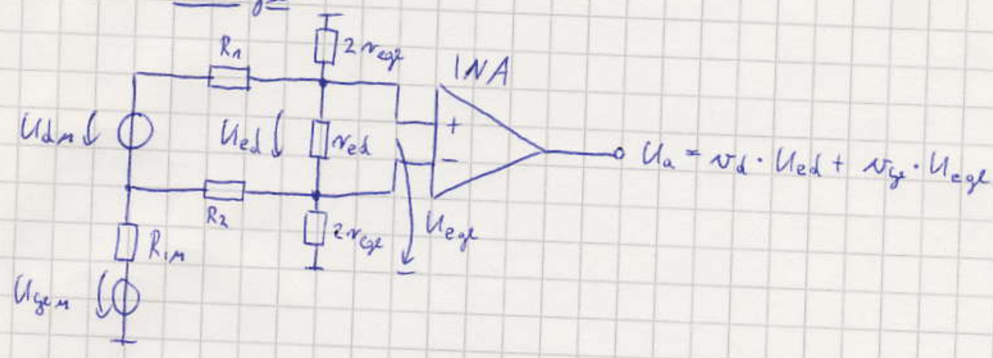
Instrumentationsverstärker

- Aufgabe: · Verstärkung von Differenzspannungen mit einstellbarem v
  · sehr hohe Gleichtaktunterdrückung
  · sehr hoher Eingangswiderstand

Analyse



U_{dm} ... Meßspannung – Nutzsignal

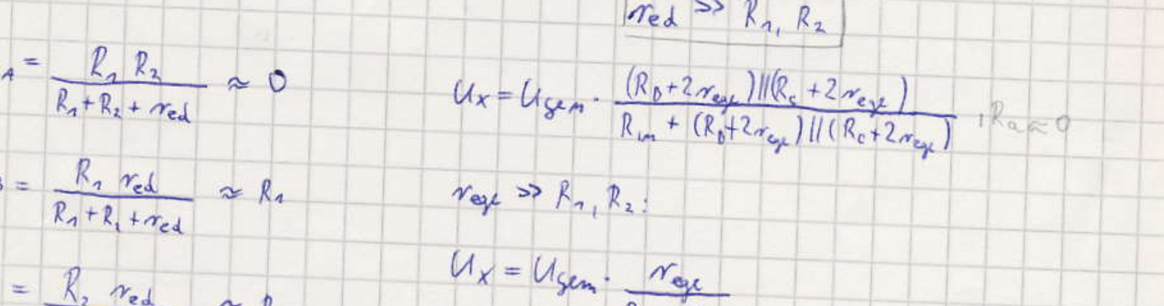
U_{gem} ... Gleichtaktspannung / Störspannung

R_{im} ... Isolationswiderstand des Sensors (Gehäuse – Erde)

$R_{1/2}$ ... Leitungswiderstände, z.B. bei direktem Anschluß des Sensors: $R_1 = R_i(U_{dm})$, $R_2 \ll R_1$ $(R_2 \to 0)$

Angestrebt: $R_1, R_2 \ll r_{ed}, r_{egl} \to U_{ed} \approx U_{dm}$

Fehler durch $r_{ed}, r_{gl} < \infty$: → Gleichtakt → Gegentakt-Wandlung



$r_{ed} \gg R_1, R_2$

$$R_A = \frac{R_1 R_2}{R_1 + R_2 + r_{ed}} \approx 0$$

$$R_B = \frac{R_1 r_{ed}}{R_1 + R_1 + r_{ed}} \approx R_1$$

$$R_C = \frac{R_2 r_{ed}}{R_1 + R_2 + r_{ed}} \approx R_2$$

$$U_x = U_{gem} \cdot \frac{(R_B + 2r_{egl}) \| (R_C + 2r_{egl})}{R_{im} + (R_B + 2r_{egl}) \| (R_C + 2r_{egl})} \quad ; R_A \approx 0$$

$r_{egl} \gg R_1, R_2$:

$$U_x = U_{gem} \cdot \frac{r_{egl}}{R_{im} + r_{egl}}$$

$$U_{ed} = U_x \left(\frac{2r_{egl}}{R_B + 2r_{egl}} - \frac{2r_{egl}}{R_C + 2r_{egl}} \right) = U_x \left(\frac{2r_{egl}}{R_1 + 2r_{egl}} - \frac{2r_{egl}}{R_2 + 2r_{egl}} \right)$$

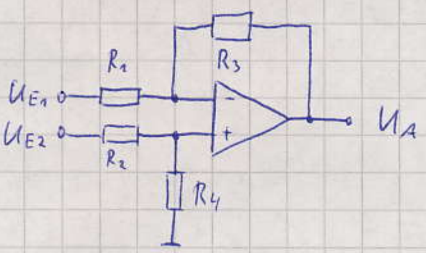
$U_{ed} = U_x \frac{2 r_{egl}(R_2 - R_1)}{(R_1+2r_{egl})(R_2+2r_{egl})} \approx \frac{R_2-R_1}{2r_{egl}} \cdot U_x$ für

$U_{ed} = \frac{U_{gem}}{2} \cdot \frac{R_2 - R_1}{R_{1m} + r_{egl}}$

$U_{egl} = \overbrace{\frac{2 r_{egl}}{R_{1m}+R_c+2r_{egl}}}^{\text{unterer U-Teiler}} \cdot U_{gem} + \overbrace{\frac{U_{gem}}{4}\,\frac{R_2-R_1}{R_{1m}+r_{egl}}}^{\text{halbe Udiff}} \approx \frac{2r_{egl}}{R_{1m}+2r_{egl}} U_{gem}$

→ R_{1m}, r_{egl} möglichst groß, $R_2 \approx R_1$

Instrumentationsverstärker mit 1 OPV



$+: \quad U_P = U_{E2} \cdot \frac{R_4}{R_2+R_4}$

$-: \quad U_N = U_{E1} \frac{R_3}{R_1+R_3} + U_A \cdot \frac{R_1}{R_1+R_3}$

idealer OPV: $U_P = U_N$

$U_A = \frac{R_1+R_3}{R_1}\left(U_{E2}\frac{R_4}{R_2+R_4} - U_{E1}\frac{R_3}{R_1+R_3}\right)$ → Dimensionierung auf $v_{gl} = 0$

→ $\frac{R_4}{R_2+R_4} = \frac{R_3}{R_1+R_3}$

→ $R_1 + R_3 = R_2 + R_4$

↳ $R_1 = R_2$, $R_3 = R_4$

→ $U_A = \underbrace{\frac{R_3}{R_1}}_{v_d'} \underbrace{\left(U_{E2} - U_{E1}\right)}_{U_d'}$

$v_{gl,ideal} = 0$

Gleichtaktunterdrückung, real (Toleranzbehaftete R, $G_{OV} < \infty$ - Gleichtaktunterdrückung)

$R_i = R_{i0} \cdot (1 \pm \sigma)$ $\quad i = 1 \ldots 4$ $\qquad G_{OV} = \frac{v_d}{v_{gl}} = CMR$

~~Fehler durch v_{gl}:~~

~~$U_{egl} = U_{gl} \cdot \frac{R_4}{R_2+R_4}$~~ ~~$U_{a,v_{gl}} = U_{gl} \cdot v_{gl} \cdot \frac{R_4}{R_2+R_4}$~~

~~$\left(v_{gl}' = \frac{|v_d|}{G_{OV}} + \frac{1}{1+|v_d|} 4\sigma \right.$~~ ← worst case für alle 4 R)

$$G = \frac{1}{\frac{1}{G_{0V}} + \frac{46}{|v_d'|+1}}$$

Bsp. $\sigma = 0{,}1\%$

$|v_d'| = 1$ $\Rightarrow G = 500 \mathrel{\hat{=}} 54\,dB$

$G_{0V} = 120\,dB = 10^6$

→ 4 hochgenaue R notwendig zur Gleichtaktunterdrückung

- weitere Nachteile: - r_{egl} und r_{ed} klein
  - zur Änderung von v' sind 2 Rs zu ändern

~~Inpu~~ <u>Common Mode Input Range</u>

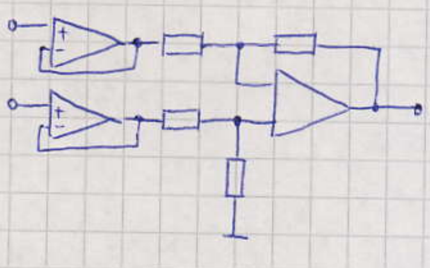
$$U_+ = U_{gl} \frac{R_4}{R_2 + R_4} = U_-$$

~~$U_{+max} =$~~ $U_{gl,max} = U_{+max}\left(1 + \frac{R_2}{R_4}\right) = U_{+max}\left(1 + \frac{1}{v'}\right)$

für $v' \gg 1$ wird der Gleichtaktbereich nicht vergrößert

Folie INA 105

Erhöhung des Eingangswiderstandes durch OPV als Spannungsfolger



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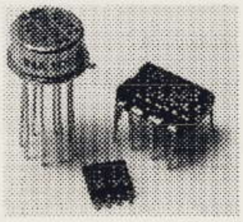


INA105

Precision Unity Gain DIFFERENTIAL AMPLIFIER

FEATURES

- CMR 86dB min OVER TEMPERATURE
- GAIN ERROR: 0.01% max
- NONLINEARITY: 0.001% max
- NO EXTERNAL ADJUSTMENTS REQUIRED
- EASY TO USE
- COMPLETE SOLUTION
- HIGHLY VERSATILE
- LOW COST
- PLASTIC DIP, TO-99 HERMETIC METAL, AND SO-8 SOIC PACKAGES

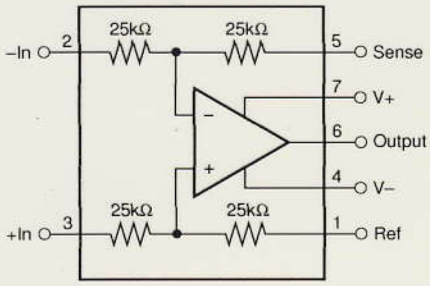
APPLICATIONS

- DIFFERENTIAL AMPLIFIER
- INSTRUMENTATION AMPLIFIER BUILDING BLOCK
- UNITY-GAIN INVERTING AMPLIFIER
- GAIN-OF-1/2 AMPLIFIER
- NONINVERTING GAIN-OF-2 AMPLIFIER
- AVERAGE VALUE AMPLIFIER
- ABSOLUTE VALUE AMPLIFIER
- SUMMING AMPLIFIER
- SYNCHRONOUS DEMODULATOR
- CURRENT RECEIVER WITH COMPLIANCE TO RAILS
- 4mA TO 20mA TRANSMITTER
- VOLTAGE-CONTROLLED CURRENT SOURCE
- ALL-PASS FILTERS

DESCRIPTION

The INA105 is a monolithic Gain = 1 differential amplifier consisting of a precision op amp and on-chip metal film resistors. The resistors are laser trimmed for accurate gain and high common-mode rejection. Excellent TCR tracking of the resistors maintains gain accuracy and common-mode rejection over temperature.

The differential amplifier is the foundation of many commonly used circuits. The INA105 provides this precision circuit function without using an expensive precision resistor network. The INA105 is available in 8-pin plastic DIP, SO-8 surface-mount and TO-99 metal packages.



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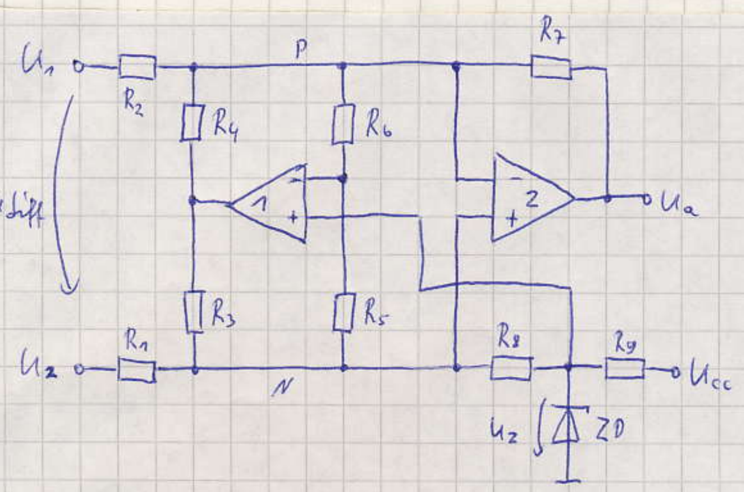
2-OPV Instrumentationsverstärker



- U_z wird in die Mitte der Versorgungsspannungen gelegt
- $U_{diff_2} = 0 \rightarrow I_{R5}, I_{R6} = 0$, $U_{diff_1} = 0$
  $U_+ = U_- = U_z$ für beide OPV

  für $U_1 = U_2 = U_z \rightarrow I_{R1} = I_{R2} = 0 \rightarrow I_{R7} = 0$, $U_a = U_z$

- Gleichtakt-Eingangsspannung:

  $I_{R1} = I_{R2}$ $= I_{R3} = I_{R4}$ — OPV₁ stellt den Gleichtakt $U_P = U_N$ auf U_z

  $r_{egl} = R_1 \| R_2$

- Differenzaussteuerung

  $U_{diff_2} = 0$ wegen OPV2 $(U_P = U_N)$

  $i_{diff} = \frac{U_{diff}}{R_1 + R_2}$ => $r_{ediff} = R_1 + R_2$

  wegen $U_{1-} = U_Z \rightarrow U_{R8} = 0$, $I_{R8} = 0$

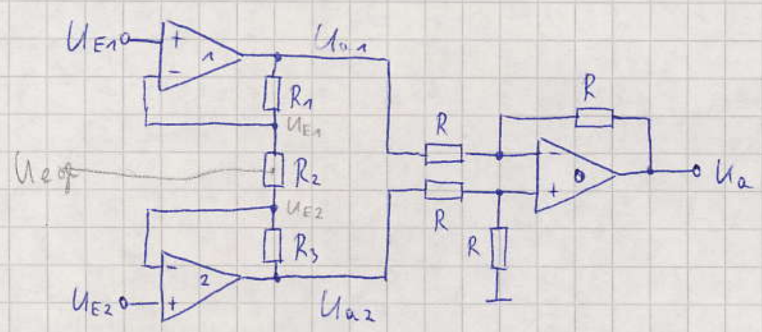
  $I_{R1} = I_{R3}$, $I_{R5} = I_{R6} = 0$

  $I_{R7} = I_{R4} + I_{R2} = 2 I_{R4}$

  $\Rightarrow U_a = U_z - \frac{2 R_7}{R_1 + R_2} \cdot U_{diff}$

- Nur noch R_7 zur Verstärkungseinstellung zu ändern
- anderen Nachteile bleiben

3-OPV Instrumentationsverstärker



ideale OPV:

$$v_d' = \frac{U_{a1} - U_{a2}}{U_{E1} - U_{E2}}$$

Querstrom KS

$$\frac{U_{a1} - U_{a2}}{R_1 + R_2 + R_3} = \frac{U_{E1} - U_{E2}}{R_2} \rightarrow v_d' = \frac{R_1 + R_2 + R_3}{R_2} = 1 + \frac{R_1 + R_3}{R_2}$$

Gleichtaktverstärkung:

$U_{E1} = U_{E2} = U_{Egl}$, wegen $U_d = 0 \rightarrow I_{R2} = 0 \rightarrow U_{a1} = U_{a2} = U_{Egl}$

$v_{gl}'{}_{1.\,Stufe} = 1$

$v_{gl\,ges} = v_{gl1} \cdot v_{gl0}$

Gleichtaktunterdrückung:

$$G' = \frac{v_d'}{v_{gl}'} = v_d' = 1 + \frac{R_1 + R_3}{R_2} \quad \text{erste Stufe}$$

($v_{gl}' = 1$)

$$G_{ges} = \frac{v_{d\,ges}}{v_{gl\,ges}} = G' G_0 = v_d' G_0 \quad \text{gesamt}$$

Nichtideale OPV

$$\frac{U_{a1} - U_{a2}}{U_{Egl}} = \frac{U_{ad}}{U_{Egl}} \approx v_d' \left(\frac{1}{G_1} - \frac{1}{G_2} \right)$$

- ohne Ableitung

- Gleichtakt-Gegentakt-Konversion
- für $G_1 = G_2 \rightarrow U_{ad} = 0$, keine Gleichtakt-Gegentakt-Konversion

$$v_{gl,ges} = v_{gl,0} \cdot 1 + v_{d0} \cdot v_d' \left(\frac{1}{G_1} - \frac{1}{G_2} \right) \qquad v_{d0} = A$$

$$G_{ges} = \frac{v_d'}{v_{gl,0} + v_d' \left(\frac{1}{G_1} - \frac{1}{G_2} \right)} = \frac{v_d' G_0}{1 + G_0 v_d' \left(\frac{1}{G_1} + \frac{1}{G_2} \right)}$$

Folie PGA 204

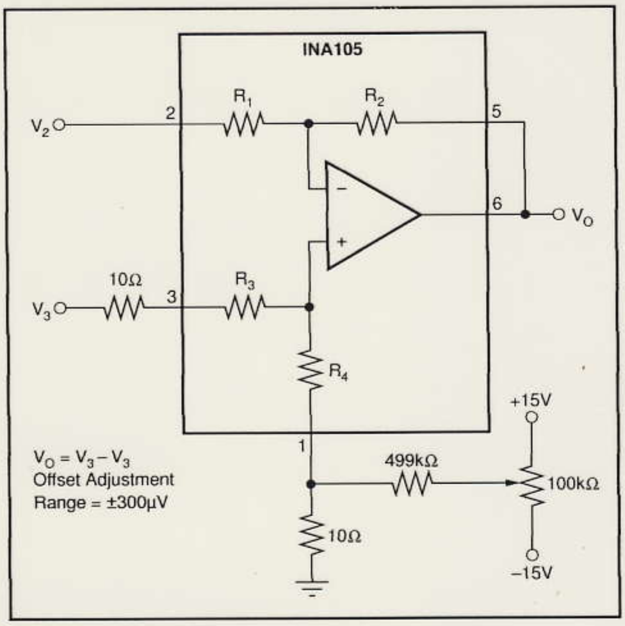


FIGURE 2. Offset Adjustment.

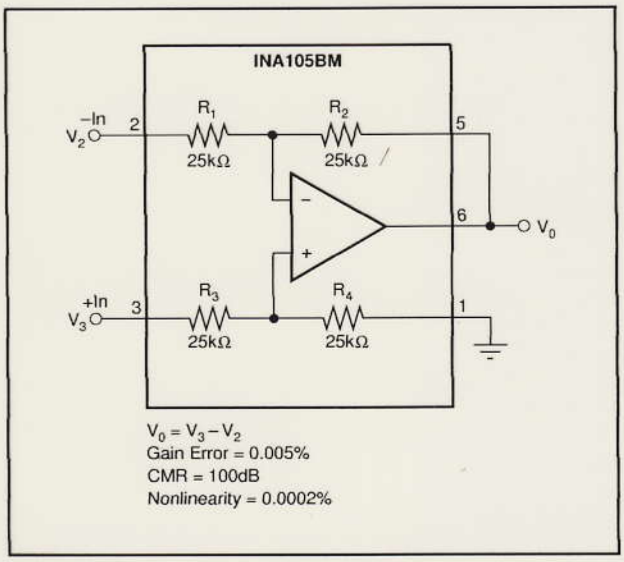
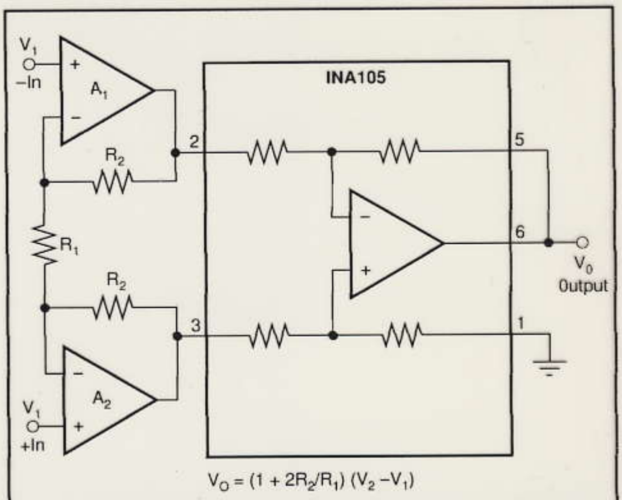


FIGURE 3. Precision Difference Amplifier.



For low source impedance applications, an input stage using OPA27 op amps will give the best low noise, offset, and temperature drift performance. At source impedances above about 10kΩ, the bias current noise of the OPA27 reacting with the input impedance begins to dominate the noise performance. For these applications, using the OPA111 or dual OPA2111 FET input op amp will provide lower noise performance. For lower cost use the OPA121 plastic. To construct an electrometer use the OPA128.

A_1, A_2	R_1 (Ω)	R_2 (Ω)	GAIN (V/V)	CMRR (dB)	MAX I_B	NOISE AT 1kHz ($nV/\sqrt{HZ}$)
OPA27A	50.5	2.5k	100	128	40nA	4
OPA111B	202	10k	100	110	1pA	10
OPA128LM	202	10k	100	118	75fA	38

FIGURE 4. Precision Instrumentation Amplifier.

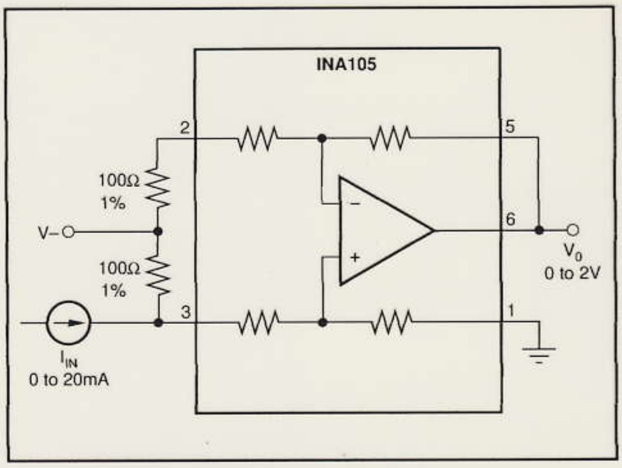


FIGURE 5. Current Receiver with Compliance to Rails.

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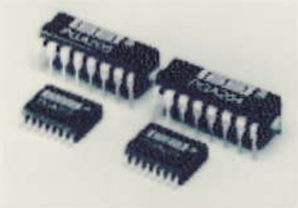


PGA204
PGA205

Programmable Gain
INSTRUMENTATION AMPLIFIER

FEATURES

- DIGITALLY PROGRAMMABLE GAIN:
  PGA204: G=1, 10, 100, 1000V/V
  PGA205: G=1, 2, 4, 8V/V
- LOW OFFSET VOLTAGE: 50µV max
- LOW OFFSET VOLTAGE DRIFT: 0.25µV/°C
- LOW INPUT BIAS CURRENT: 2nA max
- LOW QUIESCENT CURRENT: 5.2mA typ
- NO LOGIC SUPPLY REQUIRED
- 16-PIN PLASTIC DIP, SOL-16 PACKAGES

APPLICATIONS

- DATA ACQUISITION SYSTEM
- GENERAL PURPOSE ANALOG BOARDS
- MEDICAL INSTRUMENTATION

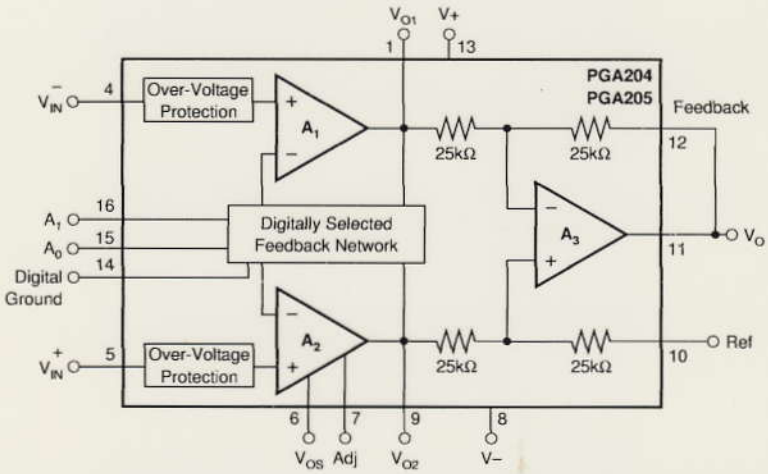
DESCRIPTION

The PGA204 and PGA205 are low cost, general purpose programmable-gain instrumentation amplifiers offering excellent accuracy. Gains are digitally selected: PGA204—1, 10, 100, 1000, and PGA205—1, 2, 4, 8V/V. The precision and versatility, and low cost of the PGA204 and PGA205 make them ideal for a wide range of applications.

Gain is selected by two TTL or CMOS-compatible address lines, A_0 and A_1. Internal input protection can withstand up to ±40V on the analog inputs without damage.

The PGA204 and PGA205 are laser trimmed for very low offset voltage (50µV), drift (0.25µV/°C) and high common-mode rejection (115dB at G=1000). They operate with power supplies as low as ±4.5V, allowing use in battery operated systems. Quiescent current is 5mA.

The PGA204 and PGA205 are available in 16-pin plastic DIP, and SOL-16 surface-mount packages, specified for the –40°C to +85°C temperature range.



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SBOS022

SPECIFICATIONS

ELECTRICAL

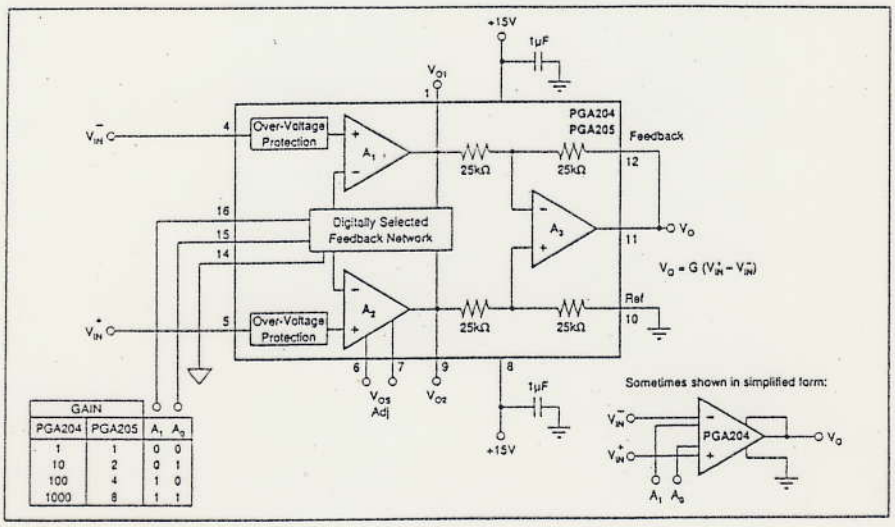
PGA204 G=1, 10, 100, 1000V/V

At T_A = +25°C, V_S = ±15V, and R_L = 2kΩ unless otherwise noted.

PARAMETER	CONDITIONS	PGA204BP, BU MIN	PGA204BP, BU TYP	PGA204BP, BU MAX	PGA204AP, AU MIN	PGA204AP, AU TYP	PGA204AP, AU MAX	UNITS
INPUT								
Offset Voltage, RTI	T_A=+25°C		±10+20/G	±50+100/G		±25+30/G	±125+500/G	µV
vs Temperature	T_A=T_{MIN} to T_{MAX}		±0.1+0.5/G	±0.25+5/G		±0.25+5/G	±1+10/G	µV/°C
vs Power Supply	V_S=±4.5V to ±18V		0.5+2/G	3+10/G		*	*	µV/V
Long-Term Stability			±0.2+0.5/G			*		µV/mo
Impedance, Differential			10^{10}‖6			*		Ω ‖ pF
Common-Mode			10^{10}‖6			*		Ω ‖ pF
Input Common-Mode Range	V_O=0V (see text)	±10.5	±12.7		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM}=±10V, ΔR_S=1kΩ							
	G=1	80	99		75	90		dB
	G=10	96	114		90	106		dB
	G=100	110	123		106	110		dB
	G=1000	115	123		106	110		dB
BIAS CURRENT			±0.5	±2		*	±5	nA
vs Temperature			±8			*		pA/°C
Offset Current			±0.5	±2		*	*	nA
vs Temperature			±8			*		pA/°C
NOISE, Voltage, RTI(1): f=10Hz	G≥100, R_S=0Ω		16			*		nV/√Hz
f=100Hz	G≥100, R_S=0Ω		13			*		nV/√Hz
f=1kHz	G≥100, R_S=0Ω		13			*		nV/√Hz
f_B=0.1Hz to 10Hz	G≥100, R_S=0Ω		0.4			*		µVp-p
Noise Current								
f=10Hz			0.4			*		pA/√Hz
f=1kHz			0.2			*		pA/√Hz
f_B=0.1Hz to 10Hz			18			*		pAp-p
GAIN, Error	G=1		±0.005	±0.024		*	±0.05	%
	G=10		±0.01	±0.024		*	±0.05	%
	G=100		±0.01	±0.024		*	±0.05	%
	G=1000		±0.02	±0.05		*	±0.1	%
Gain vs Temperature	G=1 to 1000		±2.5	±10		*	*	ppm/°C
Nonlinearity	G=1		±0.0004	±0.001		*	±0.002	% of FSR
	G=10		±0.0004	±0.002		*	±0.004	% of FSR
	G=100		±0.0004	±0.002		*	±0.004	% of FSR
	G=1000		±0.0008	±0.01		*	±0.02	% of FSR
OUTPUT								
Voltage, Positive(2)	I_O=5mA, T_{MIN} to T_{MAX}	(V+)–1.5	(V+)–1.3		*	*		V
Negative(2)	I_O=–5mA, T_{MIN} to T_{MAX}	(V–)+1.5	(V–)+1.3		*	*		V
Load Capacitance Stability			1000			*		pF
Short Circuit Current			+23/–17			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G=1		1			*		MHz
	G=10		80			*		kHz
	G=100		10			*		kHz
	G=1000		1			*		kHz
Slew Rate	V_O=±10V, G=10	0.3	0.7		*	*		V/µs
Settling Time(3), 0.1%	G=1		22			*		µs
	G=10		23			*		µs
	G=100		100			*		µs
	G=1000		1000			*		µs
0.01%	G=1		23			*		µs
	G=10		28			*		µs
	G=100		140			*		µs
	G=1000		1300			*		µs
Overload Recovery	50% Overdrive		70			*		µs
DIGITAL LOGIC								
Digital Ground Voltage, V_{DG}		V–		(V+)–4	*		*	V
Digital Low Voltage		V–		V_{DG}+0.8V	*		*	V
Digital Input Current			1			*		µA
Digital High Voltage		V_{DG} +2		V+	*		*	V
POWER SUPPLY, Voltage		±4.5	±15	±18	*	*	*	V
Current	V_{IN}=0V		+5.2/–4.2	±6.5		*	±7.5	mA
TEMPERATURE RANGE								
Specification		–40		+85	*		*	°C
Operating		–40		+125	*		*	°C
θ_{JA}			80			*		°C/W

* Specification same as PGA204BP.

NOTES: (1) Input-referred noise voltage varies with gain. See typical curves. (2) Output voltage swing is tested for ±10V min on ±11.4V power supplies. (3) Includes time to switch to a new gain.



GAIN			
PGA204	PGA205	A_1	A_0
1	1	0	0
10	2	0	1
100	4	1	0
1000	8	1	1