# ISOLATION AMPLIFIERS FOR EFFECTIVE DATA ACQUISITION

## They Help Designers Solve Problems in Instrumentation, Industrial Monitoring, Process Control, and Patient Monitoring

by Fred Pouliot

The isolation amplifier is a data- or instrumentation amplifier in which the output circuit is completely isolated from the input circuit. Some Analog Devices types also include power-supply isolation, for a complete 3-port isolation capability.

What is "complete isolation"? In the case of our transformer-coupled modulator/demodulator types, the resistive component of common-mode impedance is of the order of $10^{11}\Omega$, and ac leakage – at 115V, 60Hz – is as low as 1μA (a boon for clinical applications). In addition to having a completely-guarded front end, their common-mode rejection (CMR) is of the order of 140dB at high common-mode voltage (CMV up to 5kV), and input noise is low (less than 10μV p-p in a 100Hz bandwidth).

These characteristics allow small (millivolt) signals to be processed *accurately*, despite hundreds of volts of CMV, and *safely*, despite CMV or fault voltages in the thousands of volts. Since no input return path is required from the signal source to power ground, ground wires (and ground-loop headaches) may be avoided.

When low-level signals are close to lines operating at high energy levels, there is a possibility that induced voltages will mask the low-level signals and saturate the amplifier. An amplifier with high CMV and CMR capability (plus isolation) can be a big help (if not absolutely essential) in such applications.

### PREFERRED DATA AMPLIFIER

If the voltage to be measured and processed has a high common-mode component or a large impedance imbalance between the two leads from the source, designers often consider 3 popular circuit approaches: *Op-amp subtractor circuits*, in a variety of configurations and capabilities; *committed data-* or *instrumentation amplifiers**, such as the 610 (see page 14) or the AD521; or *isolation amplifiers*.†

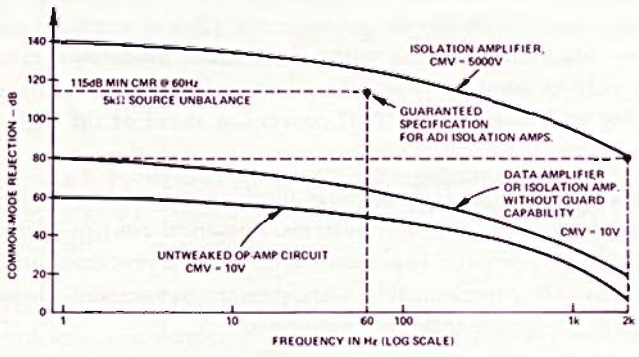


Figure 1. Common-mode rejection vs. frequency for several kinds of differencing amplifier

*For information on ADI instrumentation amplifiers, request **P1**.
†For information on isolation amplifiers, request **P2**. Request data on specific types mentioned here (if desired) by model number.

Operational-amplifier configurations generally require "tweaking" of precision resistor ratios§ and capacitance neutralization; even then, CMR better than 80dB is hard to achieve consistently, unless one is truly committed to "make rather than buy". With unbalanced source, 60dB is more typical (Figure 1).

Committed data amplifiers (or unguarded isolation amplifiers) offer more-predictable behavior, over a wider range of price-performance capabilities. Performance is generally excellent at dc and low frequencies, with small source unbalance and CMV of about 10V. At higher frequencies, capacitive source- and line-unbalances reduce CMR, often by up to 40dB at 60Hz. CMR, excellent at high gain, may be 40dB worse at unity gain.

Isolation amplifiers (from Analog Devices) are graced by a completely-guarded front end, that can be driven at the common-mode voltage (up to 5000V). The inputs are surrounded by an equipotential surface (at the CMV), greatly reducing effective capacity. CMR, for source unbalance of 5kΩ, @ 60Hz, is 115dB *min*.

### TYPICAL ISOLATION-AMPLIFIER APPLICATIONS

#### Ground-Loop Eliminator

Figure 2 shows how an isolation amplifier eliminates grounding problems in two ways. First, since a bias-current return to the supply is not necessary, the input circuit can be independent of system ground with its logic spikes, voltage drops, etc. Second (especially with 3-port isolation) the amplifier's power ground is independent of the output *low*; returning the amplifier's power ground to system ground does not cause grounding errors in the output signal line.

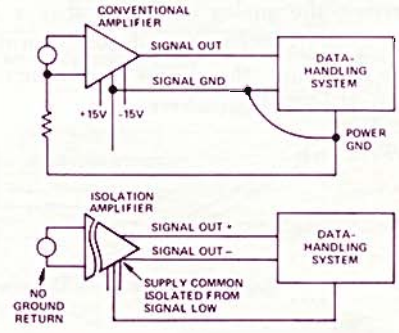


Figure 2. Comparison of grounding techniques for conventional and isolation amplifiers

#### Multichannel Series-Voltage Monitor

Figure 3 shows a system of cells in series. Each cell – which might be providing electrochemical deposition using a common current – is monitored independently by an isolation amplifier, irrespective of what may be happening elsewhere. If a cell should go open-circuit, its associated amplifier is protected

§For data on precision thin-film resistor networks, request **P3**.

against the entire open-circuit voltage. The amplifier power-supply is protected against faults in the circuit being measured.

### Isolation and Fault Protection with a 3-Port Isolator

In Figure 4, a signal that provides essential information about a process variable for use in control must also be independently monitored. The isolator's high input impedance protects the transducer against faults in either amplifier or the power supply. If the signal-processing system should fail, the amplifiers' *power supply* (hence any other amplifiers using the supply) is protected against any fault voltages that may occur, even if 115VAC should be imposed at A1's output terminal. Finally, any faults developed in the monitor do not affect performance of the control loop. The process can continue to operate uninterruptedly while the monitor is being restored.

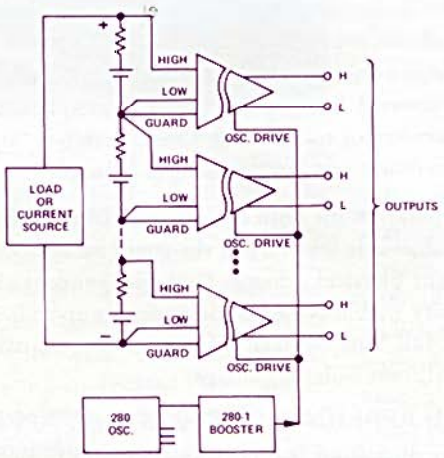


Figure 3. Multichannel amplification at high voltage using isolators with common oscillator drive to eliminate beat effects.

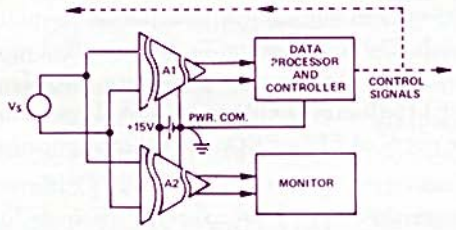


Figure 4. Use of 3-port isolator in monitoring and control for isolation and protection of source, power supplies, and connected equipment

## NEW DEVELOPMENTS IN ISOLATION AMPLIFIERS

We've come a long way since the first isolation amplifier (Model 272) appeared in *Dialogue* 5-2 (1971). Following the original medical orientation, a number of *industrial* applications have arisen, with different requirements. In addition, uses of many isolators in close proximity require intermodulation-free systems with common carriers. Here are the newcomers:

## INDUSTRIAL-INSTRUMENTATION ISOLATOR

Model 275 sets a new standard for modular isolator performance. It combines the excellent performance specifications of instrumentation amplifiers (5μV/°C drift and 0.05% nonlinearity) with the inherent performance of an isolator: 140dB common-mode rejection at 2000V CMV. Dynamic range of both input and output signals is a full 10V, and gain can be adjusted from 1 to 100 by a single external resistor.

Besides sustaining a maximum common-mode voltage application of 2500V peak sinusoidal 60Hz for 1 minute, the fully-guarded input of the Model 275 has a higher CMR than is achievable with any known commercially-available isolation amplifier. Figure 5 shows its CMR as a function of frequency for CMV up to 2000V (dc or peak ac). Note that at 60Hz, with 1kΩ source unbalance, CMR is still greater than 120dB.

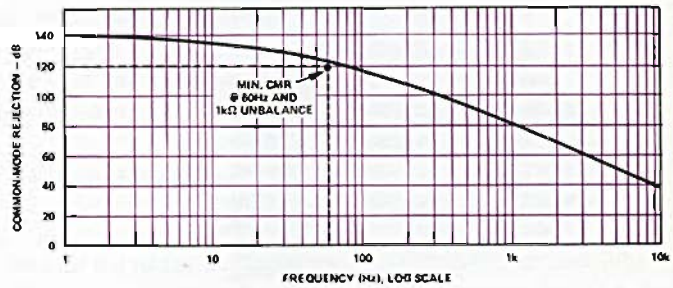


Figure 5. Common-mode rejection of Model 275 as a function of frequency

Increasing source-resistance unbalance naturally degrades CMR. One should always try to keep the unbalance as low as possible – but this is sometimes impractical. Figure 6 demonstrates that, in such cases, the Model 275 will still provide respectably-high common-mode rejection.

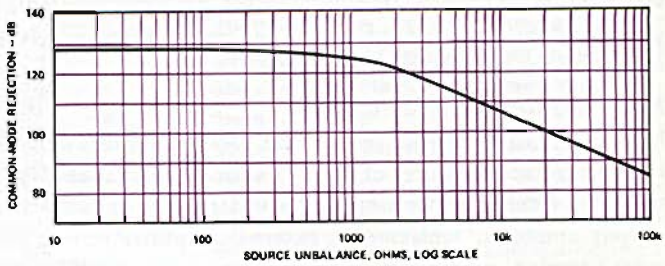


Figure 6. Common-mode rejection of Model 275 @ 60Hz as a function of resistive source unbalance

Nonlinearity of Model 275L is guaranteed to be less than 0.1% for ±10V outputs, 0.05% for ±5V outputs, and less as the output range is limited further. Model 275 is available in 3 versions, selected for linearity and temperature coefficient. The table summarizes the performance grades; Figure 7 is a plot of nonlinearity as a function of output-voltage range.

SALIENT SPECS OF MODEL 275 OPTIONS

| | 275J | 275K | 275L |
|---|---|---|---|
| Gain (adjustable by external resistor) | 1–100 | 1–100 | 1–100 |
| Nonlinearity, ±5V output range | ±0.15% *max* | ±0.1% *max* | ±0.05% *max* |
| Nonlinearity, ±10V output range | ±0.2% *max* | ±0.15% *max* | ±0.1% *max* |
| Input/Output range ($R_L$ = 50kΩ) | ±10V | ±10V | ±10V |
| Total offset voltage, referred to input (G = 100) | ±25μV/°C *max* | ±15μV/°C *max* | ±5μV/°C *max* |
| CMV, input to output, absolute max. | 2500V peak | 2500V peak | 2500V peak |
| CMV, output to power common | 200V | 200V | 200V |

### Environmental Effects

Designed to withstand rugged environments involving high humidity, shock, vibration, temperature-cycling, moisture, and other conditions to be found in MIL-STD-202E, the 275 will also withstand line voltage (115VAC) directly across the inputs.

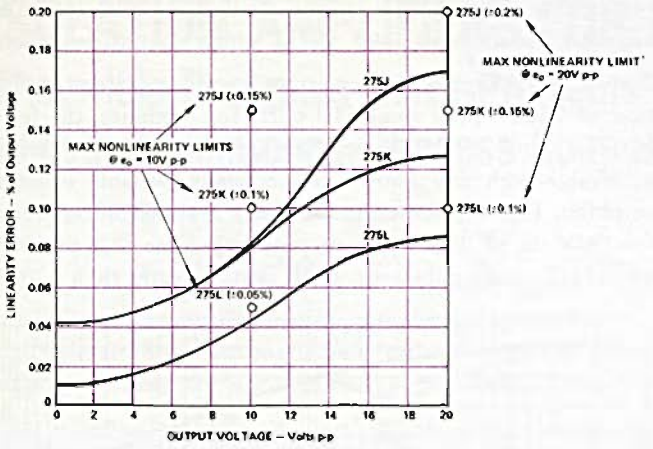


Figure 7. Linearity error as a function of output voltage, $R_L$ = 50kΩ. Typical performance and limits.

In addition, integrity of performance when subjected to EMI and RFI was given careful design consideration, so that the Model 275 can provide high performance – even when subjected to industrial noise created by relay closures, motor brushes, and other machinery.

A host of new applications for modular isolation amplifiers is now evident. They can be considered for general-purpose high-voltage amplification (with exceptionally good CMR and CMV specifications), for instrument amplification with high CMR at line frequency (with or without high source unbalance), for test instrumentation – to eliminate the problems created by ground loops and ground noise, and to alleviate problems caused by the introduction of high CMV's.

### Model 285 for Increased Flexibility

Model 285, to be introduced in June, 1975, combines most of the performance features of the 275 with an additional output stage for filtering, offsetting, and a wider range of gains. The output amplifier, replacing an external amplifier serving the same function, provides its increased convenience at the sacrifice of 3-port freedom: the output and power grounds can be separated by only a few volts instead of Model 275's 200V.

## MULTICHANNEL APPLICATIONS

Those familiar with our earlier isolation-amplifier designs know that the dc supply energizes an oscillator, which couples power (via a proprietary transformer-coupling arrangement) into both the input modulator and the output demodulator sections; the only coupling between the input and the output is via an isolation transformer for carrier-frequency information. Since perfect carrier attenuation around a small, compact module is difficult to achieve (if one wants all its other blessings), users have had to minimize beat-frequency generation with shielding and power-supply decoupling in systems using a number of the modules. A better solution, now available, is to use a single oscillator for a number of channels of isolation amplifiers in close proximity and sharing a common power supply.

### Synchronized Single Channels

An example that illustrates the technique is the system of isolation amplifiers shown in Figure 3. The amplifiers comprising the system might well be Model 279 single-channel isolation amplifiers, designed to be driven by a common external oscillator, Model 280, which is capable of providing excitation for as many as 16 Model 279's. For larger numbers of channels, a power booster, the 280-1, can increase the system capability to as many as 200 channels from a single oscillator.

The use of a single oscillator eliminates the effects of beat frequencies. The common oscillator is itself protected from faults occurring in any of the amplifiers (or their output circuits) by protective resistor strings in each amplifier.

Performance is otherwise typical of what one might expect from an isolation amplifier: CMV of 5000V, and CMR of 120dB. Other salient features include 10μV noise for a 100Hz bandwidth and ground-fault current less than 10μA.

### 2- and 3-Channel Isolators

Most applications do not require the many channels and extreme flexibility provided by combinations of the 279, 280, and 280-1. A common multi-channel requirement is for just 2 or 3 channels. Models 282 and 283 provide this capability, with low input noise (4μVp-p in 100Hz), adjustable gain (1 to 100), and isolated floating ±6V and ±3V outputs for powering isolated circuitry or transducers. Construction is "open-board" for user flexibility and lowest cost per-channel.

Channel separation for both designs is 60dB at 100Hz. CMR of 130dB is achievable when using the guard assembly AC1043 or an equivalent physical scheme. Each independent channel provides linearity within 0.2% for input signals up to 0.5V and can withstand full line voltage of 220V rms across its input terminals without isolator damage.

## MEDICAL APPLICATIONS: 276, L.A. APPROVAL

The present discussion is especially pertinent to the use of isolators in industrial applications; but one should bear in mind that the earliest purpose of Analog Devices' isolator designs was to help ensure patient safety in the wake of the increased use of electronics in clinical instrumentation for patient monitoring. Models 272 & 273 were, in fact, the first modular isolation amplifiers in the industry to feature 10μA fault current and CMR of 115dB min at 60Hz with a 5kΩ source unbalance, to meet the needs of EEG, EKG, and other applications.

The newest entry to the market, Model 276, offers two additional features that have been expressly desired: lower noise (8μV p-p in a 100Hz bandwidth) and lower cost (less than $50 in 100's).

In addition, both the 273 and the 276 now bear the seal of approval of the Los Angeles City Testing Laboratory, which sets standards for all medical equipment sold in California, regardless of where it is manufactured. Use of these devices in equipment front-ends should simplify the lives of medical-OEM equipment designers, since the isolator is usually the key element affecting equipment safety. The use of an approved isolator should make system approval easier to obtain.