SENSOR DESIGN, SIGNAL CONDITIONING, AND INTERFACING PROJECT

MAE 534 Mechatronics Design
SPRING 1999
Dr. Ramasubramanian

DUE: FEBRUARY 24, 1999 WEDNESDAY AT CLASS TIME.

PROJECT DESCRIPTION:

Design a Beam-based load cell that will have a maximum capacity of 2.0 Pounds. The complete system consists of the beam type load cell, signal conditioning electronics, and microprocessor interface for readout. You will use the Handyboard for the project. Your group will be provided with a 3/4" wide, 1/8" thick Aluminum bar, 12 inches long, four strain gages (CEA-13-240UZ-120) from Measurements Group, Inc., chemicals and supplies to mount the gages, a breadboard to install the system, and of course, the Handyboard and associated hardware needed to download the program, etc. Further, an instrumentation amplifier IC (INA 125 made by Burr-Brown) and a bipolar power supply will be provided. Miscellaneous resistors and components are available. The data sheet for the amplifier IC is attached.

TESTING

The beam that you design will be C-clamped to a rigid table, and a cup will be hung from 1-inch from the tip of the beam. Known weights up to 1.5 pounds will be dropped into it. The display should accurately show the results on the LCD.

REPORTING AND DEMONSTRATION

Write a complete report describing the problem, the solution approach, description of your design, experience gained, testing of your system, and all diagrams and parts list. The report is due on the day of the project demonstration. I will test the system in the laboratory at class time.

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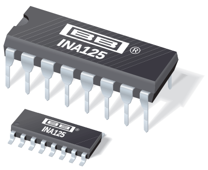


INA125

INSTRUMENTATION AMPLIFIER
With Precision Voltage Reference

FEATURES

- LOW QUIESCENT CURRENT: 460μA
- PRECISION VOLTAGE REFERENCE: 1.24V, 2.5V, 5V or 10V
- SLEEP MODE
- LOW OFFSET VOLTAGE: 250μV max
- LOW OFFSET DRIFT: 2μV/°C max
- LOW INPUT BIAS CURRENT: 20nA max
- HIGH CMR: 100dB min
- LOW NOISE: $38nV/\sqrt{Hz}$ at f = 1kHz
- INPUT PROTECTION TO ±40V
- WIDE SUPPLY RANGE
  - Single Supply: 2.7V to 36V
  - Dual Supply: ±1.35V to ±18V
- 16-PIN DIP AND SO-16 SOIC PACKAGES

APPLICATIONS

- PRESSURE AND TEMPERATURE BRIDGE AMPLIFIERS
- INDUSTRIAL PROCESS CONTROL
- FACTORY AUTOMATION
- MULTI-CHANNEL DATA ACQUISITION
- BATTERY OPERATED SYSTEMS
- GENERAL PURPOSE INSTRUMENTATION

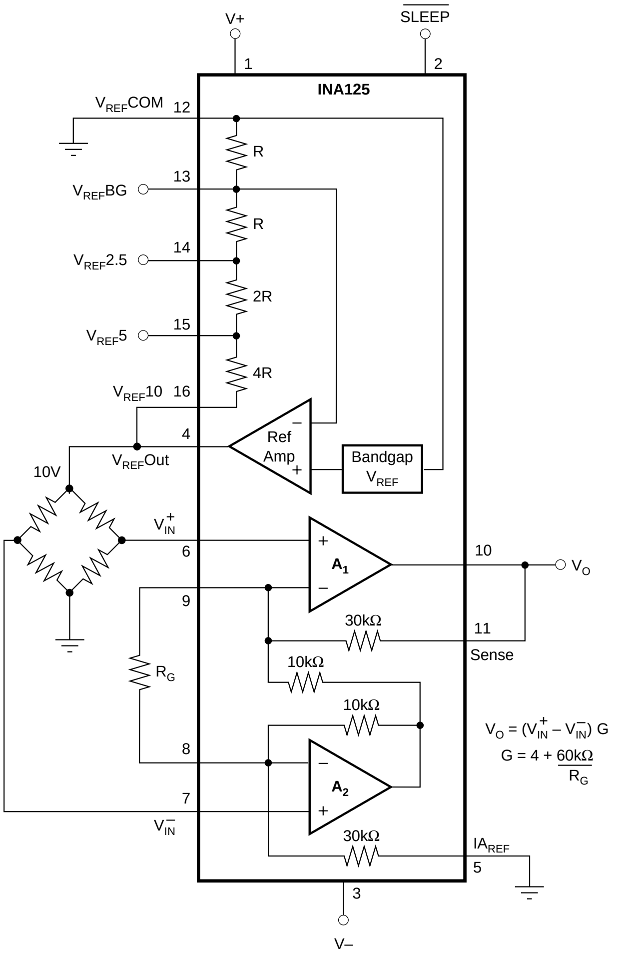
DESCRIPTION

The INA125 is a low power, high accuracy instrumentation amplifier with a precision voltage reference. It provides complete bridge excitation and precision differential-input amplification on a single integrated circuit.

A single external resistor sets any gain from 4 to 10,000. The INA125 is laser-trimmed for low offset voltage (250μV), low offset drift (2μV/°C), and high common-mode rejection (100dB at G = 100). It operates on single (+2.7V to +36V) or dual (±1.35V to ±18V) supplies.

The voltage reference is externally adjustable with pin-selectable voltages of 2.5V, 5V, or 10V, allowing use with a variety of transducers. The reference voltage is accurate to ±0.5% (max) with ±35ppm/°C drift (max). Sleep mode allows shutdown and duty cycle operation to save power.

The INA125 is available in 16-pin plastic DIP and SO-16 surface-mount packages and is specified for the –40°C to +85°C industrial temperature range.



International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

PDS-1361B

Printed in U.S.A., February, 1998

SPECIFICATIONS: V_S = ±15V

At T_A = +25°C, V_S = ±15V, IA common = 0V, V_{REF} common = 0V, and R_L = 10kΩ, unless otherwise noted.

		INA125P, U			INA125PA, UA			
PARAMETER	CONDITIONS	MIN	TYP	MAX	MIN	TYP	MAX	UNITS
INPUT								
Offset Voltage, RTI								
Initial			±50	±250		*	±500	µV
vs Temperature			±0.25	±2		*	±5	µV/°C
vs Power Supply	V_S = ±1.35V to ±18V, G = 4		±3	±20		*	±50	µV/V
Long-Term Stability			±0.2			*		µV/mo
Impedance, Differential			$10^{11} \parallel 2$			*		Ω ∥ pF
Common-Mode			$10^{11} \parallel 9$			*		Ω ∥ pF
Safe Input Voltage				±40			*	V
Input Voltage Range			See Text			*		
Common-Mode Rejection	V_{CM} = –10.7V to +10.2V							
	G = 4	78	84		72	*		dB
	G = 10	86	94		80	*		dB
	G = 100	100	114		90	*		dB
	G = 500	100	114		90	*		dB
BIAS CURRENT	V_{CM} = 0V		10	25		*	50	nA
vs Temperature			±60			*		pA/°C
Offset Current			±0.5	±2.5		*	±5	nA
vs Temperature			±0.5			*		pA/°C
NOISE, RTI	R_S = 0Ω							
Voltage Noise, f = 10Hz			40			*		nV/√Hz
f = 100Hz			38			*		nV/√Hz
f = 1kHz			38			*		nV/√Hz
f = 0.1Hz to 10Hz			0.8			*		µVp-p
Current Noise, f = 10Hz			170			*		fA/√Hz
f = 1kHz			56			*		fA/√Hz
f = 0.1Hz to 10Hz			5			*		pAp-p
GAIN								
Gain Equation			4 + 60kΩ/R_G			*		V/V
Range of Gain		4		10,000	*		*	V/V
Gain Error	V_O = –14V to +13.3V							
	G = 4		±0.01	±0.075		*	±0.1	%
	G = 10		±0.03	±0.3		*	±0.5	%
	G = 100		±0.05	±0.5		*	±1	%
	G = 500		±0.1			*		%
Gain vs Temperature								
	G = 4		±1	±15		*	*	ppm/°C
	G > 4(1)		±25	±100		*	*	ppm/°C
Nonlinearity	V_O = –14V to +13.3V							
	G = 4		±0.0004	±0.002		*	±0.004	% of FS
	G = 10		±0.0004	±0.002		*	±0.004	% of FS
	G = 100		±0.001	±0.01		*	*	% of FS
	G = 500		±0.002			*		% of FS
OUTPUT								
Voltage: Positive		(V+)–1.7	(V+)–0.9		*	*		V
Negative		(V–)+1	(V–)+0.4		*	*		V
Load Capacitance Stability			1000			*		pF
Short-Circuit Current			–9/+12			*		mA
VOLTAGE REFERENCE	V_{REF} = +2.5V, +5V, +10V							
Accuracy	I_L = 0		±0.15	±0.5		*	±1	%
vs Temperature	I_L = 0		±18	±35		*	±100	ppm/°C
vs Power Supply, V+	V+ = (V_{REF} + 1.25V) to +36V		±20	±50		*	±100	ppm/V
vs Load	I_L = 0 to 5mA		3	75		*	*	ppm/mA
Dropout Voltage, (V+) – V_{REF}(2)	Ref Load = 2kΩ	1.25	1		*	*		V
Bandgap Voltage Reference			1.24			*		V
Accuracy	I_L = 0		±0.5			*		%
vs Temperature	I_L = 0		±18			*		ppm/°C

SPECIFICATIONS: $V_S = \pm15V$ (CONT)

At T_A = +25°C, V_S = ±15V, IA common = 0V, V_{REF} common = 0V, and R_L = 10kΩ, unless otherwise noted.

PARAMETER CONDITIONS		INA125P, U			INA125PA, UA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
FREQUENCY RESPONSE								
Bandwidth, –3dB	G = 4		150			✻		kHz
	G = 10		45			✻		kHz
	G = 100		4.5			✻		kHz
	G = 500		0.9			✻		kHz
Slew Rate	G = 4, 10V Step		0.2			✻		V/µs
Settling Time, 0.01%	G = 4, 10V Step		60			✻		µs
	G = 10, 10V Step		83			✻		µs
	G = 100, 10V Step		375			✻		µs
	G = 500, 10V Step		1700			✻		µs
Overload Recovery	50% Overdrive		5			✻		µs
POWER SUPPLY								
Specified Operating Voltage			±15			✻		V
Specified Voltage Range		±1.35		±18	✻		✻	V
Quiescent Current, Positive	$I_O = I_{REF}$ = 0mA		460	525		✻	✻	µA
Negative	$I_O = I_{REF}$ = 0mA		–280	–325		✻	✻	µA
Reference Ground Current[3]			180			✻		µA
Sleep Current (V_{SLEEP} ≤ 100mV)	R_L = 10kΩ, Ref Load = 2kΩ		±1	±25		✻	✻	µA
SLEEP MODE PIN[4]								
V_{IH} (Logic high input voltage)		+2.7		V+	✻		✻	V
V_{IL} (Logic low input voltage)		0		+0.1	✻		✻	V
I_{IH} (Logic high input current)			15			✻		µA
I_{IL} (Logic low input current)			0			✻		µA
Wake-up Time[5]			150			✻		µs
TEMPERATURE RANGE								
Specification Range		–40		+85	✻		✻	°C
Operation Range		–55		+125	✻		✻	°C
Storage Range		–55		+125	✻		✻	°C
Thermal Resistance, θ_{JA}								
16-Pin DIP			80			✻		°C/W
SO-16 Surface-Mount			100			✻		°C/W

✻ Specification same as INA125P, U.

NOTES: (1) Temperature coefficient of the "Internal Resistor" in the gain equation. Does not include TCR of gain-setting resistor, R_G. (2) Dropout voltage is the positive supply voltage minus the reference voltage that produces a 1% decrease in reference voltage. (3) V_{REF}COM pin. (4) Voltage measured with respect to Reference Common. Logic low input selects Sleep mode. (5) IA and Reference, see Typical Performance Curves.

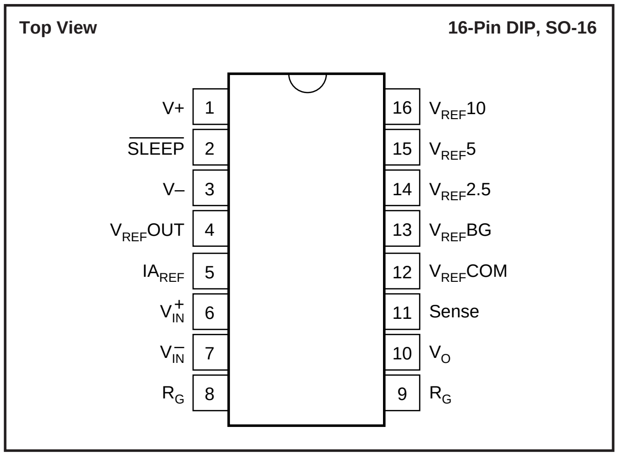
SPECIFICATIONS: $V_S = +5V$

At T_A = +25°C, V_S = +5V, IA common at V_S/2, V_{REF} common = V_S/2, V_{CM} = V_S/2, and R_L = 10kΩ to V_S/2, unless otherwise noted.

PARAMETER	CONDITIONS	INA125P, U			INA125PA, UA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
INPUT								
Offset Voltage, RTI								
Initial			±75	±500		✻	±750	µV
vs Temperature			±0.25			✻		µV/°C
vs Power Supply	V_S = +2.7V to +36V		3	20		✻	50	µV/V
Input Voltage Range			See Text			✻		
Common-Mode Rejection	V_{CM} = +1.1V to +3.6V							
	G = 4	78	84		72	✻		dB
	G = 10	86	94		80	✻		dB
	G = 100	100	114		90	✻		dB
	G = 500	100	114		90	✻		dB
GAIN								
Gain Error	V_O = +0.3V to +3.8V							
	G = 4		±0.01			✻		%
OUTPUT								
Voltage, Positive		(V+)–1.2	(V+)–0.8		✻	✻		V
Negative		(V–)+0.3	(V–)+0.15		✻	✻		V
POWER SUPPLY								
Specified Operating Voltage			+5			✻		V
Operating Voltage Range		+2.7		+36	✻		✻	V
Quiescent Current	$I_O = I_{REF}$ = 0mA		460	525		✻	✻	µA
Sleep Current (V_{SLEEP} ≤ 100mV)	R_L = 10kΩ, Ref Load = 2kΩ		±1	±25		✻	✻	µA

✻ Specification same as INA125P, U.

PIN CONFIGURATION



ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ABSOLUTE MAXIMUM RATINGS(1)

Power Supply Voltage, V+ to V–	36V
Input Signal Voltage	±40V
Output Short Circuit	Continuous
Operating Temperature	–55°C to +125°C
Storage Temperature	–55°C to +125°C
Lead Temperature (soldering, 10s)	+300°C

NOTE: Stresses above these ratings may cause permanent damage.

PACKAGE INFORMATION

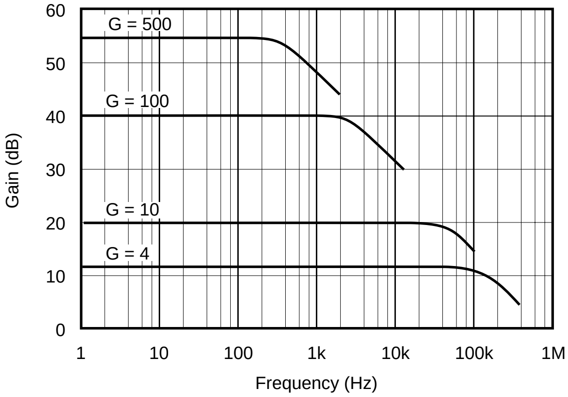
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER(1)
INA125PA	16-Pin Plastic DIP	180
INA125P	16-Pin Plastic DIP	180
INA125UA	SO-16 Surface-Mount	265
INA125U	SO-16 Surface-Mount	265

NOTES: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

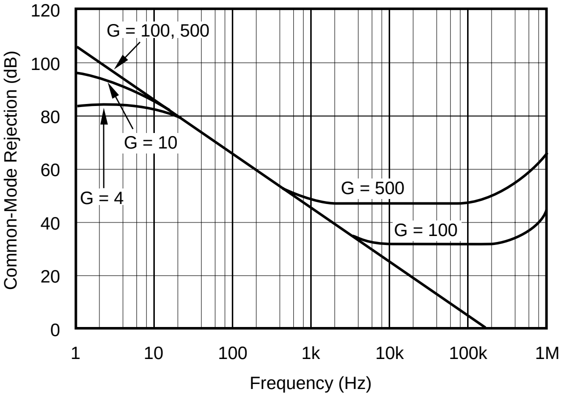
TYPICAL PERFORMANCE CURVES

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

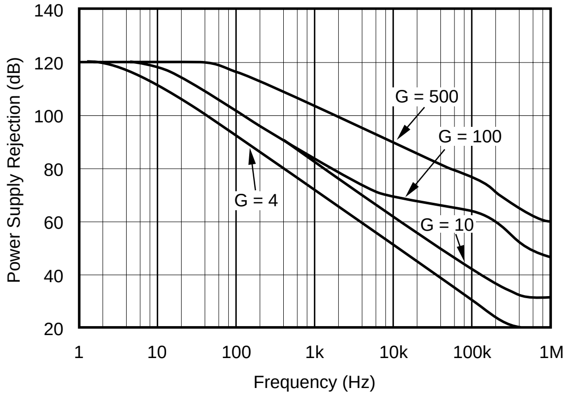
GAIN vs FREQUENCY



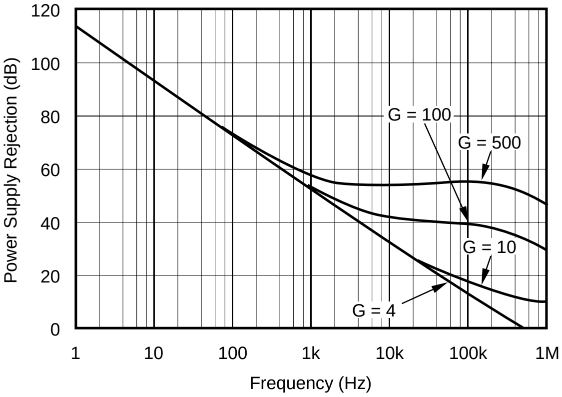
COMMON-MODE REJECTION vs FREQUENCY



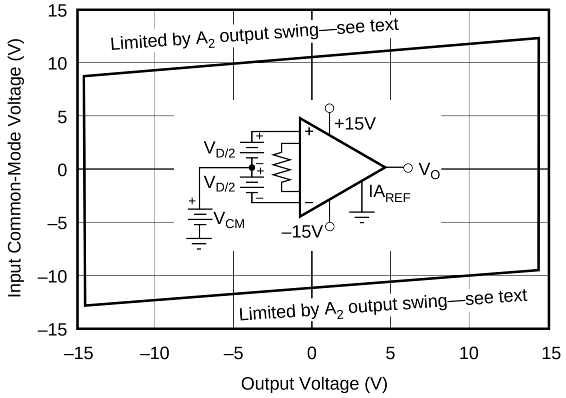
POSITIVE POWER SUPPLY REJECTION vs FREQUENCY



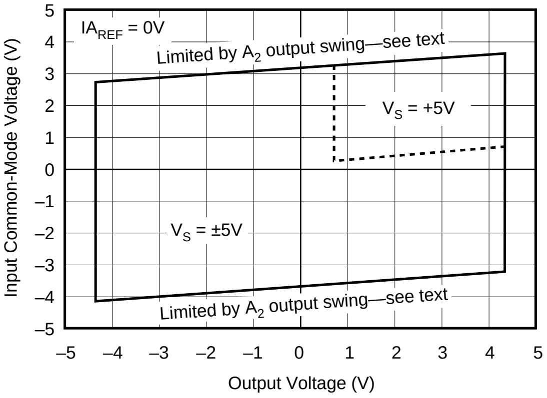
NEGATIVE POWER SUPPLY REJECTION vs FREQUENCY



INPUT COMMON-MODE VOLTAGE vs OUTPUT VOLTAGE, V_S = ±15V

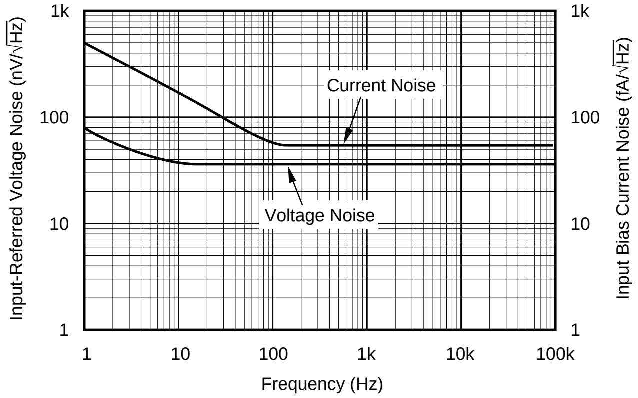


INPUT COMMON-MODE VOLTAGE vs OUTPUT VOLTAGE, V_S = ±5V

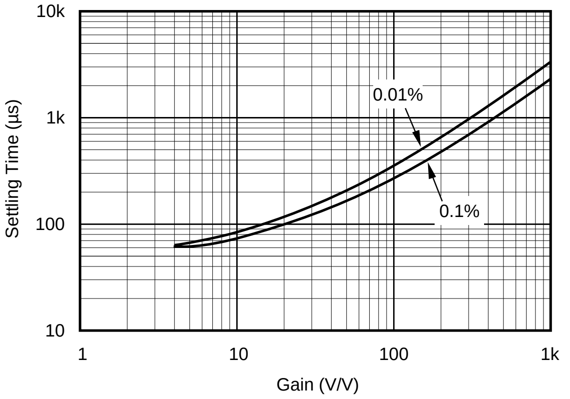


TYPICAL PERFORMANCE CURVES (CONT)

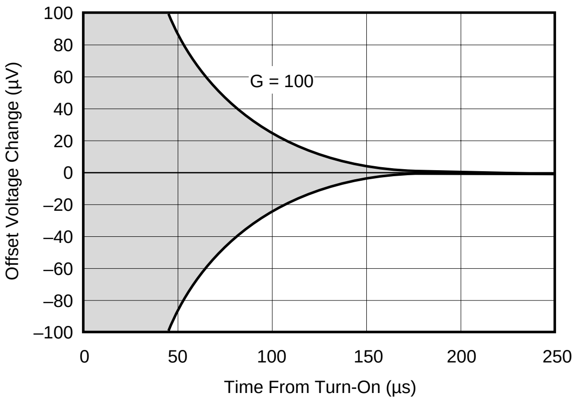
At T_A = +25°C and V_S = ±15V, unless otherwise noted.



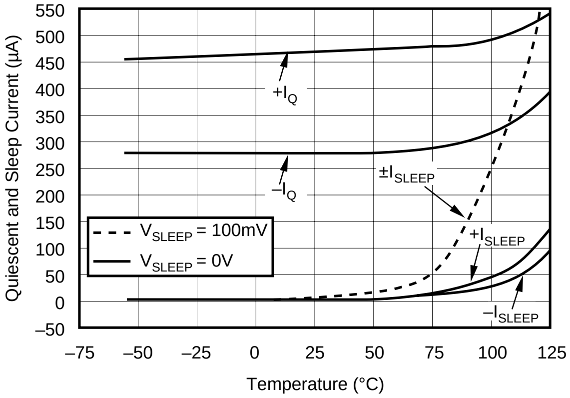
INPUT-REFERRED VOLTAGE AND CURRENT NOISE vs FREQUENCY



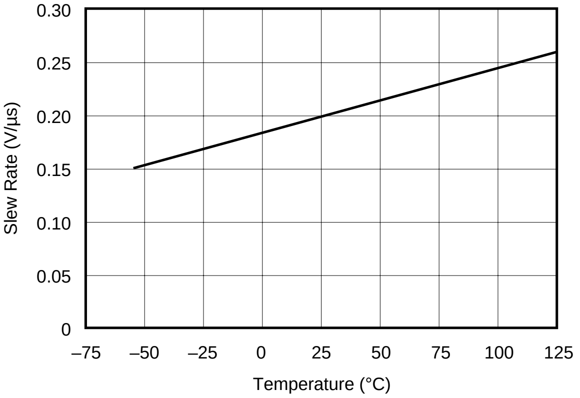
SETTLING TIME vs GAIN



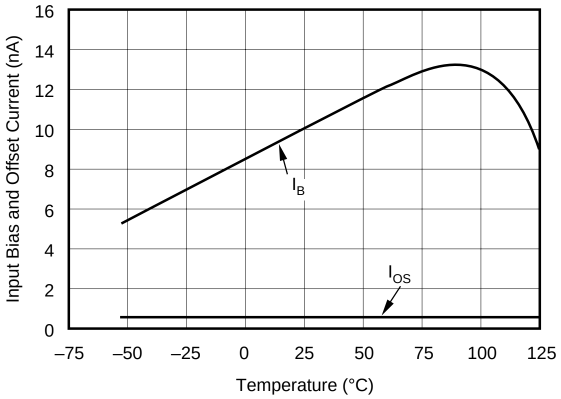
INPUT-REFERRED OFFSET VOLTAGE vs SLEEP TURN-ON TIME



QUIESCENT CURRENT AND SLEEP CURRENT vs TEMPERATURE



SLEW RATE vs TEMPERATURE

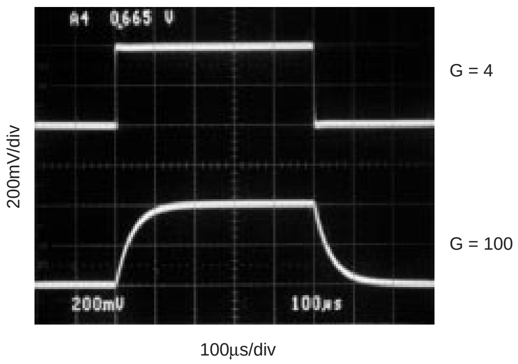


INPUT BIAS AND OFFSET CURRENT vs TEMPERATURE

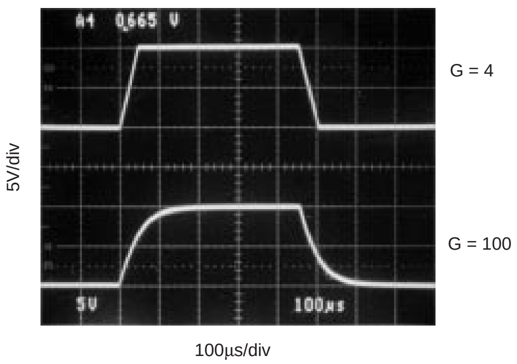
TYPICAL PERFORMANCE CURVES (CONT)

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

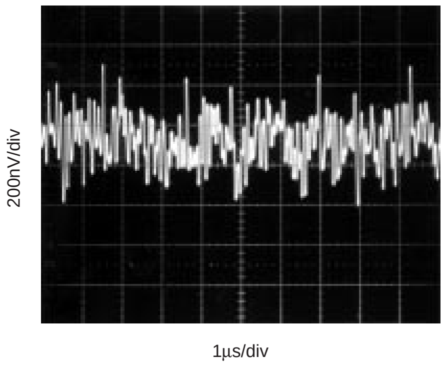
SMALL-SIGNAL RESPONSE



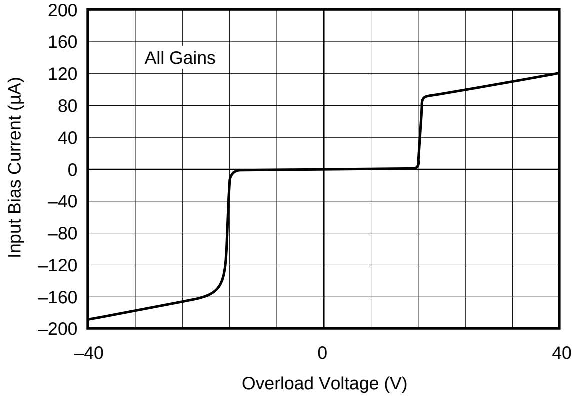
LARGE-SIGNAL RESPONSE



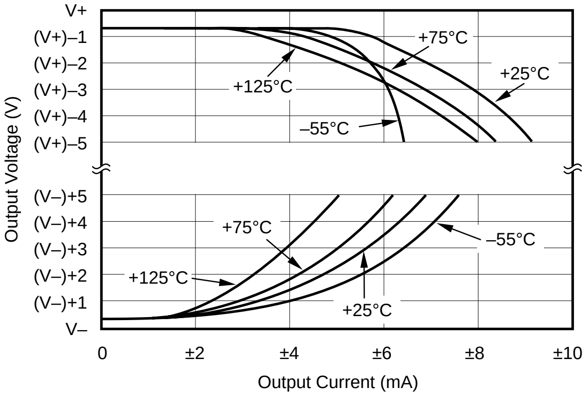
INPUT-REFERRED NOISE, 0.1Hz to 10Hz



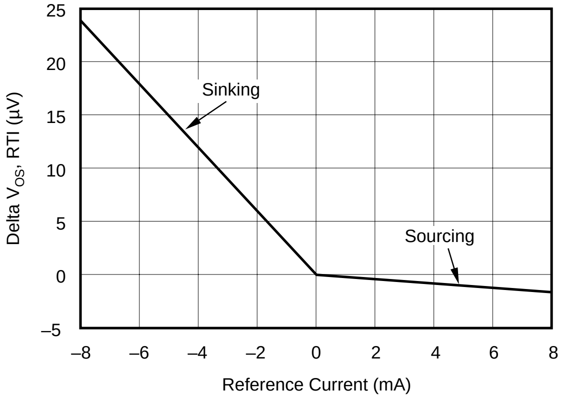
INPUT BIAS CURRENT
vs INPUT OVERLOAD VOLTAGE



OUTPUT VOLTAGE SWING
vs OUTPUT CURRENT

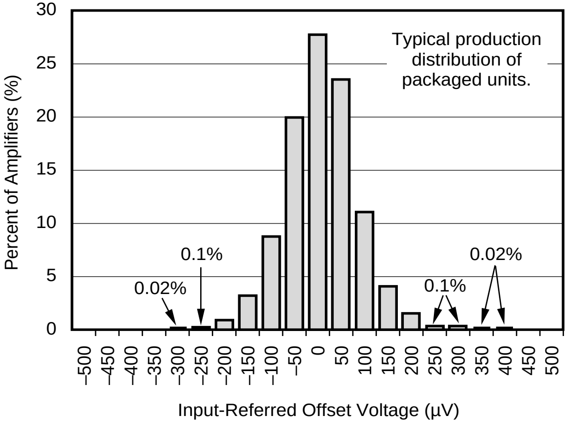


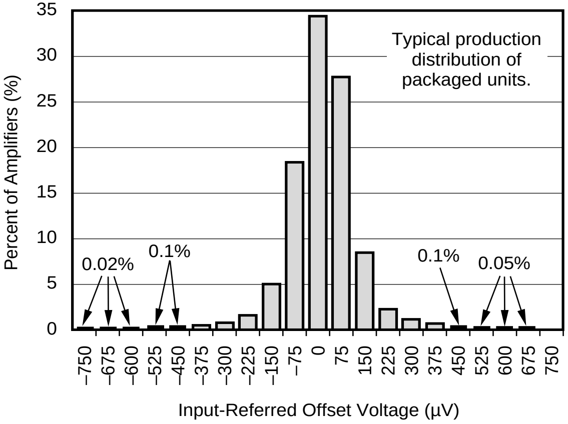
DELTA V_{OS} vs REFERENCE CURRENT

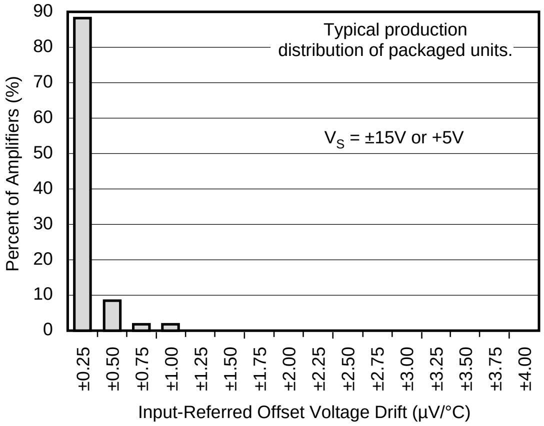


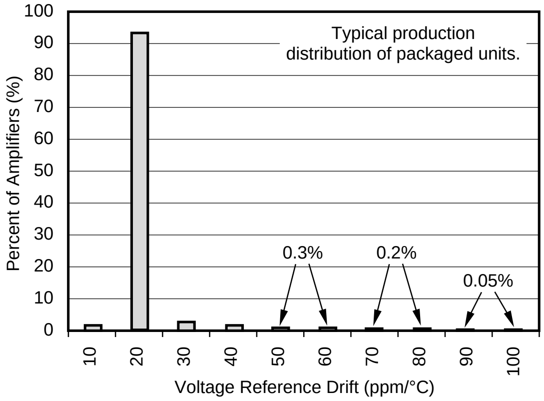
TYPICAL PERFORMANCE CURVES (CONT)

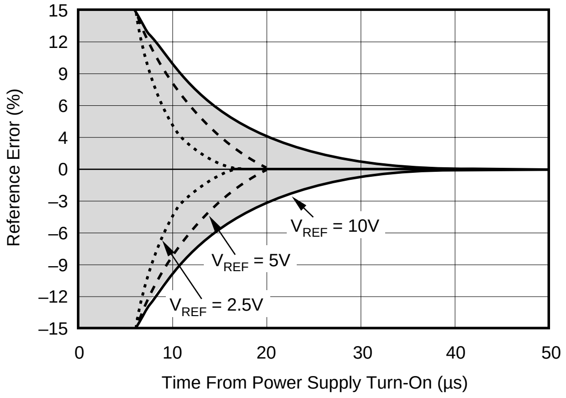
At T_A = +25°C and V_S = ±15V, unless otherwise noted.

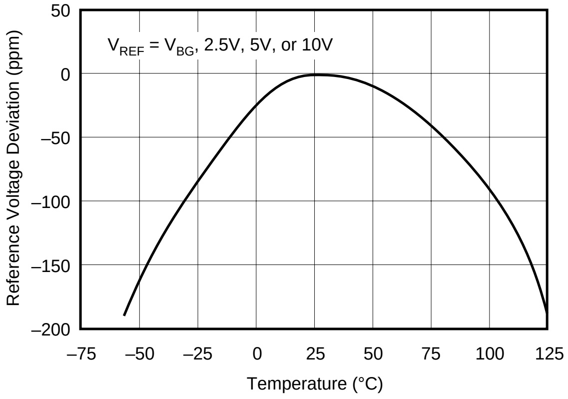

INPUT-REFERRED OFFSET VOLTAGE PRODUCTION DISTRIBUTION, V_S = ±15V


INPUT-REFERRED OFFSET VOLTAGE PRODUCTION DISTRIBUTION, V_S = +5V


INPUT-REFERRED OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION

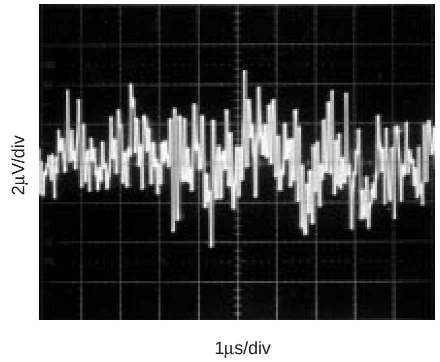

VOLTAGE REFERENCE DRIFT PRODUCTION DISTRIBUTION

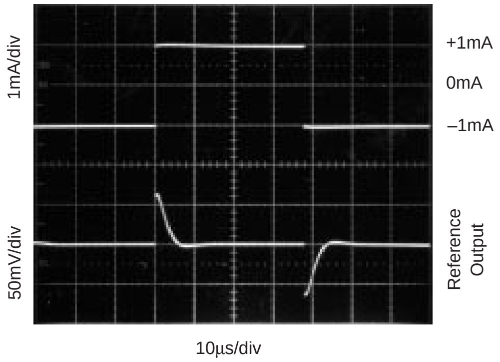

REFERENCE TURN-ON SETTLING TIME

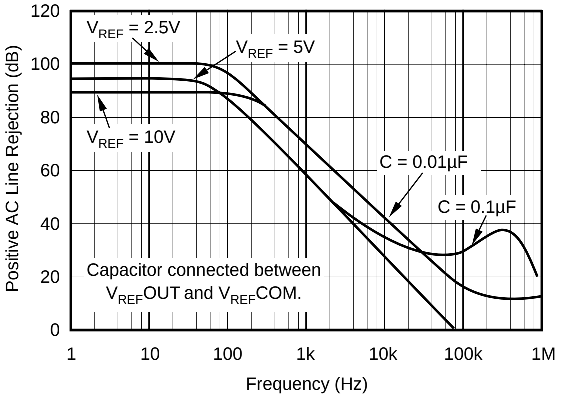

REFERENCE VOLTAGE DEVIATION vs TEMPERATURE

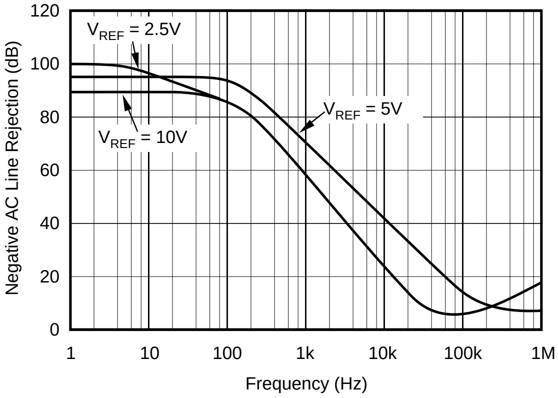
TYPICAL PERFORMANCE CURVES (CONT)

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


0.1Hz to 10Hz REFERENCE NOISE
V_{REF} = 2.5V, C_L = 100pF


REFERENCE TRANSIENT RESPONSE
V_{REF} = 2.5V, C_L = 100pF


POSITIVE REFERENCE AC LINE REJECTION
vs FREQUENCY


NEGATIVE REFERENCE AC LINE REJECTION
vs FREQUENCY

APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA125. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the instrumentation amplifier reference (IA_{REF}) terminal which is normally grounded. This must be a low impedance connection to assure good common-mode rejection. A resistance of 12Ω in series with the IA_{REF} pin will cause a typical device to degrade to approximately 80dB CMR (G = 4).

Connecting V_{REF}OUT (pin 4) to one of the four available reference voltage pins (V_{REF}BG, V_{REF}2.5, V_{REF}5, or V_{REF}10) provides an accurate voltage source for bridge applications. For example, in Figure 1 V_{REF}OUT is connected to V_{REF}10 thus supplying 10V to the bridge. It is recommended that V_{REF}OUT be connected to one of the reference voltage pins even when the reference is not being utilized to avoid saturating the reference amplifier. Driving the $\overline{\text{SLEEP}}$ pin LOW puts the INA125 in a shutdown mode.

SETTING THE GAIN

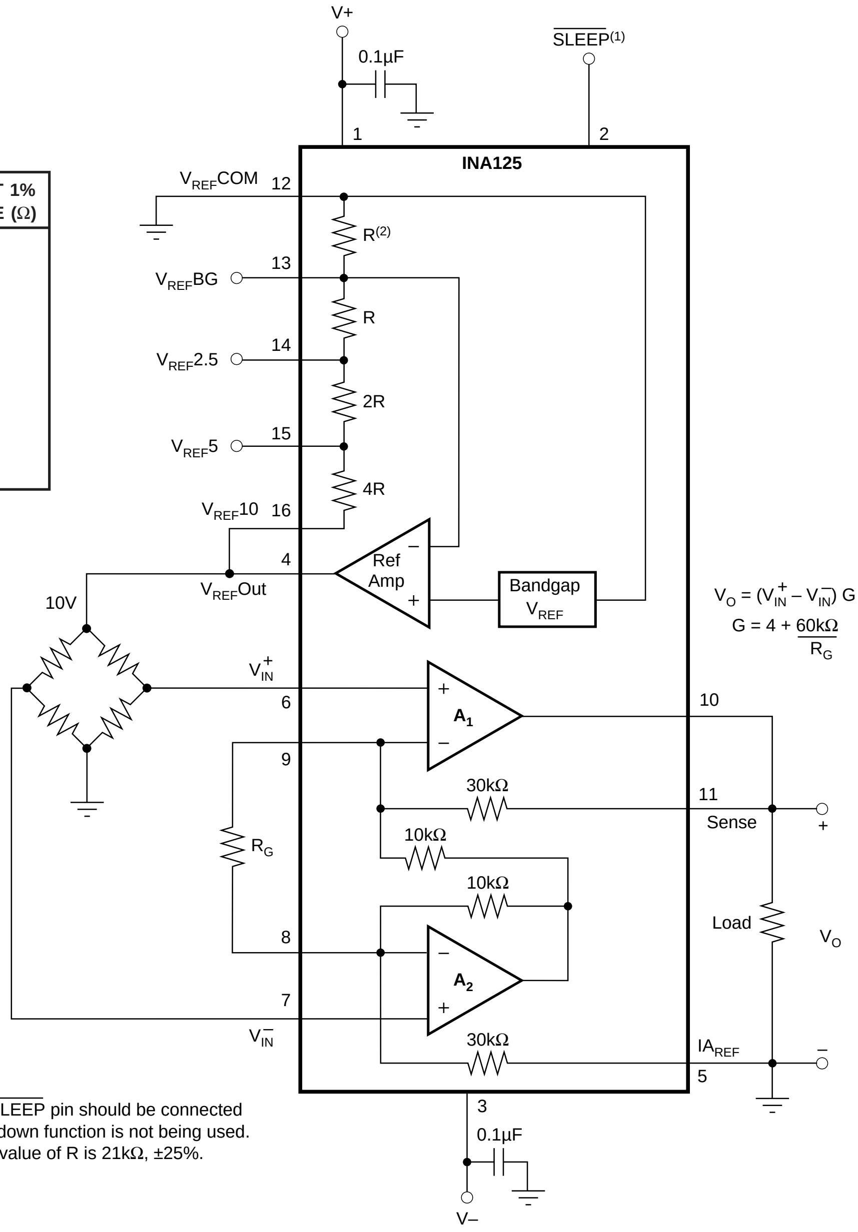
Gain of the INA125 is set by connecting a single external resistor, R_G, between pins 8 and 9:

$$G = 4 + \frac{60k\Omega}{R_G} \qquad (1)$$

Commonly used gains and R_G resistor values are shown in Figure 1.

DESIRED GAIN (V/V)	R_G (Ω)	NEAREST 1% R_G VALUE (Ω)
4	NC	NC
5	60k	60.4k
10	10k	10k
20	3750	3740
50	1304	1300
100	625	619
200	306	309
500	121	121
1000	60	60.4
2000	30	30.1
10000	6	6.04

NC: No Connection.



NOTE: (1) $\overline{\text{SLEEP}}$ pin should be connected to V+ if shutdown function is not being used.
(2) Nominal value of R is 21kΩ, ±25%.

FIGURE 1. Basic Connections.

The 60kΩ term in equation 1 comes from the internal metal film resistors which are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA125.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G's contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance, which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

OFFSET TRIMMING

The INA125 is laser trimmed for low offset voltage and offset voltage drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to the IA_{REF} terminal is added to the output signal. The op amp buffer is used to provide low impedance at the IA_{REF} terminal to preserve good common-mode rejection.

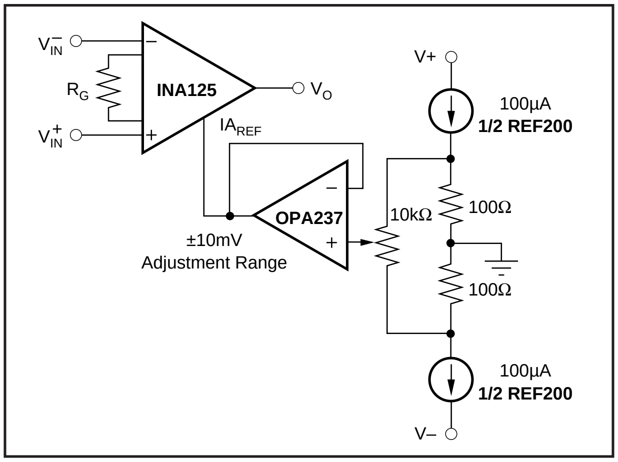


FIGURE 2. Optional Trimming of Output Offset Voltage.

INPUT BIAS CURRENT RETURN

The input impedance of the INA125 is extremely high—approximately $10^{11}\Omega$. However, a path must be provided for the input bias current of both inputs. This input bias current flows out of the device and is approximately 10nA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range, and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high frequency common-mode rejection.

INPUT COMMON-MODE RANGE

The input common-mode range of the INA125 is shown in the typical performance curves. The common-mode range is limited on the negative side by the output voltage swing of A_2, an internal circuit node that cannot be measured on an external pin. The output voltage of A2 can be expressed as:

$$V_{02} = 1.3V_{IN}^{-} - (V_{IN}^{+} - V_{IN}^{-})\ (10k\Omega/R_G)$$

(voltages referred to IA_{REF} terminal, pin 5)

The internal op amp A_2 is identical to A_1. Its output swing is limited to approximately 0.8V from the positive supply and 0.25V from the negative supply. When the input common-mode range is exceeded (A_2's output is saturated), A_1 can still be in linear operation, responding to changes in the non-inverting input voltage. The output voltage, however, will be invalid.

PRECISION VOLTAGE REFERENCE

The on-board precision voltage reference provides an accurate voltage source for bridge and other transducer applications or ratiometric conversion with analog-to-digital converters. A reference output of 2.5V, 5V or 10V is available by connecting V_{REF}OUT (pin 4) to one of the V_{REF} pins (V_{REF}2.5, V_{REF}5, or V_{REF}10). Reference voltages are laser-trimmed for low inital error and low temperature drift. Connecting V_{REF}OUT to V_{REF}BG (pin 13) produces the bandgap reference voltage (1.24V ±0.5%) at the reference output.

Positive supply voltage must be 1.25V above the desired reference voltage. For example, with V+ = 2.7V, only the 1.24V reference (V_{REF}BG) can be used. If using dual supplies V_{REF}COM can be connected to V–, increasing the

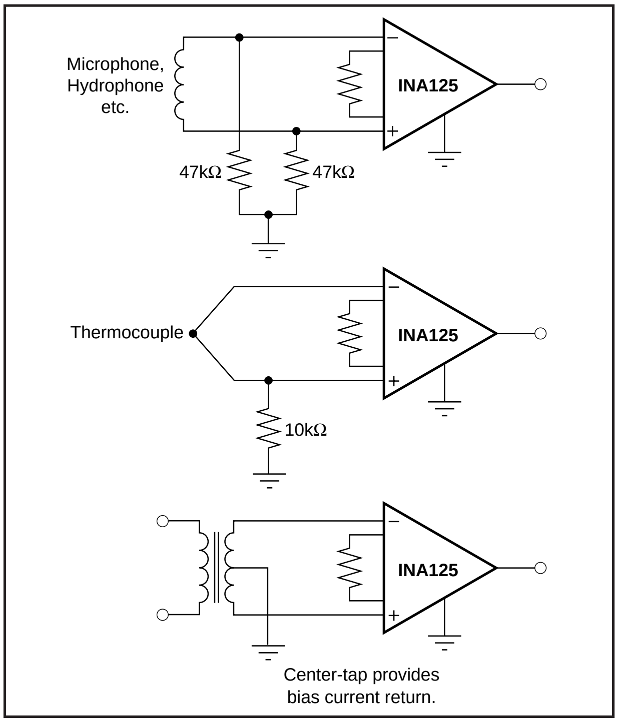


FIGURE 3. Providing an Input Common-Mode Current Path.

amount of supply voltage headroom available to the reference. Approximately 180µA flows out of the V_{REF}COM terminal, therefore, it is recommended that it be connected through a low impedance path to sensor common to avoid possible ground loop problems.

Reference noise is proportional to the reference voltage selected. With V_{REF} = 2.5V, 0.1Hz to 10Hz peak-to-peak noise is approximately 9µVp-p. Noise increases to 36µVp-p for the 10V reference. Output drive capability of the voltage reference is improved by connecting a transistor as shown in Figure 4. The external transistor also serves to remove power from the INA125.

Internal resistors that set the voltage reference output are ratio-trimmed for accurate output voltages (±0.5% max). The absolute resistance values, however, may vary ±25%. Adjustment of the reference output voltage with an external resistor is not recommended because the required resistor value is uncertain.

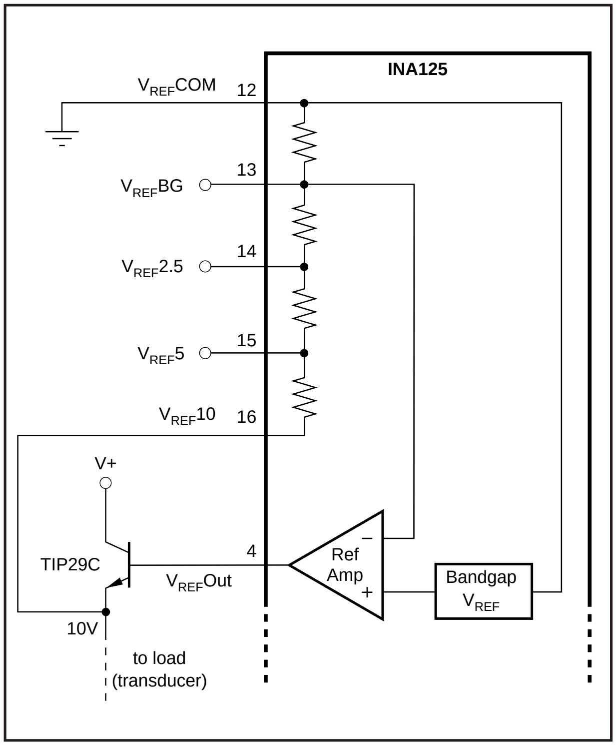


FIGURE 4. Reference Current Boost.

SHUTDOWN

The INA125 has a shutdown option. When the $\overline{\text{SLEEP}}$ pin is LOW (100mV or less), the supply current drops to approximately 1µA and output impedance becomes approximately 80kΩ. Best performance is achieved with CMOS logic. To maintain low sleep current at high temperatures, V_{SLEEP} should be as close to 0V as possible. This should not be a problem if using CMOS logic unless the CMOS gate is driving other currents. Refer to the typical performance curve, “Sleep Current vs Temperature.”

A transition region exists when V_{SLEEP} is between 400mV and 2.7V (with respect to V_{REF}COM) where the output is unpredictable. Operation in this region is not recommended. The INA125 achieves high accuracy quickly following wake-up (V_{SLEEP} ≥ 2.7V). See the typical performance curve “Input-Referred Offset Voltage vs Sleep Turn-on Time.” If shutdown is not being used, connect the $\overline{\text{SLEEP}}$ pin to V+.

LOW VOLTAGE OPERATION

The INA125 can be operated on power supplies as low as ±1.35V. Performance remains excellent with power supplies ranging from ±1.35V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to ensure that the common-mode voltage remains within its linear range. See “Input Common-Mode Voltage Range.” As previously mentioned, when using the on-board reference with low supply voltages, it may be necessary to connect V_{REF}COM to V– to ensure $V_S - V_{REF} \geq 1.25V$.

SINGLE SUPPLY OPERATION

The INA125 can be used on single power supplies of +2.7V to +36V. Figure 5 shows a basic single supply circuit. The IA_{REF}, V_{REF}COM, and V– terminals are connected to ground. Zero differential input voltage will demand an output voltage of 0V (ground). When the load is referred to ground as shown, actual output voltage swing is limited to approximately 150mV above ground. The typical performance curve “Output Voltage Swing vs Output Current” shows how the output swing varies with output current.

With single supply operation, careful attention should be paid to input common-mode range, output voltage swing of both op amps, and the voltage applied to the IA_{REF} terminal. V_{IN+} and V_{IN-} must both be 1V above ground for linear operation. You cannot, for instance, connect the inverting input to ground and measure a voltage connected to the non-inverting input.

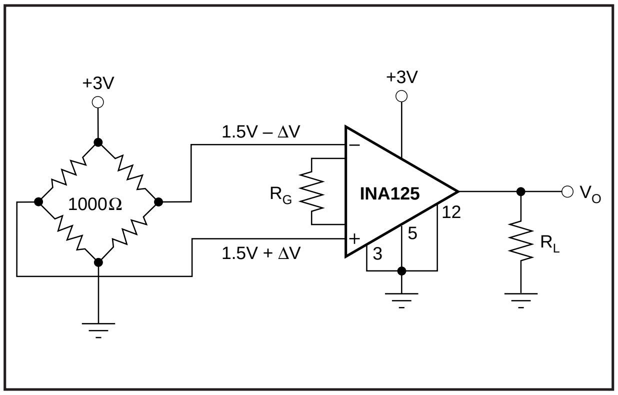
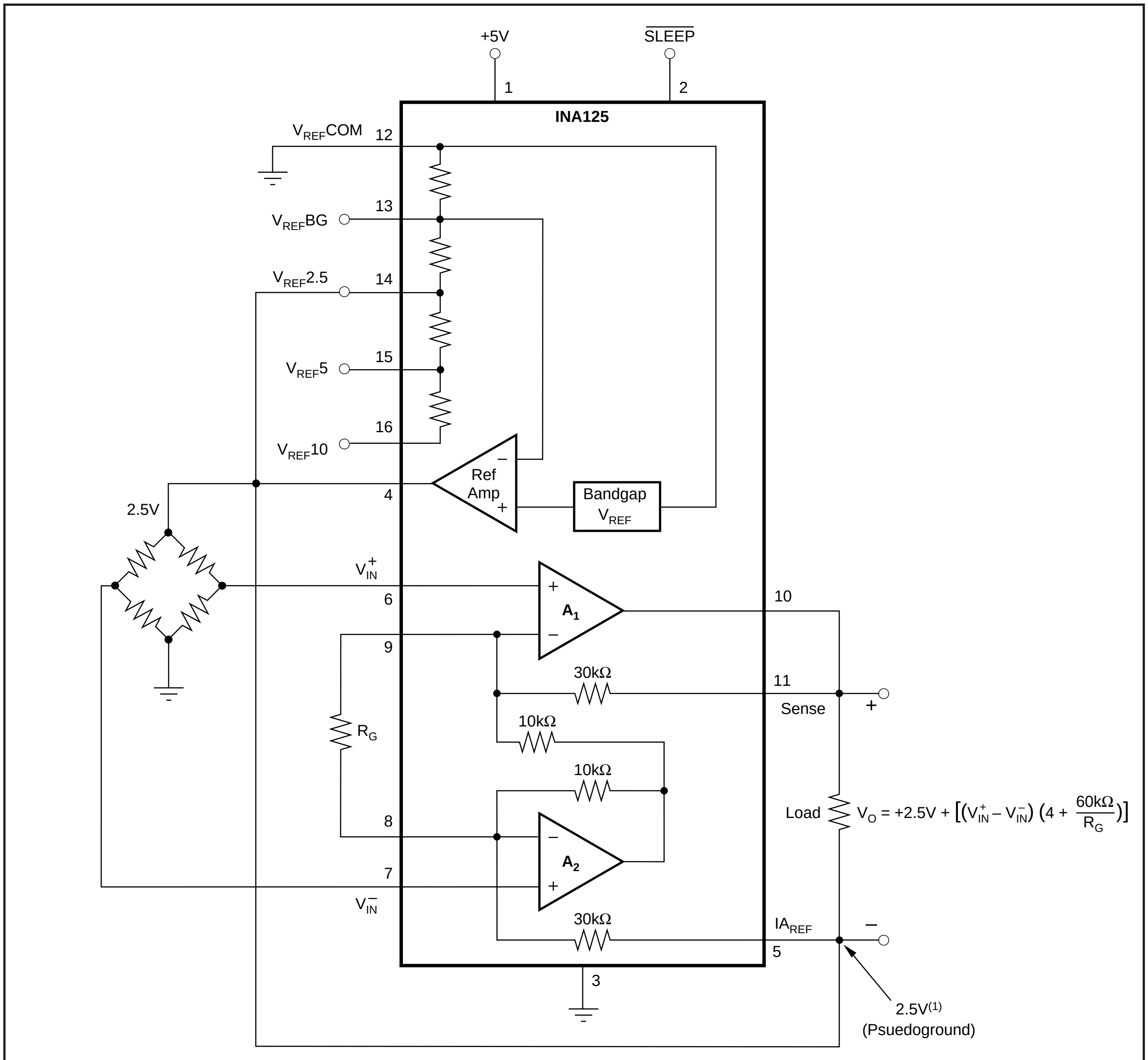


FIGURE 5. Single Supply Bridge Amplifier.

INPUT PROTECTION

The inputs of the INA125 are individually protected for voltage up to ±40V. For example, a condition of –40V on one input and +40V on the other input will not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. To provide equivalent protection, series input resistors would contribute excessive noise. If the input is overloaded, the protection circuitry limits the input current to a safe value of approximately 120µA to 190µA. The typical performance curve "Input Bias Current vs Input Overload Voltage" shows this input current limit behavior. The inputs are protected even if the power supplies are disconnected or turned off.



$$V_O = +2.5V + \left[(V_{IN}^+ - V_{IN}^-)\left(4 + \frac{60k\Omega}{R_G}\right)\right]$$

NOTE: (1) "Psuedoground" is at +2.5V above actual ground. This provides a precision reference voltage for succeeding single-supply op amp stages.

FIGURE 6. Psuedoground Bridge Measurement, 5V Single Supply.

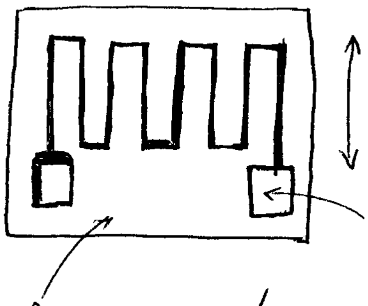
Power Calculation for Resistors.

$$P = vi = i^2 R$$

Application of Resistors:

Eg: Using Resistance to measure Strain.

Strain gage: Ni-Cu alloy foil is photoetched to obtain multiple conductors aligned in the direction of load or strain.



As strain is applied, the length and the area change, resulting in change in resistance.

Strain is related to resistance by GAGE FACTOR.

$$R = \frac{\rho L}{A} \quad \text{and} \quad G = \frac{\Delta R / R_0}{\epsilon}$$

$$G = \frac{\Delta R / R_0}{\epsilon}$$

R_0 = Resistance of the gage before Strain.

$\cong$ Typically 100 - 400 Ω

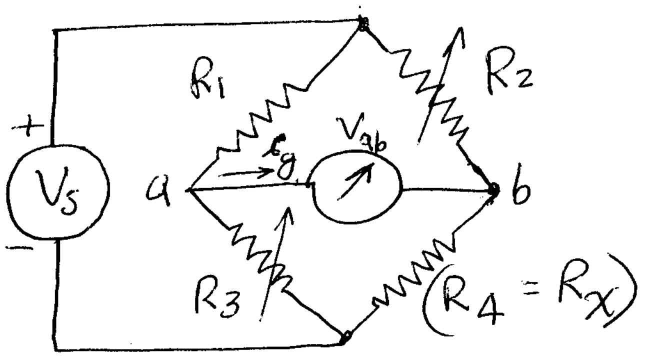
$G \cong$ Typically 2.0

Thus for a 1% Strain, assuming $R_0 = 350\,\Omega$

$$2.0 = \frac{\Delta R / 350}{.01} \Rightarrow \underline{\underline{\Delta R = 7.0\,\Omega}}$$

- Useful for various Sensor development.
  (Force, Torque, pressure, etc..)

WHEATSTONE BRIDGE



The detector should be capable of responding to very small currents.

In operation. R_2 & R_3 are adjusted so that

$V_{ab} = 0$ $i_g = 0$: the bridge is balanced.

Under balanced conditions:

$$V_a = V_b \quad \text{or:} \quad \frac{R_3}{R_1+R_3}\cancel{V_S} = \frac{R_X}{R_2+R_X}\cancel{V_S}$$

$$\text{or} \quad \frac{R_1+R_3}{R_3} = \frac{R_2+R_X}{R_X}$$

$$\frac{R_1}{R_3}\cancel{+1} = \frac{R_2}{R_X}\cancel{+1} \qquad \frac{R_X}{R_2} = \frac{R_3}{R_1}$$

$$\boxed{R_X = \left(\frac{R_2}{R_1}\right)R_3}$$

usually, $\left(\frac{R_2}{R_1}\right)$ is called the scale factor.

Example

$R_1 = 1\,k\Omega$ R_3 can be adjusted in $1\text{-}\Omega$ increments from 0 to $1100\,\Omega$

$R_2 = 1\,k\Omega, 10\,k\Omega, 100\,k\Omega$, or $1\,M\Omega$

a) Bridge is balanced when $R_3 = 732\,\Omega$ and $R_2 = 10\,k\Omega$
What is R_x?

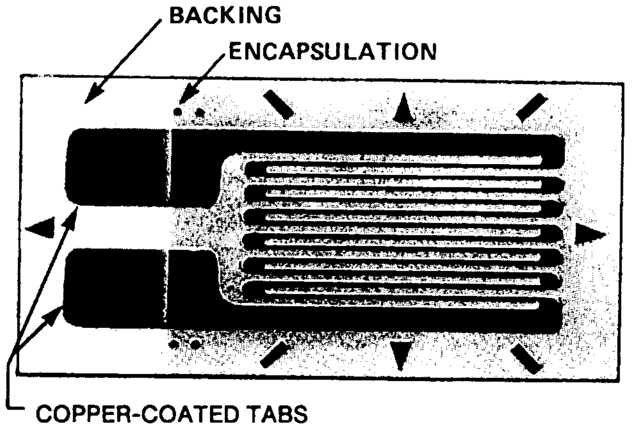
ⓑ what is $\left.R_x\right)_{max}$ for which the bridge can be balanced?

ⓒ If $R_2 = 1\,M\Omega$, what is the increment between values of R_x, for which the bridge is precisely balanced?

ⓐ $R_x = \frac{R_2}{R_1} \cdot R_3 = \frac{10\,k\Omega}{1\,k\Omega} \times 732\,\Omega = \underline{7320\,\Omega}$

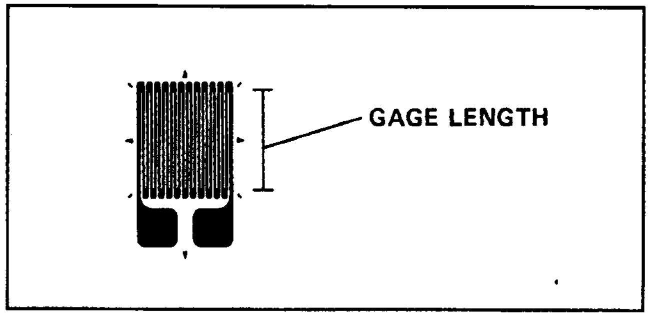
ⓑ $\left.R_x\right)_{max} = \frac{\left.R_2\right)_{max}}{R_1} \cdot \left.R_3\right)_{max} = \frac{1\,M\Omega}{1\,k\Omega} \times 1100\,\Omega = \underline{\underline{1.1\,M\Omega}}$

ⓒ $\left.R_x\right)_{inc} = \frac{R_2}{R_1} \left.R_3\right)_{inc} = \frac{1\,M\Omega}{1\,k\Omega} \times 1\,\Omega \quad = \underline{\underline{1\,k\Omega}}$

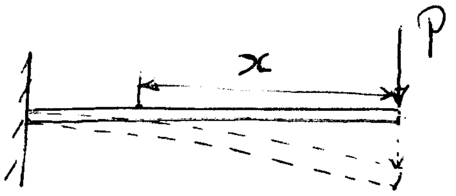


2.4 Gage Length

The gage length of a strain gage is the active or strain-sensitive length of the grid, as shown below. The endloops and solder tabs are considered insensitive to strain because of their relatively large cross-sectional area and low electrical resistance. To satisfy the widely varying needs of experimental stress analysis and transducer applications, the Micro-Measurements Division offers gage lengths ranging from 0.008 in *(0.2 mm)* to 4 in *(100 mm)*.



BEAM - TYPE LOAD CELL.



Under tip load, the beam deflects.

Assuming pure bending (for small deflections), the beam formula can be applied

$$M_x = P.x$$

$$\frac{M}{I} = \frac{E}{\rho} = \frac{\sigma}{y} \quad \therefore \quad \sigma = \frac{My}{I} = E\epsilon$$

At the top & bottom surfaces, $y = \frac{h}{2}$

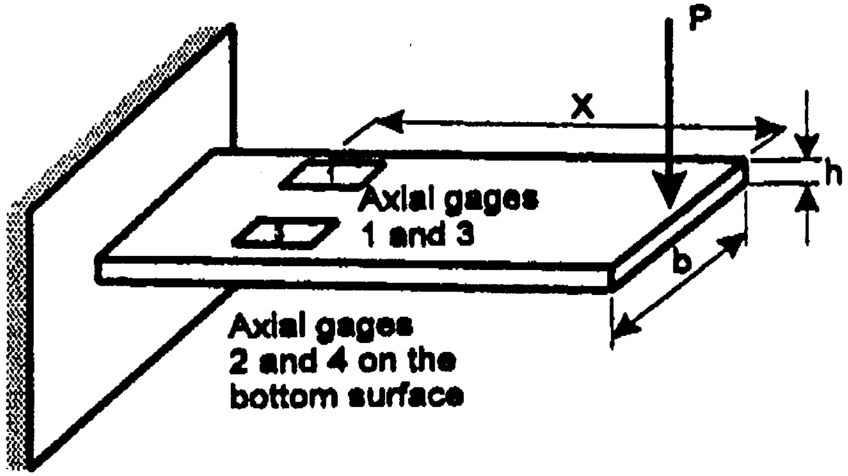
$$\therefore \quad \epsilon = \frac{M}{EI} \cdot \frac{h}{2} = \frac{M h}{E \frac{bh^3}{12} \cdot 2}$$

Where b is the width of the beam, h is thickness.

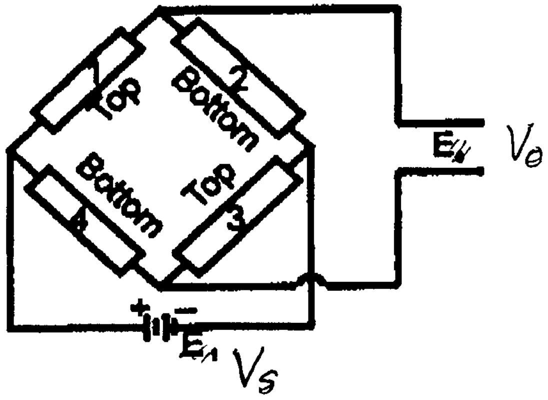
$$\epsilon = \frac{6M}{Ebh^2} = \frac{6Px}{Ebh^2}$$

E = Elastic Modulus.

Beam-type Load Cell



(a)



(b)

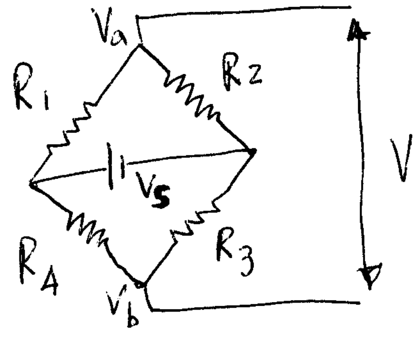
For the Beam-type load cell shown,

$$\epsilon_1 = -\epsilon_2 = \epsilon_3 = -\epsilon_4 = \epsilon = \frac{6Px}{Ebh^2}$$

For the strain gage, we know:

$$\left(\frac{\Delta R_1}{R_1}\right) = G \cdot \epsilon_1 \quad \cdots$$

$$\therefore \frac{\Delta R_1}{R_1} = -\frac{\Delta R_2}{R_2} = \frac{\Delta R_3}{R_3} = -\frac{\Delta R_4}{R_4} = G\epsilon = \frac{6GPx}{Ebh^2}$$



$$V_a = \frac{R_2}{R_1+R_2} \cdot V_s$$

$$V_b = \frac{R_3}{R_3+R_4} \cdot V_s$$

$$\therefore V_o = (V_b - V_a) = \left[\frac{R_3}{R_3+R_4} - \frac{R_2}{R_1+R_2}\right] V_s$$

Assume $R_1 = R_2 = R_3 = R_4$ (identical gages);

then, the bridge is balanced.

When a load P is applied at the tip;

$$V_o = \left[\frac{R_3 + \Delta R_3}{(R_3+\Delta R_3)+(R_4-\Delta R_4)} - \frac{R_2 - \Delta R_2}{(R_1+\Delta R_1)+(R_2-\Delta R_2)}\right] V_s$$

Since, gages are identical, $|\Delta R_1| = |\Delta R_2| = |\Delta R_3| = |\Delta R_4| = \Delta R$

and $R_1 = R_2 = R_3 = R_4 = R$

$$V_o = \left[\frac{R + \Delta R}{2R} - \frac{R - \Delta R}{2R}\right] V_s$$

$$V_o = \left(\frac{\Delta R}{R}\right) V_s = \left(\frac{6 G P x}{E b h^2}\right) V_s$$

or $$V_o = \left[\frac{6 G x V_s}{E b h^2}\right] P$$

$$\boxed{V_o = K \cdot P}$$

Hence, output voltage is $\propto$ tip load.

Design such a way that

you get about 500 μstrain / lb of Load

1000 μs is maximum capacity

at full load (2 lb), you'll get 2 mV / Volt of Excitation.

Example: a load of 1 lb, 10V excitation.
you'll got 10mV output.

This has to be amplified to 2.5V or 2500 mV
(assuming 5V is full scale for Handyboard)

Then you need a gain of 250.

- Mount the gage symmetrically top & bottom
- Use solder tabs for Excitation voltage input and V_o.
- Use equal length wires.

P^+ to Tension Gage to S^-
S^- to Compression Gage to P^-
P^- to Tension Gage to S^+
S^+ to Compression Gage to P^+

- Expect that there will be a null offset
- You can correct it in hardware or software

Assuming $G = 2$, $x = 9.75''$ $V_s = 10\,V$

$E = 10{,}000$ ksi $b = 0.75''$ $h = 1/8''$

$$\epsilon = \frac{6Px}{Ebh^2} = \frac{6.(9.75)}{10\times10^6 \times 0.75 \times (1/8)^2} = \underline{4.992 \times 10^{-4}}$$

$$\epsilon = 499.2 \simeq \underline{500\ \mu\text{strain Units}} / \#\text{ of Load}$$

$$V_o = \frac{6(2)(9.75)(10)}{10\times10^6\,(.75)\,(1/8)^2}\,P'' = 9.984\times10^{-3}\,V$$

$\underline{\underline{\simeq 10\,mV}}$

Amplification by 250 is good:

10 mV → 2.5V

The instrumentation amplifier can easily do that.

Interfacing with the Handyboard.