Bidirectional optoisolator puts two LEDs nose to nose

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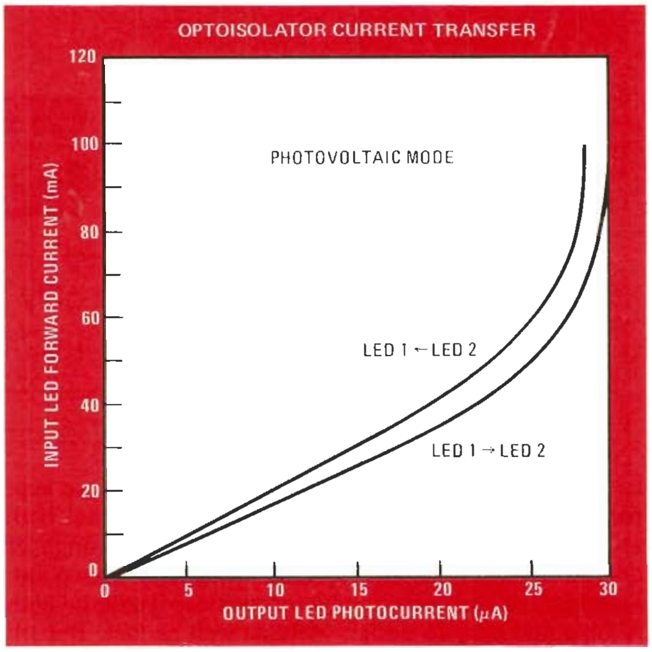


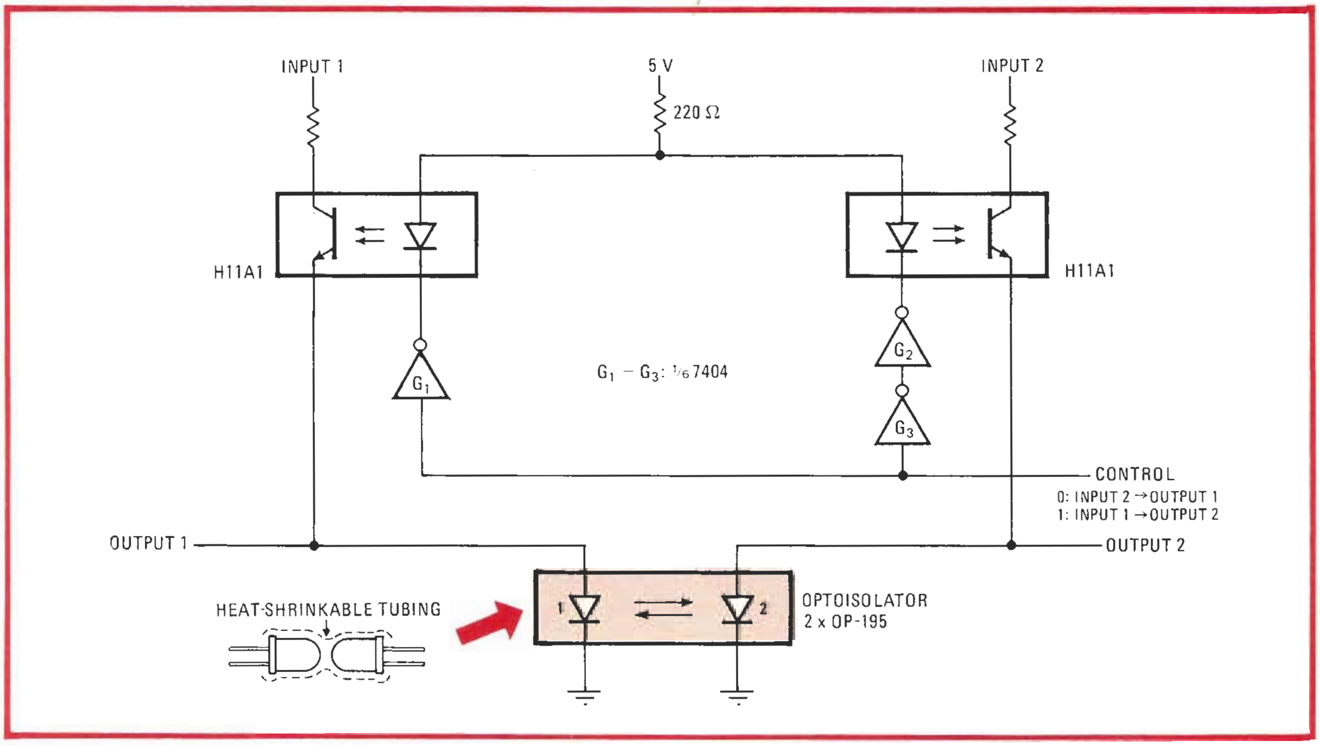
As conventional optoisolators employ a separate source and sensor, they can transfer current in only one direction. A few photodetectors and electroluminescent diodes can double as both a source and sensor, however, and when they are suitably connected they offer users a convenient way to build a low-cost bidirectional optoisolator, as shown here.

Two OP-195 LEDs, which have gallium-arsenide-silicon infrared emitters, can be made to transfer signals in either direction if they are placed nose to nose in a short length of heat-shrinkable tubing and secured in place by heating the tubing. Alternatively, the LEDs may be quite far apart if they are coupled by a plastic or glass-fiber waveguide.

In either case, the current transfer ratio (I_o/I_{in}) for the pair, with proper biasing, will be 0.06% for an input current of 20 milliamperes. This ratio is far too low for many applications but is good enough for some specialized roles where a bidirectional path is required. In any case, the output signal can be amplified or buffered, as necessary.

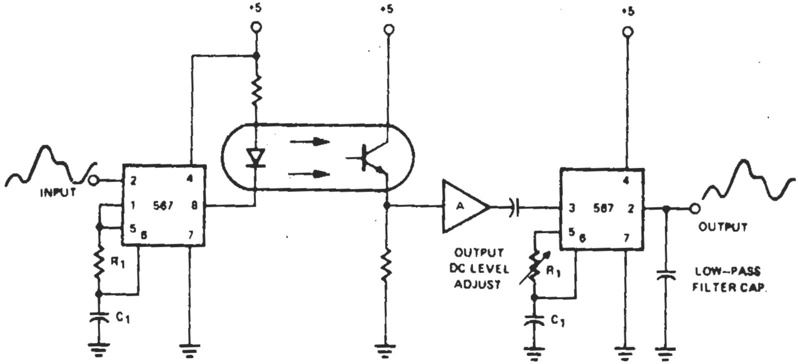
A logic-control voltage and two H11A1 optoisolators serve as the input/output port selector. Whichever of the OP-195 devices is designated the output diode may be connected in the reverse-biased photo-conductive mode or the unbiased photovoltaic mode. In the latter case, the output device is not biased. The response of the optocoupler operating in this mode for a given signal-input current is shown in the plot. Note the device linearity is completely adequate for duplex voice communication.

The photovoltaic current transfer ratio is virtually identical to that for photoconductive operation up to an input current of 20 milliamperes. The ratios begin to depart considerably above 40 mA. ☐



Either way. Standard light-emitting diodes encased in heat-shrink tubing can be made to function as a bidirectional transmission link. Alternatively, LEDs may be coupled through optical fibers. Control circuit for selecting input/output port arrangement is simple, using two optoisolators and three inverters. Circuit's current-transfer ratio suffices for many small-signal applications.

INFORMATION TRANSFER



SOMETIMES it is necessary to transfer an analogue signal from one system to another without making any electrical connections.

This can be done with two phase-locked-loops in an fm system using light as the transmission medium. Because of the high degree of electrical isolation obtained, low level signals can be transmitted without interference, even if there is a large potential difference between the sending and receiving circuits.

The circuit is shown above right.

Transmitter is an NE 567 phase-locked-loop IC operating as a voltage controlled oscillator which drives the LED section of an opto-coupler. The LED will flash at the operating frequency of the oscillator which is in turn dependent on the input signal level and the values of R, and C.

The output signal from the opto-coupler drives an amplifier which provides an output of sufficient amptitude (50 to 200 mV) to drive the receiving NE 567 phase-locked-loop. The receiver operates as an fm detector which demodulates the output of the opto-coupler to provide the original input signal. The inherent non-linearity of the transfer function in the two phase-locked-loops cancel one another out to give an extremely linear information transfer.

Optical coupling extends isolation-amplifier utility

Faster response and larger bandwidth overcome disadvantages of transformer-coupled amplifiers

by Bill Olschewski, *Burr-Brown Research Corp., Tucson, Ariz.*

☐ Sooner or later, almost every analog designer will have to solve an isolation problem. It may arise when a signal to be amplified is superimposed on a high potential, a signal must be transmitted between systems having separate grounds, or a signal path must be completely isolated from a source.

Until recently, the only analog components commercially available to solve such problems were transformer-coupled isolation amplifiers. They work fine for most isolation tasks, but they are usually bulky, costly and have limited bandwidth, as well as slow response. Now, however, optically coupled isolation amplifiers not only eliminate these disadvantages, but also can be used in a number of applications that were previously closed to isolation amplifiers.

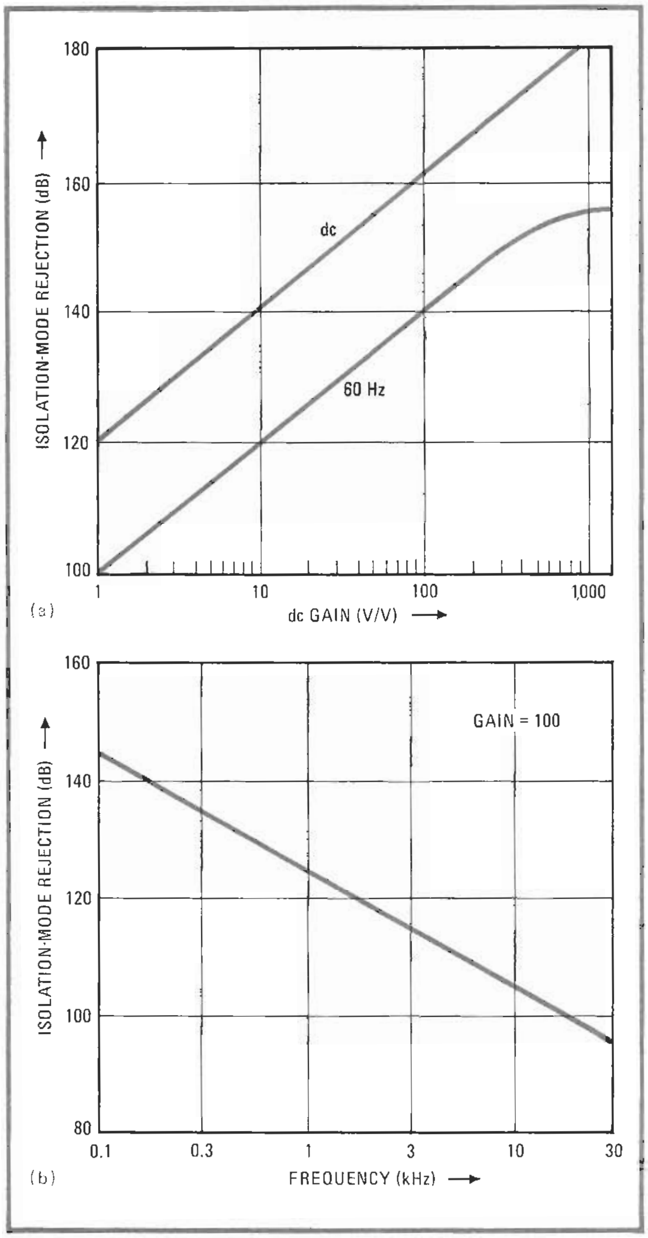
Because of the small size and light weight of these hybrid thick-film optically coupled devices, they are the first isolation amplifiers to be suitable for electronic gear in aircraft. And because their optical isolation barrier can be closely controlled, they are also useful for medical electronics, as well as for monitoring and fail-safe equipment in nuclear-power generation, where isolation must be maintained under all possible conditions.

Although not as linear as some transformer-coupled units, these new optically isolated amplifiers provide an operating bandwidth that is 10 times broader and a response time that is five to 10 times faster. High operating frequency is especially important in such biomedical applications as electromyography, which is a method of monitoring the body's nervous system. Additionally, since optical isolation amplifiers do not generate any electromagnetic interference at all, they do not require shielding, as transformer-coupled units do.

Transformer-isolated amplifiers are comparatively large modular units whose volume may even reach 10 cubic inches. In contrast, optical isolation amplifiers are supplied in integrated-circuit-compatible dual in-line packages that measure less than 0.5 in.^{3} Price differences are significant, too. Optical units cost half as much as transformer units and often less.

One version of the optical amplifier even has a field-effect-transistor input buffer, together with built-in overvoltage-protection resistors. This model is particularly suited to patient-monitoring applications in biomedical instrumentation when high impedances are involved.

As a matter of fact, all the optical amplifiers surpass



1. Typical characteristics. Isolation-mode rejection, an important property for an isolation amplifier, indicates the change in output voltage as a function of the voltage across the isolation barrier. This specification increases with gain (a), decreases with frequency (b).

Which amplifier is which?

With today's proliferation of specialized dc amplifiers, the differences between the three fundamental types—operational, instrumentation, and isolation—can easily become a bit muddled. In fact, though, the differences are easy to spot, and the type selected depends on what must be done.

As a rule, the op amp is a general-purpose device that can be used in a variety of ways, as an integrator, an oscillator, a level detector, or a straightforward amplifier. For stable operation, the feedback loop between the device's output and its inverting input is usually closed externally.

In transducer-sensing applications, the signal to be amplified—typically a differential voltage of a few millivolts between two wires—is generally superimposed on a higher common-mode voltage of up to several volts from both wires to the ground, guard, or shield connection. To amplify the desired signal and reject unwanted common-mode signals—like hum, interference, spikes, or attenuated bridge-supply voltages—the amplifier must have high common-mode rejection, as well as a true balanced or floating input.

Although the op amp can be used in a differential fashion, the input-resistor matching it requires in this mode of operation reduces its common-mode rejection and lowers its input impedance. In fact, even if the op amp has a field-effect-transistor input and the input resistors used are matched within 0.1%, common-mode rejection is only around 60 decibels, and common-mode input impedance is just a few megohms.

On the other hand, in a differential sensing configuration, the instrumentation amplifier or the isolation amplifier can provide considerably higher—by several orders of magnitude—common-mode rejection and common-mode input impedance than the op amp.

The instrumentation amplifier achieves its superior dc-sensing performance by means of an internal voltage-feedback loop, as opposed to the external current-feedback loop of the op amp. Although the instrumentation amplifier is committed to a voltage-in/voltage-out transfer function, its gain can be varied, and it offers ultra-stable closed-loop performance. Common-mode input impedance is typically greater than 100 megohms, and common-mode rejection is about 90 dB. However, this device's common-mode voltage capability is usually limited to a voltage somewhat lower than that of the power supply.

Like the instrumentation amplifier, the isolation amplifier has an internal voltage-feedback loop, but its input stage is electrically isolated; that is, the input is completely floating because it is separated from the output by a large dielectric impedance. This input-to-output separation enables the isolation amplifier to withstand, as well as operate with, extremely high common-mode voltages.

For three-wire input connections, the common-mode-input characteristics of the isolation amplifier are the same order of magnitude as those of the instrumentation amplifier. Additionally, though, the isolation amplifier provides an impedance of several gigohms between input and output. And rejection of common-mode signals applied between input and output is generally around 120 dB, but can even be as high as 160 dB. Typically, isolation-mode test voltages range from 2,000 to 8,000 v, making the isolation amplifier suitable for continuous operation at common-mode voltages, between input and output, of 500 to 3,500 v.

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the standard established by Underwriters Laboratories for this type of component, holding leakage-current levels 20 times below permissible limits. Additionally, they are the first isolation amplifiers to provide completely balanced inputs, so that residual hum, which is often encountered in patient-monitoring applications, is negligible.

Analyzing isolation amplifiers

Isolation amplifiers are best suited for sensing and conditioning dc analog signals and ac signals in the low-frequency range. In addition to isolation, these devices can provide linear amplification and high input impedance to avoid loading the signal source. In effect, an isolation amplifier takes the capability of an instrumentation amplifier, which has a very high common-mode input impedance, one step further—to provide a completely floating input that is insulated from the output by a high withstanding voltage.

To achieve this floating input, an isolation amplifier must have a built-in isolation barrier. The component most often used to create the barrier is a transformer. Its excellent linearity and low noise are ideal for signal isolation, and various modulation techniques can be utilized for isolating dc signals.

Instead of a transformer, an optically coupled isolator, consisting of a gallium-arsenide light-emitting diode paired with a silicon photodetector, can be used as the barrier element. With this device, however, special feedback techniques are needed to compensate for the inherently nonlinear output of a GaAs LED. Other possible isolation techniques include acoustical coupling, Hall-effect devices, and utilization of electric or electromagnetic fields.

An isolation amplifier's characteristics are much like those of an instrumentation amplifier (see "Which amplifier is which?" above) so that most specifications correspond one for one. As might be expected, an isolation amplifier requires additional characterization for its isolation properties between input and output. Depending on the manufacturer, these properties may be referred to as isolation-barrier characteristics, input-to-output common-mode characteristics, or common-mode II characteristics.

Considering key specifications

There are three principal isolation-related characteristics—isolation impedance, isolation-mode rejection, and isolation voltage. Isolation impedance is usually specified as the resistance and capacitance across the isolation barrier. But sometimes the leakage current at a specific voltage and frequency is given instead.

Isolation-mode rejection reflects the change in the output voltage as a function of the voltage applied across

COMPARISON OF ISOLATION AMPLIFIERS

Characteristic	Transformer coupling		Optical coupling
	Amplitude modulation	Pulse-width modulation	Light-intensity modulation
Nonlinearity, max (%)	0.03 – 0.25	0.005* – 0.025*	0.1* – 0.2*
Isolation voltage, test (kV)	up to 7.5	up to 5	up to 5
Isolation-mode rejection, @ 60 Hz & unity gain (dB)	up to 120	up to 120	100
Frequency response (kHz)	2.5	2.5	10 – 30
Emi generated	low, if shielded	low, if shielded	none
High-frequency susceptibility	high	low	very low
Size (in.^{3})	5 – 10	6	less than 0.5
Price in lots of 100	from $49	from $90	from $26**

*Measured at full output-voltage swing **Without input power supply

the isolation barrier. Usually expressed in volts per volt or decibels, it may be specified at unity gain or at some higher gain. Typically, isolation-mode rejection increases with rising gain (Fig. 1a), but decreases as frequency becomes higher (Fig. 1b).

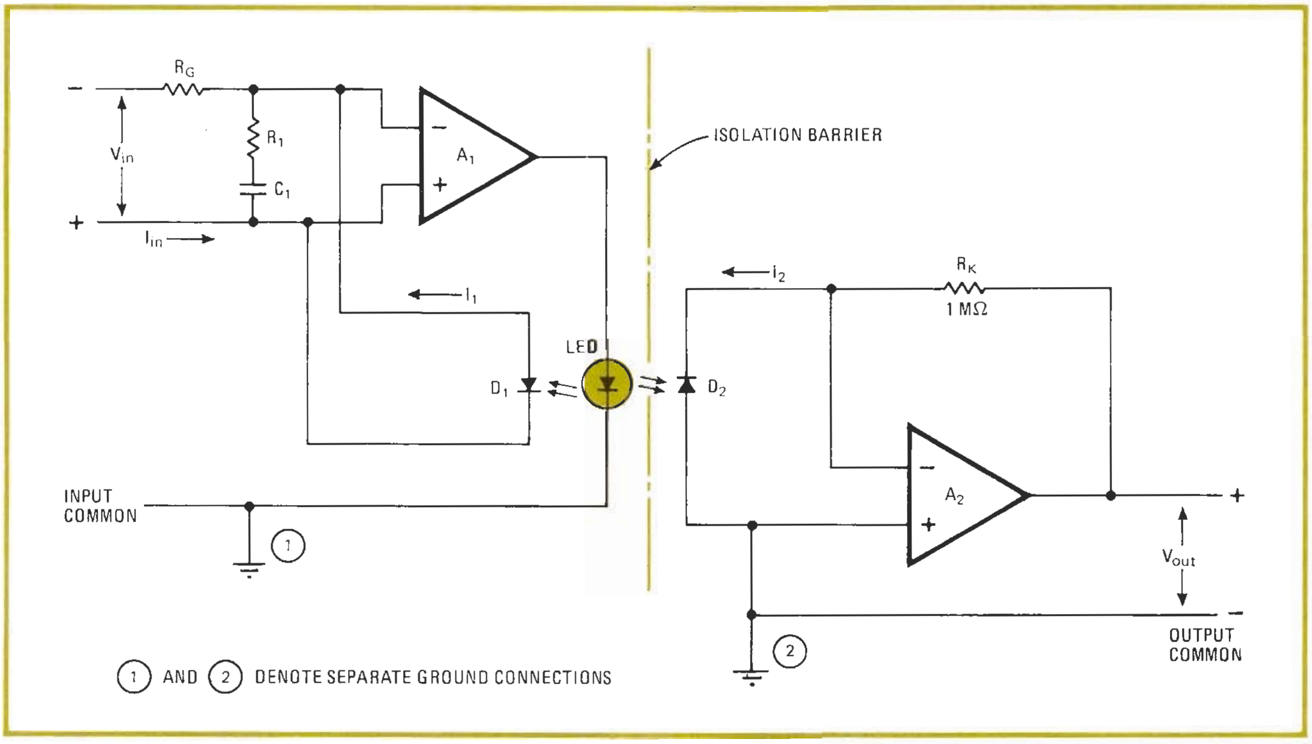
As the term implies, isolation voltage is the maximum voltage that may be present between input and output without causing internal breakdown or excessive leakage. In general, a test voltage and a continuous operating voltage, which should be derived by the manufacturer with derating factors, are specified.

Most isolation amplifiers have a three-wire input, like an instrumentation or operational amplifier, giving rise to common-mode characteristics, in addition to their isolation-mode characteristics. Common-mode parameters, however, should not be confused with isolation-mode parameters. The former are measured between both inputs and the third input connection, which is usually referred to as a common or guard connection.

Examining modulation schemes

Besides the two different types of isolation—transformer or optical—there are three different possible modulation methods: amplitude modulation or pulse-width modulation for transformer-coupled amplifiers, and light-intensity modulation for optically coupled amplifiers. In each, the isolation amplifier internally generates the carrier that is modulated with the input signal.

Amplitude modulation, the oldest technique, usually



2. Optical but linear. In optical isolation amplifier, photodiodes in differential configuration correct for inherent nonlinearities and instabilities of optical semiconductors. Since the matched photodiodes detect the same LED output, they produce equal currents.

involves a double-sideband suppressed carrier having a frequency of around 100 kilohertz. As in the a-m radio, the amplitude of the modulated signal is easily affected by electromagnetic interference, so that this technique has a high degree of emi susceptibility. For demodulation, the carrier and the modulated signal are switched on and off in synchronism, and then the residual carrier is filtered out. This is the same technique commonly employed in chopper-stabilized op amps.

With pulse-width modulation, the carrier is a fixed-frequency square wave having a duty cycle of 50% when no input modulating signal is present. Since only the duty cycle is varied with the modulating signal, all information is contained in the transition time, and the amplitude of the modulated signal can be clipped without affecting accuracy. Pulse-width modulation, therefore, is considerably less susceptible to emi than amplitude modulation. Demodulation is generally accomplished with a dc-restore circuit (like a one-shot) or a balanced diode pair followed by a low-pass filter.

With light-intensity modulation, the input signal modulates the output of a light source whose quiescent light level is fixed. Demodulation is done automatically by the photodetector. Emi susceptibility is low because this technique does not produce cross-modulation products. Also, any emi can be removed by filtering the demodulated signal.

Comparing isolation amplifiers

The table compares the key characteristics among the three classes of amplifiers. Amplitude modulation provides good linearity—sometimes at almost half the cost of pulse-width modulation. On the other hand, pulse-width modulation results in better linearity, with errors down to as little as 0.005%. In many ways, optical modulation is superior to these other techniques, providing higher frequency response and generating no electromagnetic interference at all. Cost, too, is considerably lower, but linearity is moderate in comparison.

At present, there is little compatibility between the products of various manufacturers, except that they all offer isolation. Most include an isolated power supply, but the supply voltage itself can range from the usual ±15 v dc required for conventional operational amplifiers to a single +28 v dc connection to an ac-line hookup of 115 v ac.

Additionally, input impedance can be either low or high, and a few models have a current, rather than voltage, output. Input connections also vary—from two-wire inverting or noninverting affairs to three-wire hookups that may be two differential inputs plus a common or high- and low-potential inputs plus a guard connection. What's more, since not all manufacturers specify nonlinearity at the full output-voltage swing, this specification can appear to be deceptively better than it actually is.

All of this variation is keeping many potential users at arm's length from isolation amplifiers because finding a second-source supplier, a critical requirement in numerous applications, is extremely difficult, if not impossible. The isolation amplifier that delivers the best cost-performance combination will ultimately gain the widest market acceptance. The optically isolated amplifier may well represent the first step toward realizing a cost-effective, yet versatile, industry standard.

Optical couplers have a number of inherent stability problems. The luminance of LEDs and the quantum efficiency of photodiodes vary with temperature. LED luminance is also degraded appreciably over a long period of time. What's more, the transfer function of LED input current versus light output is nonlinear, and the LED light output is noisy.

Linearizing the optics

To overcome these instabilities and nonlinearities, a differential photodiode arrangement can correct for errors much like the differential input transistor pair of a dc operational amplifier. Figure 2 shows a simplified schematic of a linear, stable, optical amplifier circuit.

Amplifier A_1 drives the LED; diodes D_1 and D_2 form the differential photodiode pair. Diode D_1 closes the feedback loop around A_1, so that A_1 drives the LED until:

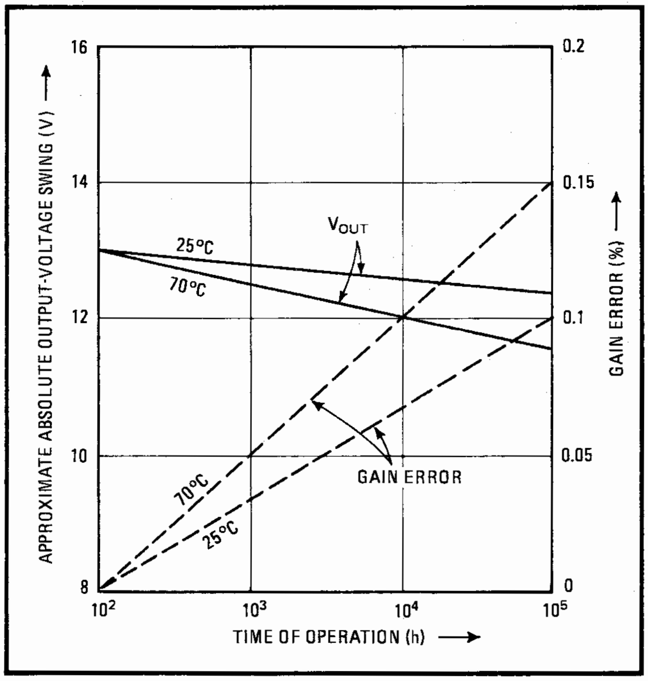
$$I_1 = I_{in}$$

where I_1 is the current generated by diode D_1. The output amplifier, A_2, performs as a current-to-voltage converter; it is driven by diode D_2. Since the photodiodes are matched and are detecting the light output of the same LED:

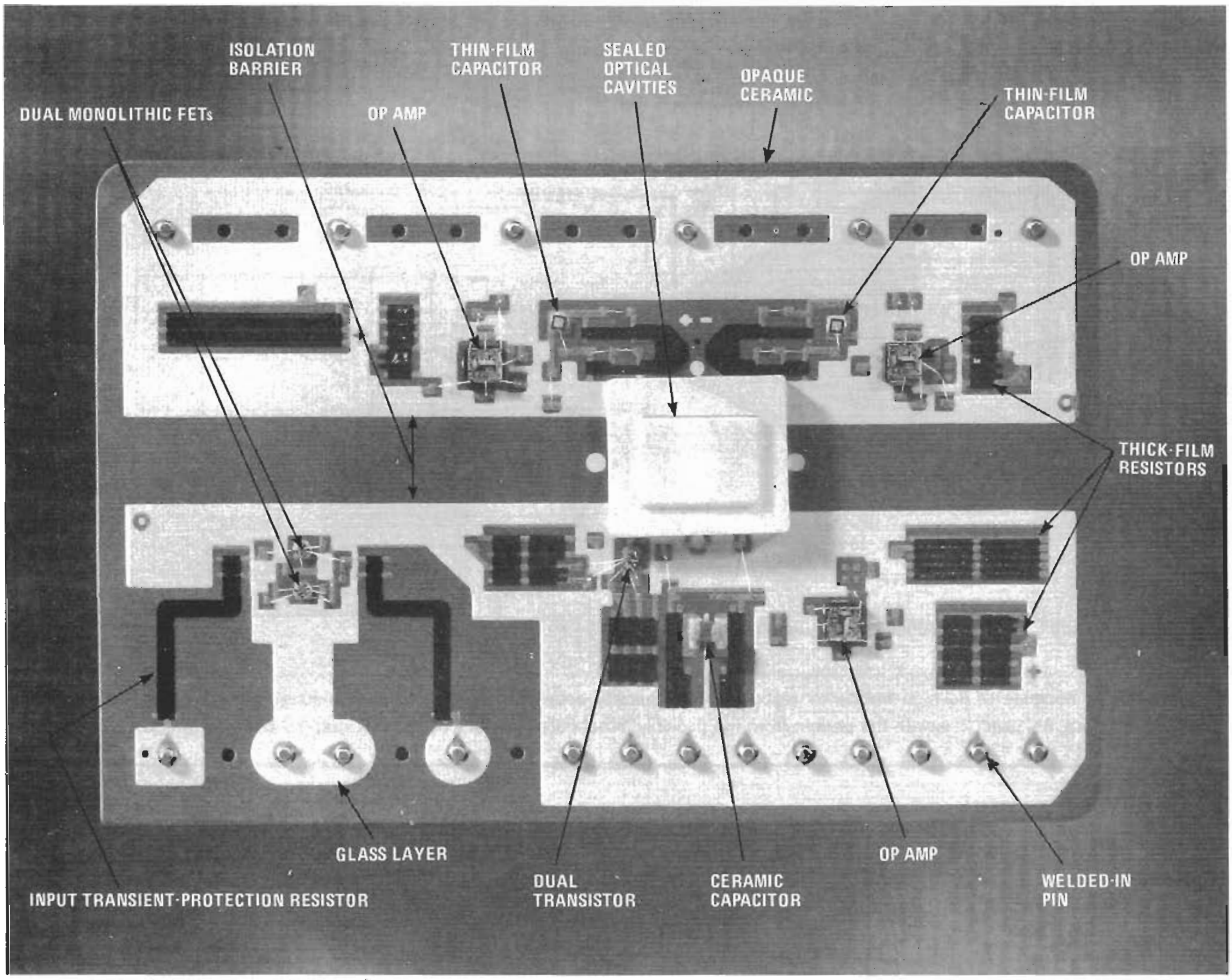
$$I_2 = I_1$$

where I_2 is the current generated by diode D_2. The transfer function of the current-to-voltage converter can be written as:

$$V_{out} = I_2R_K = I_{in}R_K$$



3. Optical but stable. Gain error of optical isolation amplifier is only about 0.1% after 100,000 hours of operation at 25°C. Similarly, under the same conditions, output-voltage swing drops by 0.5 V.



4. Under the lid. Opaque ceramic header serves as substrate for hybrid isolation amplifier. The circuit consists of nine chips, excluding the optical semiconductors, which are encapsulated and sealed in their own housing. The resistors and interconnect pattern are made of thick films. This version of the amplifier includes a differential FET-buffer input and overvoltage-protection resistors.

where R_K is the integral feedback resistance for amplifier A_2. The overall transfer function for the entire circuit becomes:

$$V_{out} = I_{in}R_K = (V_{in}/R_G)R_K,$$

which is linear and independent of the LED parameters. Resistor R_G is the user-selected gain-setting resistance.

For this circuit, the direction of the unipolar photodiode light current limits amplification to positive signals only. To provide bidirectional signal capability, a second set (not shown here) of LED and differential photodiodes must be employed. Alternate biasing techniques could be used instead, but employing a duplicate set of optical components is more cost-effective in a thick-film hybrid circuit. Resistor R_1 and capacitor C_1 simply phase-compensate the closed-loop input circuit, generating a rolloff of 6 dB per octave.

The long-term stability of such a design is more than adequate. In Fig. 3, output voltage and gain error are plotted against time for the optical isolation amplifier. After 100,000 hours of operation at 25°C, gain error is around 0.1%, and output voltage drops by about 0.5 V from its 100-hour value. At 70°C operation, gain error increases to 0.15%, while output voltage decreases by approximately 1.5 V.

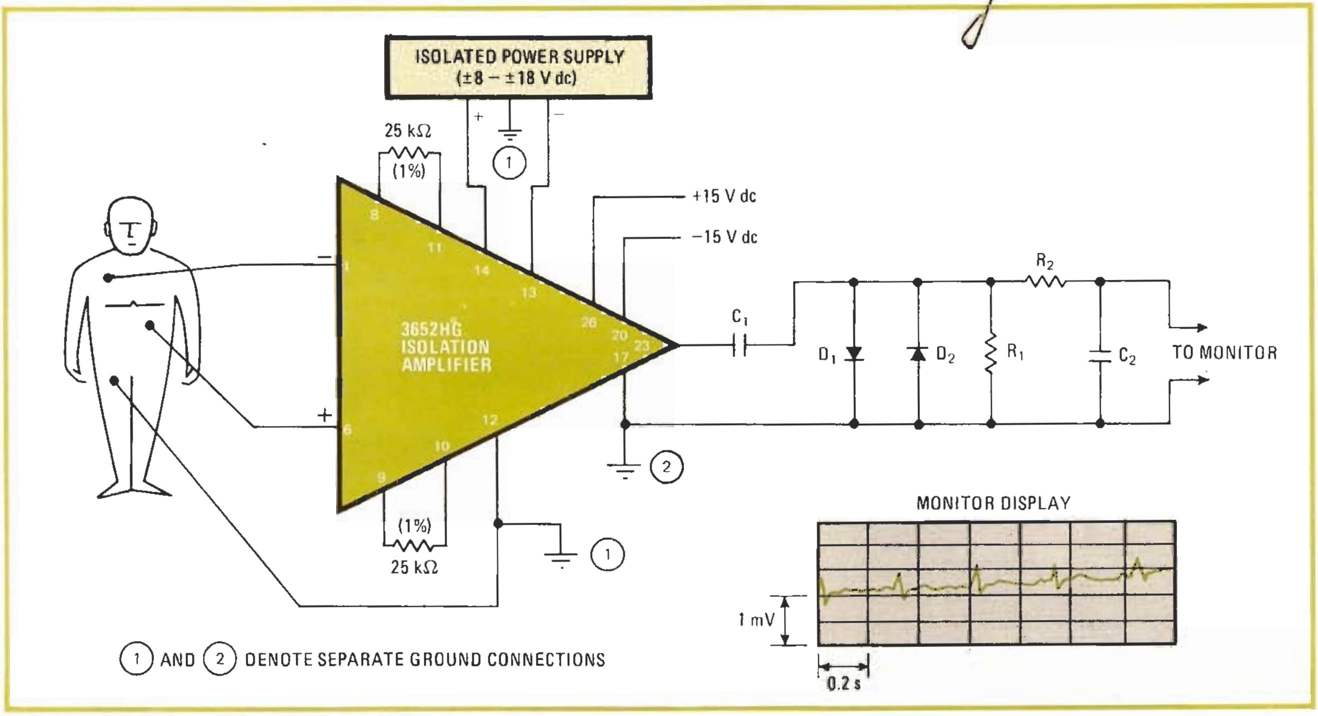
The voltage gain of the optical isolation amplifier is determined by the input resistors selected. But if high gain is desired, the input impedance drops to a low value, for example, 10 kilohms for a gain of 100.

To overcome this limitation for applications involving high source resistances, one version of the optical isolation amplifier has a differential FET buffer at its input. This model also has integral high-voltage transient-protection resistors for safe operation in the presence of overvoltages as large as 6 kilovolts.

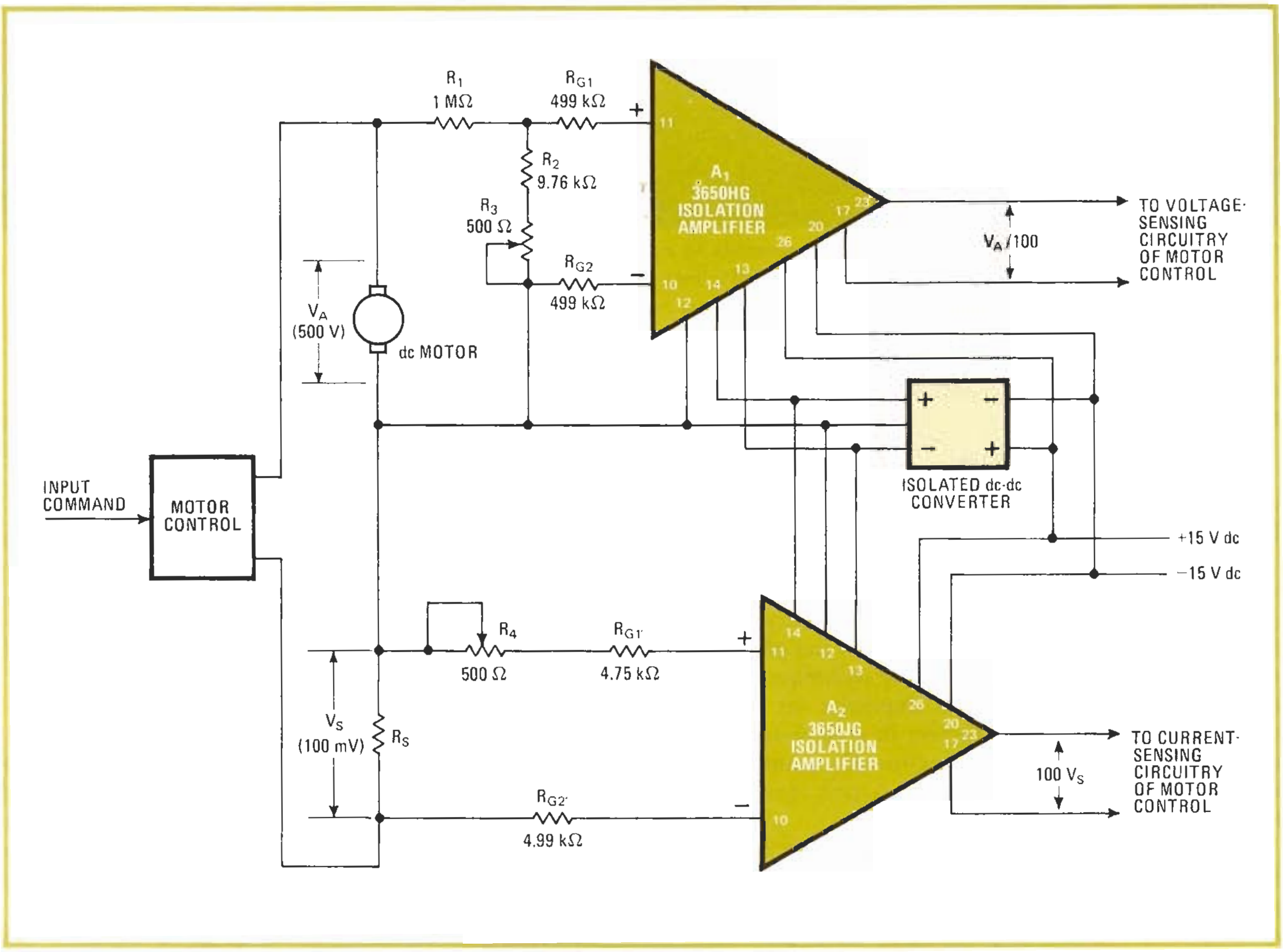
How the hybrid is made

To obtain high isolation breakdown voltage and to space input and output pins as far apart as possible, the amplifier is housed in a DIP that is three times wider than a standard IC DIP. The package is ceramic, with an opaque header that also serves as the circuit substrate and has welded-in pins.

The fully assembled substrate (Fig. 4) contains the optoelectronic circuit, as well as all active and passive chips, plus the interconnect pattern. Not visible here, the



5. Biomedical. Because of its high frequency response, the optically coupled isolation amplifier is suitable for a variety of biomedical applications. Here, it's used to isolate the patient from the possibly lethal potentials of electrocardiographic instrumentation.



6. Motor control. Pair of optical isolation amplifiers put a voltage barrier between driving circuitry for the motor and the circuits for voltage and current sensing. A single dc-dc converter is used to supply isolated power for both of the amplifiers.

photodiodes are made from silicon, and the LEDs from gallium arsenide. All resistors are screened on with a thick-film cermet material, and the interconnect pattern is printed with a thick-film gold paste. Extra insulation is provided by a layer of printed thick-film glass. Interconnections between the chips and the conductor patterns are made with thermocompression-bonded gold wire.

The isolation barrier is 200 mils wide, narrowing to a 15-mil gap between the LEDs and the photodiodes. This gap is encapsulated in a transparent resin having a high dielectric withstanding voltage, thereby providing a light-transmission medium that has good insulation properties. The resin is contained inside a cavity that is bonded onto the substrate. The cavity also serves as a reflector to distribute the infrared light emitted by the LEDs onto the photodiodes.

After the substrate is complete, the thick-film resistors are laser-trimmed to bring the amplifier's gain and offset voltage within data-sheet limits. Prior to capping with a ceramic lid, the substrate is put through temperature cycling and a stabilization bake.

The device does not have a built-in isolated power supply like most other commercially available isolation amplifiers. This may be less convenient in some applications, but gives the user more flexibility in multiple-channel systems or in systems where isolated power is already available elsewhere.

A companion isolated power-supply module is available for those users who need isolated power. This module can drive from three to 10 amplifiers, depending on the amplifier model and the required output-voltage swing.

Helping medical electronics

Optical isolation amplifiers are particularly suited to biomedical applications because of their clearly defined isolation gap and their extremely low coupling capacitance. Moreover, such monitoring functions as electromyography require a fairly wide frequency response—too wide for most transformer-coupled isolation amplifiers.

In electrocardiography (ECG), for example, the electrical activity of the heart is analyzed by measuring potentials at various surface points of the body. Electrodes are applied to certain body points, and the measured potentials are displayed in real time, usually on a cathode-ray-tube monitor. The signal levels thus generated by the heart range from 300 microvolts to 2 millivolts, superimposed on a galvanic potential of up to 500 mV.

When used as an ECG amplifier (Fig. 5), the optical isolation amplifier is dc coupled, with its gain limited to 20 to prevent it from being saturated by the galvanic potential. The dc-coupled input also provides the fastest possible recovery from input overvoltages of up to several kilovolts, such as those caused by the application of a defibrillator pulse to stimulate the patient's heart.

The galvanic-potential dc component is decoupled at the output of the amplifier by resistor R_1 and capacitor C_1, which form a high-pass filter having a cutoff frequency of 0.05 hertz. Diodes D_1 and D_2 speed up the discharge of capacitor C_1 after the amplifier has been saturated by a defibrillator pulse. (This particular circuit has a settling time of less than 0.1 second.) Resistor R_2 and capacitor C_2 serve as a low-pass noise filter. The amplifier's frequency response of better than 15 kilohertz far exceeds the required ECG range of 80 Hz.

Vectorcardiography is a variation of ECG. With this technique, electrodes pick up the heart's signal along three axes, and two of the three axes are displayed as vectors on a CRT monitor. The resulting display is similar to a Lissajous pattern. Such a system requires three isolation-amplifier circuits (identical to the one in Fig. 5) that can utilize a common isolated power source.

Electromyography, a different method of monitoring electrical body impulses, also requires an isolation amplifier for patient safety. In this procedure, the electrodes detect electrically stimulated or normal nerve pulses.

Yet another biomedical application for an optical isolation amplifier is electroencephalography, which involves the measurement of brain waves on the surface of the head. An isolation-amplifier circuit for these waves must have low noise. The circuit of Fig. 5 would have to be modified for higher gain, say, around 1,000.

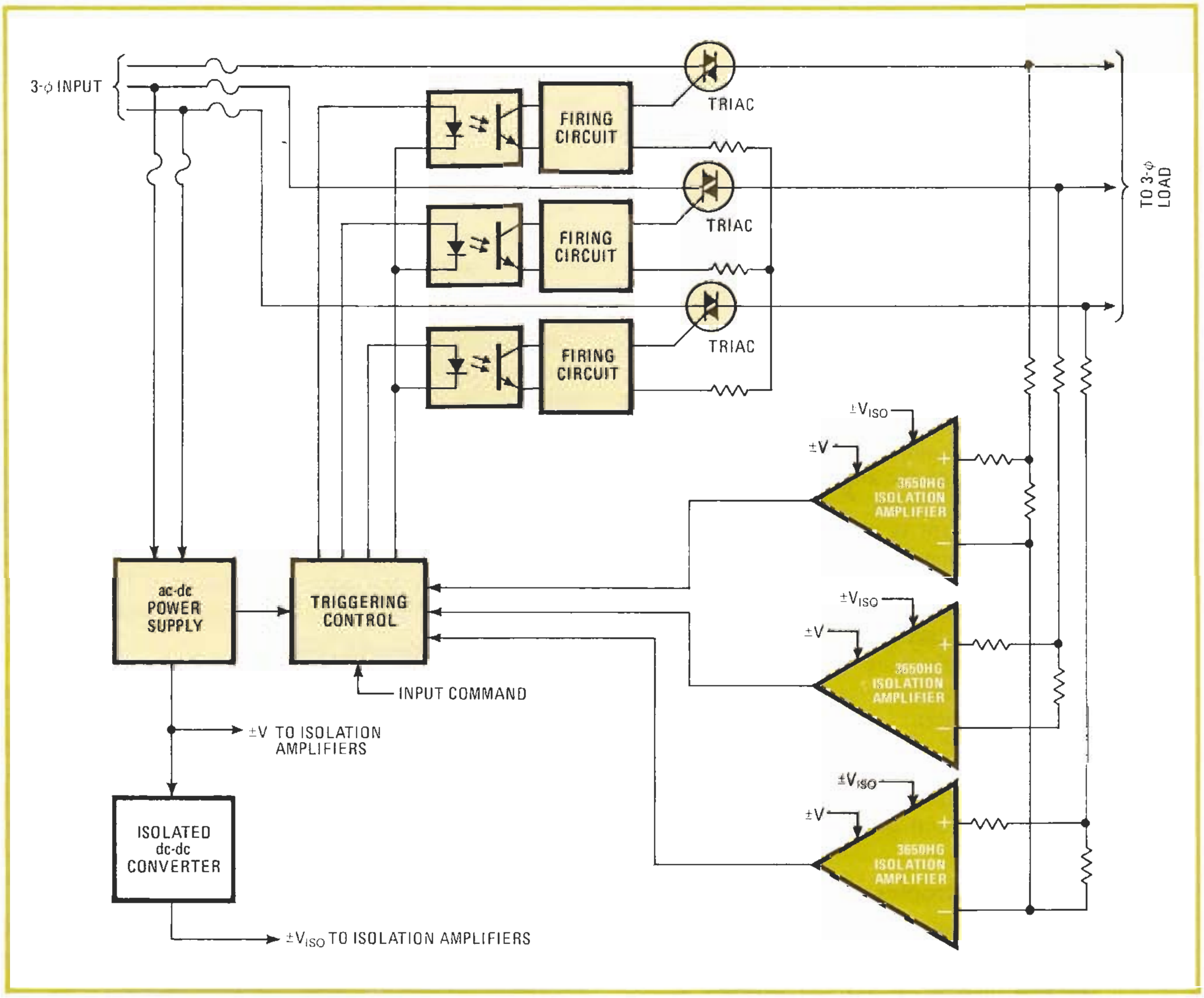
Controlling industrial motors

Because of their low phase shift, optical isolation amplifiers are also suitable for motor-control applications. In the circuit of Fig. 6, two devices are isolating the drive circuitry from the sensing circuitry for a dc motor requiring an armature voltage of 500 V. This sort of circuit is frequently needed in industrial situations because ground connections are usually dictated by safety considerations, rather than the convenience of the design for the motor-control circuit.

Amplifier A_1 delivers an isolated output that is 1% of the armature voltage ($V_A/100$) to the voltage-sensing portion of the motor-control circuitry. Gain-setting resistors R_{G1} and R_{G2} fix A_1's gain at unity, while resistors R_1, R_2, and R_3 simply serve as a voltage divider, and R_3 permits fine adjustment of the gain. Amplifier A_2 develops an isolated output for the current-sensing portion of the control circuit by amplifying the voltage (V_S) across shunt resistor R_S, which parallels the amplifier's differential input. The gain of A_2 is set at approximately 100 by resistors $R_{G1'}$ and $R_{G2'}$, with resistor R_4 to provide fine gain adjustment. A single dc-dc converter is used to generate the isolated power-supply voltage for both amplifiers.

Controlling single- or three-phase ac loads is still another application for optical isolation amplifiers. Their broad frequency response makes them good candidates even for 400-Hz systems in which transformer-isolated devices would be too slow. In ac applications, isolation becomes necessary when the potentials between input and output are not well controlled because of lengthy wire runs and safety requirements for grounding.

In the bidirectional (triac) control circuit of Fig. 7, three optical isolation amplifiers operate from the same isolated power supply. Each isolation amplifier senses the output voltage of one phase of the line. The phases are sensed against an artificial neutral generated by the output-resistor bridge. Because of the fast frequency



7. Load control. In circuit for switching three-phase ac loads, three optical isolation amplifiers operate from the same isolated dc source. The triacs provide bidirectional control of the load, while the optical couplers guard against false triggering by transients.

response of the amplifiers, the phase-controlled ac waveform is accurately reproduced at the input of the triggering control, permitting further processing, such as averaging or root-mean-square conversion, if desired.

Observing fundamental precautions

To get the most out of any isolation amplifier, some basic guidelines should be followed:

- For low-noise applications, twisted-pair shielded input cable should be used.
- To reduce the effects of output-stage parameters on overall accuracy, the amplifier gain should be set as high as possible without saturating the input. This is a customary practice with instrumentation amplifiers.
- External capacitance across the isolation barrier should be minimized, or it will degrade the amplifier's isolation-mode rejection.
- To reduce the possibility of arc-over, external components and conductors should be located at a distance equal to or greater than the spacing between input and output pins. And in very high-voltage applications, the entire assembled circuit should be conformally coated.

In the future, optical isolation will certainly be a major factor in linear isolation-amplifier designs. Although today's devices have a limited operating-temperature range (0°C to 70°C) and their linearity is comparatively moderate, there are likely to be vast improvements in both parameters shortly. What's more, product cost will probably drop as manufacturing technology improves.

Size reductions are also well within reach. However, user acceptance of smaller units having closer pin spacing is questionable, at least for amplifiers having isolation test voltages in the 5-kv region. Layout standards, as well as just good design practice, will probably continue to keep isolation amplifiers in somewhat larger packages than other amplifier products. ☐

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Optical isolators yield benefits in many linear circuits

by Mark Hodapp, *Hewlett-Packard Co., Optoelectronics division, Palo Alto, Calif.*

☐ For eliminating noise and breaking unwanted ground loops in digital circuits, optically coupled isolators have earned a well deserved reputation. It is perhaps less well known that optical isolators also can do a fine job in analog circuits. Although the optical isolator is not strictly a linear device—the output is not necessarily linearly proportional to the input—with the right circuit techniques, the isolator's advantages can be applied to such linear tasks as sensing circuits, patient-monitoring equipment, adaptive controls, power supplies, and audio or video amplifiers.

A number of isolators are suitable

Four kinds of isolators are appropriate for linear work—the phototransistor coupler, the photodiode coupler, the transistor-amplifier coupler, and the logic-gate coupler. All of these have an infrared or near-infrared light-emitting diode as their input stage, but their outputs are different, as reflected by their names. Both the transistor-amplifer and logic-gate coupler employ photodiodes as their photodetectors, which are followed by amplifying and/or conditioning circuitry.

For strictly analog circuits, the photodiode and transistor-amplifier isolators are most effective because they are faster and more linear than phototransistor types. In the phototransistor coupler, the collector-base junction of the phototransistor serves as the photodetector, and the capacitance of this junction impairs the rise time of the signal at the collector. Also, amplified photocurrent flows in the collector-base junction and modulates the photoresponse.

In a transistor-amplifier coupler, however, the photodetector and the amplifier are separately integrated devices, so that the coupler's photoresponse is not affected by amplified photocurrent. Also, so long as the bias voltage for the photodiode remains constant, the photodiode's capacitance will not hamper isolator speed. Similarly, the photodiode coupler, which has a very small current gain, usually operates with a separate, though external, amplifier. In contrast, although the logic-gate coupler has a separate photodetector, it is difficult to bias at a stable quiescent point for analog applications—its output is usually either on or off.

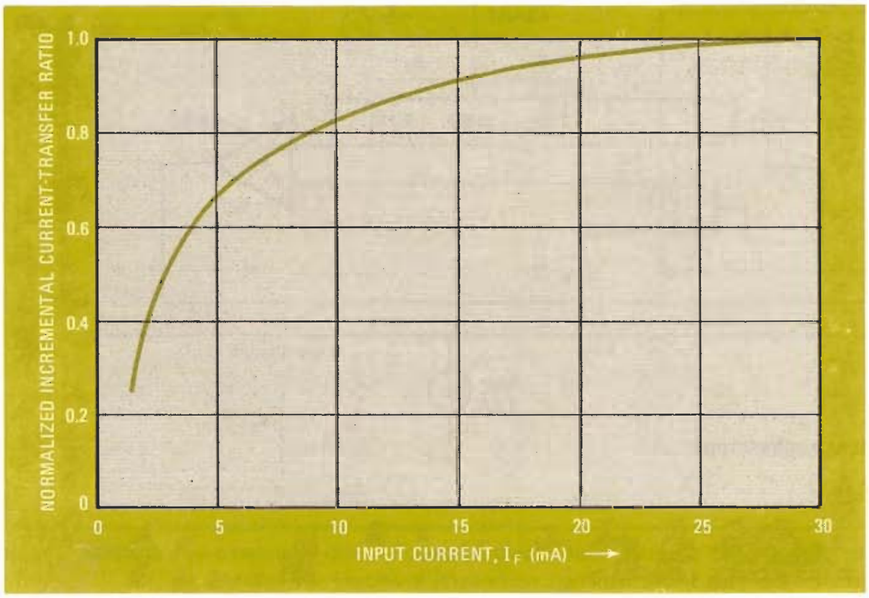
However, the logic-gate coupler is ideal for linear circuits in which analog signals are converted to digital at very high speeds. For slower rates, the phototransistor and transistor-amplifier couplers are suitable—and they usually can provide greater noise immunity. Photodiode isolators are seldom used in these linearized conversion circuits because of the output buffer they require.

Examining isolator linearity

To evaluate the linearity of an optical coupler, its transfer function can be expressed as:

$$I_o = K(I_F/I_F')^n$$

where I_o is the isolator's output current, I_F is the input current to the isolator (the forward current through its LED), I_F' is the input current (other than zero) at which K is measured, K is the output current at I_F', and n is the linearity factor. For a transistor-amplifier coupler, I_o is the collector current of the output transistor, whereas



1. Current characteristic. Linearity of optical coupler depends on where its input LED is biased. At low currents, its response is quite nonlinear. But at values of 10 mA or higher, the device's response, depicted here as $\delta I_o/\delta I_F$ becomes more nearly linear.

for a photodiode coupler, I_o is the current flowing into the cathode of the output photodiode.

The linearity factor, n, can also be thought of as the slope of the log-log curve of output current I_o vs. input current I_F. When $n = 1$, the coupler's transfer function is linear, and its current-transfer ratio, which is the current gain expressed as a percentage ($I_o/I_F \times 100\%$), becomes constant. Similarly, when $n = 1$, the device's incremental current-transfer ratio, or the ratio of the change in output current to the change in input current ($\delta I_o/\delta I_F$), is constant and independent of the input current level, as shown in Fig. 1.

A LED's emission is nonlinear, particularly at low input-current levels. For low values of I_F, say, 5 milliamperes or less, n is usually equal to or greater than 2. At higher input currents, the response of a LED becomes essentially linear. Usually, at an I_F value of 10 mA or more, n approximately equals 1.

More than one coupler may be needed

An analog isolation amplifier is used to transfer a low-level ac or dc signal from one ground reference to another in the presence of a large potential difference or induced noise. Since a dc reference must be maintained in a direct-coupled isolation amplifier, the quiescent input current to the optical coupler is normally set at some low level to minimize the device's thermal drift. As a result, two couplers are usually needed for a direct-coupled isolation amplifier, so that each balances out the other's nonlinearity. This balance can be achieved by means of either servo or differential techniques.

On the other hand, an ac-coupled isolation amplifier needs only a single coupler if it is biased properly because there is no need to maintain a dc reference. The isolator's input LED can be biased at some high current level where the isolator's transfer function is more nearly linear.

For the servo-type dc isolation amplifier of Fig. 2, the input current of one isolator is made to track the input current of a second isolator. To do this, the couplers must be matched—that is, their linearity factors must be equal. Here, a single dual-channel transistor-amplifier isolator is used, and the matching is good, since both couplers are fabricated at the same time.

Building a servo amplifier

The input signal is applied to the noninverting input of amplifier A_1, which drives the LED of the upper isolator. The LED of the lower isolator is driven by amplifier A_2, which compares the outputs of the two couplers and forces the forward current through each LED to be equal. The output current of the upper isolator can be written as:

$$I_{C1} = K_1(I_{F1}/I_{F1}')^{n_1}$$

where I_{C1} is the collector current of the isolator's output transistor, I_{F1} is the forward current through the input LED, K_1 is the output current for an input current of I_{F1}', and n_1 is the linearity factor. Similarly, the output current of the lower isolator is:

$$I_{C2} = K_2(I_{F2}/I_{F2}')^{n_2}$$

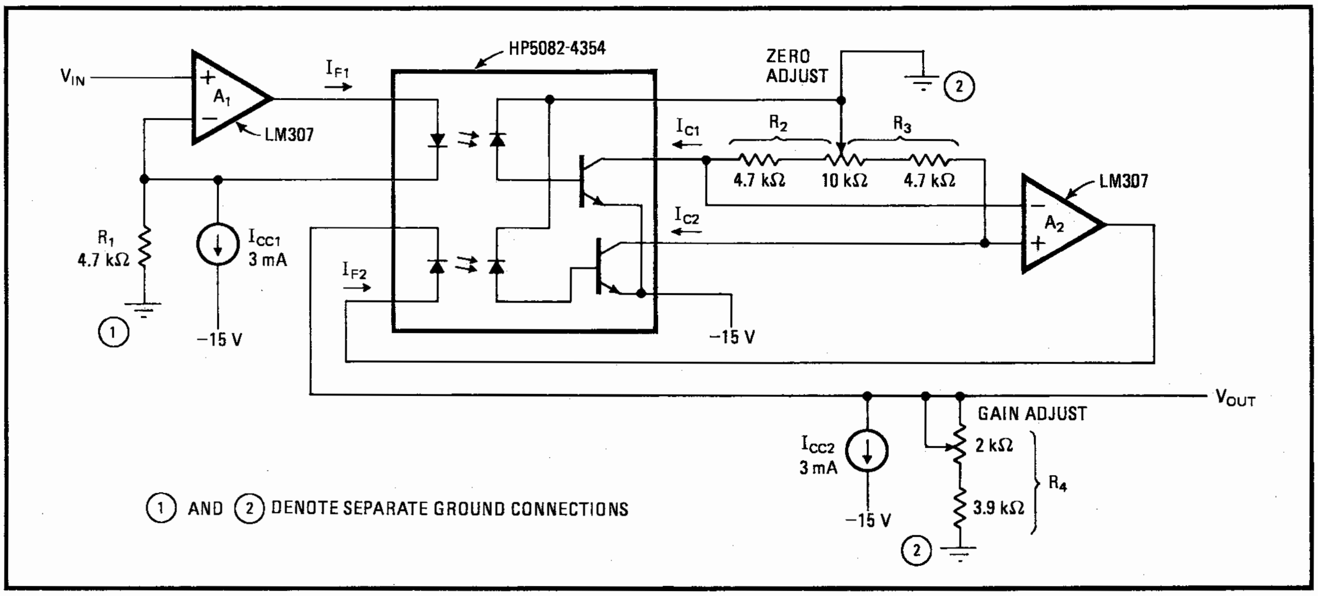
where I_{C2} is the collector current of the isolator's output transistor, I_{F2} is the forward current through the input LED, K_2 is the output current for an input current of I_{F2}', and n_2 is the linearity factor.

The transfer function for the circuit is:

$$V_{OUT} = R_4\left[I_{F2}'(I_{F1}')^{-n_1/n_2}\left(\frac{K_1R_2}{K_2R_3}\right)^{1/n_2}\right.$$

$$\left.\left(I_{CC1} + \frac{V_{IN}}{R_1}\right)^{n_1/n_2} - I_{CC2}\right]$$

where V_{OUT} is the circuit's output voltage, V_{IN} is the circuit's input voltage, I_{CC1} is the value of the constant-current source for the upper isolator's LED, and I_{CC2} is the value of the constant-current source for the lower isolator's LED. Some simple ways of realizing these con-



2. Dc servo amplifier. Dual-channel transistor-amplifier coupler provides input-to-output isolation of 500 V for servo-type amplifier. Isolator input currents are forced to track each other, and since the couplers are matched, nonlinearity is virtually eliminated.

stant current sources are shown in "Some biasing basics," p. 110. After the circuit's null point has been adjusted, this transfer function can be expanded:

$$V_{OUT} = R_4 I_{CC2}\left[\frac{n_1}{n_2}\left(\frac{V_{IN}}{R_1 I_{CC1}}\right)\right.$$

$$\left. + \frac{n_1}{n_2}\left(\frac{n_1}{n_2} - 1\right)\left(\frac{V_{IN}}{R_1 I_{CC1}}\right)^2 / 2! + \ldots\right.$$

When n_1 and n_2 are approximately equal as in these matched couplers, all the higher-order terms of this expression become very small, so that the transfer function is essentially linear.

The output voltage, V_{OUT}, for the servo amplifier can also be written as a generalized proportionality:

$$(1+x)^{n_1/n_2} - 1$$

where x is the ratio of modulation current to quiescent current for the upper coupler's input LED:

$$x = (V_{IN}/R_1)/I_{CC1}$$

The nonlinearity, or linearity error, of the entire circuit can then be expressed as:

$$[(1+x)^{n_1/n_2} - (n_1/n_2)x - 1]/(n_1/n_2)x$$

For this circuit, x is less than or equal to $|0.35|$ and $n_1/n_2 = 1.05$, so that the linearity error can be computed as 0.99%.

Resistor R_1 determines the input range of the circuit. For the R_1 value of 4.7 kilohms given here, current I_{F1} varies between 2 and 4 mA as the input voltage ranges between −5 and +5 volts. The circuit's null point is zeroed by adjusting the ratio of resistor R_2 to resistor R_3. For unity-gain operation, R_4 is varied until $V_{OUT}/V_{IN} = 1$ when V_{IN} is at some value other than zero. Both resistors R_2 and R_3 should be selected to accommodate the worst-case spread between isolator current-transfer ratios.

The bandwidth of the circuit is limited by its operational amplifiers to about 25 kilohertz. Common-mode rejection is 46 decibels at an input frequency of 1 kHz, and temperature stability is good—gain drift is held to −0.03%/°C, offset drift to ±1 millivolt/°C. Insulation of the dual-channel coupler is limited by the spacing between its package pins. If separate couplers are used instead, the insulation can be increased to around 2,500 V.

Handling differential dc signals

For a differential-type dc isolation amplifier like the one shown in Fig. 3, the input current of one isolator is increased by the same amount that the input current of a second isolator decreases. In other words, the rise of current gain in one isolator is approximately balanced by a gain reduction in the other. Of course, the couplers must be matched with the same linearity factors, so that their gains change by an equal amount over the same operating range. Again, a dual-channel transistor-amplifier isolator is used.

Amplifiers A_1 and A_2 act as a differential-input pair, while amplifiers A_3 and A_4 form a differential current amplifier. The circuit's output voltage can be written as:

$$V_{OUT} = R_5\,[(R_3/R_4)I_{C1} - I_{C2}]$$

where:

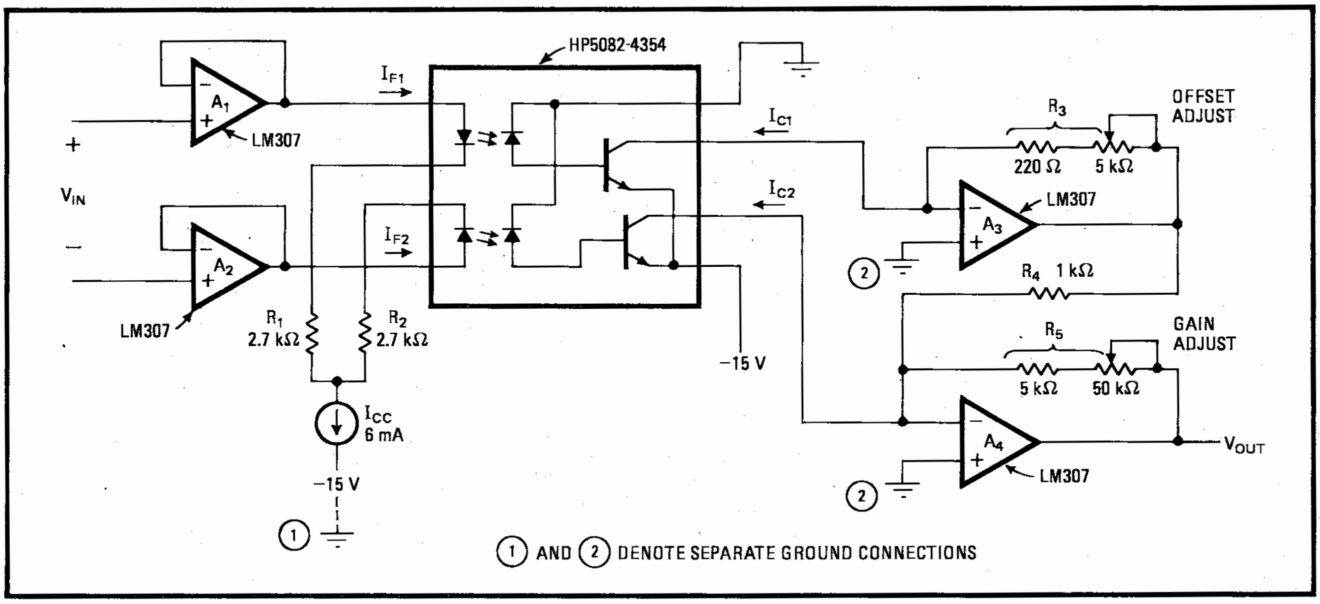
$$I_{C1} = K_1(I_{F1}/I_{F1}')^{n_1}$$

for the upper isolator, and:

$$I_{C2} = K_2(I_{F2}/I_{F2}')^{n_2}$$

for the lower isolator. Since the values of resistors R_1 and R_2 are the same ($R_1 = R_2 = R$), then the transfer function for the circuit can be expressed as:

$$V_{out}' = R_5\left[\frac{R_3K_A}{R_4}\left(1+\frac{V_{IN}}{RI_{CC}}\right)^{n_1} - K_B\left(1-\frac{V_{IN}}{RI_{CC}}\right)^{n_2}\right]$$



① AND ② DENOTE SEPARATE GROUND CONNECTIONS

3. Dc differential amplifier. Because of matched characteristics of dual-channel transistor-amplifier coupler, an increase in current gain of one isolator is balanced by an identical gain reduction in the other. Linearity error is held to around 3% over 10-V input range.

where:

$$K_A = K_1(I_{CC}/2I_{F1}')^{n_1}$$

and:

$$K_B = K_2(I_{CC}/2I_{F2}')^{n_2}$$

and I_{CC} is the value of the constant-current source biasing the input LEDs of the coupler. After the circuit's zero has been adjusted, this transfer function can be written as:

$$V_{OUT} = R_5K_B\Big[(n_1 + n_2)\left(\frac{V_{IN}}{RI_{CC}}\right) + [n_1(n_1 - 1) - n_2(n_2 - 1)]\left(\frac{V_{IN}}{RI_{CC}}\right)^2 / 2! + \ldots$$

Since the couplers are matched, n_1 is approximately equal to n_2, the higher-order terms of this expression become very small, and the transfer function can be regarded as linear.

When expressed as a generalized proportionality, the output voltage, V_{OUT}, for the differential amplifier is proportional to:

$$(1+x)^{n_1} - (1-x)^{n_2}$$

where x is the ratio of modulation current to the quiescent current of the isolators' input LEDs:

$$x = (V_{IN}/R)/I_{CC}$$

The linearity error of the circuit can be computed from:

$$[(1+x)^{n_1} - (1-x)^{n_2} - (n_1+n_2)x]/(n_1+n_2)x$$

For the circuit of Fig. 3, x is less than or equal to $|0.35|$, $n_1 = 1.9$, and $n_2 = 1.7$. The linearity error, then, is around 2.8% when the linearity factors of the isolators are matched to about 12%. If the linearity factors are within 5% of each other, the circuit's linearity error can be reduced to less than 1.5%.

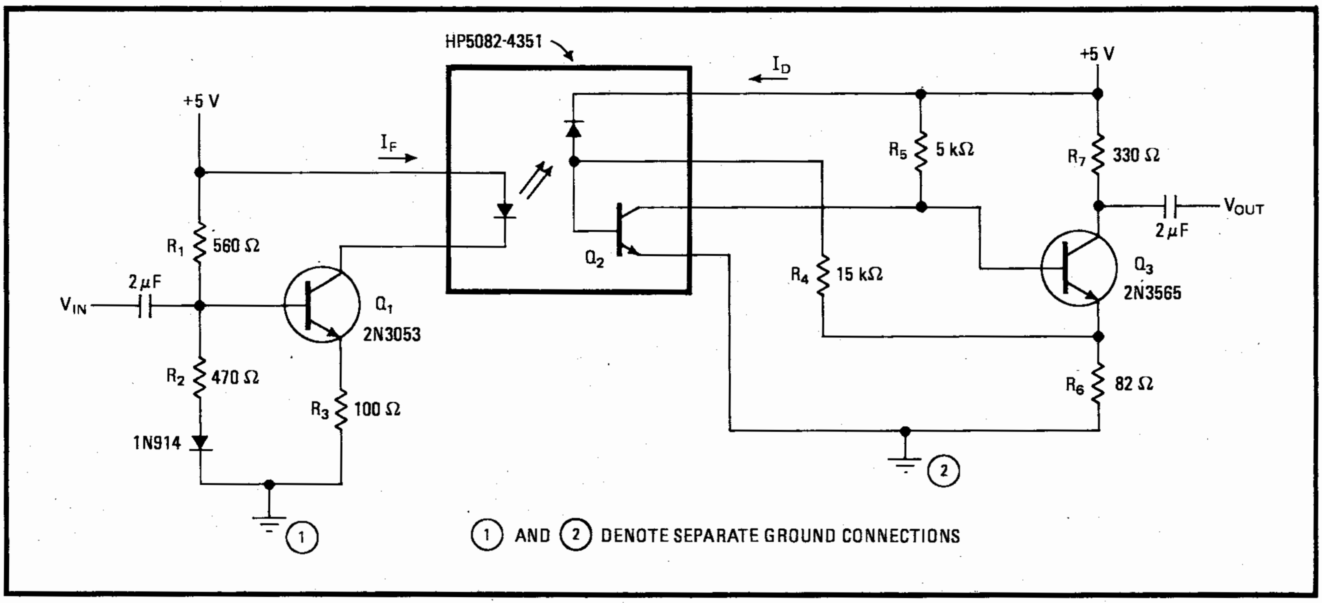
Resistors R_1 and R_2, which set the circuit's input range, must have the same resistance value. Here, they limit the current to the isolator's LEDs to between 2 and 4 mA over the input range of −5 to +5 V. Resistors R_3, R_4, and R_5 are selected to handle the worst-case spread in isolator current-transfer ratios and to set the circuit's total gain at unity.

As an alternative to a dual-channel transistor-amplifier coupler, a pair of individual transistor-amplifier or photodiode isolators can implement either a servo or differential isolation amplifier. Although it is essential for the couplers to have the same linearity factor (n), they need not have identical output currents (K) for the same input current (I_F'). However, when the K or current-transfer ratio of each coupler is equal, it is easier to zero the isolation amplifier.

In addition, both couplers should exhibit similar behavior as the temperature changes. In the servo amplifier, changes in the current-transfer ratios of the isolators have only a small effect on total gain and offset, so long as the ratio of the isolators' current gains stays the same when the temperature changes.

However, in the differential amplifier, a change in either isolator's current-transfer ratio caused by a temperature change will cause the circuit's gain to change. Such a change in gain can be compensated for by placing a thermistor in the circuit's output differential current amplifier. Output offset, referenced to the input, will be stable as long as the ratio of the isolators' current gains remains constant during temperature changes.

To prevent the capacitance of the photodiode detector in either a photodiode or transistor-amplifier coupler from impeding isolator speed, the photodiode should always be biased on a constant voltage. In a direct-coupled isolation amplifier, the speed of a transistor-amplifier coupler is also limited by the capacitance of the base-collector junction of its output transistor. Similarly, the speed of a photodiode coupler is also limited by how quickly it can operate into its external circuit.



4. Isolating ac signals. For ac-coupled isolation amplifier, optical isolator is biased at high input level, where its transfer function is essentially linear. Here, with single transistor-amplifier coupler, linearity error is typically 2% over 1-V peak-to-peak input range.

For an ac-coupled isolation amplifier, the optical coupler can be biased at a current level higher than that for a dc isolation amplifier. The isolator's incremental current-transfer ratio, therefore, remains fairly constant. The isolator's transfer function is essentially linear (n = 1), so that only a single coupler is needed.

Working with the ac analog signal

The ac isolation amplifier of Fig. 4, is built with a transistor-amplifier coupler. The transfer function for this circuit is simply:

$$V_{OUT}/V_{IN} = (1/R_3)(R_4R_7/R_6)(\delta I_D/\delta I_F)$$

where I_D is the photodiode current, and I_F is the forward current though the LED. As long as $\delta I_D/\delta I_F$ is constant, this transfer function is linear.

Transistor Q_1—along with resistors R_1, R_2, and R_3—bias the isolator's LED at a quiescent current of 20 mA. Resistor R_3 determines the circuit's input range. Here, the LED current varies from 15 to 25 mA over an input range of 1 V pk-pk. Transistors Q_2 and Q_3 form a cascade amplifier having feedback paths through resistors R_4 and R_6. The circuit's closed-loop gain can be adjusted with resistor R_4, while resistor R_6 should permit transistor Q_3 to operate at its maximum gain-bandwidth product. Resistor R_5 simply provides a dc bias path for transistor Q_3, and resistor R_7 limits the maximum excursions of the circuit's output voltage without clipping it.

Linearity error for this circuit is typically 2% over its 1-V pk-pk input range. At the expense of signal-to-noise ratio, the linearity can be improved by reducing the excursions of the isolator's input current. To do this, the value of the resistor R_3 is increased, and an additional resistor is connected between the collector of transistor Q_1 and ground. Its value should return the LED bias current to 20 mA quiescent.

A photodiode coupler is also suitable for building an ac isolation amplifier. But whether the coupler is a photodiode or transistor-amplifier type, its photodiode detector must be biased at a constant voltage for optimum isolator speed.

In the ac-coupled amplifier, the input diode of the optical isolator is biased at a fixed quiescent current and the circuit's output amplifier has negative feedback for stable gain. Since this circuit has no feedback around the isolator, any parameter that causes the coupler's incremental current-transfer ratio to vary will cause a change in the gain of the circuit. Because the photon emission of the coupler's input diode varies with temperature, the coupler's current gain will also vary with temperature. However, a thermistor can be used in the circuit's output amplifier to compensate for this change in gain.

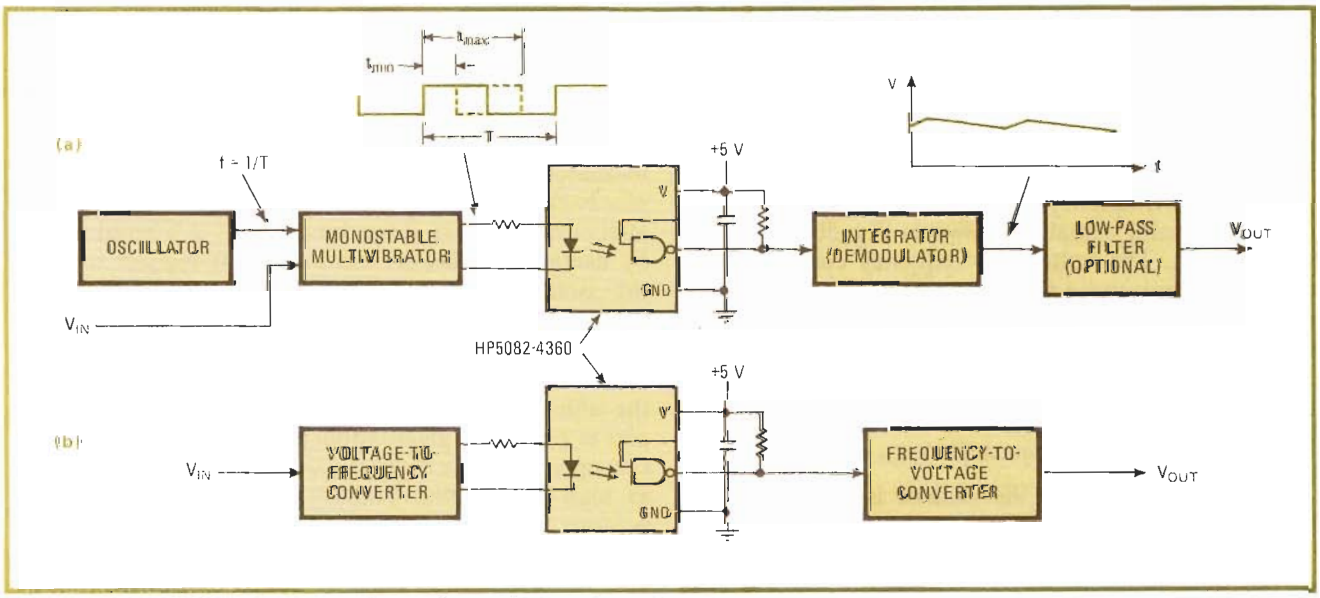
Exploring various digital techniques

With conventional ac and dc analog-isolation techniques such as those discussed above, the least linearity error that can be achieved with optical couplers is limited to 0.5% to 1%. For better linearity, as well as improved temperature stability, digital techniques are needed.

The analog signal is converted to a digital one, transmitted through an optical isolator, and then converted back again. Since the isolator acts only as a switch, the total linearity of circuit depends primarily on how accurately the analog-to-digital and digital-to-analog conversions are made. The circuit's bandwidth, however, is limited by the isolator's propagation delay.

Figure 5 shows a pulse-width-modulation technique for isolating an analog signal with a logic-gate coupler. The oscillator operates at a fixed frequency (f), and the monostable multivibrator varies the duty factor of the square wave from the oscillator, producing a signal that is proportional to the input (V_{IN}).

The maximum frequency of the oscillator is determined by the required linearity of the circuit and the propagation delay of the optical isolator: $(t_{max} - t_{min}) \times$



5. Digital yet analog. Logic-gate coupler can be used to transfer analog data that has been converted to digital form. Analog signal can be pulse-width modulated, as in a, or converted into train of pulses whose frequency is proportional to input level, as in b.

Some biasing basics

When an optically coupled isolator is used in a direct-coupled isolation amplifier, its input light-emitting diode must be biased by a constant-current source. Although the regulation of this source is important, the circuit need not be an elaborate design—a simple one will work just as well.

If the supply voltage is stable, the current source can be a mirror-type circuit, built with a pair of npn or pnp transistors, as shown in a. The output current is approximately:

$$I_o = (V_{CC} + V_{EE} - V_{BE})/R$$

where V_{CC} is the positive supply voltage, V_{EE} the negative supply voltage, and V_{BE} the base-emitter voltage of transistor Q_1.

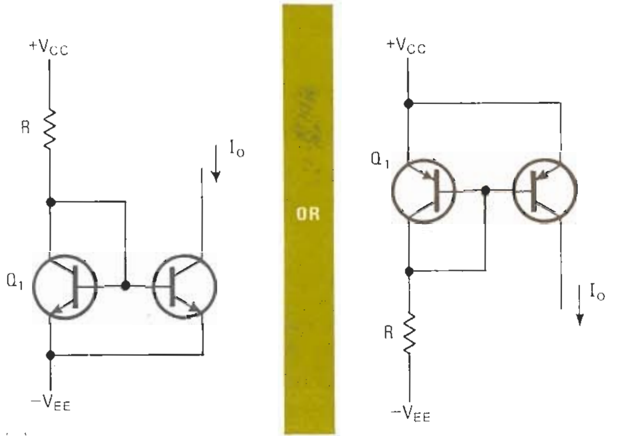
If the supply voltage is not stable, an LED can be used as an effective, yet simple and inexpensive, voltage regulator. As illustrated in b, the current source can be built with either an npn or pnp transistor. The LED compensates the transistor for changes in temperature because the temperature coefficient of the LED's forward-voltage drop is approximately equal to that of the transistor's base-emitter voltage. Usually, this junction-voltage drift with temperature changes is about –2 millivolts/°C. The value of resistor R can be computed from:

$$R = (V_{CC} + V_{EE} - V_F)/I_F$$

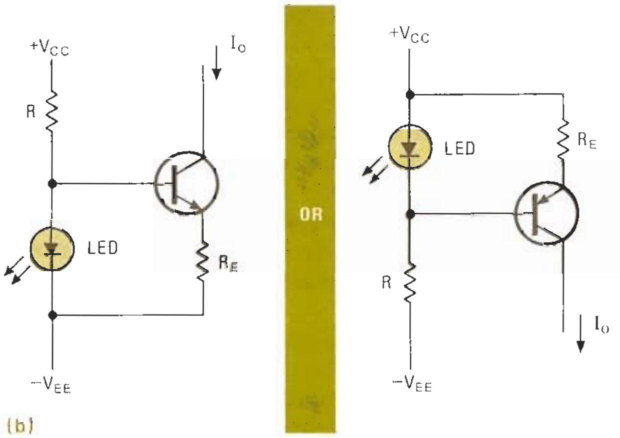
where V_F is the forward-voltage drop of the LED, and I_F is its forward current. The circuit's output current can simply be expressed as:

$$I_o = (V_F - V_{BE})/R_E$$

where V_{BE} is the base-emitter voltage of the transistor.



(a)



(b)

(required linearity) must be greater than or equal to $|t_{PLH} - t_{PHL}|$, where t_{max} is the maximum pulse width of the modulated signal, t_{min} is the minimum pulse width of the modulated signal, t_{PLH} is the propagation delay of the isolator as its output switches from logic low to logic high, and t_{PHL} is the isolator propagation delay for an output transition from logic high to logic low.

After the modulated signal passes through the isolator, it is converted back to the original analog signal by means of a demodulator. Here, the demodulator is the integrator and optional low-pass filter.

Voltage-to-frequency conversion can also be used to isolate an analog signal, as shown in Fig. 5b for a logic-gate coupler. The voltage-to-frequency converter produces an output-pulse train having a frequency proportional to the level of the analog input. The maximum rate at which the pulse train can be transmitted through the optical isolator is limited by the coupler's propagation delay:

$$f_{max} \text{ approximately equals } [1/(t_{PLH} + t_{PHL})]$$

The output signal from the isolator is then converted back to an analog voltage by a frequency-to-voltage converter. The linearity of the complete system is mainly determined by the linearity of the converter circuits.

Frequency modulation, which is similar to voltage-to-frequency conversion, is yet another technique for transferring an analog signal through an optical isolator. By this method, a carrier frequency (f_0) is modulated by some change in frequency (Δf_0) so that the $f_0 \pm \Delta f_0$ is proportional to the analog input. The original signal can then be reconstructed at the output of the isolator with a phase-locked-loop or similar circuit.

Analog-to-digital converters also enable optical couplers to isolate analog signals. The binary output from an a-d converter drives an optical coupler, and a digital-to-analog converter changes the output from the coupler back to analog form. If the a-d converter has a parallel output format, it can be changed to a serial format by using a parallel-in/serial-out shift register to drive the isolator. When high resolution is needed, this method is useful, as well as economical, since it saves the expense of several isolators.

The rate at which data must be transmitted through the isolator more or less determines which type of coupler is best for a given application. Logic-gate couplers can operate at the highest speeds, attaining frequencies as high as 10 MHz. Transistor-amplifier isolators can achieve data rates as fast as 1 MHz, while phototransistor devices have a top speed of around 100 kHz. Usually, noise immunity must be traded off against speed—the faster the coupler operates, the lower its noise immunity will be. ☐

Matched optical couplers stabilize isolation circuit

by Arnold Nielsen
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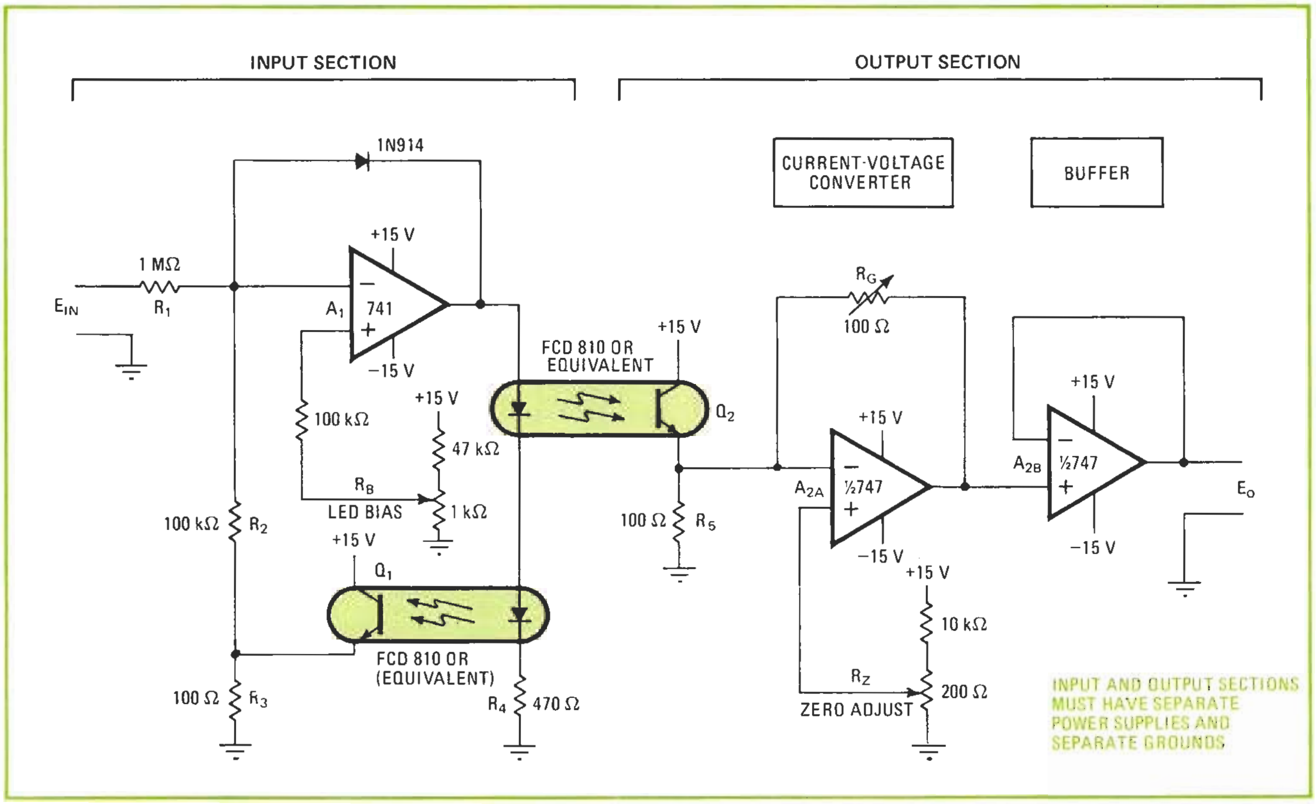
Temperature independence in an isolation circuit can be achieved by using a matched pair of optical couplers. In any optocoupler, the transfer characteristic is a function of T, and therefore the gain of an isolator with a single coupler depends on the temperature. But a second coupler in a feedback arrangement can cancel out temperature effects if the thermal characteristics of the two couplers are alike.

As the diagram shows, the light-emitting diodes of the two couplers are connected in series so that an input signal causes the same current to flow through both of them. One LED couples the input section of the circuit to the output section, and the other LED provides the feedback path that stabilizes the circuit. Thus, any temperature effect that changes coupling to the output section also changes the amount of feedback so that over-all circuit gain remains constant. The feedback also compensates for coupling nonlinearity.

A voltage from the LED bias potentiometer is fed to the noninverting-input terminal of operational amplifier A_1. This voltage, amplified through A_1, sets the LEDs in their most linear operating range. When an input signal is applied to the inverting terminal, operational amplifier A_1 drives the LEDs to a level at which collector current from Q_1 makes $I_{R2} = I_{R1}$, so that the inverting input is at virtual ground. (The 1N914 diode protects the LEDs against negative overvoltages; it is not part of the feedback circuit for A_1.) Because the LEDs are in series and are matched, $I_{R3} = I_{R5}$.

In the output section, the collector-to-base capacitance of Q_2 tends to decrease the frequency response of the circuit. This tendency is overcome by operating op amp A_{2A} in the current-to-voltage-converter mode, which maintains the signal voltage at the inverting input of A_{2A} and across Q_2 at virtual ground. Amplifier A_{2B} provides buffering at the output. The output voltage, E_O, is given by

$$\begin{aligned} E_O &= I_{R5}R_G = I_{R3}R_G \\ &\approx (R_2 + R_3)I_{R2}R_G/R_3 \\ &\approx (R_2 + R_3)E_{IN}R_G/R_1R_3 \end{aligned}$$



Stabilized by feedback. To avoid ground loop in instrumentation system, isolation between input and output is provided by optical coupling and by use of separate power supplies for each section. Temperature-sensitivity of optocoupler is compensated by second coupler in feedback loop of input op amp. The light-emitting-diodes are forward-biased for best linearity, and the feedback circuit further cancels nonlinear effects. Circuit operates with input signals of 0 to ±3 V at frequencies from dc to 50 kHz. Gain is 0.1 for circuit shown.

Therefore the gain (or attenuation) of the circuit can be stated as

$$E_O/E_{IN} \approx (R_2 + R_3)R_G/R_1R_3$$

For the component values shown in the diagram, the gain is approximately 0.1.

When the circuit is turned on, a sine wave is fed into the input. The output is displayed on a scope, and R_B is adjusted for symmetrical clipping as the signal amplitude is raised to 3 V. Then the input terminals are short-circuited, and potentiometer R_Z is adjusted so that the output voltage is zero. Finally, a 1-V signal is applied to the input, and R_G is adjusted to give the desired output level (0.1 V in this example). The gain then remains constant to within ±5% for any operating temperature between 0°C and 80°C.

The input signal can have any value from 0 to ±3 V, and the frequency response is determined mainly by the op amps used. The circuit shown here operates from dc to 50 kilohertz, where the signal is down 3 dB. The degree of isolation depends on the isolation resistance of the power supplies used for the input and output sections of the circuit. Therefore, power supplies that have high isolation resistance and electrostatic shielding are recommended, especially at low-millivolt signal levels. Isolation of at least 80 dB should be achieved without difficulty.

This circuit can be used as a single isolation amplifier or as part of a signal-distribution system. In the system application, one signal is common to all of the input sections, but the output sections are completely isolated from one another. □

Optocoupler converts ac tone to digital logic levels

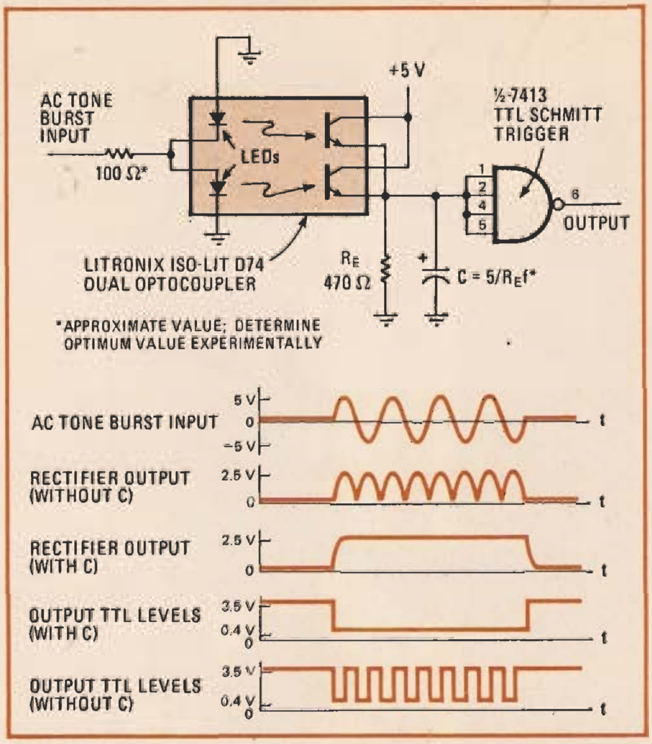
by Louis E. Frenzel
Heath Co., Benton Harbor, Mich.

In some tone signaling, telemetry, and data communications applications, it is necessary to convert an ac tone burst or a few consecutive sine-wave cycles into a logic pulse of the same duration. This can be done by rectifying and filtering the tone burst, then shaping it as required to develop the binary logic levels. In the circuit described here, the rectification of audio-frequency signals is performed by optical couplers—an approach that uses a minimum of components and therefore ensures low cost, high reliability, and small size.

A dual optocoupler using LEDs and phototransistors is connected so that it operates as a full-wave rectifier. The advantage of an optocoupler here is that the usual push-pull ac signal source (center tapped transformer, two op amps, etc.) is not required, considerably reducing the circuit's size, weight, and cost.

The ac tone burst can be applied directly to the LEDs in the optocoupler, as shown, if enough signal power is available. Otherwise, an amplifier can be used; a 741 op amp works well. The two LEDs in the coupler conduct on alternate half-cycles of the ac input, so that a pulsating dc signal is developed across emitter resistor R_E. The transistors in the optocoupler are connected as emitter followers with a common emitter resistor. Capacitor C filters the pulses across R_E into a dc level. The value of C is a function of the size of R_E, the frequency of the tone burst, f, and the size of the load. A capacitance of $5/R_E f$ is a good starting value, but it should then be adjusted for optimum results.

The dc across R_E and C is shaped by a 7413 TTL Schmitt trigger IC. The output is a clean rectangular pulse with the proper TTL logic levels, as shown in the attached waveforms.



Rectify lightly. Dual optocoupler is full-wave rectifier for ac pulse signals, driving Schmitt trigger to produce rectangular pulses at TTL logic levels. Parts count, cost, size, and weight of circuit are all low; reliability is high. Waveforms show performance and also illustrate frequency-doubler operation of circuit when capacitor is removed.

An optocoupler can be used to advantage in any application requiring full-wave rectification for frequencies well beyond the audio range.

Removing the filter capacitor from the circuit described turns the output into a series of rectangular pulses occuring at twice the frequency of the input. With this minor modification, the circuit performs as a frequency doubler. □

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Optocoupler transmits pulse width accurately

by Tadeuz Goszczyński
Industrial Institute of Automation and Measurements, Warsaw, Poland

Though optocouplers work fine in most pulse applications, shortcomings in their switching and temperature characteristics make them poor at such tasks as transmitting pulse-width modulated signals accurately. Adding an operational amplifier to the optocoupler circuit will improve its response time and reduce the effects of temperature on output voltage, enabling it to transmit a pulse width as small as 2 microseconds with an error of only 200 nanoseconds. If a second optocoupler is added to the circuit, temperature problems will be virtually eliminated.

An optocoupler is limited in its ability to transmit pulse width accurately because of two major factors: the response speed of the device is reduced by feedback currents that flow from the output port of the phototransistor to its base, and the current-transfer ratio is highly dependent on temperature. In either the emitter-follower or common-emitter configuration, an output voltage change produces the feedback current and an equal change across the collector-to-base capacitance. A certain time is required for the capacitor to charge to the voltage; this limits the response time and can cause errors in pulse-width transmission.

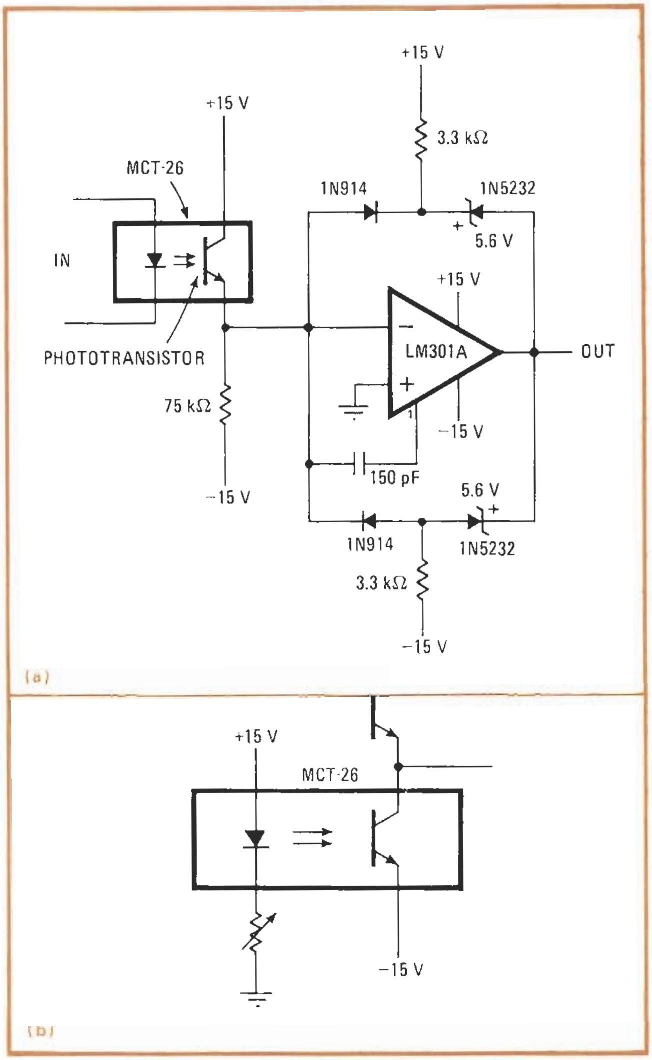
In addition, the switching times as well as the amplitude of the output pulse generated by this current source vary with temperature. All errors may be greatly reduced if the output voltage of the phototransistor is clamped to a near-zero level for any level of output current, in effect making its load resistance zero so that no feedback current is generated.

Tying a current-limiting resistor and an op amp to the output port of an MCT-26 optocoupler does the job, as shown in Fig. 1a. Two separate bidirectional feedback loops, comprising a diode in series with a 5.6-volt zener diode, are connected across the op amp. The 3.3-kilohm resistors supply sufficient bias to the zeners.

The op amp works as a zero-cross detector having essentially open-loop gain. Any signals emanating from the MCT-26 will be introduced to the LM301A op amp, causing it to saturate and switching on one of the two zeners in the feedback loop (depending on the signal polarity). The input voltage is thus forced to zero.

The switching speed of the optocoupler is high, being determined mainly by the op amp's slew rate of approximately 10 volts per microsecond. The circuit speed can thus be raised above the rated bandwidth of the optocoupler, assuming the MCT-26 equivalent load resistance is only a few ohms.

A small temperature error will still exist, because temperature variations will cause a current change in the MCT-26, and this will cause a change in the op amp's zero-crossing times. Replacing the 75-kilohm resistor with the phototransistor of another optocoupler, as shown in (b), will reduce the temperature error below 3 ns per °C. This ensures equal temperature-dependent voltage drops across both optocouplers, and with them connected as shown, the temperature-generated voltages will cancel. The op amp's temperature coefficient is negligible in comparison and need not be considered. ☐



Accurate transmission. Phototransistor passes signals to output without pulse distortion. Two feedback loops with op amp work in zero-crossing detector (a) to reduce response time and prevent feedback currents that slow circuit speed, causing errors. Replacing a load resistor by second phototransistor (b) reduces temperature-generated errors by an order of magnitude.

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TTL line drivers link fiber optics

by Vernon P. O'Neil and Imre Gorgenyi
Motorola Inc., Discrete Semiconductor Division, Phoenix, Ariz.

Designers who need to convert an existing twisted-pair communications interface into an optical-fiber link can minimize their efforts by simply combining their fiber-optic detector-preamplifiers with TTL line receivers like the industry-standard MC75107 devices. Such an arrangement has other advantages besides simplicity, namely, providing the builder with access to two receivers, complete with strobing inputs, in a single 75107. And although no similar optical line receivers are yet offered as a standard product, this interface will yield good performance at low cost. Building fiber-optic transmitters using TTL line drivers is equally simple.

The union of the 75107 with Motorola's MFOD404F optical detector is shown in (a) of the figure. The detector is packaged in a nose-cone type of fixture that can be directly mounted in standard AMP-connector bushings, making the connection to the optical-fiber cables extremely simple.

The resulting optical receiver will handle data rates of up to 10 megabits per second at a sensitivity as low as 1 microwatt. For even greater data rates, an MFOD405F can be used to extend the data-rate capacity to 50 Mb/s at a sensitivity of 6 μW.

Because the receiver is ac-coupled to the detector, it is necessary to restrict the duty cycle of incoming signals to the range of 40% to 60%. Coupling components between the detector and the 75107 are selected to ensure that the reference level developed at the input of the receiver tracks the average voltage of the input data stream. In this way the circuit self-adjusts to a wide range of input optical power levels.

At the other end of the system (b), a compatible ac-coupled optical transmitter can be constructed from an ordinary 75452 line driver. A 0-to-2-Mb/s fiber-optic transmitter suitable for handling bipolar-pulse (dc-coupled) encoded data (c) is almost as simple. ☐

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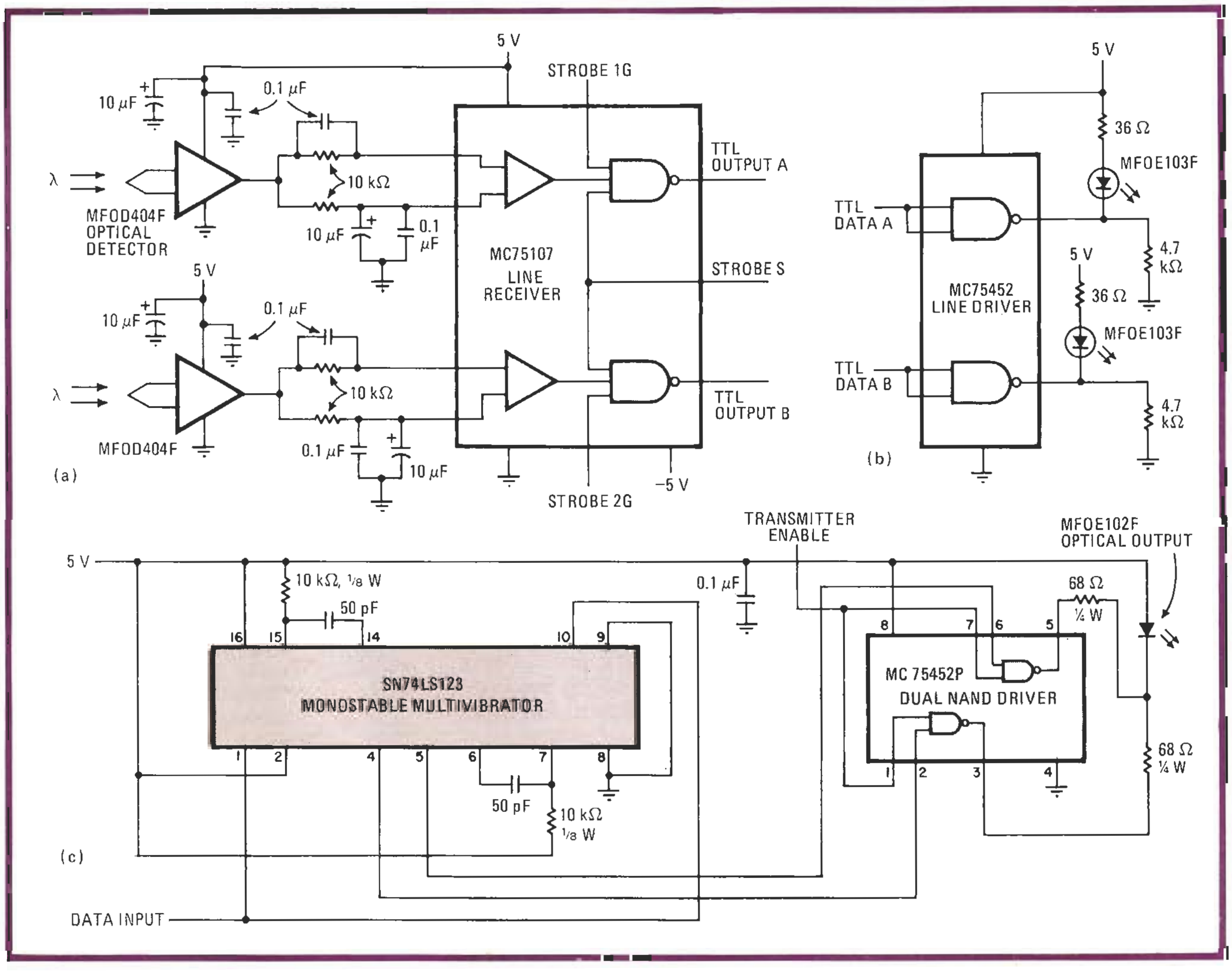
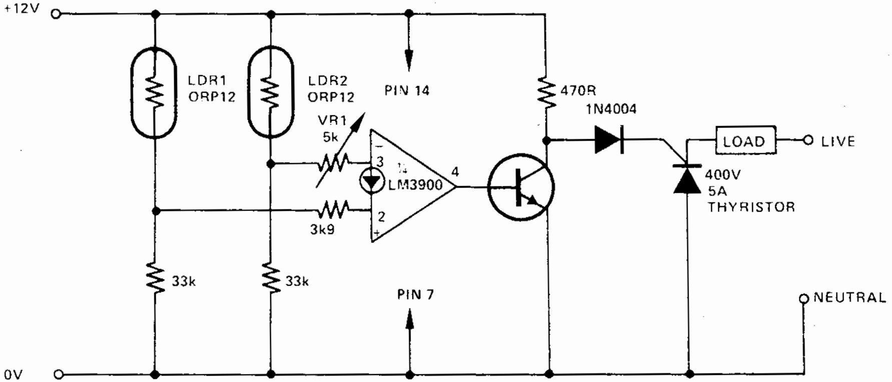


Light line. Standard line receivers such as the 75107 serve well in interface for fiber-optic systems (a). Off-the-shelf TTL line drivers at the transmitting end (b) makes possible low-cost systems. A 0-to-2-Mb/s bipolar-pulse–encoded transmitter (c) is almost as simple to build.

LDR MAINS CONTROL



This circuit is used to turn off and on a light of up to 100W. When LDR1 is shaded from any incident light it will cause the output of the amplifier to fall, thus switching of TR1 and causing the thyristor to be turned on. The light will remain on because of the introduction of LDR2, which feeds the inverting input of the amplifier.

To turn the light off, LDR2 must be shielded from the light of the bulb.

To set the circuit up it is necessary to adjust VR1 by trial and error until LDR1 turns the light on and LDR2 switches it back off, and the normal level of background illumination has no effect.

LDR1 and LDR2 should be placed in full view of the light they are switching.

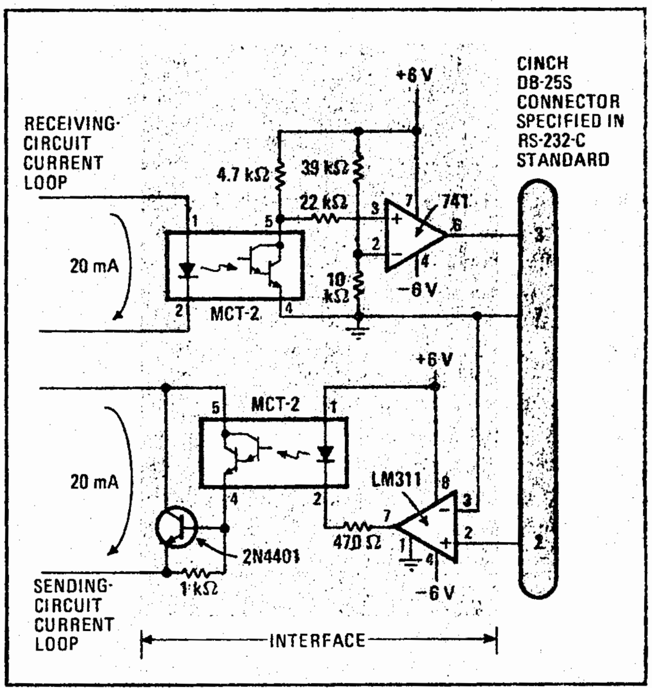
Opto-isolators couple CRT terminals to printer lines

by Andrew Longacre, Jr.
University of New Orleans, New Orleans, La.

When a terminal with a cathode-ray-tube display replaces a teleprinter terminal at the end of a full-duplex 20-milliampere current loop, the new interface is often complicated by the fact that the current loop must not be grounded at the terminal end. The University of New Orleans ran into this problem recently. It wanted to plug new CRT terminals into existing teleprinter hookups in its university-wide time-shared computer network in which the current loops are grounded at the computer. It succeeded with a simple and direct interface—receiving and sending circuits that are built round a pair of opto-isolators and take full advantage of the current driven in the loops.

Each circuit uses the 20-mA loop current to power one side of its opto-isolator. In the receiving circuit, which carries signals going to the screen of the terminal, the loop current directly drives the isolator's light-emitting diode, and the emitted light drives the integral photo-Darlington pair into saturation. ASCII-encoded signals occur as momentary interruptions in the 20-mA current, which in turn cause the photo-Darlington to cut off. The operational amplifier senses this condition and generates positive pulses corresponding to the interruptions.

The sending circuit, which carries signals coming from the keyboard, employs an analog comparator to sense the sign of the terminal's output and drive the opto-isolator LED on for the normally negative output. Once again, the light emitted from the LED saturates the photo-Darlington pair, which in turn drives the 2N4401 npn transistor into saturation so that it easily passes the 20-mA loop current. ASCII-encoded symbols occur here as positive pulses leaving the terminal, causing the LED to be turned off, the transistors to be cut off, and thus the loop current to be interrupted periodically.



Interface. Opto-isolator couples CRT-display terminal to current loops used for electromechanical teleprinters, in arrangement where loops are not grounded at the terminals. Output of the graphic terminal is compatible with RS-232-C standard, which specifies signal levels and connector types for a modem/teleprinter interface.

Two device characteristics primarily determine the maximum speed of the interface. In the receiving circuit, the output slew rate of the 741 proves the limiting factor, and the relatively low ±6-volt supplies were chosen to minimize its effect. In the sending circuit, the slowest part—indeed, the slowest link in the entire interface—is the phototransistor, which, however, would take even longer to turn off completely if it weren't for the 1-kilohm resistor.

In a closed-loop mode over more than 200 feet of cable, these interface circuits have run reliably and without errors at speeds up to 4,800 baud (480 characters per second). ☐

Low-level-light detector checks optical cables fast

by Edward W. Rummel
A. B. Dick Co., Chicago, Ill.

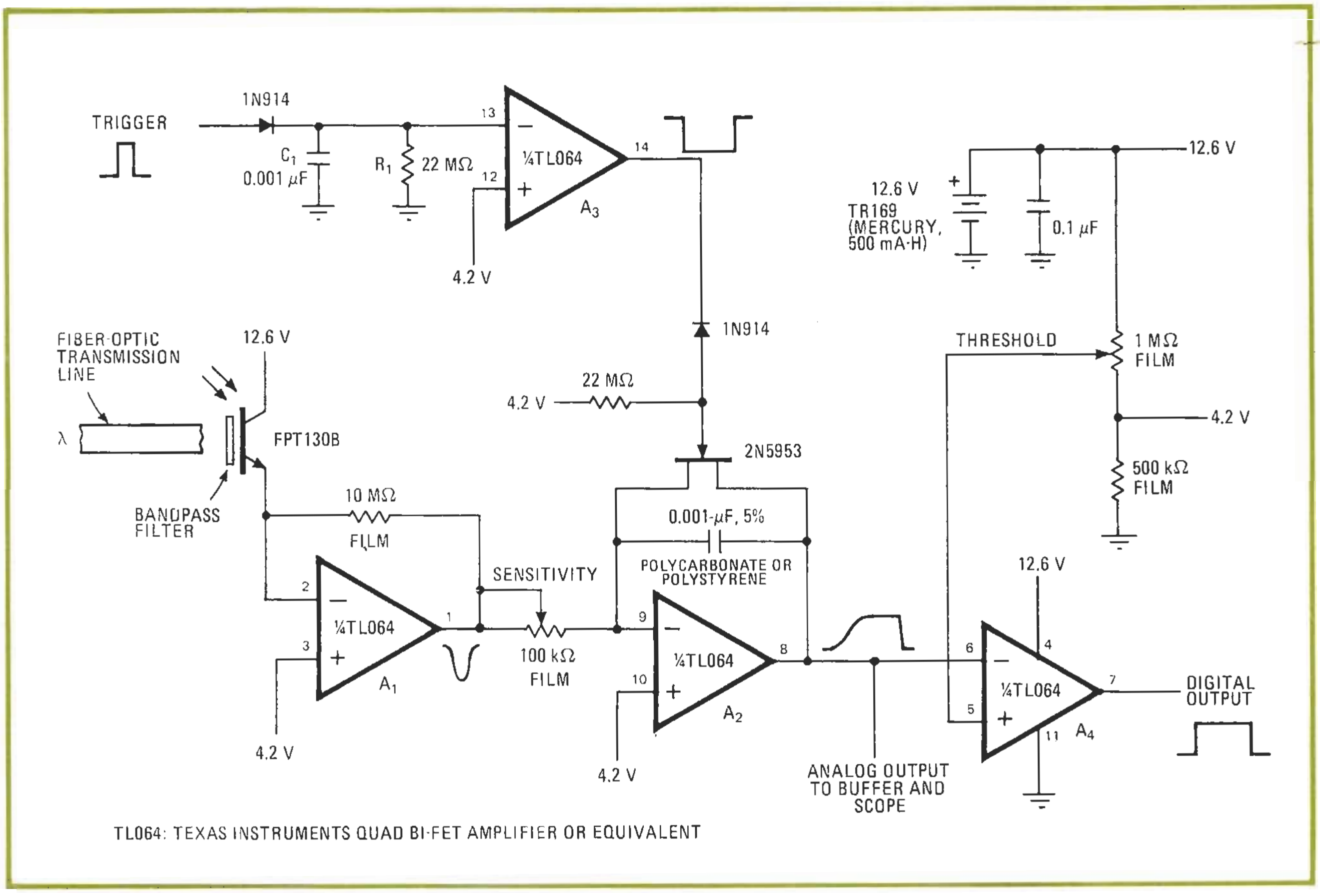
A standard phototransistor and a quad operational amplifier can be used as a total-energy detector of pulsed-light signals that propagate through fiber-optic communications systems. Such a circuit is especially useful for checking and comparing the condition of long fibers when the light intensity at the source is kept constant. Alternatively, it may detect changes in light intensity or pulse widths with a given fiber.

Current from the Fairchild FPT130B phototransistor drives A_1, a bipolar–field-effect-transistor op amp that serves as a current-to-voltage converter with an extremely high input impedance (see figure). The phototransistor has high sensitivity and a low dark current—only 10 nanoamperes flows for zero radiant-input flux. It has been given a flat lens to facilitate the addition of fiber-optic couplers, spectral band-pass filters, and so on.

This input configuration enables the circuit to give a linear response to light levels ranging from 100 to 10,000 ergs per square centimeter, provided each pulse in a given train has a width of no less than 10 microseconds. The phototransistor's low parasitic capacitances contribute to the high response speed of the circuit. The low input bias current (0.4 nanoampere) and high slew rate (3.5 volts per microsecond) of A_1 and subsequent bi-FET amplifiers also contribute to the speed and accuracy. The 100-kilohm trimming resistor at the output of A_1 is provided to eliminate the variations in sensitivity caused by the 2:1 gain spread of the combination of the phototransistor and the optical components.

A_2 is a standard RC integrator that produces a voltage directly proportional to the total light energy received. As both A_1 and A_2 operate in the inverting mode and are on the same bi-FET chip, offset voltages appearing at the output of A_1 are virtually canceled by the input offset voltage of A_2. The cascade connection of A_1 and A_2 shown also allows a high degree of freedom in the choice of source voltages for the circuit.

The low input-bias current of the bi-FET amplifiers makes it feasible to use low-value, and hence low-cost,



Light monitor. Phototransistor and bi-FET op amps form $5 light detector useful for checking optical communications systems. Circuit responds linearly to light levels in the range of 100 to 10,000 erg/cm². Circuit runs for 500 hours from a 12.6-V mercury battery.

polycarbonate capacitors. The low leakage of these capacitors preserves system accuracy. In order to limit long-term integration errors that are introduced by ambient and steady-state light or by dark-current and bias-current leakage, A_2 must be held in the reset mode by the n-channel junction FET, whose gate is connected to A_3 through a diode. Therefore, the input signal cannot be sampled continuously. The integrator is activated by applying a trigger to the JFET through A_3. A_3 stretches the trigger pulse with the R_1C_1 integrator. With the circuit values as shown, a 10-millisecond integration time will be generated from a 10-microsecond pulse.

A_2's output may be observed directly, or it can be compared to a fixed level (go/no-go indicator) through the use of A_4. The low bias current in bi-FET amplifier A_4 enables the use of a low-current resistive divider network for establishing bias and threshold levels. This in turn keeps the circuit's operating current low, enabling the circuit to work for 500 hours on a small 12.6-volt battery.

The output duration at A_4 is approximately equal to the duration of the pulse stretcher minus the time taken by the integrator to reach A_4's threshold level. The input to A_3 and the output A_4 can be made compatible with complementary-metal-oxide-semiconductor logic-level requirements by proper choice of supply voltage. ☐

Go/no-go tester checks optocoupler's transfer ratio

by S. Ashok
Rensselaer Polytechnic Institute, Troy, N. Y.

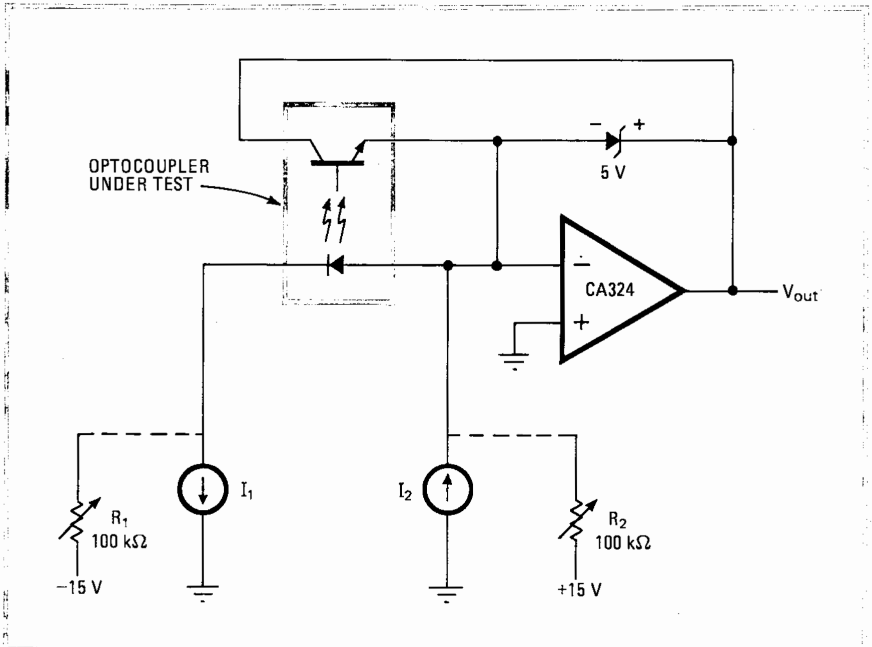
This extremely simple circuit performs a go/no-go test on the quality of an optocoupler. Here, an operational amplifier and a zener diode are used to determine if the most fundamental parameter of the optocoupler, its forward current-transfer ratio, α (which is the ratio of the phototransistor's output current to the photodiode input current), is greater or less than a preset value.

The operation of the circuit is based on the principle that the phototransistor tends to saturate if the current forced into its collector lead is less than α_i, where i is the photodiode current, and that it tends toward avalanche breakdown if the current is higher than that amount. The forced current is $(I_1 - I_2)$, where I_1 and I_2 are current sources. The preset value of α corresponding to these currents will thus be $(I_1 - I_2)/I_1$. Adequate current sources for I_1 and I_2 can be implemented by using variable resistors returned to +15- and −15-volt supplies as shown in the figure.

Typically, the phototransistor breakdown voltage is greater than 5 v, so that if the value of α is lower than the preset figure (bad optocoupler), the current into the zener-transistor combination will be greater than α_i, the 5-v zener will break down, and V_{out} will then go to 5 v (logic 1). If on the other hand, α is higher than the preset value (good optocoupler), the phototransistor will saturate and there will be a logic 0 at the output.

Note that the polarity of I_2 should be reversed if optocouplers with Darlington outputs are tested, because Darlington circuits have an α that is greater than unity.

Light test. Op amp and zener diode check optocoupler quality by determining if its forward current-transfer ratio, α, is above or below preset value. If α is above value set by current sources I_1 and I_2, phototransistor saturates and $V_{out} = 0$, indicating good element. Otherwise, the zener breaks down, and $V_{out} = 5$, indicating bad device.



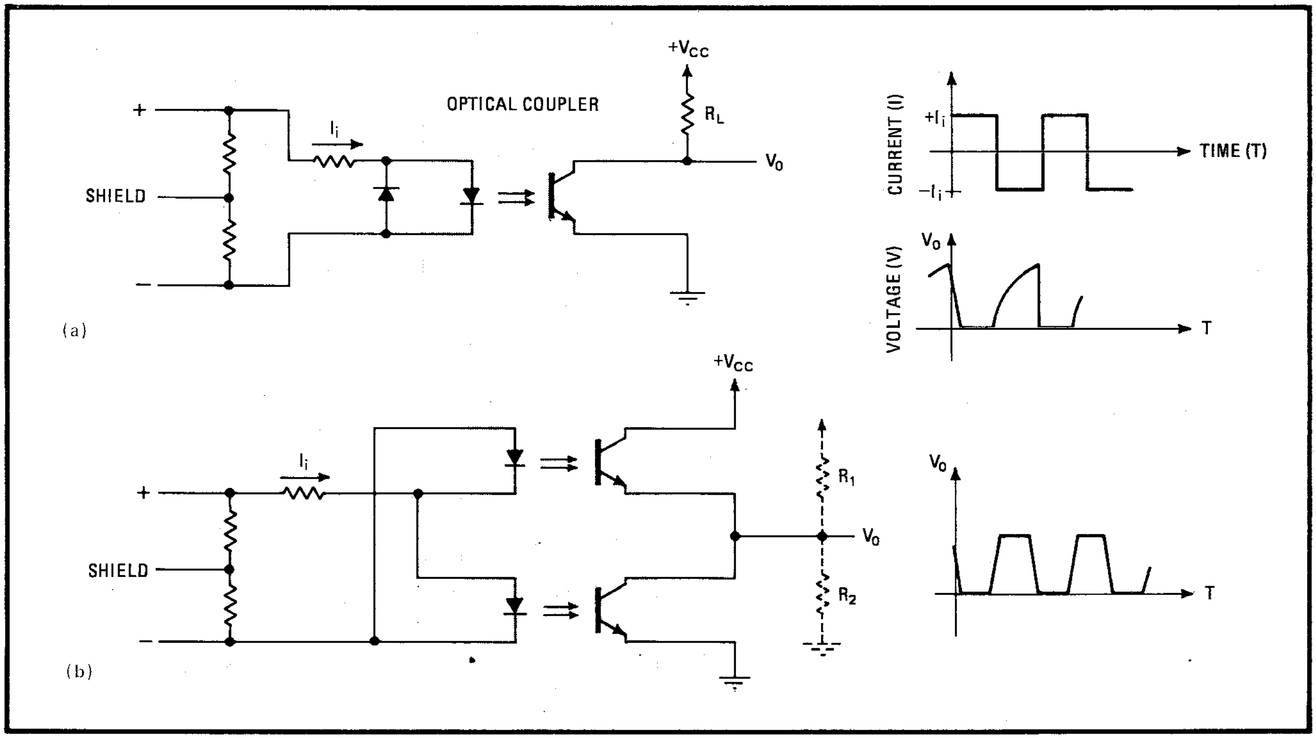
Twin optocouplers raise serial transmission speed

by Luis E. Murguis
Autotrol SA, Buenos Aires, Argentina

In a balanced 20-milliampere current loop for long-distance serial data transmission, optical couplers are a convenient way of connecting both receiver and transmitter to the transmission line, and provide isolation as well. However, an active pullup scheme employing an additional optical coupler at the receiver can improve transmission speed by an order of magnitude.

In the setup shown in (a), the fall time of the output voltage depends on the saturation current, I_i, of the coupler's input. However, the rise time of the output voltage, which determines the maximum transmission frequency, corresponds to the turn-off time of the coupler's output and is a function of load resistor R_L. Lowering the value of R_L raises the transmission rate, but only up to a limit set by the amount of current the optical coupler can handle.

Instead of trading off transmission speed and coupler loading, a second optical coupler produces a faster rise time and improves the transmission frequency almost 10 times over systems configured in the conventional way. The two optical couplers are connected as shown in (b) to produce an active pull-up and pull-down circuit at the output and thus speed up the output-voltage rise time. Both the rise and fall times are now a function of I_i, as the couplers alternate between their on and off states. Resistors R_1 and R_2 are optional and provide a fixed bias in case a circuit failure causes I_i to fall to zero. Another advantage of this circuit is that it improves fanout since a load resistor is no longer needed. □

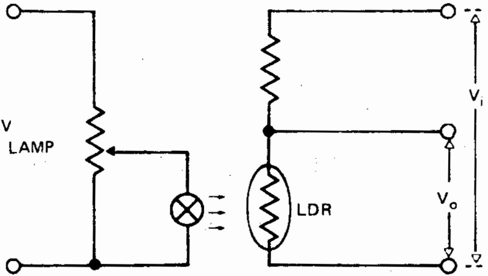


Active output. A conventional, single-coupler design for a 20-milliampere current loop (a) limits the transmission rate because the signal rise time is a function of resistor R_L. Using two couplers in an active pull-up output (b) forces faster rise times and hence higher transmission rates.

CRACKLE-FREE POTENTIOMETER OPTO-ISOLATOR

The resistance of a light dependent resistor (LDR) varies as the light falling upon it varies – hence its name! When wired into a divider network it forms an excellent crackle-free potentiometer.

It also provides excellent electrical isolation of the manual control – often a valuable feature where high voltage circuits must be isolated from low voltage circuits.



Test circuit measures optical coupler's speed

by John R. Torok
National Semiconductor Corp., Santa Clara, Calif.

Although the performance of optical couplers has improved considerably in the last year or so, the method of measuring their switching times has not. Data sheets for most optical couplers still specify switching time at some unknown LED drive current, making it difficult, to say the least, for a designer to know what the actual switching time is.

Generally, the forward current applied to the coupler's input LED is increased until the collector current of the coupler's output phototransistor reaches some specified value. (This current limit is typically 1 or 2 milliamperes.) Then, the rise and fall times of the collector current are measured at the 10% and 90% points of the specified value.

However, this type of measurement does not accurately define the coupler's switching speed because the output rise and fall times are not referenced to the input current applied to the LED. For example, a 1-microsecond rise time for the output collector current is meaningless if the LED input current must flow for 2 μs before there is any output current at all.

A far better indication of coupler speed is device on time, which includes the input-to-output delay time, as well as the rise time of the output current. Likewise, device off time, which accounts for the phototransistor's storage time and the fall time of the output current, should also be determined. These two measurements can be referenced directly to the input current.

Since most couplers having a phototransistor output are driven from TTL signals, the input current to the LED is constant—that is, the input drive can be considered to be fixed and constant with respect to pulse width, pulse amplitude, and duty cycle.

The test circuit for determining a coupler's on and off times is shown in the figure. For this measurement, the base terminal of the phototransistor must be defined electrically, rather than leaving it open, as is usually done. Therefore, a high-value resistor (R_2) is placed between the phototransistor's base and emitter terminals. This resistor has only a negligible effect on the coupler's speed and current-transfer ratio.

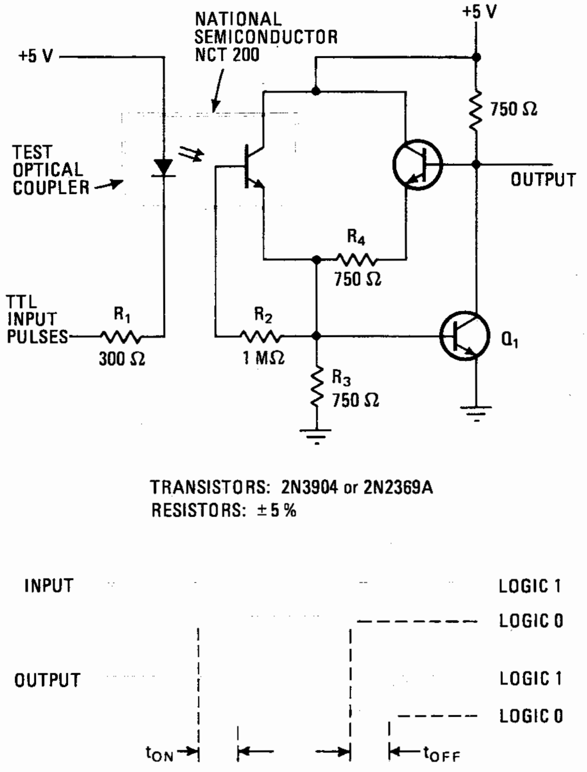
The input driving-pulse waveform has a peak amplitude of 10 mA, constant to within +10% and -0%, a duration of 8 μs, and a maximum duty cycle of 10%. The phototransistor's collector-emitter voltage must also be kept as constant as possible. Here, it is held to 4 V between +10% and -0%.

The apparent load seen by the phototransistor is approximately 25 ohms with the components shown. This load impedance is established by the base-emitter junction of transistor Q_1. If desired, the load-impedance value can be increased by inserting a resistor in series with the base terminal of transistor Q_1.

The coupler's true switching speed can be measured by comparing the input pulse drive voltage with the output voltage at transistor Q_1. The on time will be the delay between the application of the leading edge of the input pulse and the time when the phototransistor's collector current exceeds 1 mA. The off time will be the delay between the trailing edge of the input pulse and the time when the collector current drops below 1 mA.

The magnitude of the LED drive current, which is set at 10 mA here, can be increased or decreased by simply changing the value of series resistor R_1. If more drive current is needed, be certain that the input TTL circuitry can sink it.

Resistor R_3 determines the test level of the phototransistor's collector current. The size of this current is computed by dividing the base-emitter (on) voltage (about 0.75 V) of transistor Q_1 by the value of resistor R_3. Therefore, if the collector current is to be doubled, then the value of R_3 must be halved. Or, in contrast, if the collector current is to be halved, then the value of R_3 must be doubled. In this way, collector-current values

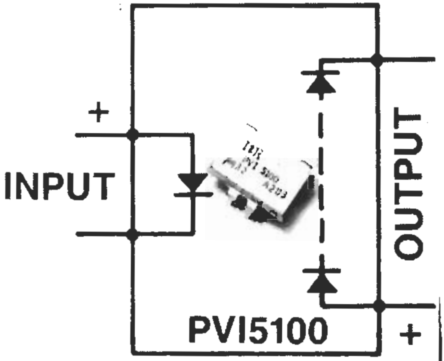


TRANSISTORS: 2N3904 or 2N2369A
RESISTORS: ±5%

Speed check. Test circuit permits the true switching time of an optical coupler to be measured with reference to the input driving current to the coupler's LED. The circuit determines device on time (t_{ON}) and device off time (t_{OFF}), both of which take the inherent device turn-on and turn-off delay times into account, as well as the rise and fall times of the coupler's phototransistor output current.

can be varied from about 100 μA to around 100 mA. (To assure a logic 1 output level at transistor Q_1, the value of resistor R_4 must be the same as that of resistor R_3.)

Besides checking the switching time of an optical coupler, the test circuit is also useful as an interface to a TTL buffer amplifier. □



OCTOCOUPLER NEEDS NO POWER SUPPLY

Markham, ON

A photovoltaically operated opto-coupler provides a 5 V, 10 μA output at signal inputs of 10 mA. Dielectric isolation is 2500 VRMS.

The PVI5100 Photovoltaic Isolator (PVI) opto-coupler from International Rectifier eliminates an external power supply needed for conventional photoresistive opto-couplers such as phototransistors, cadmium sulphide cells, photodiodes and photoSCRs.

Unlike earlier devices that sense the significant change in output resistance and require a voltage source separate from the input signal, the PVI produces its output voltage internally from a photovoltaic generator (PVG) developed by IR. The PVG input is used in the IR microelectronic Photovoltaic Relays (PVRs).