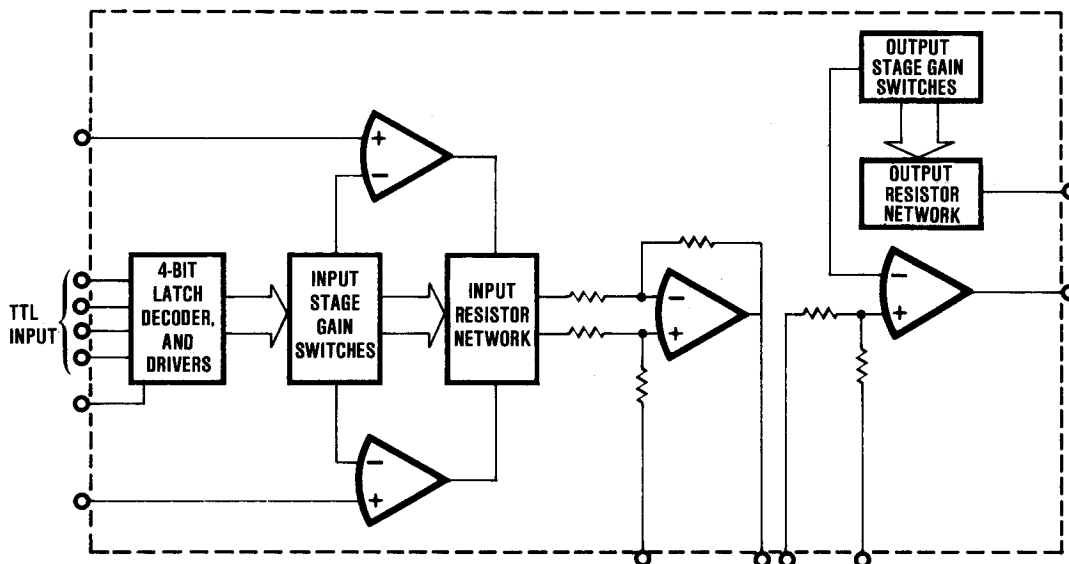


3606

Digitally Controlled Programmable Gain INSTRUMENTATION AMPLIFIER

FEATURES

- 11 BINARY GAINS - 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024V/V
- 4-BIT TTL GAIN CONTROL
- EXCELLENT GAIN NONLINEARITY
0.01% max at $G = 1024V/V$
- LOW GAIN ERRORS - 0.02% max
- LOW GAIN DRIFT - 10ppm/°C max
- LOW VOLTAGE DRIFT
 $1\mu V/^\circ C$ max RTI, $G = 1024V/V$
- HIGH CMR - 110dB min, $G = 1024V/V$
- HIGH INPUT IMPEDANCE - $10 \times 10^9\Omega$
- LOW OFFSET VOLTAGE
 $22\mu V$ max RTI, $G = 1024V/V$
 $2mV$ max RTI, $G = 1V/V$



DESCRIPTION

The 3606 is a self-contained, Programmable Gain Instrumentation Amplifier (PGIA) whose gain can be changed in 11 binary weighted steps from 1 to 1024V/V. The gain control is accomplished through a 4-bit TTL input.

The PGIA function allows the user to deal with wide dynamic range signals while maintaining high system resolution. For example: when used with a 10-bit A to D converter in a "floating point" system, the 2^{10} gain range of the 3606, plus the 2^{10} range of the converter produces a total system resolution of 2^{20} ($\approx 1,000,000:1$).

Desirable characteristics of a high performance instrumentation amplifier are offered by the 3606: high input impedance ($10G\Omega$), excellent gain nonlinearity (0.01% max, $G = 1024V/V$; 0.02% max, $G = 1V/V$), high common-mode rejection (100dB min, $G \geq 4V/V$), low gain error (0.02% max with no trimming required), low gain temperature coefficient (10ppm/ $^{\circ}C$ max), and low offset voltage drift vs temperature ($1\mu V/^{\circ}C$ max, RTI, $G = 1024$).

Added to these outstanding instrumentation amplifier characteristics is the ability to change 3606's gain under control of a 4-bit TTL input word. An important characteristic of the 3606 PGIA is its low change in offset

plus laser trimming minimized this change to a maximum of $\pm 25mV$ with no external adjustments. With two simple offset adjustments the change can be limited to less than 2mV (1mV typ) at the output over the entire 1V/V to 1024V/V gain range.

A simplified schematic of the 3606 is shown in Figure 1. The circuit consists of a variable gain high input impedance voltage follower input stage (A1 and A2) followed by a unity gain difference amplifier (A3) with a variable gain output stage (A4).

Common-mode voltage is derived for active guard drive to improve system common-mode rejection. Two-pole, low-pass filtering can easily be implemented on the output stage to reduce noise bandwidth and improve system signal-to-noise operation. A latch function is provided to inhibit gain changes while the digital gain control input is changed.

Burr-Brown's instrumentation grade monolithic operational amplifiers, high stability precision thin-film resistor networks and advanced laser-trimming techniques are used by the 3606 to achieve a performance, size and cost combination never before achieved in a PGIA. It is available in a 32-pin dual-in-line package in either ceramic or metal (hermetic) configurations.

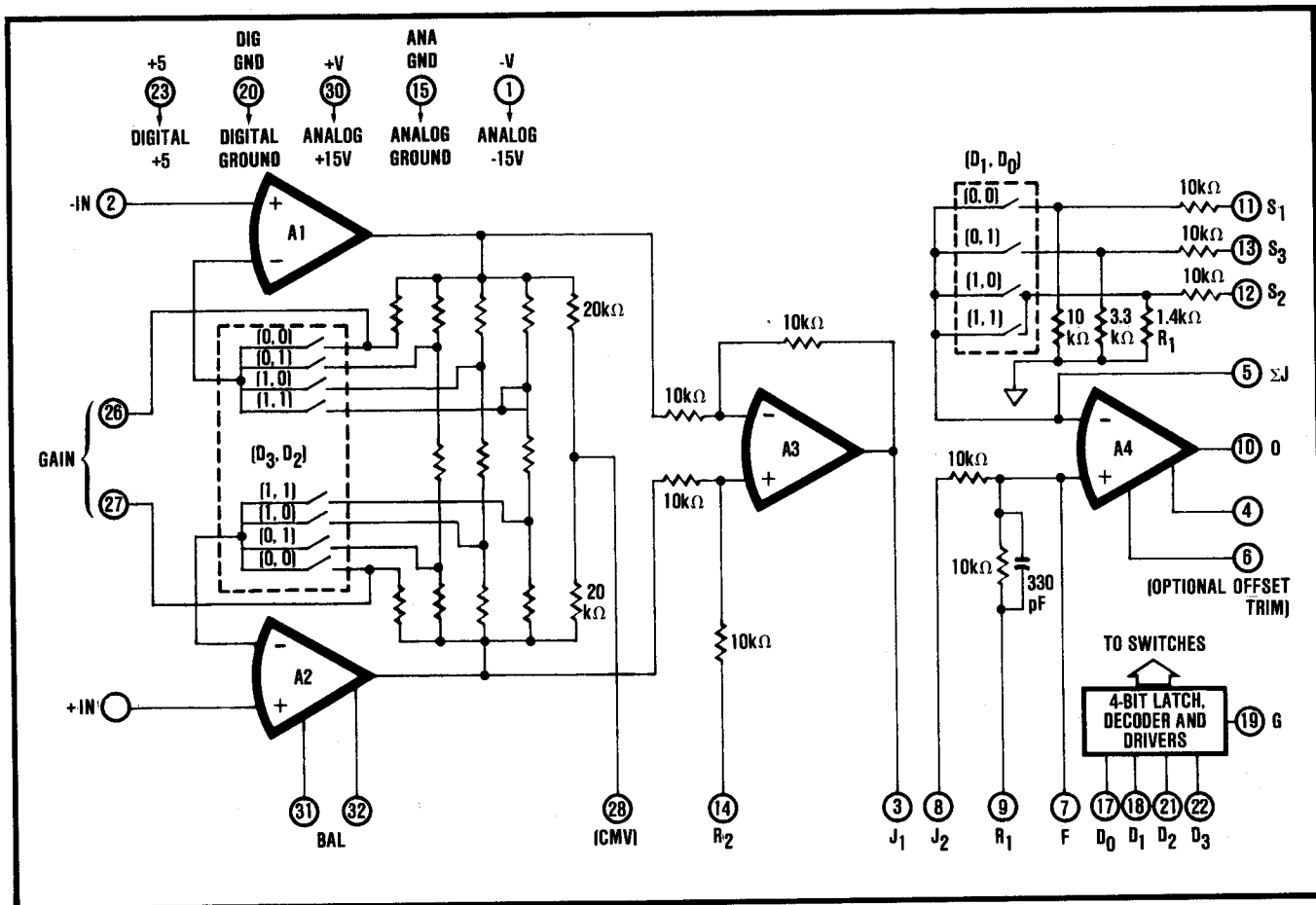


FIGURE 1. Simplified Schematic.

SPECIFICATIONS

ELECTRICAL

Typical at +25°C, unless otherwise noted.

| PARAMETER | CONDITIONS | 3606A ⁽¹⁾ | | | 3606B ⁽¹⁾ | | | UNITS |
|--|---------------------------------------|----------------------|------------------------------------|-----------------------------------|----------------------|------------------------------------|-----------------------------------|-------------------------|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| GAIN, G⁽²⁾ | | | | | | | | |
| Inaccuracy | G = 1 to 1024, I _O = 1mA | | ±0.02 | ±0.05 | | ±0.01 | ±0.02 | % |
| Nonlinearity ⁽³⁾ | G = 1 to 16 | | 0.001 | 0.002 | | * | * | %(5) |
| | G = 32 to 128 | | 0.003 | 0.004 | | * | * | % |
| | G = 256 to 1024 | | 0.005 | 0.01 | | * | * | % |
| Drift vs Temperature | G = 1 to 1024 | | ±5 | ±10 | | * | * | ppm/°C |
| vs Time | G = 1 to 1024 | | ±0.01 | | | | | %/1000 hrs |
| RATED OUTPUT | | | | | | | | |
| Voltage | I _O = ±5mA | ±10 | ±12 | | * | * | | V |
| Current | V _O = ±10V | ±5 | ±10 | | * | * | | mA |
| Impedance | | | 0.05 | | | * | | Ω |
| INPUT CHARACTERISTICS | | | | | | | | |
| Absolute Max Voltage | No damage | | | ±V _{CC} | | | * | V |
| Common-Mode Voltage Range | Linear operation | ±10 | ±10.5 | | * | * | | V |
| Differential Impedance | | | 10 3 | | | * | | 10 ⁹ Ω pF |
| Common-Mode Impedance | | | 10 3 | | | * | | 10 ⁹ Ω pF |
| OFFSET VOLTAGE, RTO⁽⁴⁾ | | | | | | | | |
| Initial at +25°C ⁽⁵⁾ | | | ±(0.02G +1) | ±(0.04G +2) | | ±(0.01G +1) | ±(0.02G +2) | mV |
| vs Temperature | -25°C to +85°C | | (±0.0015G ±0.03G ₂) | (±0.003G ±0.05G ₂) | | (±0.0005G ±0.01G ₂) | (±0.001G ±0.02G ₂) | mV/°C |
| vs Time | | | (±0.001G ±0.01G ₂) | | | * | | mV/mo |
| vs Supply | | | (±0.002G ±0.04G ₂) | | | * | | mV/V |
| vs Gain ⁽⁶⁾ | With trimming | | ±1 | ±2 | | * | * | mV |
| INPUT BIAS CURRENT | | | | | | | | |
| Initial | +25°C | | ±15 | ±50 | | ±5 | ±20 | nA |
| vs Temperature | -25°C to +85°C | | ±0.3 | | | * | | nA/°C |
| vs Supply Voltage | | | ±0.1 | | | * | | nA/V |
| INPUT DIFFERENCE CURRENT | | | | | | | | |
| Initial | +25°C | | ±15 | ±50 | | ±5 | ±20 | nA |
| vs Temperature | -25°C to +85°C | | ±0.5 | | | * | | nA/°C |
| vs Supply Voltage | | | ±0.1 | | | * | | nA/V |
| INPUT NOISE | | | | | | | | |
| Voltage | R _{SOURCE} ≤ 5kΩ G = 1024 | | 1.4 | | | * | | μV, p-p |
| 0.01Hz to 10Hz | | | | | | * | | μV, rms |
| 10Hz to 1kHz | | | | | | * | | |
| Current | | | 70 | | | * | | nA, p-p |
| 0.01Hz to 10Hz | | | | | | * | | nA, rms |
| 10Hz to 1kHz | | | 20 | | | * | | |
| COMMON-MODE REJECTION | | | | | | | | |
| DC, 1kΩ Source Imbalance | | | 80 | 90 | | 90 | 100 | dB |
| G = 1, 2 | | | | | | | | dB |
| G = 4 to 6 | | | 90 | 100 | | 100 | 110 | dB |
| G = 32 to 1024 | | | 100 | 114 | | 110 | 114 | dB |
| 60Hz, 1kΩ Source Imbalance | | | | | | * | * | dB |
| G = 1, 2 | | | 80 | 86 | | * | * | dB |
| G = 4 to 16 | | | 90 | 96 | | * | * | dB |
| G = 32 to 1024 | | | 100 | 106 | | * | * | dB |
| DYNAMIC RESPONSE | | | | | | | | |
| ±3dB Response | Small Signal | | | | | | | kHz |
| G = 1 | | | 100 | | | * | | kHz |
| G = 32 to 128 | | | 40 | | | * | | kHz |
| G = 256 to 1024 | | | 10 | | | * | | kHz |
| ±1% Response | Small Signal | | | | | | | kHz |
| G = 1 | | | 40 | | | * | | kHz |
| G = 32 to 128 | | | 8 | | | * | | kHz |
| G = 256 to 1024 | | | 3 | | | * | | kHz |
| Slew Rate | G = 1 | 0.2 | 0.5 | | | * | | V/μsec |
| Settling Time | G = 128 | | | | | | | μsec |
| to 1% | | | 75 | | | * | | μsec |
| to 0.1% | | | 100 | | | * | | μsec |
| to 0.01% | | | 200 | | | * | | μsec |

ELECTRICAL (CONT)

Typical at +25°C, unless otherwise noted.

| PARAMETER | CONDITIONS | 3606A ⁽¹⁾ | | | 3606B ⁽¹⁾ | | | UNITS |
|------------------------------------|------------|----------------------|------|------|----------------------|-----|-----|-------|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| LOGIC VOLTAGES | | | | | | | | |
| "0" Level ⁽⁷⁾ | No damage | | 0 | +0.4 | * | * | * | V |
| "1" Level ⁽⁷⁾ | | +2.4 | +5.0 | | * | * | * | V |
| Absolute Max | | | | | +7 | | | * |
| ANALOG SUPPLY | | | | | | | | |
| Rated Voltage | | | ±15 | | * | * | * | VDC |
| Voltage Range, Derated Performance | | ±8 | | ±18 | * | * | * | VDC |
| Current, quiescent | | | ±10 | ±20 | * | * | * | mA |
| DIGITAL SUPPLY | | | | | | | | |
| Rated Voltage | | | +5 | | * | * | * | VDC |
| Voltage Range | | +4.5 | | +5.5 | * | * | * | VDC |
| Current, quiescent | | | 10 | | * | * | * | mA |
| TEMPERATURE RANGE | | | | | | | | |
| Specification | | -25 | | +85 | * | * | * | °C |
| Storage | | -40 | | +100 | * | * | * | °C |

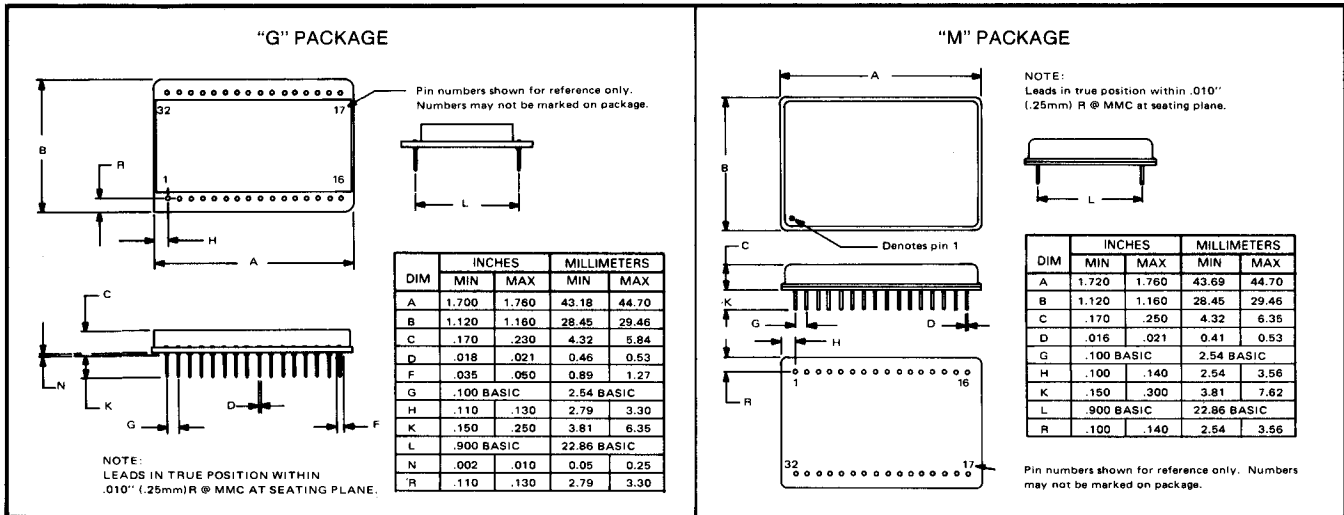
⁽¹⁾Specifications same as 3606A.

NOTES:

- Specify 3606AG or 3606BG for ceramic package and 3606AM or 3606BM for metal package—see below.
- $G = G_1 \times G_2$.
- Nonlinearity is the maximum peak deviation from the best straight-line as a percent of full scale peak-to-peak output.
- RTO = Referred To Output. May be referred to input by dividing by gain G.
- May be adjusted to zero.
- Trimmed according to Figure 8.
- All digital inputs are 1 TTL unit load.

The information in this publication has been carefully checked and is believed to be reliable; however, no responsibility is assumed for possible inaccuracies or omissions. Prices and specifications are subject to change without notice. No patent rights are granted to any of the circuits described herein.

MECHANICAL

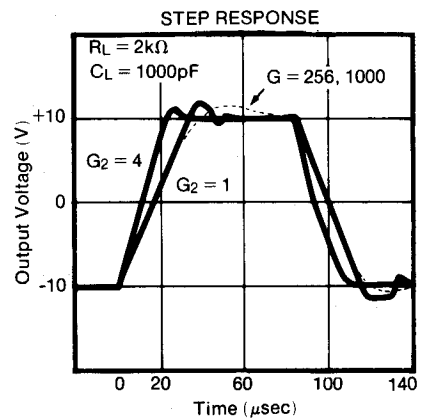
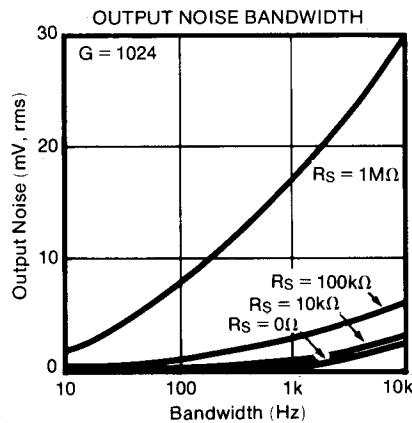
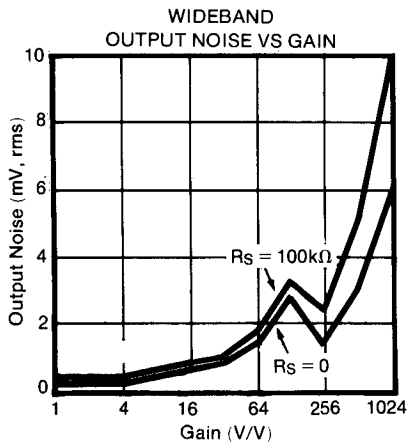
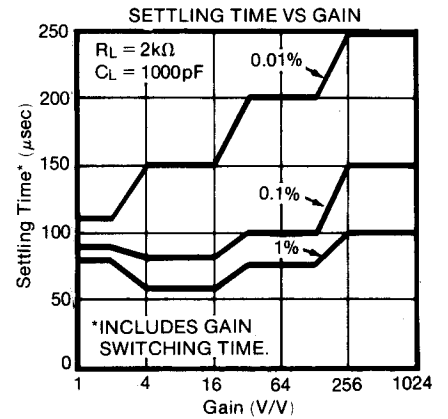
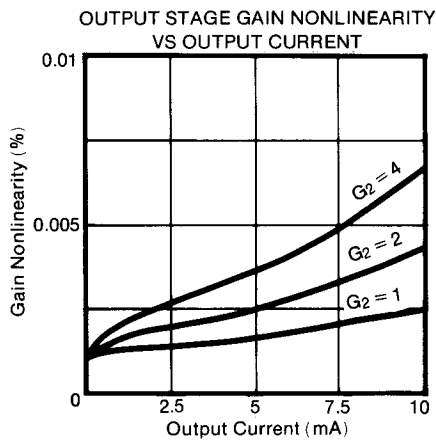
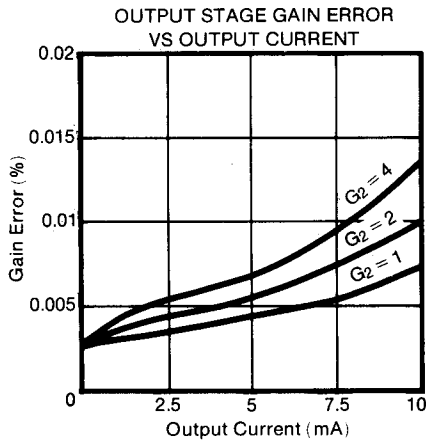
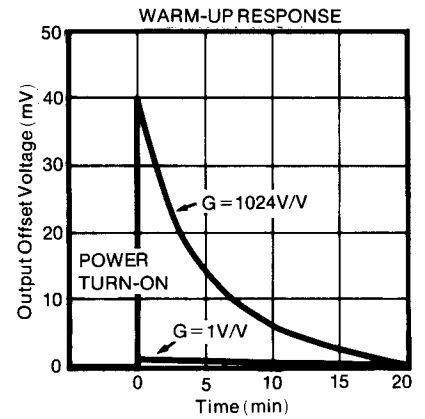
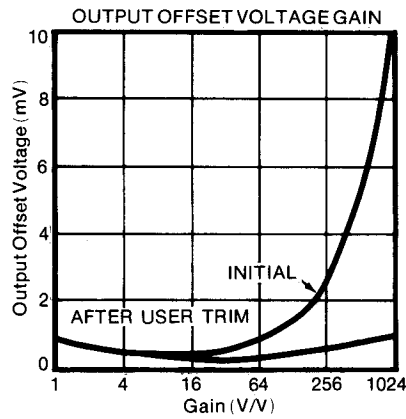
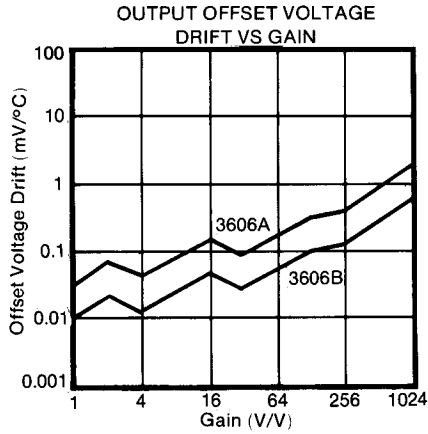
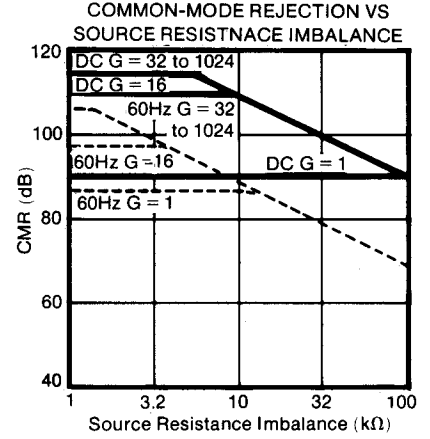
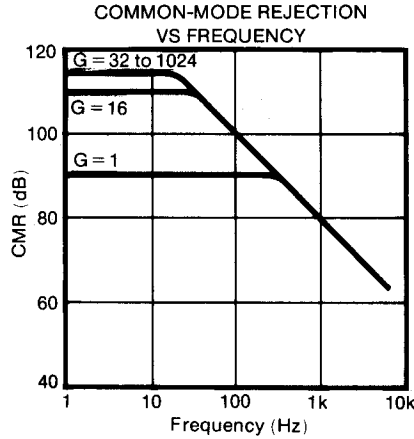
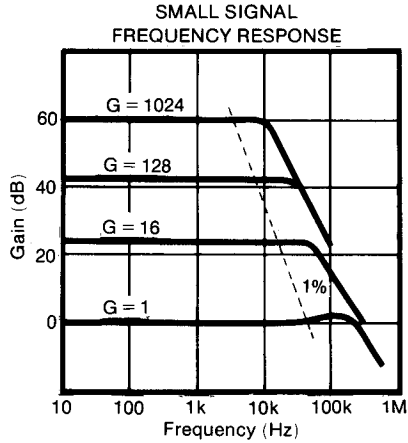


PIN DESIGNATIONS

| PIN NO. | DESIG. | FUNCTION | PIN NO. | DESIG. | FUNCTION |
|---------|----------------|-------------------------------------|---------|----------------|-------------------------------------|
| 1 | -V | -15V Analog Supply | 17 | D ₀ | Digital Input, LSB |
| 2 | -IN | Inverting Input | 18 | D ₁ | Digital Input, next LSB |
| 3 | J ₁ | Output of A ₃ | 19 | G | Latch |
| 4 | (None) | Optional A ₄ Offset Trim | 20 | DIG GND | Digital Ground |
| 5 | ΣJ | Summing Junction of A ₄ | 21 | D ₂ | Digital Input, next MSB |
| 6 | (None) | Optional A ₄ Offset Trim | 22 | D ₃ | Digital Input, MSB |
| 7 | F | Low-Pass Filter Pin | 23 | +5 | +5 Digital Supply |
| 8 | J ₂ | Input to A ₄ | 24 | (None) | No Internal Connection |
| 9 | R ₁ | Output Reference | 25 | (None) | No Internal Connection |
| 10 | O | Output | 26 | Gain | Optional External Gain |
| 11 | S ₁ | Sense G = 1 | 27 | Gain | Optional External Gain |
| 12 | S ₂ | Sense G = 4 | 28 | (None) | Input CMV |
| 13 | S ₃ | Sense G = 2 | 29 | +IN | Noninverting Input |
| 14 | R ₂ | Output Reference | 30 | +V | +15V Analog Supply |
| 15 | ANA GND | Analog Ground | 31 | BAL | Optional Input Stage Offset Null |
| 16 | (None) | No Internal Connection | 32 | BAL | |

TYPICAL PERFORMANCE CURVES

Typical at +25°C unless otherwise noted.



INSTALLATION AND OPERATING INSTRUCTIONS

POWER SUPPLY CONNECTIONS

Figure 2 shows the proper analog and digital power supply connections. The analog supplies should be decoupled with 1 μ F tantalum and 1000pF ceramic capacitors as close to the amplifier as possible. Because the amplifier is direct-coupled it must have a ground return path for the bias currents associated with the amplifier inputs at pins 2 and 29. If the ground return path is not inherent in the signal source (floating source) it must be provided externally. The ground return resistance (R_{GR}) should be kept as low as practical. An upper limit of approximately 50M Ω is established by the input bias currents of the amplifier and its common-mode voltage.

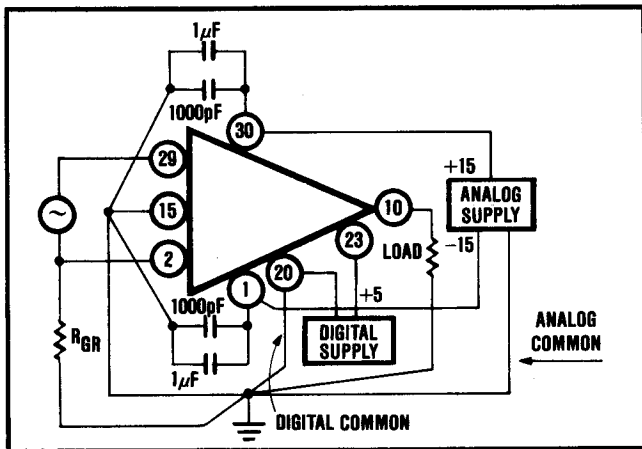


FIGURE 2. Power Supply and Ground Connections.

SIGNAL CONNECTIONS

Basic signal connections are shown in Figure 3. The connection to pin 14 completes the difference amplifier of A_3 (see Figure 1). The 3 to 8 jumper connects the output stage. The pin 9 connection provides a divide-by-two attenuator for the A_4 stage. This is necessary to limit the signal on the output stage switches to maintain signal linearity. The pin 11, 12 and 13 connections to pin 10 close the feedback loop around A_4 .

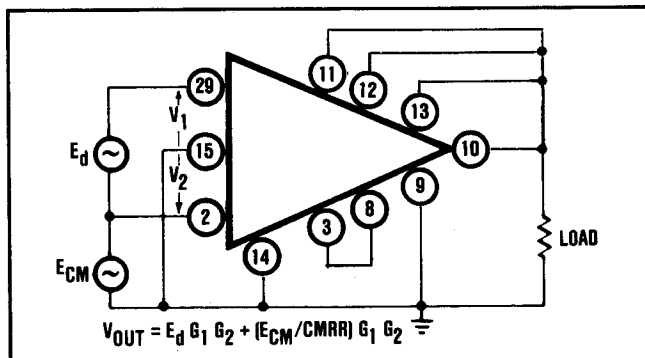


FIGURE 3. Basic Signal Connections.

In the equation shown in Figure 3, G_1 is the input stage gain and G_2 is the output stage gain. CMRR is the

common-mode rejection ratio [CMR (in dB) = 20 log CMRR (in V/V)]. Common-mode voltage shown as E_{CM} is actually the average of the two voltages appearing at the two inputs (pins 29 and 2) with respect to pin 15 (V_1 and V_2).

GAIN SETTING

Gain is determined by a 4-bit digital word applied to the input D_0 through D_3 (see Figure 1). Pin 19 provides a latch function for the inputs. When pin 19 is a logic 0, changes on the D_0 through D_3 inputs are inhibited. Pin 19 should be at +5V if the latch is not used.

A gain state truth table is shown in Table I. Gains are determined by the resistor networks shown in Figure 1. For the state $D_3, D_2 = 0, 0$, the input stage gain is a function of the gain setting resistor R_G connected between pins 26 and 27. If gains of 1, 2 and 4 are desired, no connection should be made to pins 26 and 27 and the resistance across these pins should be kept high with respect to 40k Ω ($> 400M\Omega$).

Gain accuracy is established by laser-trimming the thin-film resistor networks during assembly. No external, user trimming is required.

OUTPUT OFFSET

Output offset may be varied by either of two methods shown in Figure 4. Sources at pin 9 and pin 14 apply voltages to the noninverting inputs of A_4 and A_3 respectively (see Figure 1). Since the output stage gain occurs after these points, the output voltage bias established with V_{R1} and V_{R2} will vary with the output gain, G_2 . Sources connected at pins 9 and 14 must have resistances low with respect to 10k Ω in order not to disturb gain accuracy and common-mode rejection.

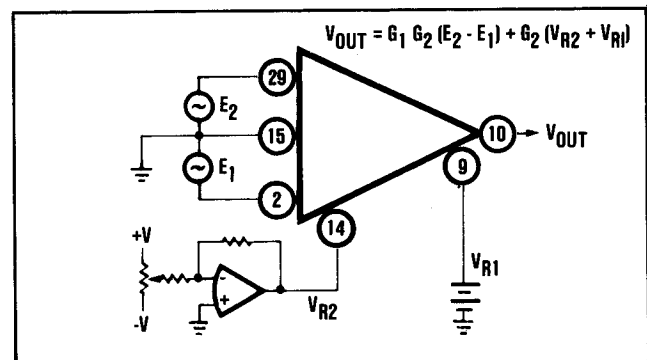


FIGURE 4. Output Offsetting.

LOW-PASS FILTER

For low frequency signals, system performance may be improved by reducing noise bandwidth in the amplifier. This may be accomplished with the addition of one or two external capacitors as shown in Figure 5. C_2 is connected to a 10k/10k attenuator and C_1 is connected as a feedback element across A_4 (see Figures 1 and 5). The transfer function is:

$$\frac{V_o}{V_{in}} = \left[\frac{10 \times 10^3}{100 \times 10^6 S (C_2 + 330 \times 10^{-12}) + 20 \times 10^3} \right] \left[1 + \frac{10 \times 10^3}{10 \times 10^3 R_1 S C_1 + R_1} \right]$$

TABLE I. Gain State Truth Table.

| Digital Inputs (G ₁) (G ₂) | | | | G ₁ (A ₁ and A ₂) (Pins 2 & 29 to 3) | G ₂ (A ₄) (Pin 8 to Pin 10) | G ₁ · G ₂ (R _{C1} * = ∞) | G ₁ · G ₂ (R _{C1} * ≠ ∞) |
|--|----------------|----------------|----------------|--|--|---|---|
| D ₃ | D ₂ | D ₁ | D ₀ | | | | |
| 0 | 0 | 0 | 0 | 1 + 40k/R _{C1} | 1 | 1 | 1(1 + 40k/R _{C1}) |
| 0 | 0 | 0 | 1 | | 2 | 2 | 2(1 + 40k/R _{C1}) |
| 0 | 0 | 1 | 0 | | 4 | 4 | 4(1 + 40k/R _{C1}) |
| 0 | 0 | 1 | 1 | | 4 | 4 | 4(1 + 40k/R _{C1}) |
| 0 | 1 | 0 | 0 | 4 | 1 | 4 | 4 |
| 0 | 1 | 0 | 1 | | 2 | 8 | 8 |
| 0 | 1 | 1 | 0 | | 4 | 16 | 16 |
| 0 | 1 | 1 | 1 | | 4 | 16 | 16 |
| 1 | 0 | 0 | 0 | 32 | 1 | 32 | 32 |
| 1 | 0 | 0 | 1 | | 2 | 64 | 64 |
| 1 | 0 | 1 | 0 | | 4 | 128 | 128 |
| 1 | 0 | 1 | 1 | | 4 | 128 | 128 |
| 1 | 1 | 0 | 0 | 256 | 1 | 256 | 256 |
| 1 | 1 | 0 | 1 | | 2 | 512 | 512 |
| 1 | 1 | 1 | 0 | | 4 | 1024 | 1024 |
| 1 | 1 | 1 | 1 | | 4 | 1024 | 1024 |

*R_{C1} connected between pins 26 and 27.

The first term is a first order filter. The second term is more complex. R₁ varies with the output stage gain -1.4k for G₂ = 4 (see Figure 1). The "1 + ..." nature of the transfer function prevents a true first order filter rolloff. For most applications, the first order low-pass filter obtained by C₂ provides sufficient filtering. The value C₂ required for a desired cutoff frequency (f₂ in Hz) is obtained by the equation shown in Figure 5.

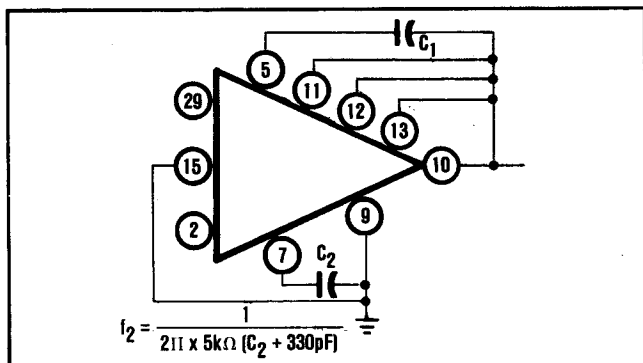


FIGURE 5. Low-Pass Filter Connections.

LARGER OUTPUT CURRENT

The output current rating of the 3606 is a minimum of ±5mA. The linearity of the gain is affected by output current. See Typical Performance Curves. Optimum linearity is achieved with I_o ≤ 1mA, I_o ≤ 5mA is acceptable. Above 5mA it may be desirable to use a power or current booster as shown in Figure 6. Burr-

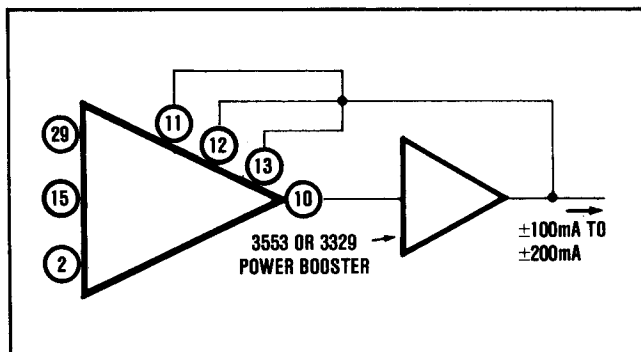


FIGURE 6. Output Current Booster.

Brown's 3329 will provide ±100mA output while Burr-Brown's 3553 will supply ±200mA. When either booster is placed inside the feedback loop as shown, the booster's offset voltage produces no significant errors since it is divided by the open-loop gain of the output stage.

GUARD DRIVE CONNECTIONS

Use of the guard drive connection shown in Figure 7 can improve system common-mode rejection when the distributed capacitance of the input lines is significant. The

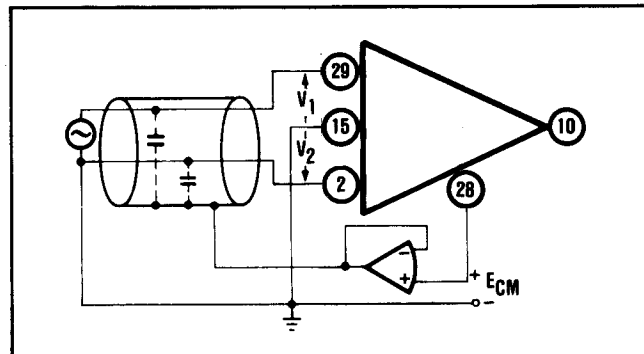


FIGURE 7. Guard Drive Connections.

common-mode voltage which appears on the input lines and on pins 29 and 2 is computed by the 3606 [(V₁ + V₂)/2] and appears at pin 28. It is then fed back to the shield so that the voltage across the distributed capacitances is minimized. This reduces the common-mode current and improves common-mode rejection. The operational amplifier in the voltage follower configuration is used to supply more current than can be obtained from the 20k resistors connected internally to pin 28 (see Figure 1).

OFFSET TRIM

Offset voltages of the 3606 are reduced by laser-trimming during assembly. This reduces the initial offset voltage and the offset voltage change with gain change to levels that are acceptable for most applications. For more critical applications the offset voltages can be externally

nulled to zero. The following steps should be followed (see Figure 8).

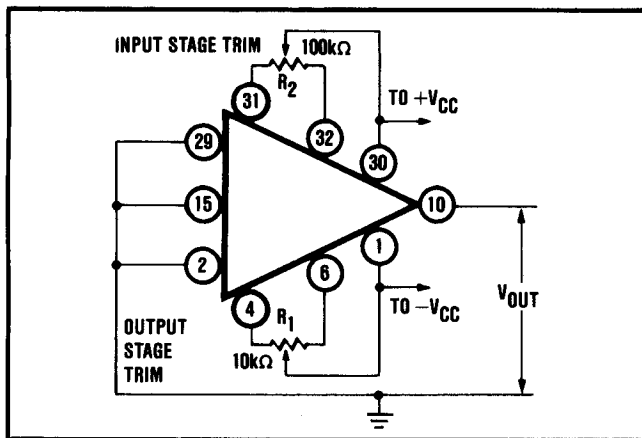


FIGURE 8. Optional Offset Trim.

1. Adjust both R_1 and R_2 to mid-range.
2. Set the gain to minimum (1V/V).
3. Adjust R_1 to make V_{OUT} equal zero.
4. Set the gain to maximum (1024V/V).
5. Adjust R_2 to make V_{OUT} equal zero.

By using this technique, the change in output offset voltage caused by a gain change of 1V/V to 1024V/V may be reduced to, typically 1mV instead of 10mV with no external trimming. Trimming may cause the offset voltage drift vs temperature to increase slightly.

APPLICATIONS

A typical application of 3606 in a microcomputer based data acquisition system is shown in the block diagram below.

The purpose of this system is to be able to acquire data from a specific analog input channel, suitably condition it (amplify it and convert it to digital form) and store it or transmit it for further processing.

Initially the Microcomputer loads the RAM (random access memory) with the required coding for various desired gains via Data Bus. The coding associates the gain state truth table for 3606 with corresponding address locations in the computer memory. So when the computer puts out an instruction to multiplex a specific analog input channel through the multiplexer via the Address Bus, the RAM also receives the same address information and puts out corresponding gain code to the PGIA 3606. The 3606 amplifies the multiplexed signal by the programmed gain value, and outputs it to S/H (sample and hold). The S/H holds the output value when it receives the control signal from the computer and the A/D converts it and outputs it to the computer via the Data Bus under computer control.

The PGIA 3606 allows the system user to modify and reprogram gain values for different analog input channels merely by changing the software computer program. Since different dedicated instruments are not required for various input channels, the PGIA also saves space and overall system costs.

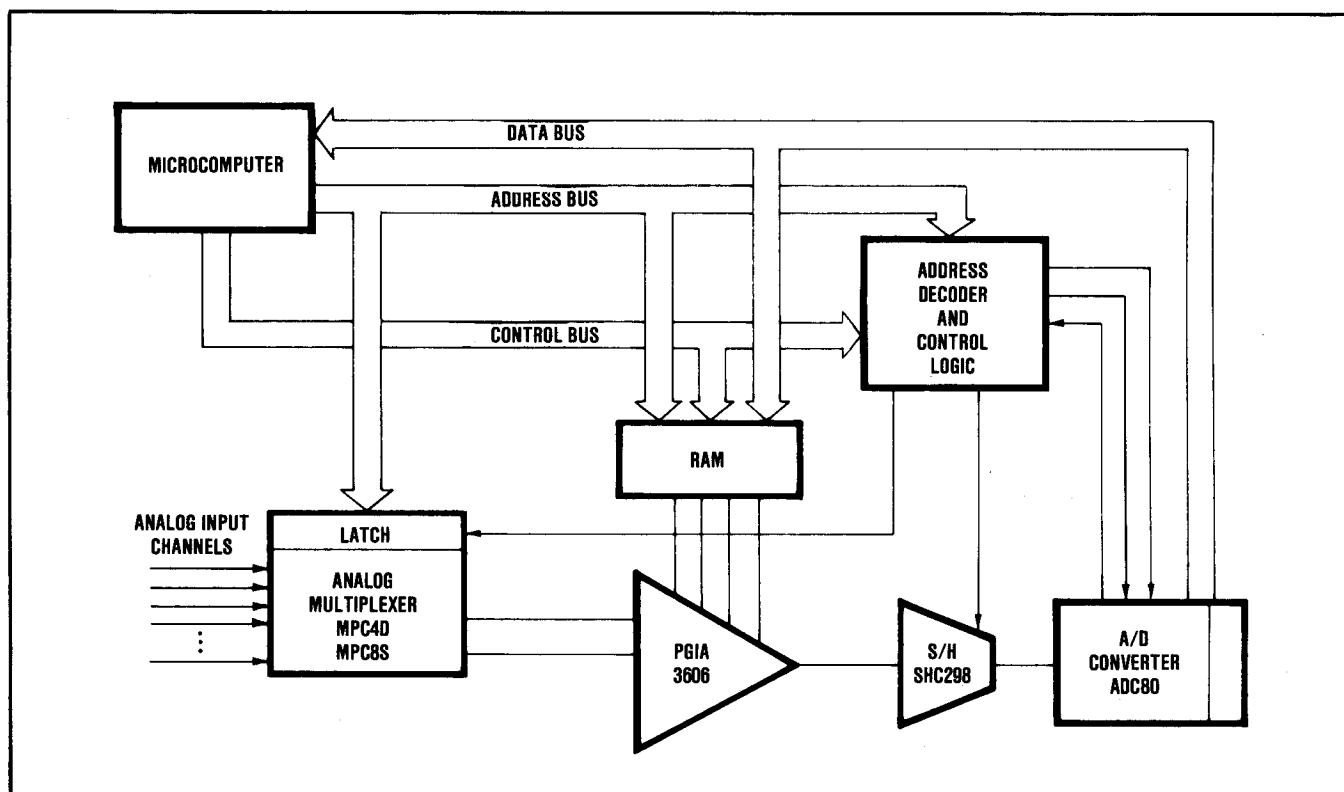


FIGURE 9. Use of 3606 in Data Acquisition System.

PACKAGING INFORMATION

| ORDERABLE DEVICE | STATUS(1) | PACKAGE TYPE | PACKAGE DRAWING | PINS | PACKAGE QTY |
|------------------|-----------|--------------|-----------------|------|-------------|
| 3606BG | NRND | CDIP | JNC | 32 | 10 |

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

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Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265

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