detector. A neon lamp analog optoisolator/coupler makes an ideal telephone ring indicator as shown in Fig. 11. The neon lamp is very compatible with the high voltage ac telephone line. The output goes to a low resistance state whenever the telephone rings.

True RMS Measurement. A photocell type of analog optoisolator/coupler is ideal for true rms (root mean squared) measurement. Since the light output of an incandescent lamp is directly related to the rms value of the applied voltage, the resistance of the photocell viewing the lamp is an accurate measure of the rms voltage applied to the lamp. A typical rms measurement circuit is shown in Fig. 12.

Conclusion. Analog optoisolator/couplers are available commercially from several manufacturers. A list of manufacturers is provided. The manufacturers can provide specifications and additional data.

Analog optoisolator/couplers can easily be made up from readily available components. Simply select the input and output devices from the many available. Add extension leads to the devices and couple them together optically within electrical tape or a piece of heat shrink tubing. Experiment with different configurations until you find one that exactly meets your needs. ■

ANALOG OPTOISOLATOR/COUPLER MANUFACTURERS

EG&G Reticon Corp.
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Hewlett Packard
Optoelectronics Division
350-370 W. Trimble Rd.
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International Rectifier Corp.
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Tel. 310-322-3331

Motorola Semiconductor
Products Sector
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NEC Electronics, Inc.
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NTE Electronics Inc.
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Optotek Limited
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Philips Semiconductors
Philips Electronics N. A. Corp.
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