Miniature
Low Drift - Wide Bandwidth
ISOLATION AMPLIFIER

FEATURES
- EASY TO USE, SIMILAR TO AN OP AMP
  \[ V_{out}/V_{in} = R_{L} \text{ Current Input} \]
  \[ V_{out}/V_{in} = R_{L}/R_{m} \text{ Voltage Input} \]
- 100% TESTED FOR BREAKDOWN
  750V Continuous Isolation Voltage
- ULTRA-LOW LEAKAGE, 0.3\(\mu\)A, max. at 240V/60Hz
- WIDE BANDWIDTH, 60kHz
- LOW COST
- 18-PIN DIP PACKAGE

DESCRIPTION

The ISO100 is a miniature low cost optically-coupled isolation amplifier. High accuracy, linearity, and time-temperature stability are achieved by coupling light from an LED back to the input (negative feedback) as well as forward to the output. Optical components are carefully matched and the amplifier is actively laser-trimmed to assure excellent tracking and low offset errors.

The circuit acts as a current-to-voltage converter with a minimum of 750V (2500V test) between input and output terminals. It also effectively breaks the galvanic connection between input and output commons as indicated by the ultra-low 60Hz leakage current of 0.3\(\mu\)A at 250V. Voltage input operation is easily achieved by using one external resistor.

Versatility along with outstanding DC and AC performance provide excellent solutions to a variety of challenging isolation problems. For example, the ISO100 is capable of operating in many modes, including: noninverting (unipolar and bipolar) and inverting (unipolar and bipolar) configurations. Two precision current sources are provided to accomplish bipolar operation. Since these are not required for unipolar operation, they are available for external use (see Applications section).

Designs using the ISO100 are easily accomplished with relatively few external components. Since \(V_{out}\) of the ISO100 is simply \(I_{in}\cdot R_{out}\), gains can be changed by altering one resistor value. In addition, the ISO100 has sufficient bandwidth (DC to 60kHz) to amplify most industrial and test equipment signals.
### ELECTRICAL (CONT)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>ISO100AP</th>
<th>ISO100BP</th>
<th>ISO100CP</th>
<th>UNITS</th>
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<tbody>
<tr>
<td><strong>POWER SUPPLIES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Input Stage</td>
<td></td>
<td>±7</td>
<td>±15</td>
<td>±18</td>
<td>V</td>
</tr>
<tr>
<td>Voltage - rated performance</td>
<td></td>
<td>±7</td>
<td>±15</td>
<td>±18</td>
<td>V</td>
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<tr>
<td>Voltage - derated performance</td>
<td></td>
<td>±1.1</td>
<td>±2.4</td>
<td>±3</td>
<td>mA</td>
</tr>
<tr>
<td>Supply Current</td>
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<td>±8.1.1</td>
<td>±3.6</td>
<td>±3.7</td>
<td>mA</td>
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<tr>
<td>Output Stage</td>
<td></td>
<td>±15</td>
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<td>±3.7</td>
<td>mA</td>
</tr>
<tr>
<td>Short Circuit Current Limit</td>
<td></td>
<td>±40</td>
<td>±40</td>
<td>±40</td>
<td>mA</td>
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**BIPOLAR OPERATION**

<table>
<thead>
<tr>
<th>GENERAL PARAMETERS</th>
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<tbody>
<tr>
<td>Input Current Range</td>
<td></td>
<td>-10</td>
<td>+10</td>
<td>-10</td>
<td>µA</td>
</tr>
<tr>
<td>Linear Operation</td>
<td>-10</td>
<td>+10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Damage</td>
<td>-1</td>
<td>+1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Impedance</td>
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<td>+10</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Output Voltage Swing</td>
<td>R_L = 2kΩ(R_c = 1MΩ)</td>
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<td></td>
<td></td>
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<tr>
<td>Output Impedance</td>
<td>1200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GAIN**

| V_O = R_L I_lw               | 2               | 5          | 2          | 2          |       |
| initial Error Adjust To Zero|                 |            | ±0.03      | ±0.07      |        |
| vs Temperature             |                 |            | ±0.01      | ±0.06      |        |
| vs Time                    |                 |            | 0.05       | ±0.01      |        |
| Nonlinearity (%)           |                 |            | ±0.05      | ±0.04      |        |

**CURRENT NOISE**

| 0.1Hz to 10kHz             | 0.2          | ±0.2       | ±0.2       | ±0.1       |        |
| 1kHz                       | 17           | ±0.1       | ±0.1       | ±0.1       |        |
| 100kHz                     | 7            | ±0.05      | ±0.05      | ±0.05      |        |
| 1kHz                       | 6            | ±0.1       | ±0.1       | ±0.1       |        |

**INPUT OFFSET CURRENT**

<table>
<thead>
<tr>
<th>I_off, bipolar (µA)</th>
<th>40</th>
<th>200</th>
<th>20</th>
<th>70</th>
<th></th>
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<tbody>
<tr>
<td>vs Temperature</td>
<td>20</td>
<td>±10</td>
<td>±2</td>
<td>±3</td>
<td>µA</td>
</tr>
<tr>
<td>vs Power Supply</td>
<td>20</td>
<td>±10</td>
<td>±2</td>
<td>±3</td>
<td>µA/V</td>
</tr>
<tr>
<td>vs Time</td>
<td>250</td>
<td>±20</td>
<td>±10</td>
<td>±10</td>
<td>µA/V</td>
</tr>
</tbody>
</table>

**POWER SUPPLIES**

| Input Stage                |                 | ±7         | ±15        | ±18        | V     |
| Voltage - rated performance|                 | ±7         | ±15        | ±18        | V     |
| Voltage - derated performance|              | ±1.1       | ±2.4       | ±3         | mA    |
| Supply Current             |                 | ±8.1.1     | ±3.6       | ±3.7       | mA    |
| Output Stage               |                 | ±15        | ±15        | ±18        | V     |
| Voltage - rated performance|                 | ±7         | ±15        | ±18        | V     |
| Voltage - derated performance|              | ±1.1       | ±2.4       | ±3         | mA    |
| Supply Current             |                 | ±8.1.1     | ±3.6       | ±3.7       | mA    |
| Short Circuit Current Limit|                 | ±40        | ±40        | ±40        | mA    |

Same as ISO100AP.

**NOTES**

1. See Typical Performance Curves for temperature effects.
2. See Theory of Operation section for definitions. For dB see Ex 2. CM and HV errors.
3. Nonlinearity is the peak deviation from a “best fit” straight line expressed as a percent of full scale output.

**MECHANICAL**

*NOTE: Leads in true position within 0.05" (0.25mm) R at MMC at seating plane.*

*Pin numbers shown for reference only. Numbers are not marked on package.*

**AC Leakage Current (µA rms)**

<table>
<thead>
<tr>
<th>INCHES</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>0</td>
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<tr>
<td>P</td>
<td>0</td>
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<tr>
<td>F</td>
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<td>G</td>
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<td>D</td>
<td>0</td>
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<tr>
<td>C</td>
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<td>B</td>
<td>0</td>
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<td>B</td>
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<tr>
<td>A</td>
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</table>
THEORY OF OPERATION

The ISO100 is fundamentally a unity gain current amplifier intended to transfer small signals between electrical circuits separated by high voltages or different references. In most applications an output voltage is obtained by passing the output current through the feedback resistor (Rf).

The ISO100 uses a single light emitting diode (LED) and a pair of photodiode detectors, coupled together, to isolate the output signal from the input.

Figure 1 shows a simplified diagram of the amplifier. Iref and Iref are required only for bipolar operation, to generate a mid-scale reference. The LED and photodiodes (D1 and D2) are arranged such that the same amount of light falls on each photodiode. Thus, the currents generated by the diodes match very closely. As a result, the transfer function depends upon optical match, rather than absolute performance. Laser-trimming of the components improves matching and enhances accuracy, while negative feedback improves linearity. Negative feedback around A1 occurs through the optical path formed by the LED and D1. The signal is transferred across the isolation barrier by the matched light path to D2.

![Figure 1. Simplified Block Diagram of the ISO100.](image)

The overall ISO amplifier is noninverting (a positive going input produces a positive going output).

INSTALLATION AND OPERATING INSTRUCTIONS

UNIPOLAR OPERATION

In Figure 1, assume a current, Io, flows out of the ISO100 (Io must be negative in unipolar operation). This causes the voltage at pin 15 to decrease. Because the amplifier is inverting, the output of A1 increases, driving current through the LED. As the LED light output increases, D1 responds by generating an increasing current. The current increases until the sum of the currents in and out of the input node (Input-to-Ac) is zero. At that point the negative feedback through D1 has stabilized the loop, and the current Io equals the input current plus the bias current. As a result no bias current flows in the source. Since D1 and D2 are matched (Io1 = Io2), Io is replicated at the output via D2. Thus, A1 functions as a unity-gain current amplifier, and A2 is a current-to-voltage converter, as described below.

Current produced by D2 must either flow into A2 or Rf. Since A2 is designed for low bias current (~10mA), almost all of the current flows through Rf to the output. The output voltage then becomes:

\[ V_o = (I_{o2})R_f = (I_{o1} \pm I_{o2})R_f \approx -I_{o1}R_f = I_oR_f \]

where, \( I_{o1} \) is the difference between A1 and A2 bias currents. For input voltage operation \( I_{o1} \) can be replaced by a voltage source (\( V_{in} \)) and series resistor (\( R_{in} \)) since the summing node of the op amp is essentially at ground. Thus, \( I_{o1} = V_{in}/R_{in} \).

Unipolar operation does have some constraints, however. In this mode the input current must be negative so as to produce a positive output voltage from A1 to turn the LED on. A current more negative than 20mA is necessary to keep the LED turned on and the loop stabilized. When this condition is not met the output may be indeterminate. Many sensors generate unidirectional signals, e.g., photoconductive and photodiode devices, as well as some applications of thermocouples. However, other applications do require bipolar operation of the ISO100.

BIPOLAR OPERATION

To activate the bipolar shown in Figure 1, an op amp. The input unipolar operation, has to supply all symmetry, \( I_{o} = I \), matched, the current. This results in no output current from the input (the currents Io1 = Io2, a current output voltage is the \( V_o \) is limited). At this point, opens. Negative \( I_{o1} \), D1 with maximum max).

DC ERRORS

Errors in the ISO100 will be shown in Figure 2.

![Figure 2. Circuit: A1 and A2: an anap and anap](image)
BIPOLAR OPERATION

To activate the bipolar mode, reference currents as shown in Figure 1, are attached to the input nodes of the op amps. The input stage stabilizes just as it did in unipolar operation. Assuming \( I_{IN} = 0 \), the photodiode has to supply all the \( I_{REF} \) current. Again, due to symmetry, \( I_{ON} = I_{OFF} \). Since the two references are matched, the current generated by \( D_2 \) will equal \( I_{REF} \). This results in no current flow in \( R_E \), and the output voltage will be zero. When \( I_{IN} \) either adds or subtracts current from the input node, the current \( D_1 \) will adjust to satisfy \( I_{ON} = I_{IN} + I_{REF} \). Because \( I_{REF} \) equals \( I_{ON} \) and \( I_{OFF} \) equals \( I_{OFF} \), a current equal to \( I_{ON} \) will flow in \( R_E \). The output voltage is then \( V_O = I_{ON} R_E \). The range of allowable \( I_{ON} \) is limited. Positive \( I_{ON} \) can be as large as \( I_{REF} \) (10.5 \( \mu A \), min). At this point, \( D_1 \) supplies no current and the loop opens. Negative \( I_{IN} \) can be as large as that generated by \( D_1 \) with maximum LED output (recommended 10 \( \mu A \), max).

DC ERRORS

Errors in the ISO100 take the form of offset currents and voltages plus their drifts with temperature. These are shown in Figure 2.

\[
A_2 \quad \text{is the gain error.} \\
A_r = \left| \frac{\text{Ideal gain}}{\text{Actual gain}} \right| - 1
\]

The output then becomes:

\[
V_{OUT} = \frac{V_{IN} \pm \pm V_{OSI} \pm (I_{OFF} + A_r) \cdot I_{OSI} \cdot A_{REF} \cdot I_{OSI}}{R_{IN}}
\]

The input offset referred output voltage of the ISO100 can be simplified in the unipolar case by assuming that \( A_r = 0 \) and \( V_{IN} = 0 \):

\[
V_{OUT} = \frac{\pm V_{OSI} \pm V_{OSI}}{R_{IN}} \pm V_{OSI}
\]

This voltage is then referred back to the input by dividing by \( R_{REF} \).

\[
v_{OSI/OUT} = \frac{V_{OSI}}{R_{REF}} \pm V_{OSI}(R_{REF}/R_{IN})
\]

Example 1: (Refer to Figure 2 and Electrical Specifications Table)

Given:

\[
I_{OSI/OUT} = \pm 35 \mu A \\
R_{IN} = 100 k\Omega \\
R_{REF} = 1 M\Omega \quad \text{gain = 10} \\
V_{OSI} = \pm 200 \mu V \\
V_{OSI} = \pm 200 \mu V
\]

Find: The total offset voltage error referred to the input and output where \( V_{IN} = 0 \).

\[
v_{OSI/OUT} = \frac{\pm V_{OSI} \pm V_{OSI} \pm V_{OSI}}{R_{IN}} \pm V_{OSI}(R_{REF}/R_{IN})
\]

Note: This error is dominated by \( I_{OSI/OUT} \) and the reference current times the gain error (which appears as an offset). The error for unipolar operation is much lower. The error due to offset current can be zeroed using circuits shown in Figures 6 and 7. The gain error is adjusted by trimming each \( R_{REF} \) or \( R_{IN} \).

COMMON-MODE AND HIGH VOLTAGE ERRORS

Figure 3 shows a model of the ISO100 that can be used to analyze common-mode and high voltage behavior.

Definitions of CMR and IMR

\( I_{OSI} \) is defined as the input current required to make the ISO100’s output zero. CMRR and IMRR in the ISO100 are expressed as conductances. CMRR defines the relationship between a change in the applied common-mode voltage \( V_{COM} \) and the change in \( I_{OSI} \) required to maintain the amplifier’s output at zero:

\[
\text{CMRR} = \frac{I_{OSI}}{V_{COM}}
\]

\[
\text{IMRR} = \frac{I_{OSI}}{V_{COM}}
\]
FIGURE 3. High Voltage Error Model.

CMRR (1-mode) = \frac{\Delta I_{CM}}{\Delta V_{CM}} \text{ in nA/V} \quad (5)

CMRR (V-mode) = \frac{\Delta I_{CM}}{\Delta V_{CM}} \text{ in pA/V} \quad (6)

IMRR defines the relationship between a change in the applied isolation mode voltage (V_{IM}) and the change in I_{CM} required to maintain the amplifier's output at zero:

IMRR (1-mode) = \frac{\Delta I_{CM}}{\Delta V_{IM}} \text{ in pA/V} \quad (7)

IMRR (V-mode) = \frac{\Delta I_{CM}}{\Delta V_{IM}} \text{ in nA/V} \quad (8)

CMRR & IMRR in V/V are a function of R_{M}.

V_{IM} is the voltage between input common and output common.

V_{CM} is the common-mode voltage (noise that is present on both input lines, typically 60Hz).

V_{ERR} is the equivalent error signal, applied in series with the input voltage, which produces an output error identical to that produced by application of V_{CM} and V_{IM}.

CMRR and IMRR are the common-mode and isolation-mode rejection ratios, respectively.

TOTAL CAPACITANCE (C_{t} and C_{2}) is distributed along the isolation barrier. Most of the capacitance is coupled to low impedance or noncritical nodes and affects only the leakage current. Only a small capacitance (C_{2}) couples to the input of the second stage, and contributes to IMRR.

**Example 2:** Refer to Figure 3 and Electrical Specification Table.

Given:

- V_{CM} = 1V AC peak at 60Hz, V_{IM} = 200V DC,
- CMRR = 3nA/V, IMRR = 5pA/V,
- R_{IN} = 100k\Omega, R_{F} = 1\Omega
  (Gain = 10)

Find:

- The error voltage referred to the input and output when V_{IM} = 0V
  - V_{ERR} = \frac{V_{CM}(CMRR/R_{IN}) + (V_{IM})}{(1 + IMRR)(R_{IN})}
  - = 1V (3nA/V)(100k\Omega) + 200V
  - (5pA/V)(100k\Omega)
  - = 0.3mV + 0.1mV
  - = 0.4mV

V_{ERR RTO} = V_{ERR RNI} (R_{F} / R_{IN})

= 0.4mV (10)

= 4mV (with DC IMRR)

(Note: This error is dominated by the CMRR term)

For purposes of comparing CMRR and IMRR directly with specifications, the following calculations can be performed:

CMRR in V/V = CMRR (1-mode)(R_{IN})

= 3nA/V (100k\Omega) = 0.3mV/V

CMRR = 20 LOG (0.3mV/V) = -70dB at 60Hz

IMRR in V/V = IMRR (1-mode)(R_{IN}) = 5pA/V(100k\Omega) = 0.5\mu mV/V

IMRR = 20 LOG (0.5 x 10^{-6}V/V) = -126dB at DC

**Example 3:**

In Example 2, V_{IN} is an AC signal at 60Hz and

IMRR = \frac{400pA}{V}

V_{ERR RNI} = V_{ERR CM} + V_{ERR IM} = 0.3mV + 200V (400pA/V)(100k\Omega)

= 8.3mV

V_{ERR RTO} = 83mV (with AC IMRR)

Given:

- Total error RTO from Examples 1 and 3 as 378mV worst case

Find:

- Percent error of +10V full scale output

% Error = \frac{V_{ERR total \times 100}}{V_{FS}}

= \frac{378mV}{10V}

= 3.78%

**NOISE ERRORS**

Noise errors in the unipolar mode are due primarily to the optical cavity. When the full 60Hz bandwidth is not needed, the output noise of the ISO100 can be limited by either a capacitor, C_{2}, in the feedback loop or by a low-pass filter following the output. This is shown in Figure 4. Noise in the bipolar mode is due primarily to the reference current sources, and can be reduced by the low-pass filters shown in Figure 5.

FIGURE 4. Two Circuit Techniques for Reducing Noise in the Unipolar Mode.
FIGURE 5. Circuit Technique for Reducing Noise from The Current Sources in the Bipolar-Mode.

OPTIONAL ADJUSTMENTS

There are two major sources of offset error: offset voltage and offset current. $V_{OS1}$ and $V_{OS2}$ of the input and output amplifiers can be adjusted independently using external potentiometers. An example is shown in Figure 17. Note that $V_{OS1}$ (500μV, max) appears directly at the output, but $V_{OS2}$ appears at the output multiplied by gain $(R_1/R_2)$. In general, $V_{OS}$ is small compared to the effect of $I_{OS}$ (see Example 1). To adjust for $I_{OS}$ use a circuit which intentionally unbalances the offset in one direction and then allows for adjustment back to zero.

Figure 6 shows how to adjust unipolar errors at zero input. The unipolar amplifier can be used down to zero input if it is made to be “slightly bipolar.” By sampling the reference current with $R_S$ and $R_D$, the minimum current required to keep the input stage in the linear region of operation can be established. $R_S$ and $R_D$ are adjusted to cancel the offset created in the input stage. This brings the output to zero, when the input is zero. Although the amplifier can now operate down to zero input voltage, it has only a small portion of the current drain and noise that the true bipolar configuration would have.

Adjusting the bipolar errors is illustrated in Figure 7. Each of the errors are adjusted in turn. With $V_{IN} = "open"$, $I_{OS}$ is trimmed by adjusting $R_0$ to make the output zero. $R_0$ is then adjusted to trim the gain error. The effects of offset voltage are removed by adjusting $R_1$. 

FIGURE 6. Adjusting the Unipolar Amplifier Errors at Zero Input.

FIGURE 7. Adjusting the Bipolar Errors.

BASIC CIRCUIT CONNECTIONS

FIGURE 8. Unipolar Noninverting.
3. Care should be taken to minimize external capacitance across the isolation barrier.

4. The distance across the isolation barrier, between external components, and conductor patterns, should be maximized to reduce leakage and arcing.

5. Although not an absolute requirement, the use of conformally-coated printed circuit boards is recommended.

6. When in the unipolar mode, the reference currents (pins 8 and 16) must be terminated. \( I_{in} \) should be greater than 20nA to keep internal LED off.

7. The noise contribution of the reference currents will cause the bipolar mode to be noisier than the unipolar mode.

8. The maximum output voltage swing is determined by \( I_{in} \) and \( R_f \):

\[
V_{SWING} = I_{in} \cdot R_f
\]

9. A capacitor (about 3pF) can be connected across \( R_1 \) to compensate for peaking in the frequency response. The peaking is caused by the pole generated by \( R_1 \) and the capacitance at the input of the output amplifier.

Figures 12 through 18 show applications of the ISO100.

**APPLICATION INFORMATION**

The small size, low offset and drift, wide bandwidth, ultra-low leakage, and low cost, make the ISO100 ideal for a variety of isolation applications. The basic mode of operation of the ISO100 will be determined by the type of signal and application.

Major points to consider when designing circuits with the ISO100:

1. Input Common (pin 18) and -IN (pin 17) should be grounded through separate lines. The Input Common can carry a large DC current and may cause feedback to the signal input.

2. Use shielded or twisted pair cable at the input, for long lines.

Burr-Brown IC Data Book
FIGURE 13. Precision Bridge Isolation Amplifier (Unipolar).

FIGURE 14. Three-Port Isolation Thermocouple Amplifier (Bipolar).

FIGURE 15. Isolated Test Equipment Amplifier (Unipolar with Offset).
FIGURE 16. Isolated 4mA to 20mA Transmitter (Example of an isolated voltage controlled current source).

FIGURE 17. Four-Port Isolated Summing Amplifier (Unipolar).

CALIBRATION PROCEDURE:
1. SET $V_{IM} = 0V$
2. ADJUST $R_b$ FOR $I_{OUT} = 20mA$
3. SET $V_{IM} = -5V$
4. ADJUST $R_h$ FOR $I_{OUT} = 4mA$

*NO ADDITIONAL CONNECTIONS TO OUTPUT AMPLIFIERS

NOTE THAT A VARIETY OF INPUT/ISOLATION CONFIGURATIONS CAN BE USED

724 ISOLATED POWER SUPPLY
FIGURE 18. Multiple Channel Isolation Amplifier (Bipolar) with programmable Gain (Useful in Data Acquisition Systems).