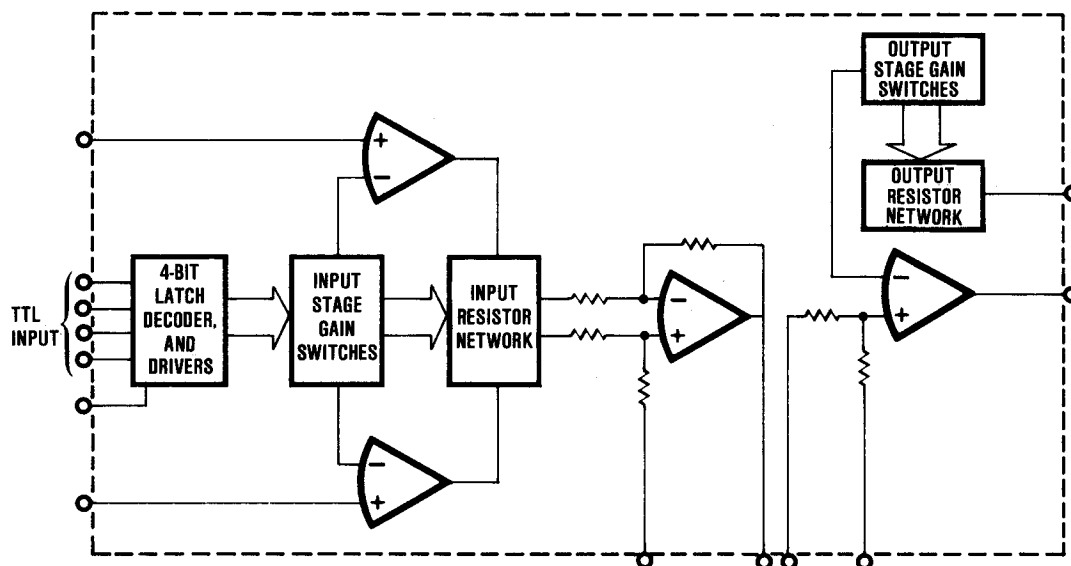


3606

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 $G = 1024\text{V/V}$
- LOW GAIN ERRORS - 0.02% max
- LOW GAIN DRIFT - 10ppm/°C max
- LOW VOLTAGE DRIFT
 $1\mu\text{V}/^\circ\text{C}$ max RTI, $G = 1024\text{V/V}$
- HIGH CMR - 110dB min, $G = 1024\text{V/V}$
- HIGH INPUT IMPEDANCE - $10 \times 10^9\Omega$
- LOW OFFSET VOLTAGE
 $22\mu\text{V}$ max RTI, $G = 1024\text{V/V}$
2mV max RTI, $G = 1\text{V/V}$



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} ($\parallel$ 1,000,000:1).

Desirable characteristics of a high performance instrumentation amplifier are offered by the 3606: high input impedance ($10\text{G}\Omega$), excellent gain nonlinearity (0.01% max, $G = 1024\text{V/V}$; 0.02% max, $G = 1\text{V/V}$), high common-mode rejection (100dB min, $G \geq 4\text{V/V}$), 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 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.

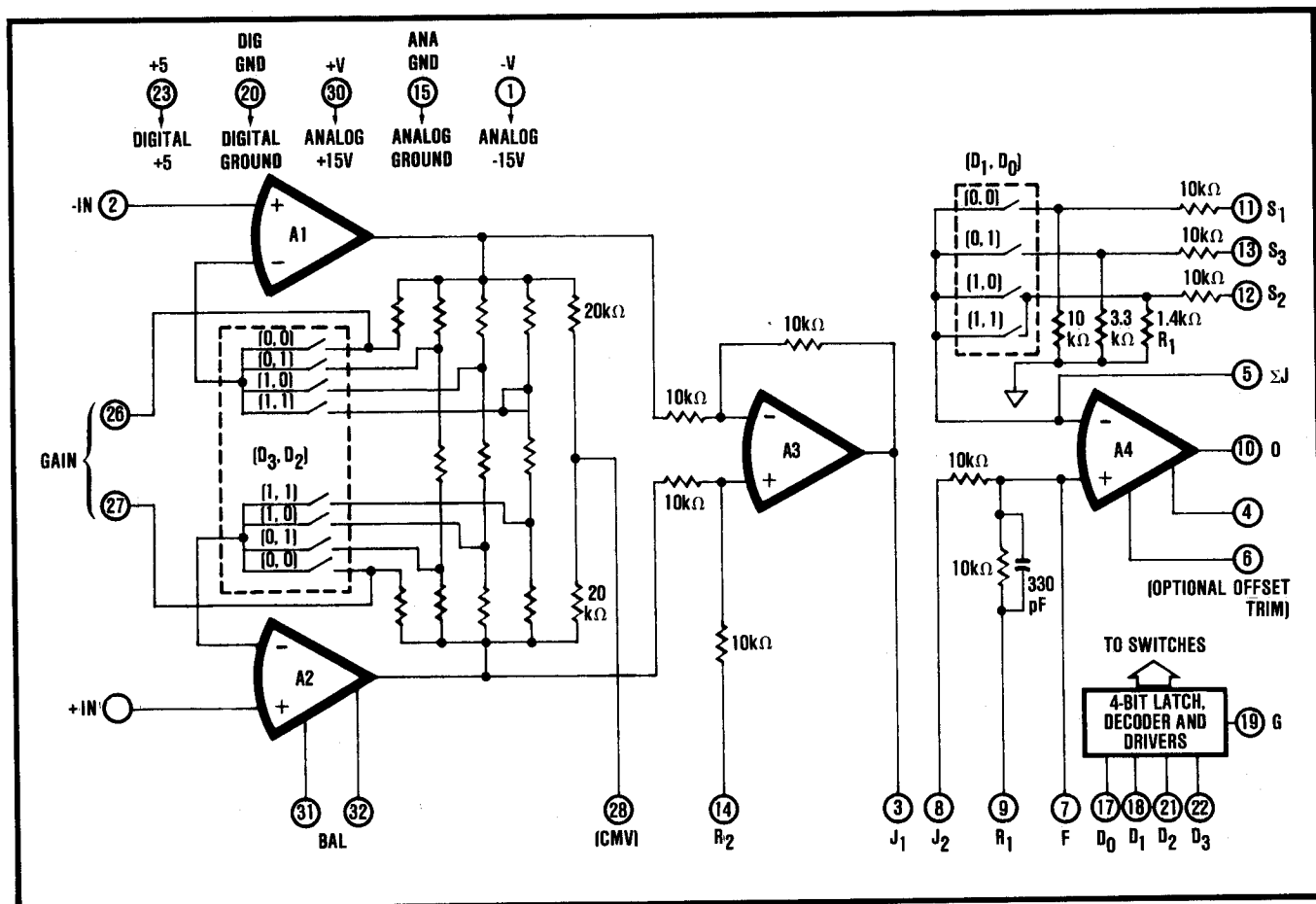


FIGURE 1. Simplified Schematic.

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							μV, p-p
0.01Hz to 10Hz	G = 1024		1.4			*		μV, rms
10Hz to 1kHz			1.0			*		
Current								nA, p-p
0.01Hz to 10Hz			70			*		nA, rms
10Hz to 1kHz			20			*		
COMMON-MODE REJECTION								
DC, 1kΩ Source Imbalance								dB
G = 1, 2		80	90		90	100		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							
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	+2.4	0	+0.4	*	*	*	V
"1" Level ⁽⁷⁾			+5.0			*	*	V
Absolute Max				+7			*	V
ANALOG SUPPLY								
Rated Voltage		±8	±15		*	*		VDC
Voltage Range, Derated Performance				±18		*	*	VDC
Current, quiescent			±10	±20		*	*	mA
DIGITAL SUPPLY								
Rated Voltage		+4.5	+5		*	*		VDC
Voltage Range				+5.5		*	*	VDC
Current, quiescent			10			*		mA
TEMPERATURE RANGE								
Specification		-25		+85	*		*	°C
Storage				-40			+100	*

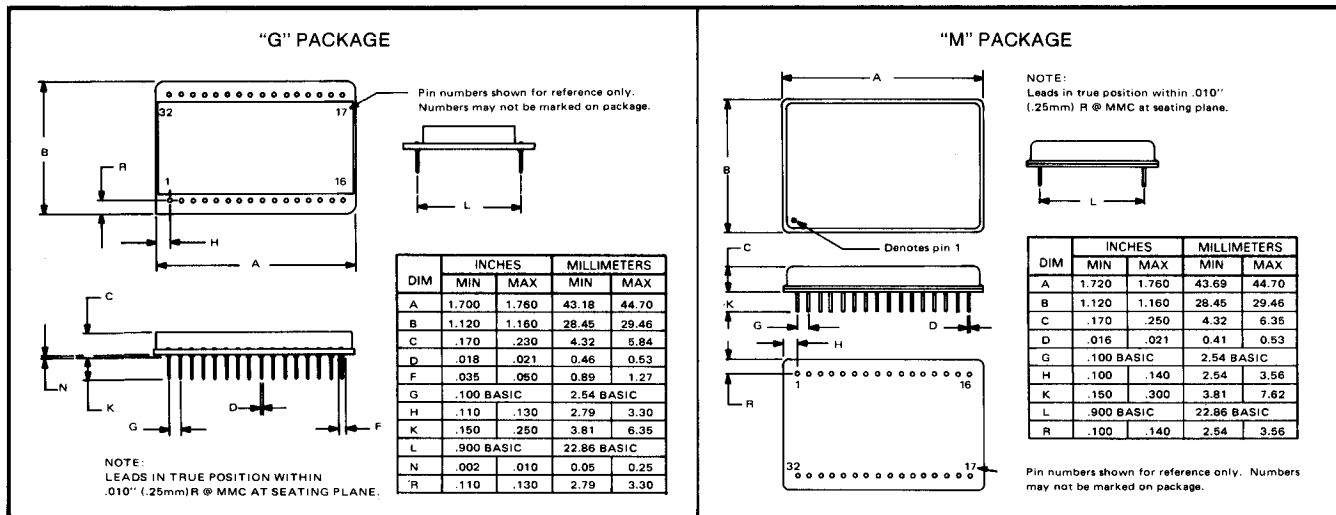
*Specifications same as 3606A.

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.

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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
16	(None)	No Internal Connection	32	BAL }	Offset Null

TYPICAL PERFORMANCE CURVES

Typical at +25°C unless otherwise noted.

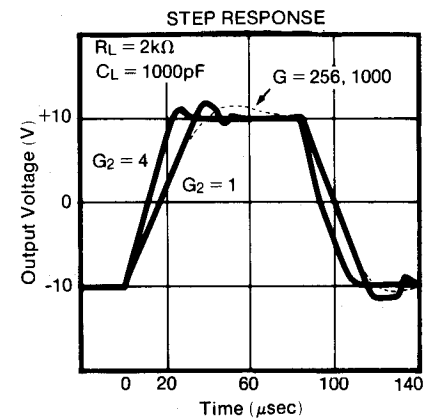
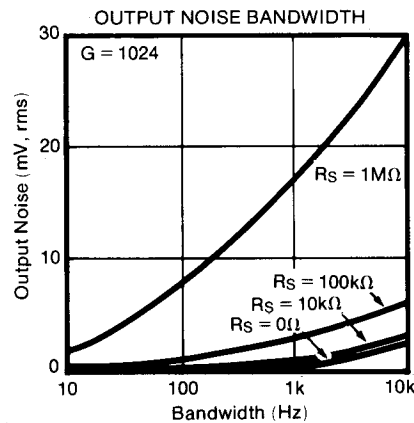
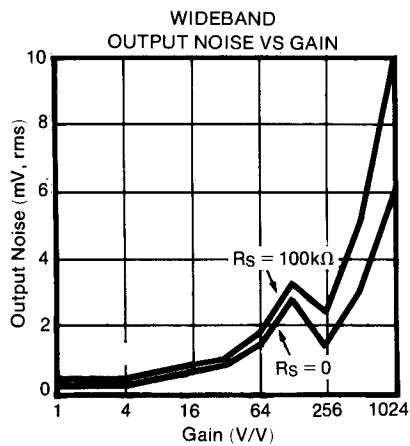
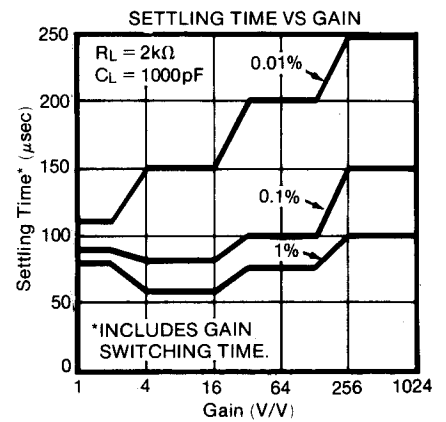
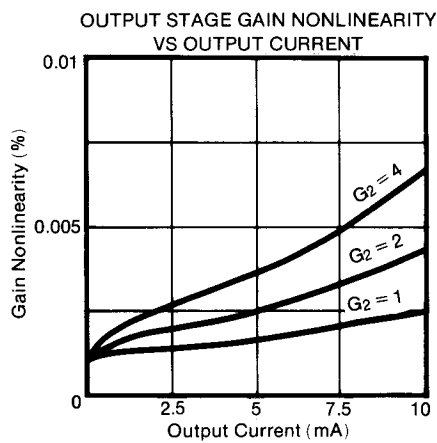
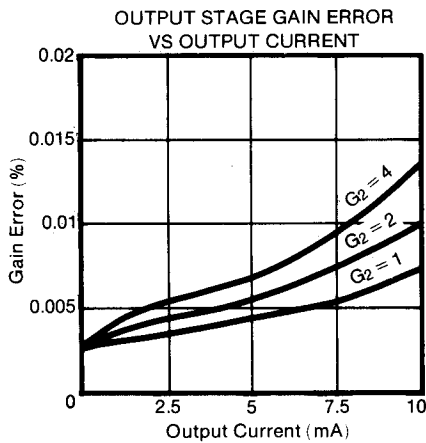
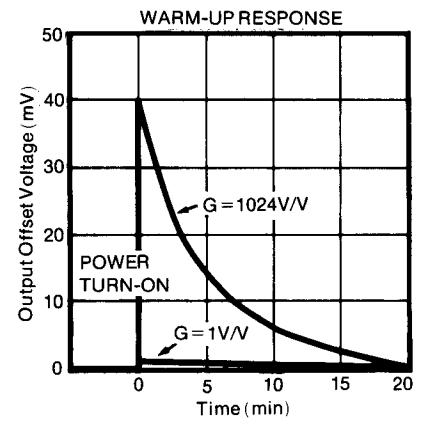
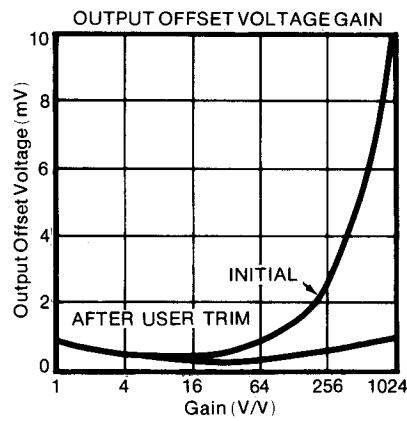
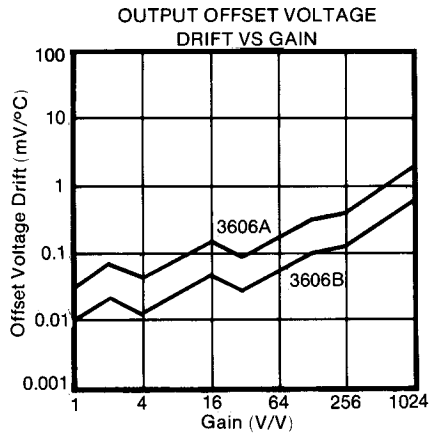
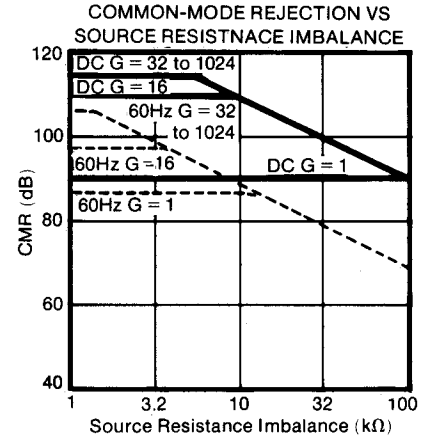
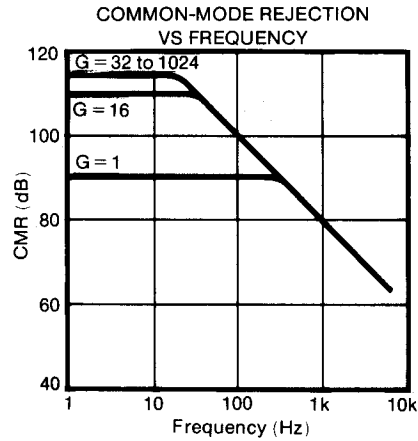
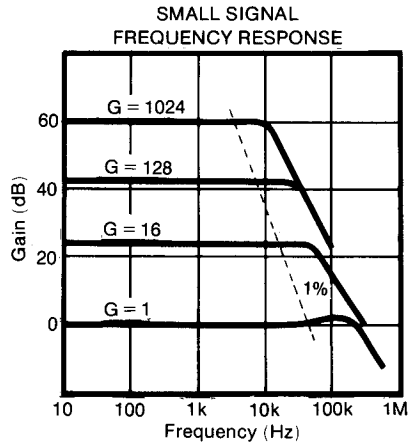


TABLE I. Gain State Truth Table.

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 _{ci} * = ∞)	G ₁ · G ₂ (R _{ci} * ≠ ∞)
D ₃	D ₂	D ₁	D ₀				
0	0	0	0	$1 + 40k/R_{ci}$	1	1	$1(1 + 40k/R_{ci})$
0	0	0	1		2	2	$2(1 + 40k/R_{ci})$
0	0	1	0		4	4	$4(1 + 40k/R_{ci})$
0	0	1	1		4	4	$4(1 + 40k/R_{ci})$
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_G 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.

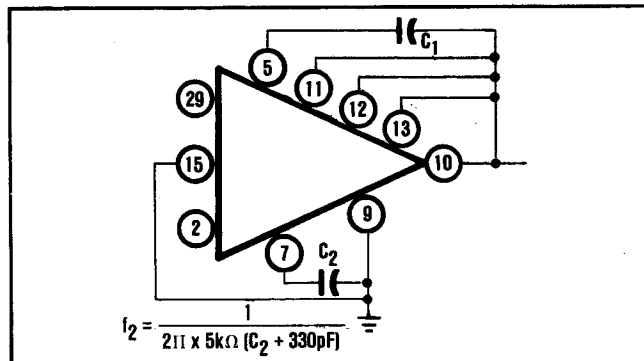


FIGURE 5. Low-Pass Filter Connections.

LARGER OUTPUT CURRENT

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

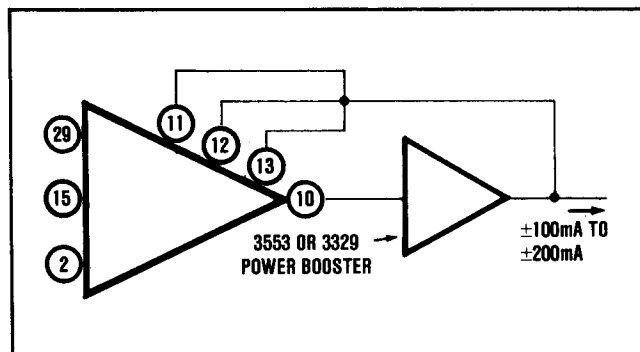


FIGURE 6. Output Current Booster.

Brown's 3329 will provide $\pm 100\text{mA}$ output while Burr-Brown's 3553 will supply $\pm 200\text{mA}$. 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

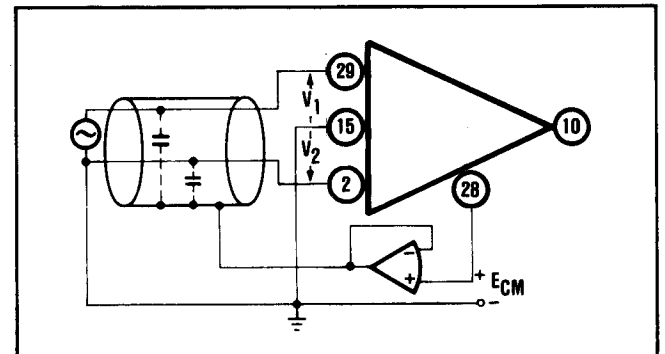


FIGURE 7. Guard Drive Connections.

common-mode voltage which appears on the input lines and on pins 29 and 2 is computed by the 3606 $[(V_1 + V_2)/2]$ 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).

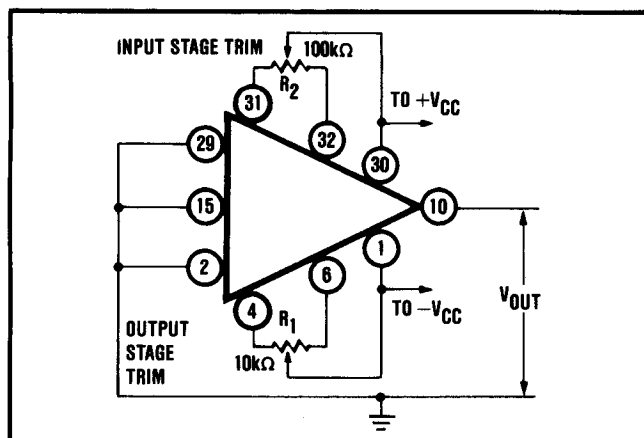


FIGURE 8. Optional Offset Trim.

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.

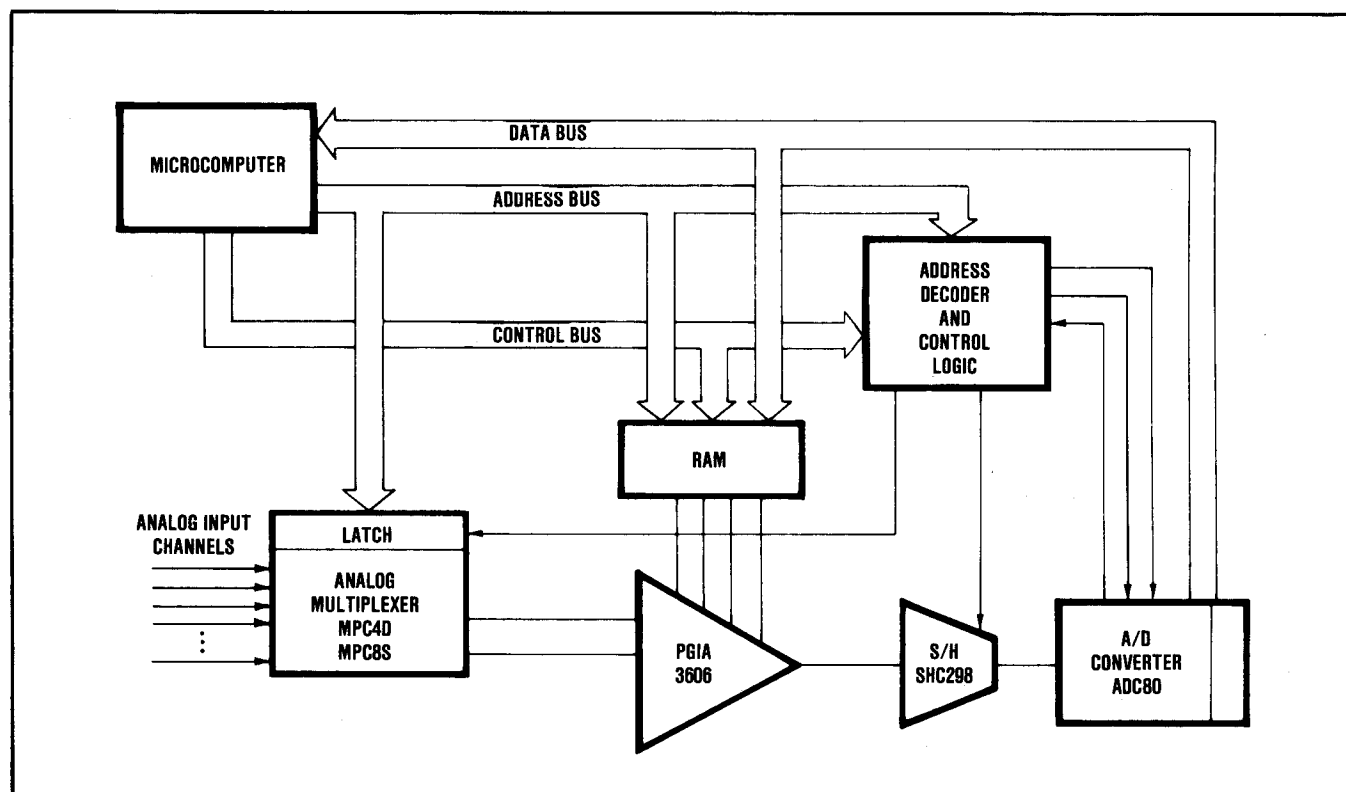


FIGURE 9. Use of 3606 in Data Acquisition System.

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/Ball Finish	MSL Peak Temp ⁽³⁾
3606BG	NRND	CDIP	JNC	32	10	TBD	Call TI	N / A for Pkg Type

⁽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.

⁽²⁾ 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)

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

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