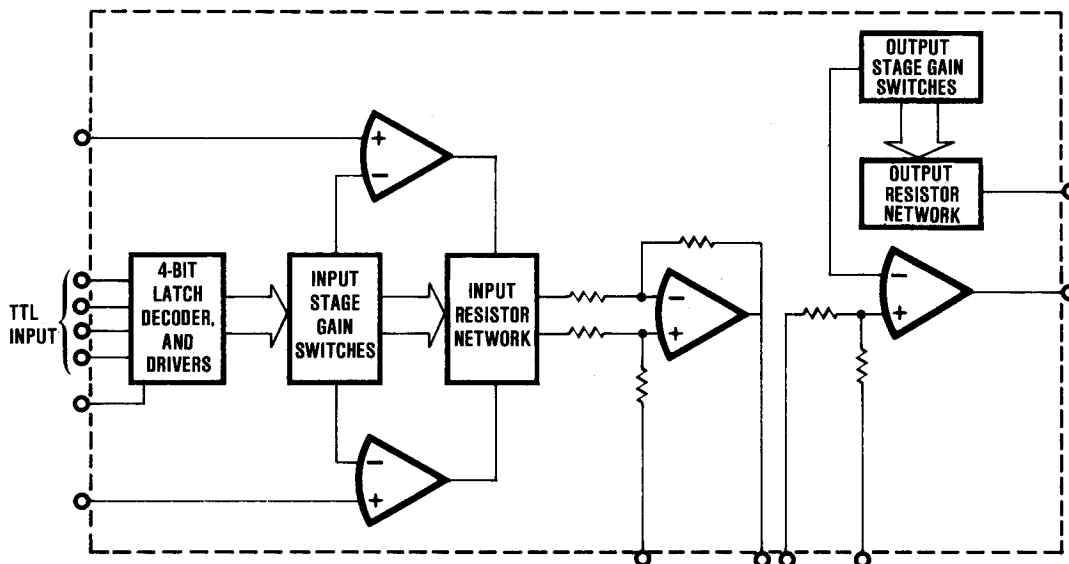


3606

## 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 ( $10\text{ppm}/^\circ\text{C}$  max), and low offset voltage drift vs temperature ( $1\mu\text{V}/^\circ\text{C}$  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  $\pm 25\text{mV}$  with no external adjustments. With two simple offset adjustments the change can be limited to less than  $2\text{mV}$  ( $1\text{mV}$  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.

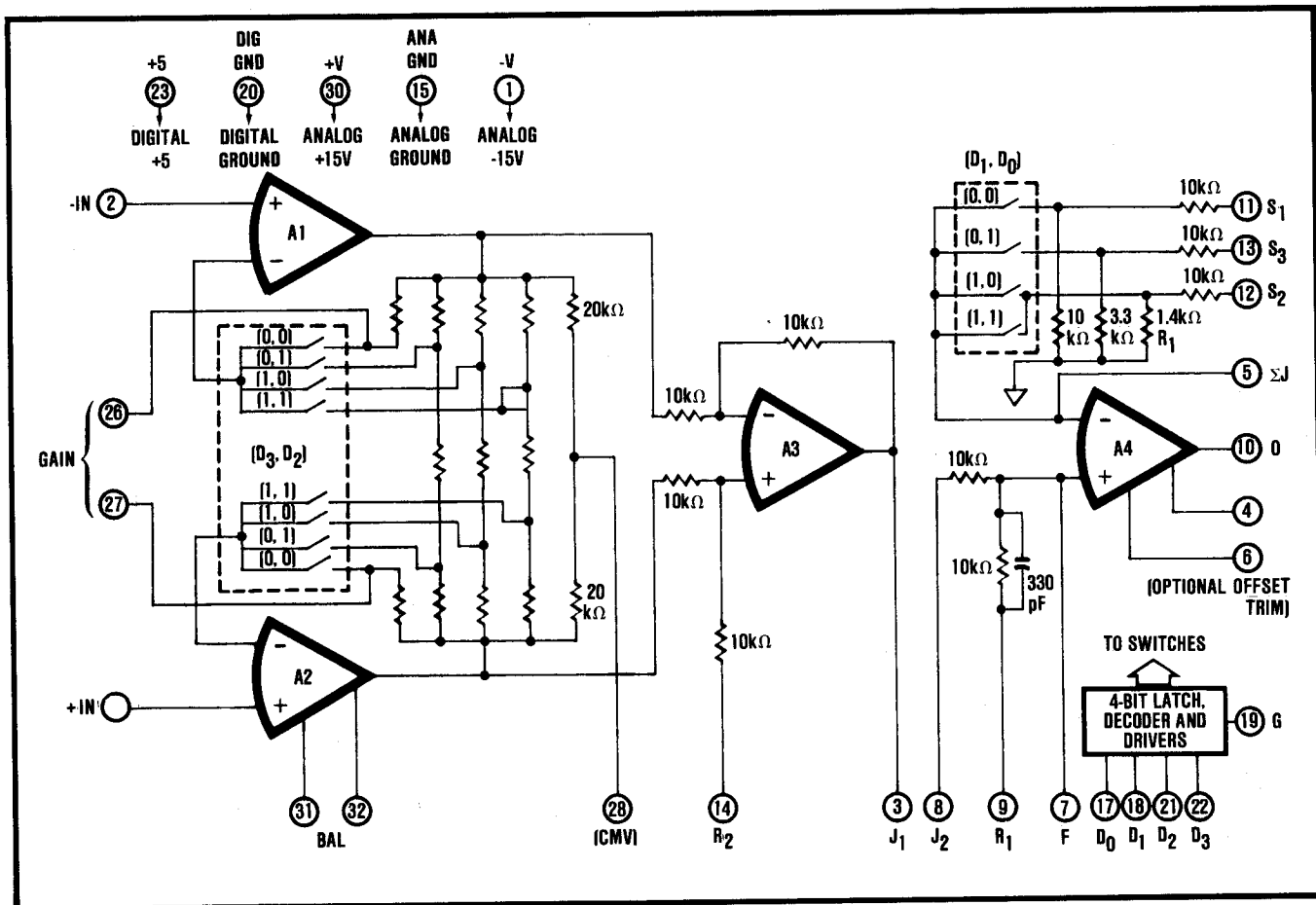


FIGURE 1. Simplified Schematic.

# SPECIFICATIONS

## ELECTRICAL

Typical at +25°C, unless otherwise noted.

PARAMETER	CONDITIONS	3606A <sup>(1)</sup>			3606B <sup>(1)</sup>			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
<b>GAIN, G<sup>(2)</sup></b>								
Inaccuracy	G = 1 to 1024, I <sub>O</sub> = 1mA		±0.02	±0.05		±0.01	±0.02	%
Nonlinearity <sup>(3)</sup>	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
<b>RATED OUTPUT</b>								
Voltage	I <sub>O</sub> = ±5mA	±10	±12		*	*		V
Current	V <sub>O</sub> = ±10V	±5	±10		*	*		mA
Impedance			0.05			*		Ω
<b>INPUT CHARACTERISTICS</b>								
Absolute Max Voltage	No damage			±V <sub>CC</sub>	*	*	*	V
Common-Mode Voltage Range	Linear operation	±10	±10.5		*	*		V
Differential Impedance			10    3			*		10 <sup>9</sup> Ω    pF
Common-Mode Impedance			10    3			*		10 <sup>9</sup> Ω    pF
<b>OFFSET VOLTAGE, RTO<sup>(4)</sup></b>								
Initial at +25°C <sup>(5)</sup>			±(0.02G +1)	±(0.04G +2)		±(0.01G +1)	±(0.02G +2)	mV
vs Temperature	-25°C to +85°C		(±0.0015G ±0.03G <sub>2</sub> )	(±0.003G ±0.05G <sub>2</sub> )		(±0.0005G ±0.01G <sub>2</sub> )	(±0.001G ±0.02G <sub>2</sub> )	mV/°C
vs Time			(±0.001G ±0.01G <sub>2</sub> )			*		mV/mo
vs Supply			(±0.002G ±0.04G <sub>2</sub> )			*		mV/V
vs Gain <sup>(6)</sup>	With trimming		±1	±2		*	*	mV
<b>INPUT BIAS CURRENT</b>								
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
<b>INPUT DIFFERENCE CURRENT</b>								
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
<b>INPUT NOISE</b>								
Voltage	R <sub>SOURCE</sub> ≤ 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			*		
<b>COMMON-MODE REJECTION</b>								
DC, 1kΩ Source Imbalance			80	90		90	100	dB
G = 1, 2			90	100		100	110	dB
G = 4 to 6			100	114		110	114	dB
G = 32 to 1024						*	*	
60Hz, 1kΩ Source Imbalance			80	86		*	*	dB
G = 1, 2			90	96		*	*	dB
G = 4 to 16			100	106		*	*	dB
G = 32 to 1024						*	*	
<b>DYNAMIC RESPONSE</b>								
±3dB Response	Small Signal		100			*		kHz
G = 1			40			*		kHz
G = 32 to 128			10			*		kHz
G = 256 to 1024						*		kHz
±1% Response	Small Signal		40			*		kHz
G = 1			8			*		kHz
G = 32 to 128			3			*		kHz
G = 256 to 1024						*		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 <sup>(1)</sup>			3606B <sup>(1)</sup>			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
<b>LOGIC VOLTAGES</b>								
"0" Level <sup>(7)</sup>	No damage		0	+0.4	*	*	*	V
"1" Level <sup>(7)</sup>		+2.4	+5.0		*	*	*	V
Absolute Max					+7			*
<b>ANALOG SUPPLY</b>								
Rated Voltage			±15		*	*	*	VDC
Voltage Range, Derated Performance		±8		±18	*	*	*	VDC
Current, quiescent			±10	±20	*	*	*	mA
<b>DIGITAL SUPPLY</b>								
Rated Voltage			+5		*	*	*	VDC
Voltage Range		+4.5		+5.5	*	*	*	VDC
Current, quiescent			10		*	*	*	mA
<b>TEMPERATURE RANGE</b>								
Specification		-25		+85	*	*	*	°C
Storage		-40		+100	*	*	*	°C

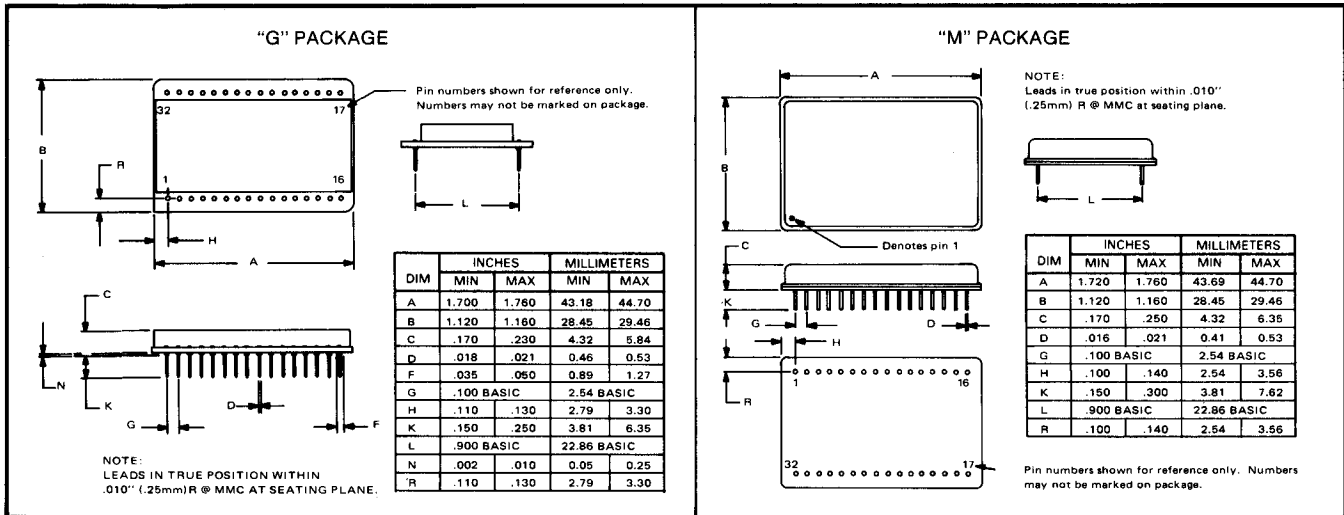
<sup>(1)</sup>Specifications same as 3606A.

### 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

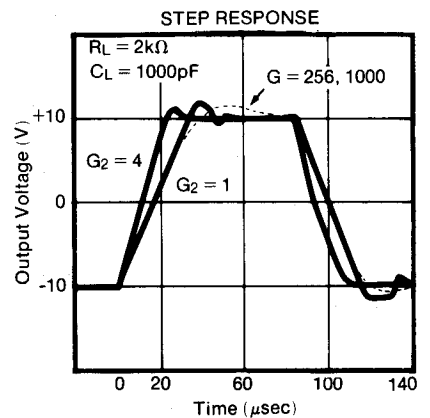
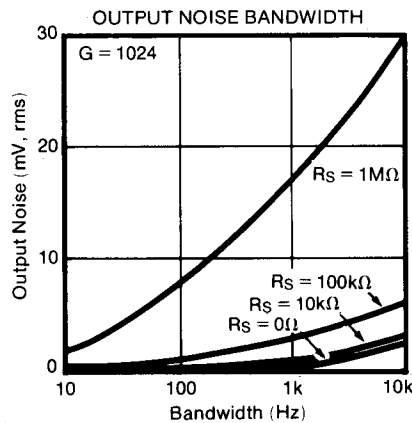
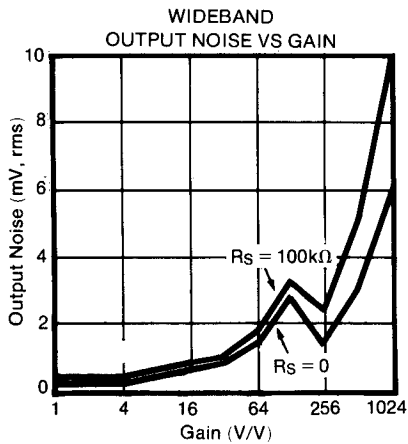
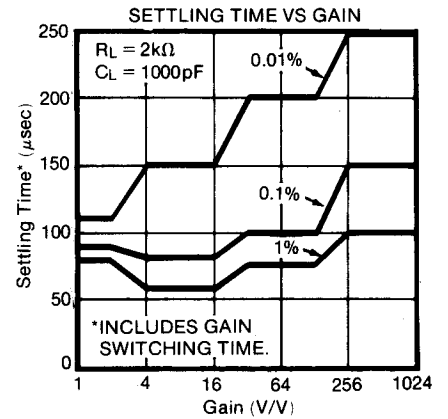
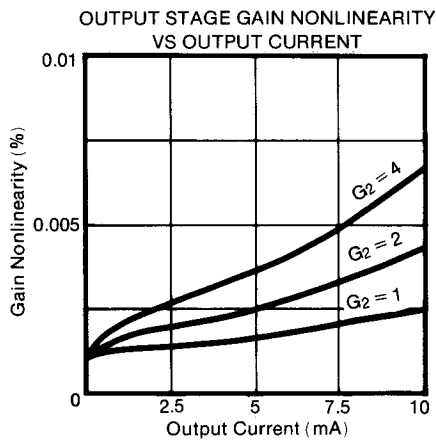
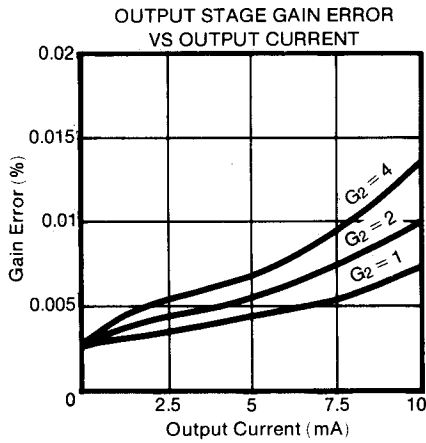
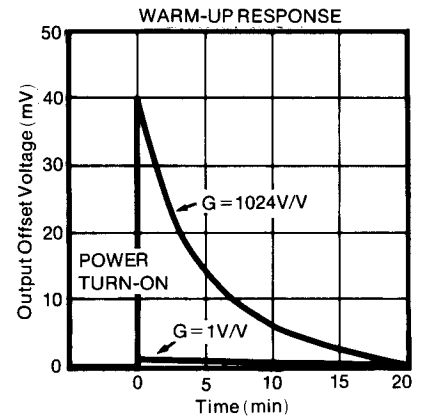
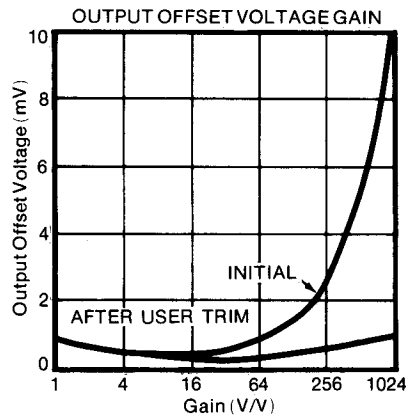
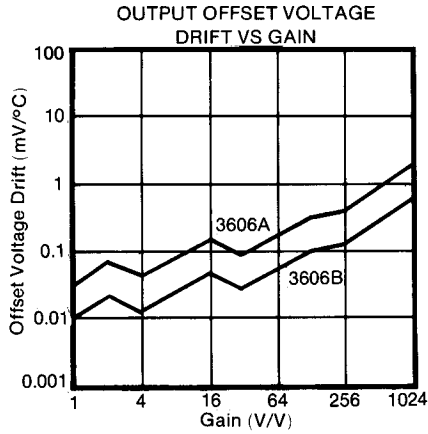
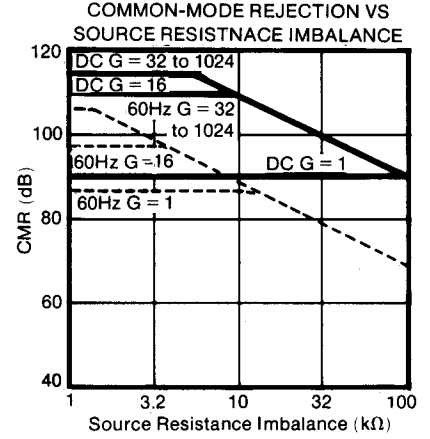
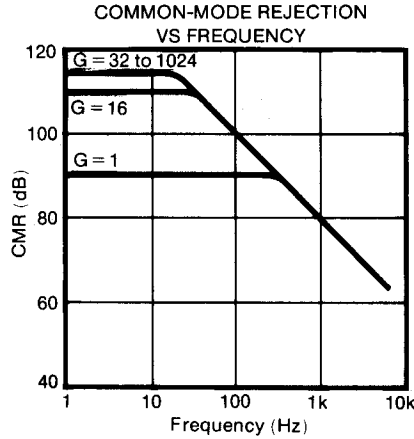
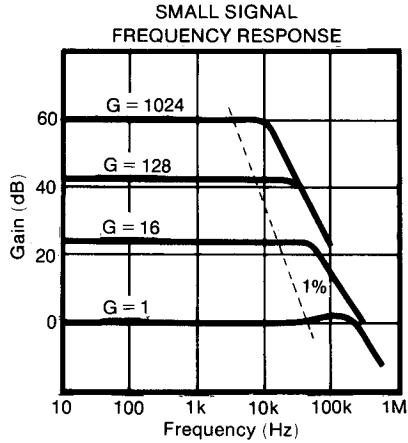


## PIN DESIGNATIONS

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

# 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  $1\mu\text{F}$  tantalum and  $1000\text{pF}$  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  $50\text{M}\Omega$  is established by the input bias currents of the amplifier and its common-mode voltage.

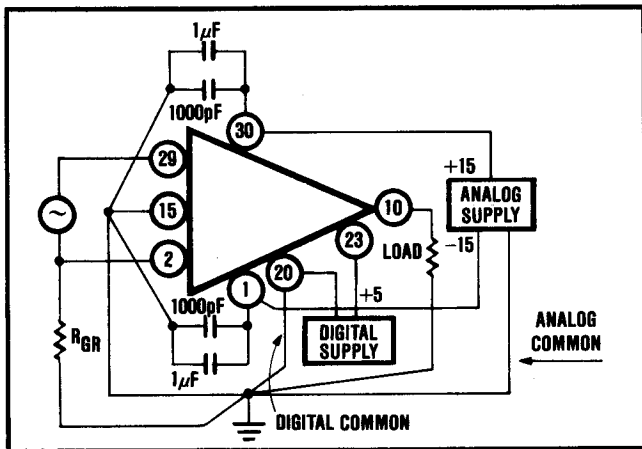


FIGURE 2. Power Supply and Ground Connections.

## 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  $A_4$ .

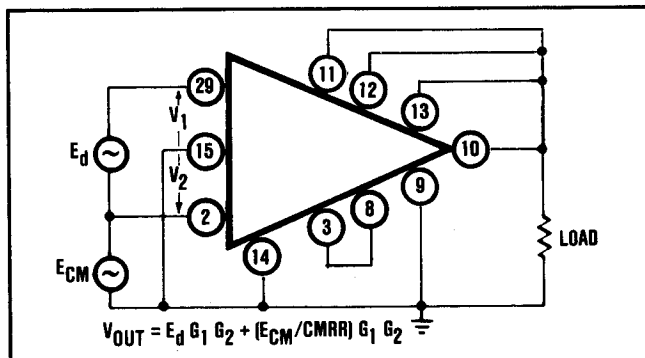


FIGURE 3. Basic Signal Connections.

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  $40\text{k}\Omega$  ( $> 400\text{M}\Omega$ ).

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  $10\text{k}\Omega$  in order not to disturb gain accuracy and common-mode rejection.

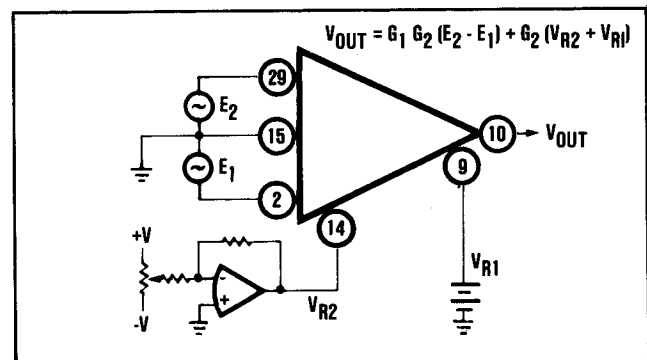


FIGURE 4. Output Offsetting.

## 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  $10\text{k}/10\text{k}$  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 <sub>1</sub> ) (G <sub>2</sub> )				G <sub>1</sub> (A <sub>1</sub> and A <sub>2</sub> ) (Pins 2 & 29 to 3)	G <sub>2</sub> (A <sub>4</sub> ) (Pin 8 to Pin 10)	G <sub>1</sub> · G <sub>2</sub> (R <sub>C1</sub> * = ∞)	G <sub>1</sub> · G <sub>2</sub> (R <sub>C1</sub> * ≠ ∞)
D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>				
0	0	0	0	1 + 40k/R <sub>C1</sub>	1	1	1(1 + 40k/R <sub>C1</sub> )
0	0	0	1		2	2	2(1 + 40k/R <sub>C1</sub> )
0	0	1	0		4	4	4(1 + 40k/R <sub>C1</sub> )
0	0	1	1		4	4	4(1 + 40k/R <sub>C1</sub> )
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<sub>C1</sub> connected between pins 26 and 27.

The first term is a first order filter. The second term is more complex. R<sub>1</sub> varies with the output stage gain -1.4k for G<sub>2</sub> = 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 C<sub>2</sub> provides sufficient filtering. The value C<sub>2</sub> required for a desired cutoff frequency (f<sub>2</sub> in Hz) is obtained by the equation shown in Figure 5.

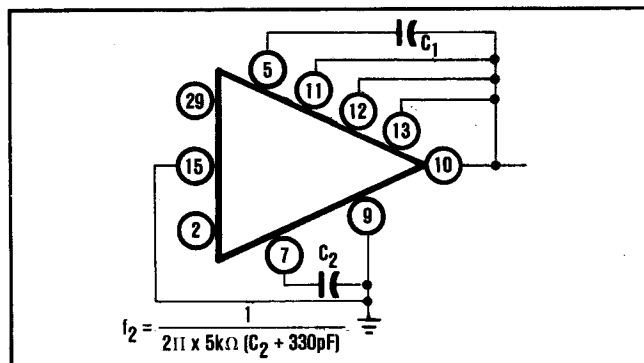


FIGURE 5. Low-Pass Filter Connections.

**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<sub>o</sub> ≤ 1mA, I<sub>o</sub> ≤ 5mA is acceptable. Above 5mA it may be desirable to use a power or current booster as shown in Figure 6. Burr-

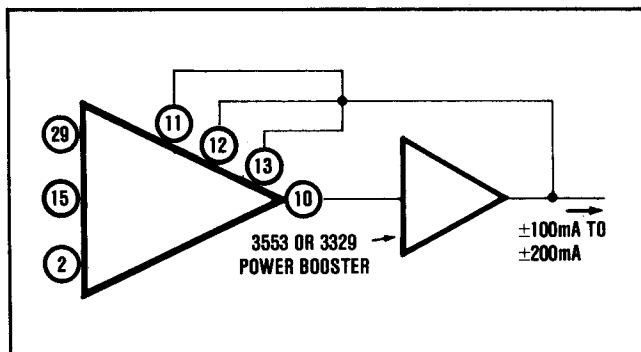


FIGURE 6. Output Current Booster.

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

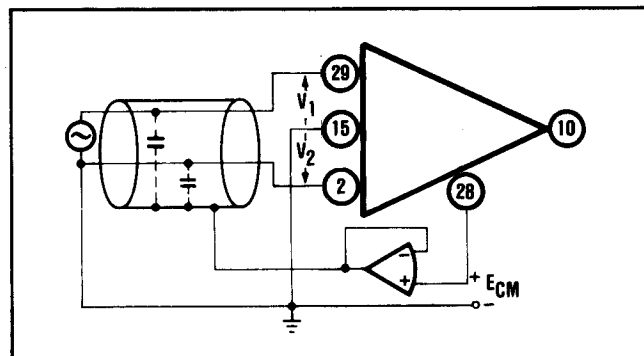


FIGURE 7. Guard Drive Connections.

common-mode voltage which appears on the input lines and on pins 29 and 2 is computed by the 3606 [(V<sub>1</sub> + V<sub>2</sub>)/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).

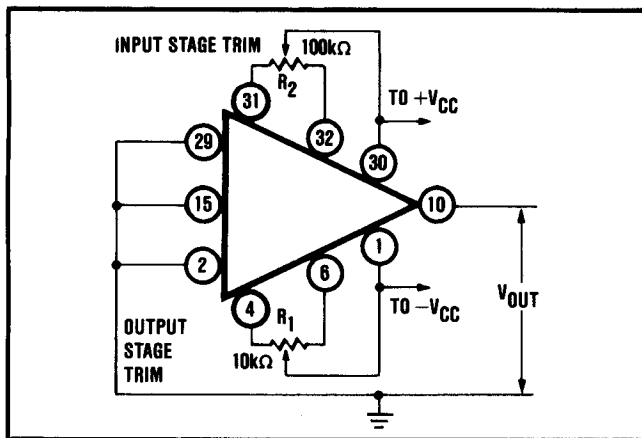


FIGURE 8. Optional Offset Trim.

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.

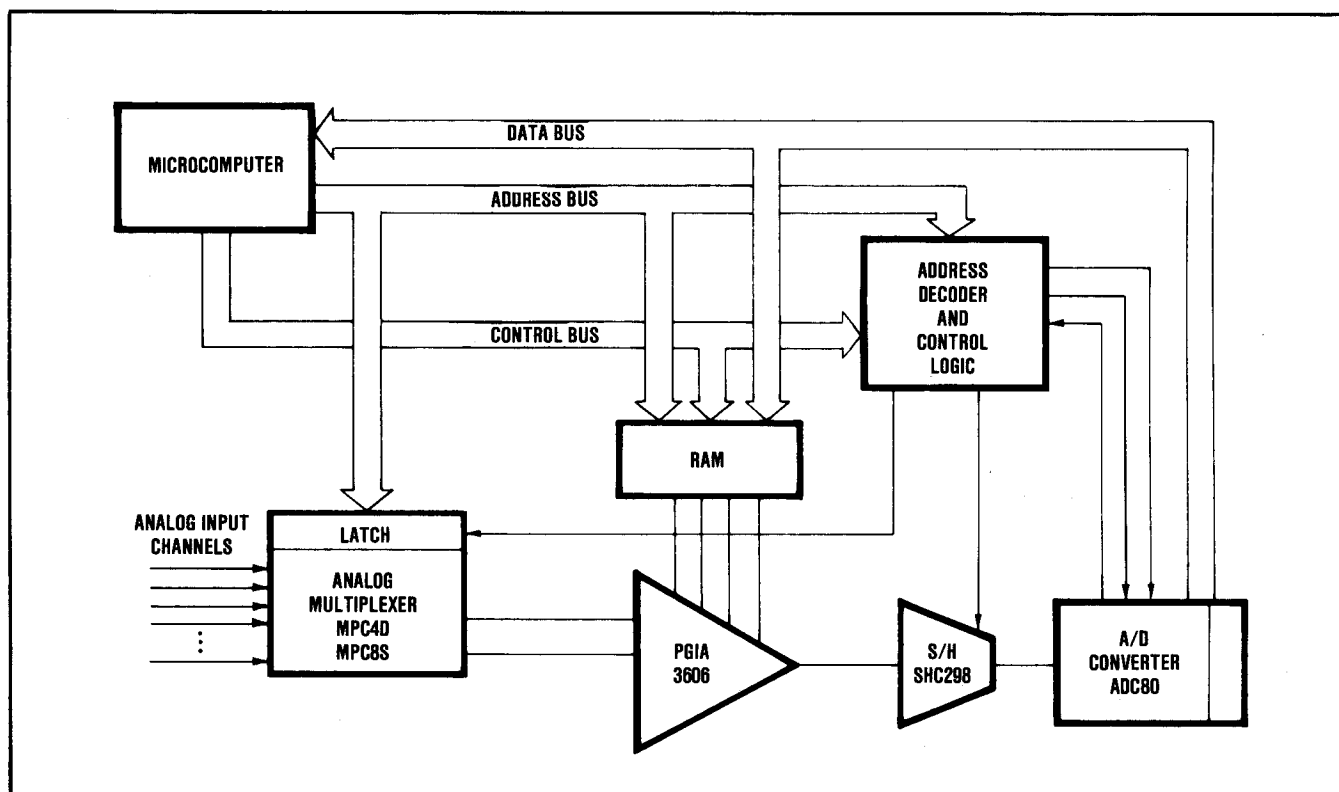


FIGURE 9. Use of 3606 in Data Acquisition System.



**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
3606BG	NRND	CDIP	JNC	32		TBD	Call TI	Call TI

<sup>(1)</sup> 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.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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