



# Low-Power, Single-Supply, CMOS INSTRUMENTATION AMPLIFIERS

## FEATURES

- DESIGNED FOR LOW COST
- HIGH GAIN ACCURACY:  $G = 5$ , 0.07%, 2ppm/°C
- GAIN SET WITH EXT. RESISTORS FOR  $> 5V/V$
- HIGH CMRR: 73dB DC, 50dB at 45kHz
- LOW BIAS CURRENT: 0.5pA
- BANDWIDTH, SLEW RATE: 2.0MHz, 5V/μs
- RAIL-TO-RAIL OUTPUT SWING:  $(V+) - 0.02V$
- WIDE TEMPERATURE RANGE:  $-55^{\circ}C$  to  $+125^{\circ}C$
- LOW QUIESCENT CURRENT: 490μA max/chan
- SHUT DOWN: 0.01μA
- MSOP-8 SINGLE AND TSSOP-14 DUAL PACKAGES

## DESCRIPTION

The INA332 and INA2332 are rail-to-rail output, low-power CMOS instrumentation amplifiers that offer wide range, single-supply, and bipolar-supply operation. Using a special manufacturing flow, the INA332 family provides the lowest cost available, while still achieving low-noise amplification of differential signals with low quiescent current of 415μA (dropping to 0.01μA when shutdown). Returning to normal operation within microseconds, this INA can be used for battery or multichannel applications.

Configured internally in a gain of 5V/V, the INA332 offers flexibility in higher gains by choosing external resistors.

## APPLICATIONS

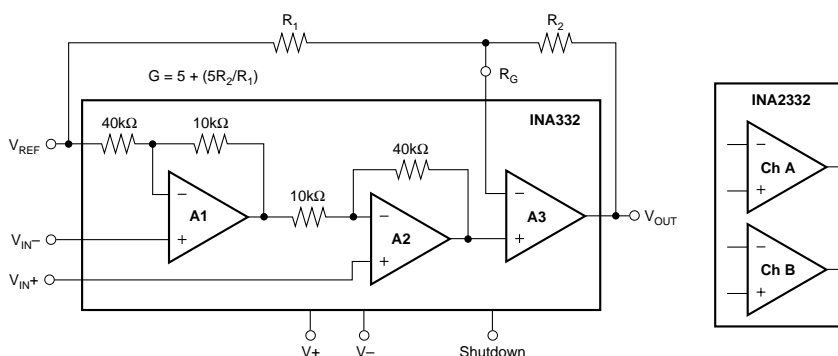
- INDUSTRIAL SENSOR AMPLIFIERS: Bridge, RTD, Thermocouple, Position
- PHYSIOLOGICAL AMPLIFIERS: ECG, EEG, EMG
- A/D CONVERTER SIGNAL CONDITIONING
- DIFFERENTIAL LINE RECEIVERS WITH GAIN
- FIELD UTILITY METERS
- PCMCIA CARDS
- AUDIO AMPLIFIERS
- COMMUNICATION SYSTEMS
- TEST EQUIPMENT
- AUTOMOTIVE INSTRUMENTATION

The INA332 rejects line noise and its harmonics because common-mode error remains low even at higher frequencies.

High bandwidth and slew rate make the INA332 ideal for directly driving sampling Analog-to-Digital (A/D) converters as well as general-purpose applications.

With high precision, low cost, and small packages, the INA332 outperforms discrete designs.

Additionally, because they are specified for wide temperature range of  $-55^{\circ}C$  to  $+125^{\circ}C$  and operating range of  $-65^{\circ}C$  to  $+150^{\circ}C$ , the INA331 family can be used in demanding industrial and automotive environments.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

Supply Voltage, V+ to V- .....	7.5V
Signal Input Terminals, Voltage <sup>(2)</sup> .....	(V-) - 0.5V to (V+) + 0.5V
Current <sup>(2)</sup> .....	10mA
Output Short-Circuit <sup>(3)</sup> .....	Continuous
Operating Temperature .....	-55°C to +125°C
Storage Temperature .....	-65°C to +150°C
Junction Temperature .....	150°C
Lead Temperature (soldering, 10s) .....	300°C

NOTES: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. (2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5V beyond the supply rails should be current limited to 10mA or less. (3) Short-circuit to ground, one amplifier per package.



## ELECTROSTATIC DISCHARGE SENSITIVITY

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

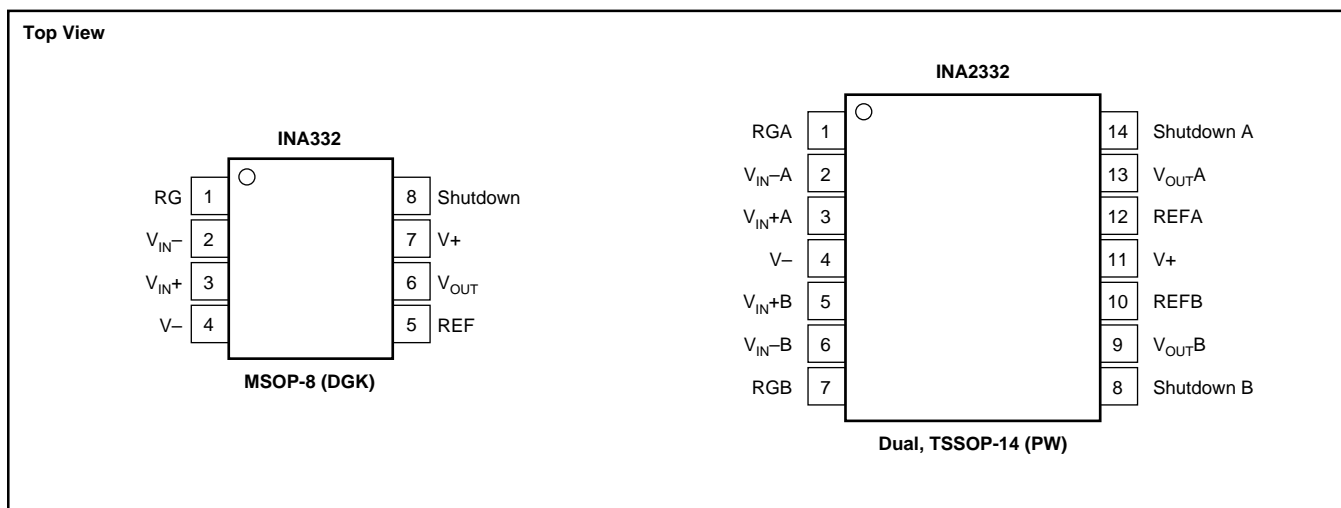
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR <sup>(1)</sup>	TEMPERATURE RANGE	SPECIFIED PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
<b>Single</b> INA332IDGK "	MSOP-8 "	DGK "	-55°C to +125°C "	B32 "	INA332IDGKT INA332IDGKR	Tape and Reel, 250 Tape and Reel, 2500
<b>Dual</b> INA2332AIPW "	TSSOP-14 "	PW "	-55°C to +125°C "	2332A "	INA2332AIPWT INA2332AIPWR	Tape and Reel, 250 Tape and Reel, 2500

NOTE: (1) For the most current specifications and package information, refer to our web site at [www.ti.com](http://www.ti.com).

## PIN CONFIGURATION



# ELECTRICAL CHARACTERISTICS: $V_S = +2.7V$ TO $+5.5V$

**BOLDFACE** limits apply over the specified temperature range,  $T_A = -55^{\circ}C$  TO  $125^{\circ}C$

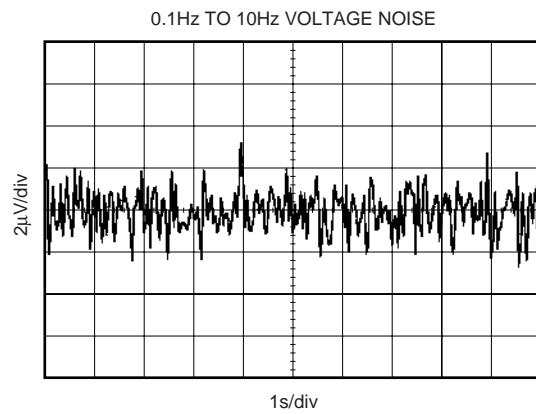
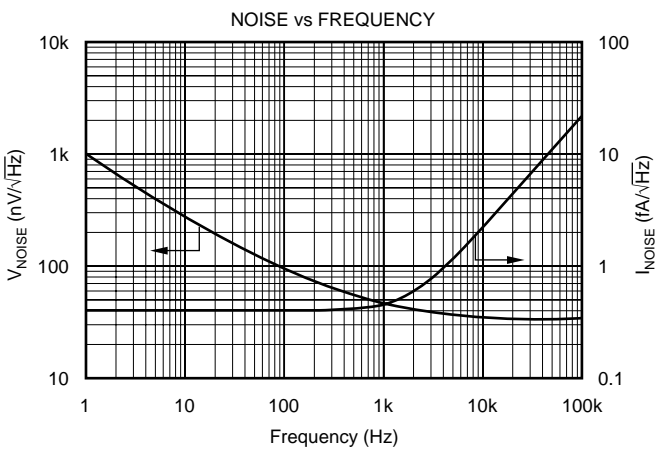
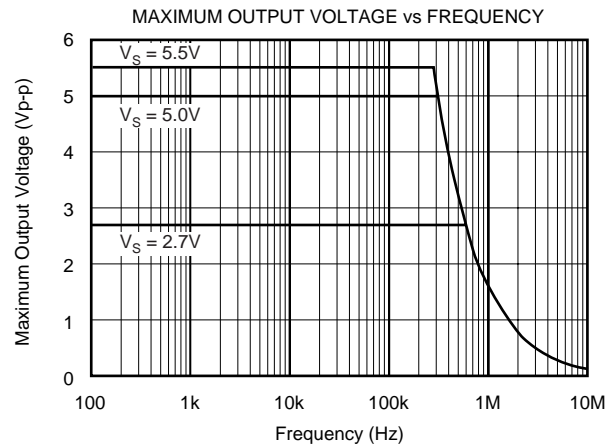
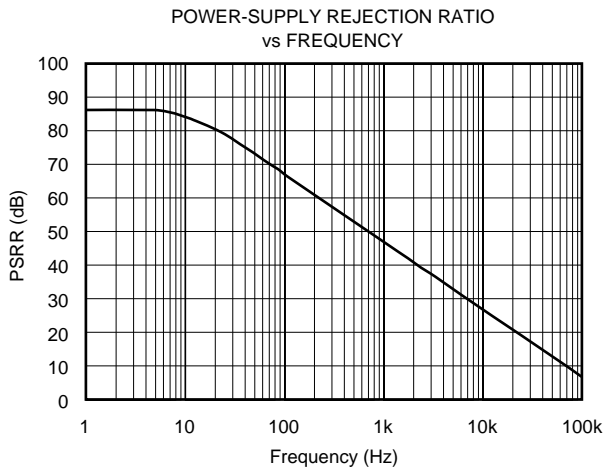
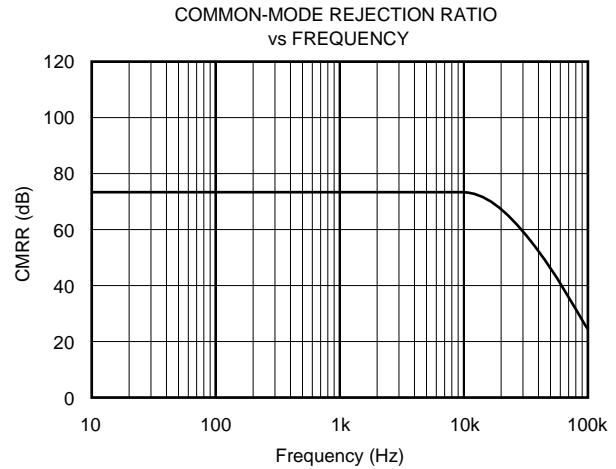
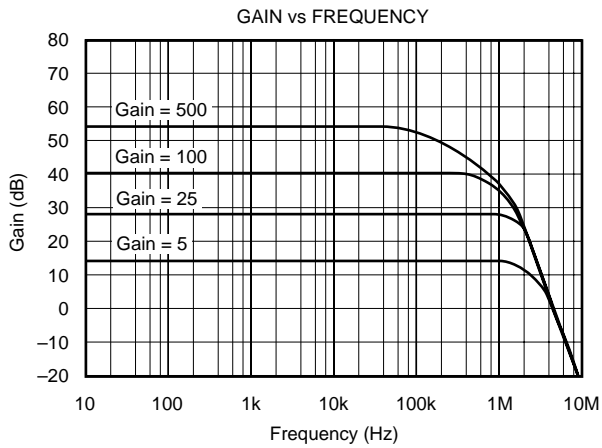
At  $T_A = +25^{\circ}C$ ,  $R_L = 10k\Omega$ ,  $G = 25$ , and  $V_{CM} = V_S/2$ , unless otherwise noted.

PARAMETER	CONDITION	INA332AIDGK INA2332AIPW			UNITS
		MIN	TYP	MAX	
<b>INPUT</b>					
Input Offset Voltage, RTI	$V_S = +5V$		$\pm 2$	$\pm 8$	mV
<b>Over Temperature</b>				$\pm 9$	mV
Temperature Coefficient $V_{OS}$			$\pm 5$		$\mu V/^{\circ}C$
vs Power Supply	$V_S = +2.7V$ to $+5.5V$		$\pm 50$	$\pm 250$	$\mu V/V$
<b>Over Temperature</b>				$\pm 260$	$\mu V/V$
Long-Term Stability			$\pm 0.4$		$\mu V/month$
Input Impedance			$10^{13}    3$		$\Omega    pF$
Input Common-Mode Range	$V_S = 2.7V$	0.35		1.5	V
	$V_S = 5V$	0.55		3.8	V
Common-Mode Rejection	$V_S = 5V, V_{CM} = 0.55V$ to $3.8V$	60	73		dB
<b>Over Temperature</b>	$V_S = 5V, V_{CM} = 0.55V$ to $3.8V$	<b>60</b>			<b>dB</b>
	$V_S = 2.7V, V_{CM} = 0.35V$ to $1.5V$		73		dB
Crosstalk, Dual			114		dB
<b>INPUT BIAS CURRENT</b>	$V_{CM} = V_S/2$				
Bias Current $I_B$			$\pm 0.5$	$\pm 10$	pA
Offset Current $I_{OS}$			$\pm 0.5$	$\pm 10$	pA
<b>NOISE, RTI</b>	$R_S = 0\Omega$				
Voltage Noise: $f = 10Hz$			280		$nV/\sqrt{Hz}$
$f = 100Hz$			96		$nV/\sqrt{Hz}$
$f = 1kHz$			46		$nV/\sqrt{Hz}$
$f = 0.1Hz$ to $10Hz$			7		$\mu Vp-p$
Current Noise: $f = 1kHz$			0.5		$fA/\sqrt{Hz}$
<b>GAIN<sup>(1)</sup></b>					
Gain Equation, Externally Set	$G > 5$		$G = 5 + 5(R_2/R_1)$		V/V
Range of Gain		5		1000	%
Gain Error			$\pm 0.07$	$\pm 0.4$	%
<b>vs Temperature</b>	$G = 5$		$\pm 2$	$\pm 10$	<b>ppm/<math>^{\circ}C</math></b>
Nonlinearity	$G = 25, V_S = 5V, V_O = 0.05$ to $4.95$		$\pm 0.001$	$\pm 0.010$	% of FS
<b>Over Temperature</b>			<b><math>\pm 0.002</math></b>	<b><math>\pm 0.015</math></b>	<b>% of FS</b>
<b>OUTPUT</b>					
Output Voltage Swing from Rail <sup>(2)</sup>	$G \geq 10$	50	25		mV
<b>Over Temperature</b>		<b>50</b>			<b>mV</b>
Capacitance Load Drive			See Typical Characteristics <sup>(3)</sup>		pF
Short-Circuit Current $I_{SC}$			$+48/-32$		mA
<b>FREQUENCY RESPONSE</b>					
Bandwidth, $-3dB$	$BW$	$G = 25$	2.0		MHz
Slew Rate	$SR$	$V_S = 5V, G = 25$	5		$V/\mu s$
Settling Time, 0.1%	$t_s$	$G = 25, C_L = 100pF, V_O = 2V$ step	1.7		$\mu s$
0.01%			2.5		$\mu s$
Overload Recovery		50% Input Overload $G = 25$	2		$\mu s$
<b>POWER SUPPLY</b>					
Specified Voltage Range			+2.7	+5.5	V
Operating Voltage Range			+2.5 to +5.5		V
Quiescent Current per Channel $I_Q$	$V_{SD} > 2.5^{(4)}$		415	490	$\mu A$
<b>Over Temperature</b>				<b>600</b>	<b><math>\mu A</math></b>
Shutdown Quiescent Current/Chan $I_{SD}$	$V_{SD} < 0.8^{(4)}$		0.01	1	$\mu A$
<b>TEMPERATURE RANGE</b>					
Specified Range			-55	+125	$^{\circ}C$
Operating/Storage Range			-65	+150	$^{\circ}C$
Thermal Resistance $\theta_{JA}$	MSOP-8, TSSOP-14 Surface Mount		150		$^{\circ}C/W$

NOTES: (1) Does not include errors from external gain setting resistors (2) Output voltage swings are measured between the output and power-supply rails. Output swings to rail only if  $G \geq 10$ . Output does not swing to positive rail if gain is less than 10. (3) See typical characteristic "Percent Overshoot vs Load Capacitance." (4) See typical characteristic "Shutdown Voltage vs Supply Voltage."

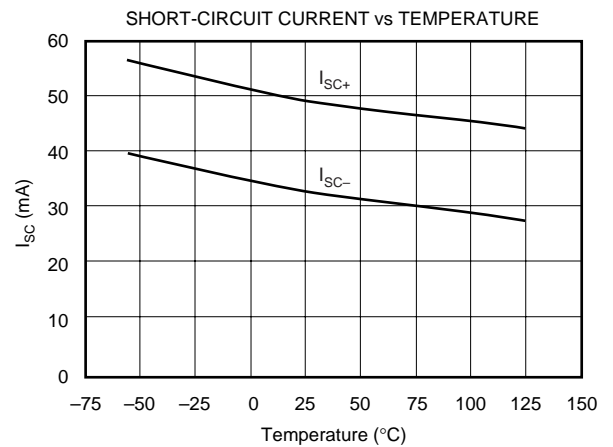
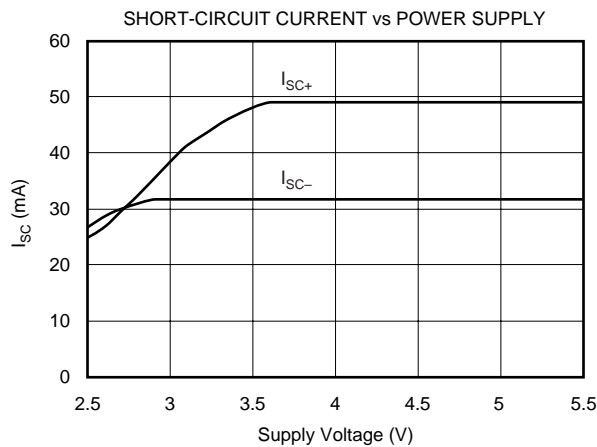
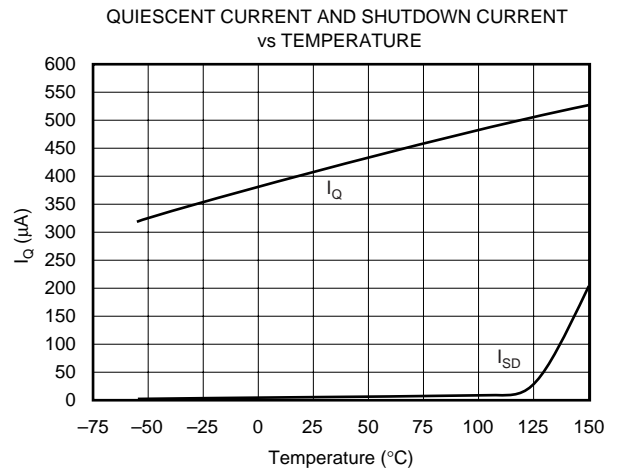
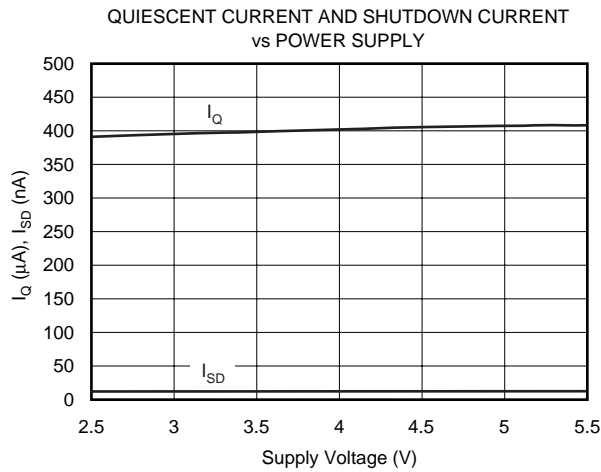
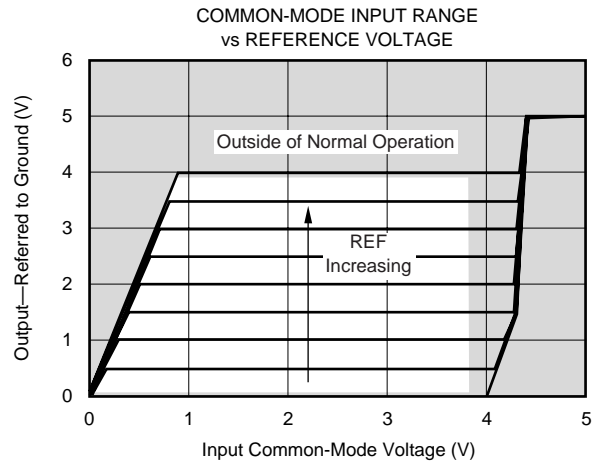
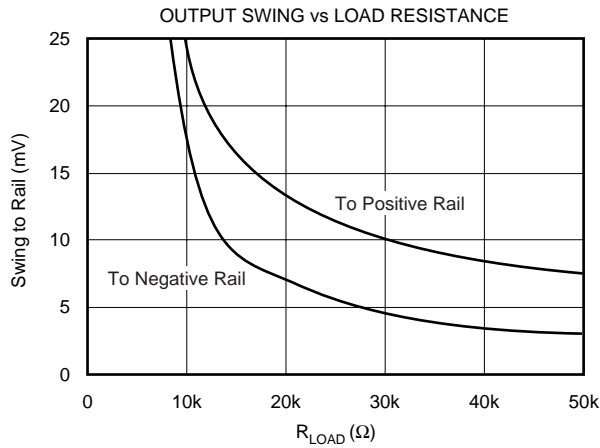
# TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ ,  $R_L = 10\text{k}\Omega$ , and  $C_L = 100\text{pF}$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont.)

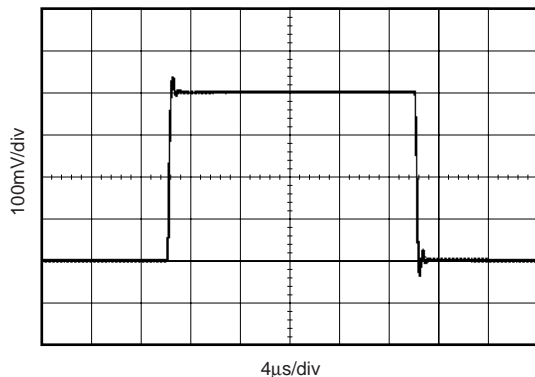
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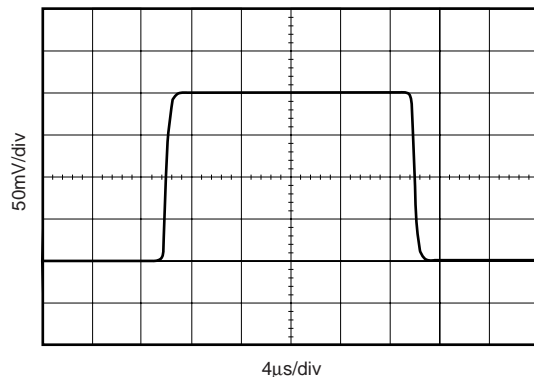
# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ ,  $R_L = 10\text{k}\Omega$ , and  $C_L = 100\text{pF}$ , unless otherwise noted.

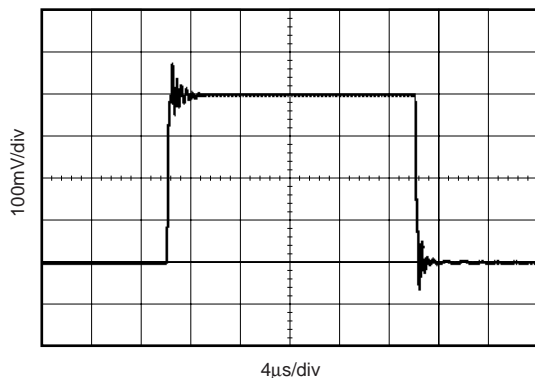
SMALL-SIGNAL STEP RESPONSE ( $G = 5$ )



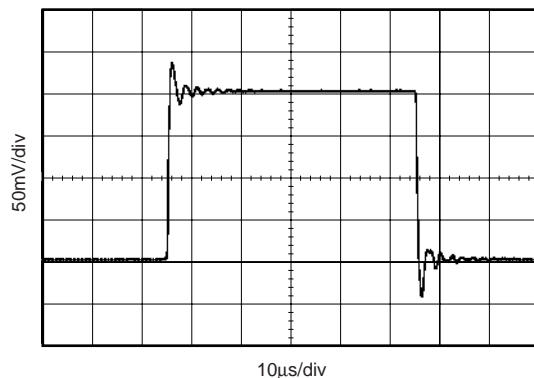
SMALL-SIGNAL STEP RESPONSE ( $G = 100$ )



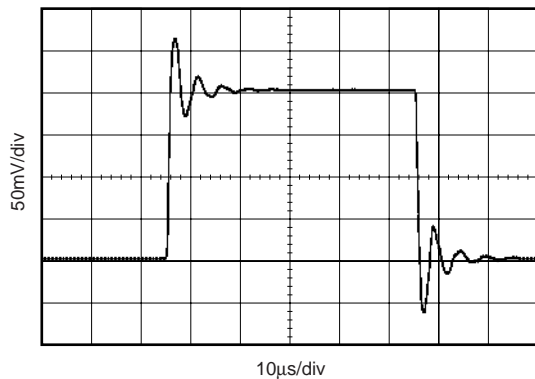
SMALL-SIGNAL STEP RESPONSE  
( $G = 5$ ,  $C_L = 1000\text{pF}$ )



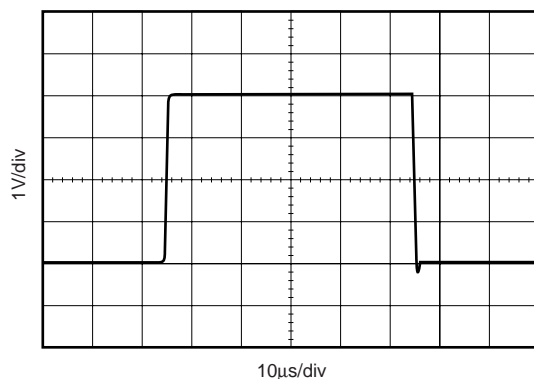
SMALL-SIGNAL STEP RESPONSE  
( $G = 100$ ,  $C_L = 1000\text{pF}$ )



SMALL-SIGNAL STEP RESPONSE  
( $G = 100$ ,  $C_L = 4700\text{pF}$ )

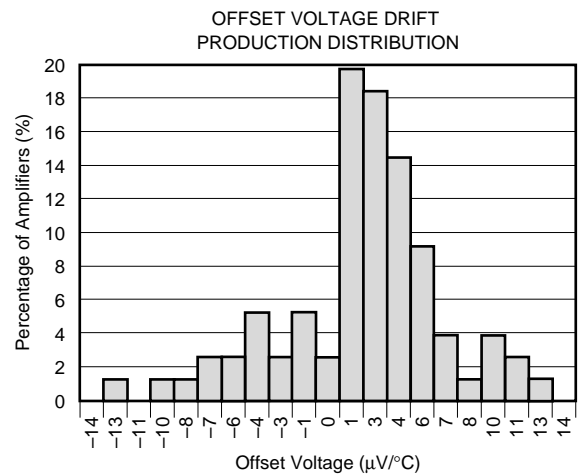
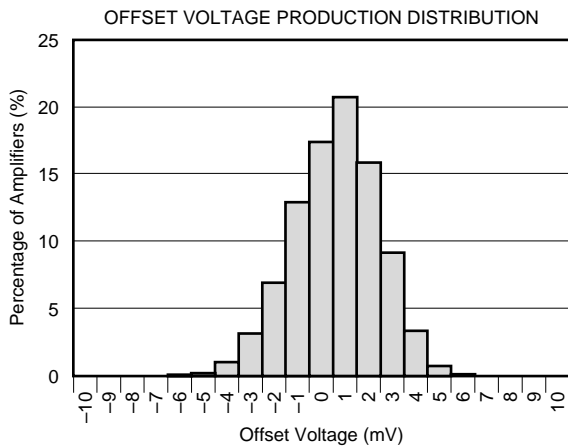
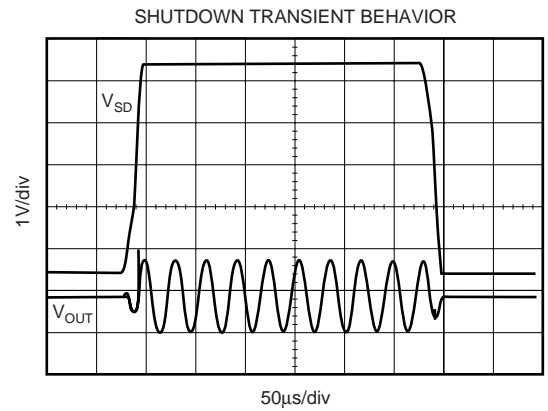
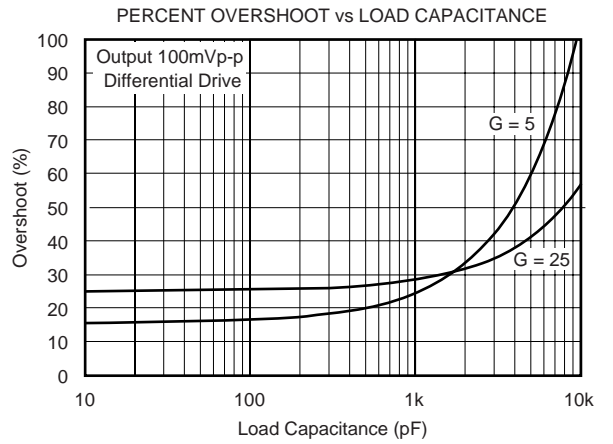
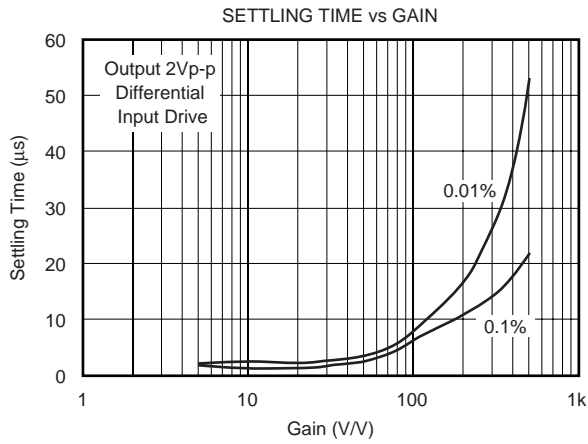


LARGE-SIGNAL STEP RESPONSE ( $G = 25$ )



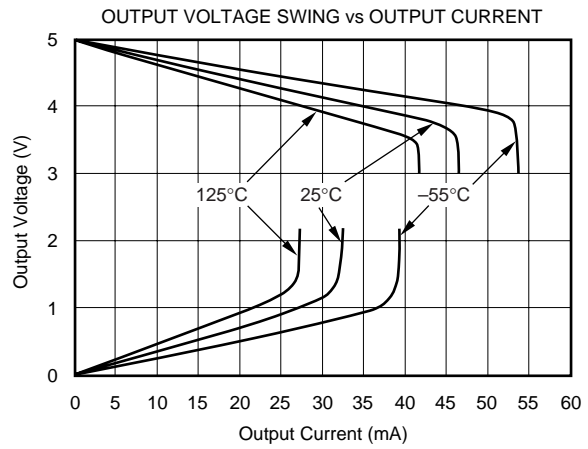
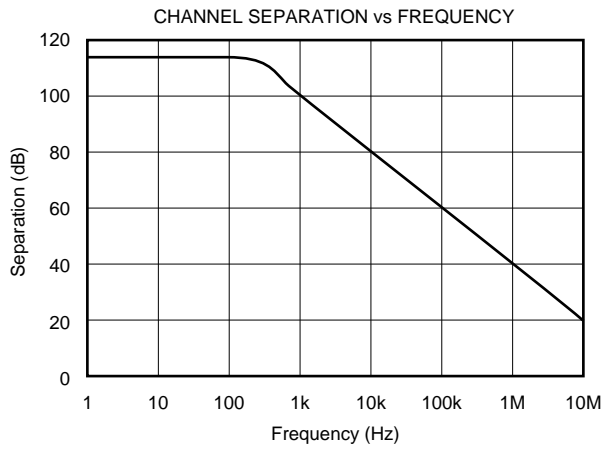
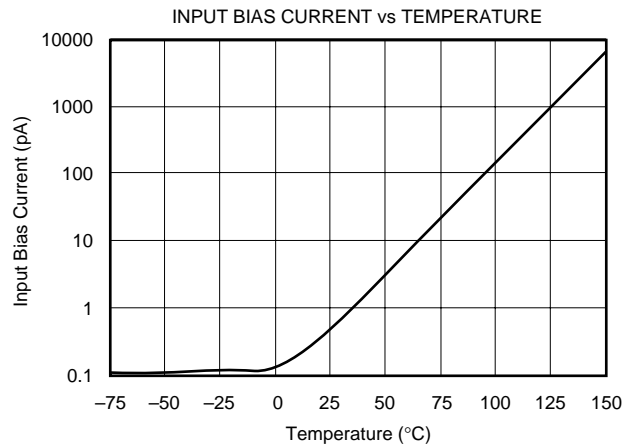
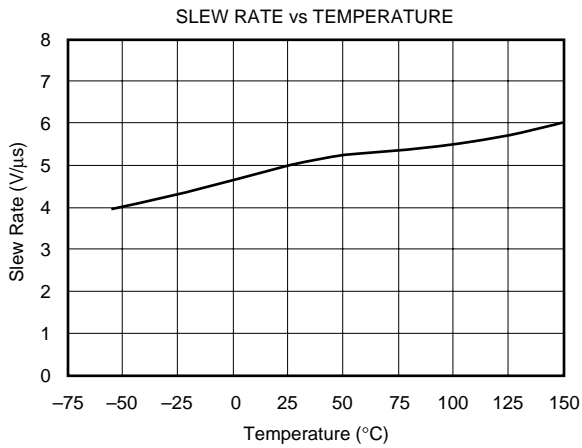
# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ ,  $R_L = 10\text{k}\Omega$ , and  $C_L = 100\text{pF}$ , unless otherwise noted.



# TYPICAL CHARACTERISTICS (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = V_S/2$ ,  $R_L = 10\text{k}\Omega$ , and  $C_L = 100\text{pF}$ , unless otherwise noted.





# APPLICATIONS INFORMATION

The INA332 is a modified version of the classic “two op amp” instrumentation amplifier, with an additional gain amplifier.

Figure 1 shows the basic connections for the operation of the INA332 and INA2332. The power supply should be capacitively decoupled with 0.1µF capacitors as close to the INA332 as possible for noisy or high-impedance applications.

The output is referred to the reference terminal, which must be at least 1.2V below the positive supply rail.

# OPERATING VOLTAGE

The INA332 family is fully specified over a supply range of +2.7V to +5.5V, with key parameters tested over the temperature range of -55°C to +125°C. Parameters that vary significantly with operating conditions, such as load conditions or temperature, are shown in the Typical Characteristics.

The INA332 may be operated on a single supply. Figure 2 shows a bridge amplifier circuit operated from a single +5V supply. The bridge provides a small differential voltage riding on an input common-mode voltage.

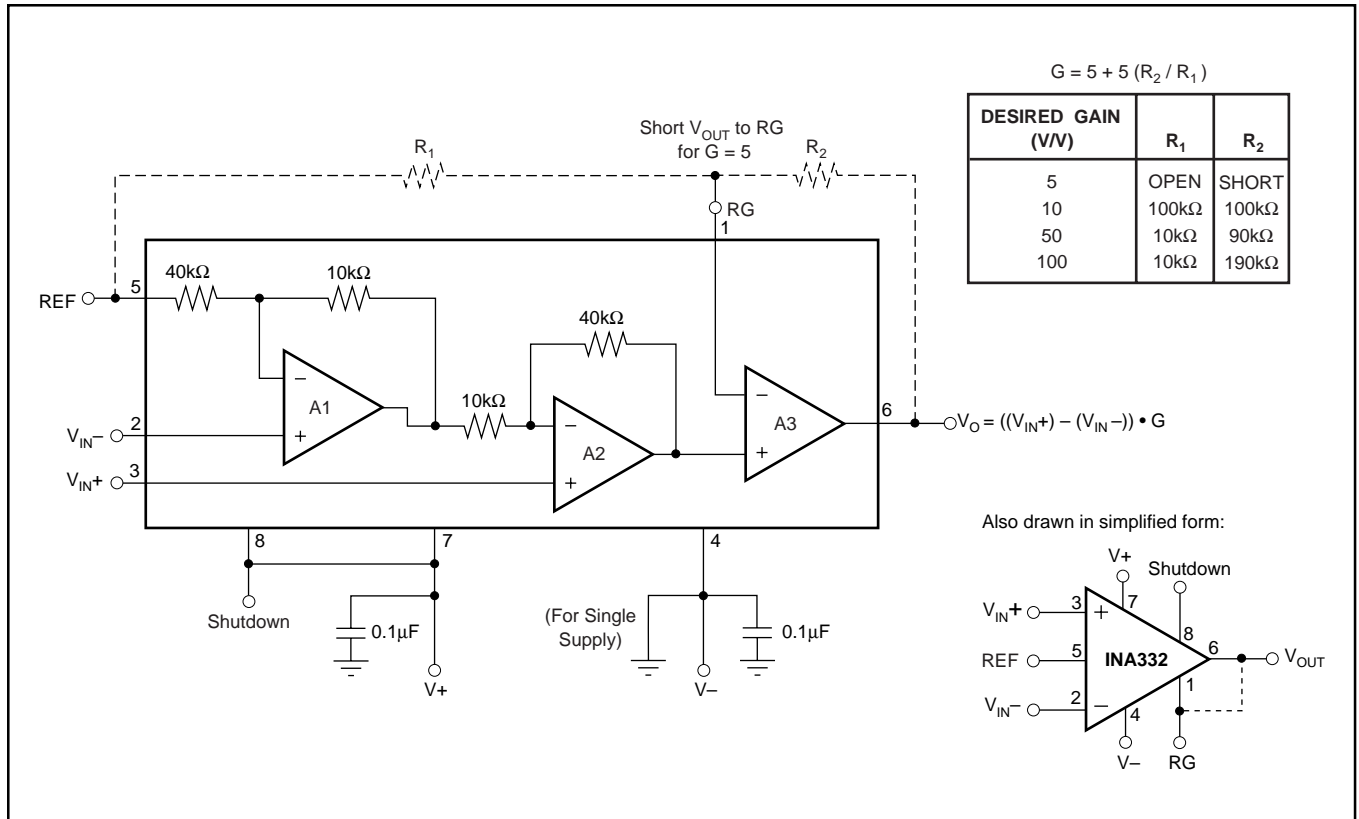


FIGURE 1. Basic Connections.

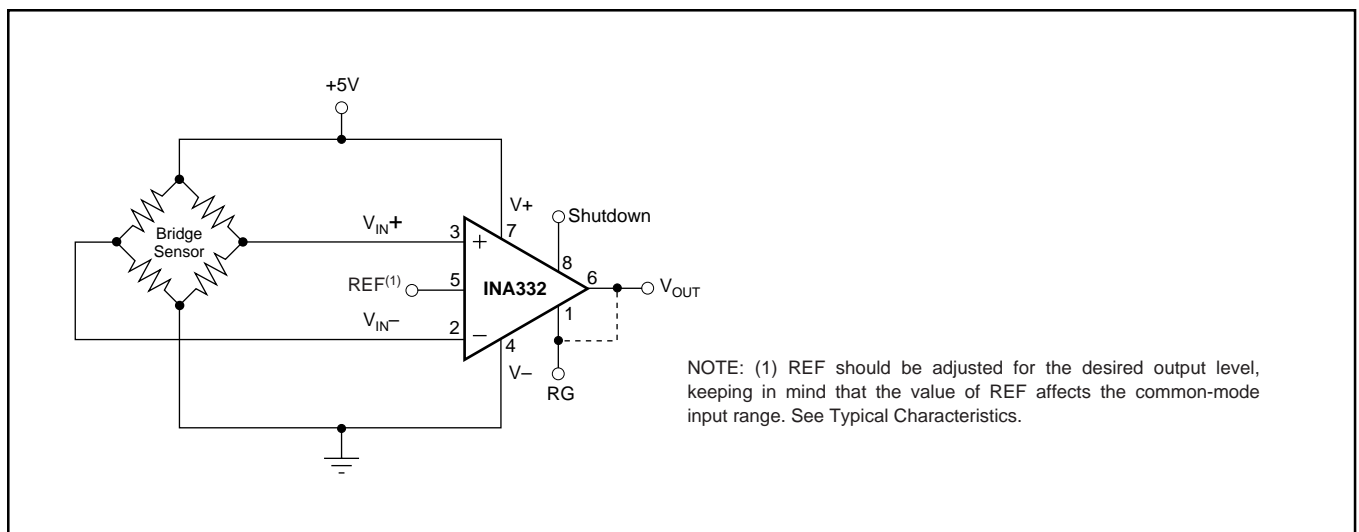


FIGURE 2. Single-Supply Bridge Amplifier.

## SETTING THE GAIN

The ratio of  $R_2$  to  $R_1$ , or the impedance between pins 1, 5, and 6, determines the gain of the INA332. With an internally set gain of 5, the INA332 can be programmed for gains greater than 5 according to the following equation:

$$G = 5 + 5 (R_2/R_1)$$

The INA332 is designed to provide accurate gain, with gain error less than 0.4%. Setting gain with matching TC resistors will minimize gain drift. Errors from external resistors will add directly to the error, and may become dominant error sources.

## COMMON-MODE INPUT RANGE

The upper limit of the common-mode input range is set by the common-mode input range of the second amplifier, A2, to 1.2V below positive supply. Under most conditions, the amplifier operates beyond this point with reduced performance. The lower limit of the input range is bounded by the output swing of amplifier A1, and is a function of the reference voltage according to the following equation:

$$V_{OA1} = 5/4 V_{CM} - 1/4 V_{REF}$$

(See typical characteristic “Common-Mode Input Range vs Reference Voltage”).

## REFERENCE

The reference terminal defines the zero output voltage level. In setting the reference voltage, the common mode input of A3 should be considered according to the following equation:

$$V_{OA2} = V_{REF} + 5 (V_{IN+} - V_{IN-})$$

For ensured operation,  $V_{OA2}$  should be less than  $V_{DD} - 1.2V$ .

The reference pin requires a low-impedance connection. As little as 160Ω in series with the reference pin will degrade the CMRR to 50dB. The reference pin may be used to compensate for the offset voltage (see Offset Trimming section). The reference voltage level also influences the common-mode input range (see Common-Mode Input Range section).

## INPUT BIAS CURRENT RETURN

With a high input impedance of  $10^{13}\Omega$ , the INA332 is ideal for use with high-impedance sources. The input bias current of less than 10pA makes the INA332 nearly independent of input impedance and ideal for low-power applications.

For proper operation, a path must be provided for input bias currents for both inputs. Without input bias current paths, the inputs will “float” to a potential that exceeds common-mode range and the input amplifier will saturate. Figure 3 shows

how bias current path can be provided in the cases of microphone applications, thermistor applications, ground returns, and dc-coupled resistive bridge applications.

When differential source impedance is low, the bias current return path can be connected to one input. With higher source impedance, two equal resistors will provide a balanced input. The advantages are lower input offset voltage due to bias current flowing through the source impedance and better high-frequency gain.

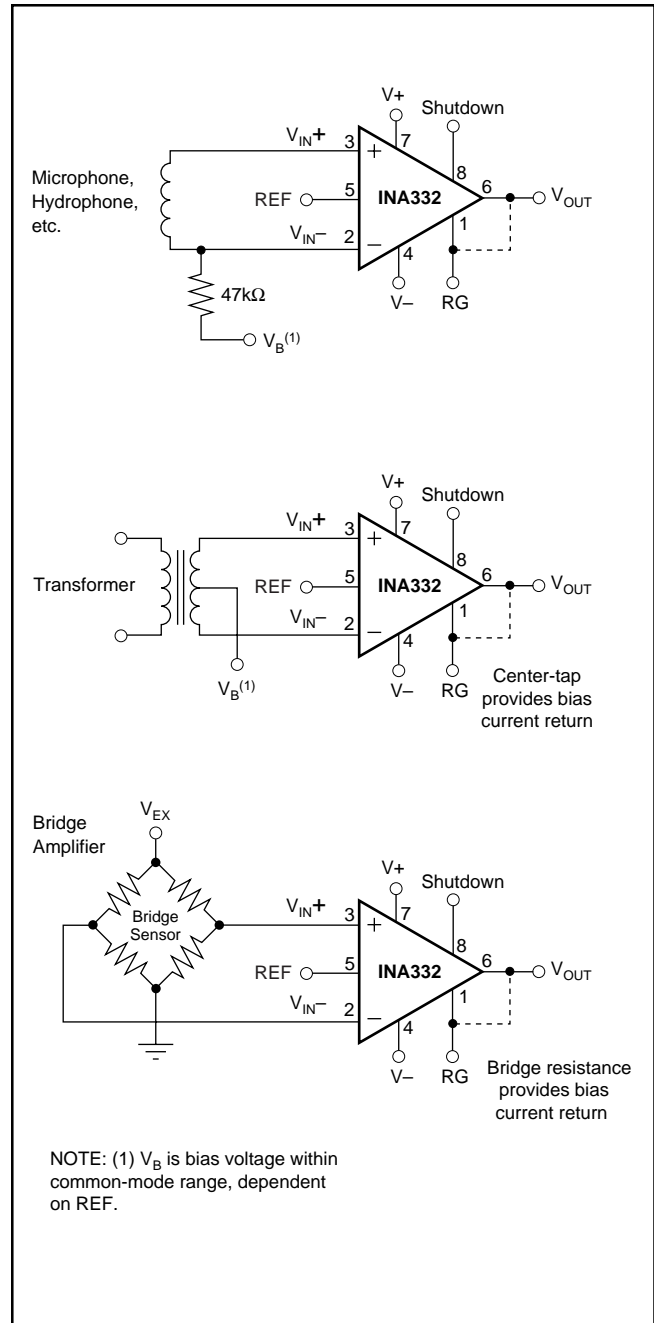


FIGURE 3. Providing an Input Common-Mode Path.

## SHUTDOWN MODE

The shutdown pin of the INA332 is nominally connected to V+. When the pin is pulled below 0.8V on a 5V supply, the INA332 goes into sleep mode within nanoseconds. For actual shutdown threshold, see typical characteristic “Shutdown Voltage vs Supply Voltage”. Drawing less than 2 $\mu$ A of current, and returning from sleep mode in microseconds, the shutdown feature is useful for portable applications. Once in ‘sleep-mode’ the amplifier has high output impedance, making the INA332 suitable for multiplexing.

## RAIL-TO-RAIL OUTPUT

A class AB output stage with common-source transistors is used to achieve rail-to-rail output for gains of 10 or greater. For resistive loads greater than 10k $\Omega$ , the output voltage can swing to within 25mV of the supply rail while maintaining low gain error. For heavier loads and over temperature, see the typical characteristic “Output Voltage Swing vs Output Current.” The INA332’s low output impedance at high frequencies makes it suitable for directly driving Capacitive-Input A/D converters, as shown in Figure 4.

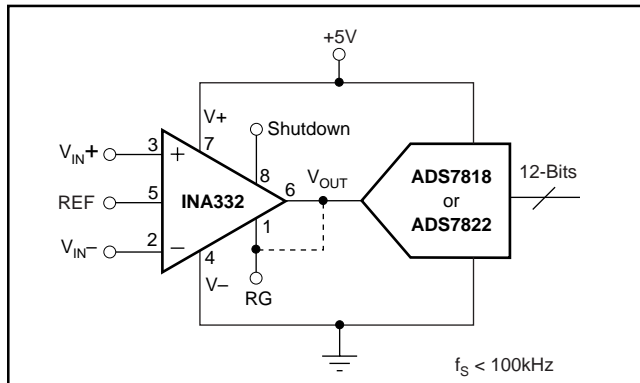


FIGURE 4. INA332 Directly Drives Capacitive-Input, High-Speed A/D Converter.

## OUTPUT BUFFERING

The INA332 is optimized for a load impedance of 10k $\Omega$  or greater. For higher output current the INA332 can be buffered using the OPA340, as shown in Figure 5. The OPA340 can swing within 50mV of the supply rail, driving a 600 $\Omega$  load. The OPA340 is available in the tiny MSOP-8 package.

## OFFSET TRIMMING

The INA332 is laser trimmed for low offset voltage. In the event that external offset adjustment is required, the offset can be adjusted by applying a correction voltage to the reference terminal. Figure 6 shows an optional circuit for trimming offset voltage. The voltage applied to the REF terminal is added to the output signal. The gain from REF to V<sub>OUT</sub> is +1. An op amp buffer is used to provide low impedance at the REF terminal to preserve good common-mode rejection.

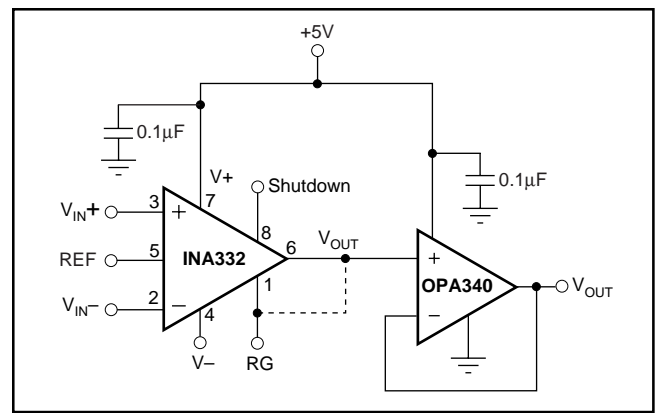


FIGURE 5. Output Buffering Circuit. Able to drive loads as low as 600 $\Omega$ .

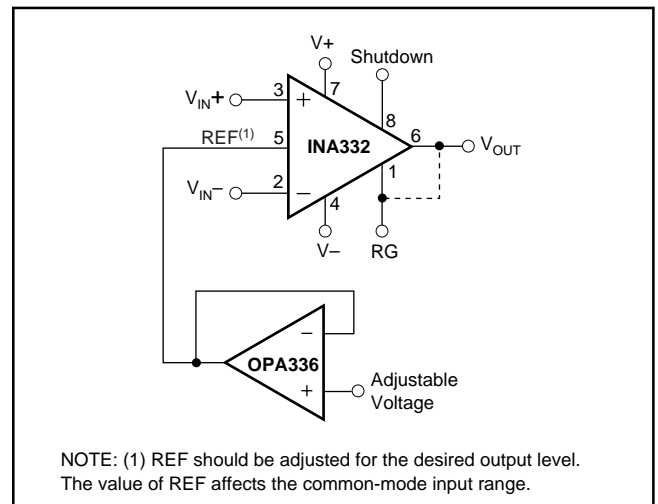


FIGURE 6. Optional Offset Trimming Voltage.

## INPUT PROTECTION

Device inputs are protected by ESD diodes that will conduct if the input voltages exceed the power supplies by more than 500mV. Momentary voltages greater than 500mV beyond the power supply can be tolerated if the current through the input pins is limited to 10mA. This is easily accomplished with input resistor R<sub>LIM</sub>, as shown in Figure 7. Many input signals are inherently current-limited to less than 10mA, therefore, a limiting resistor is not required.

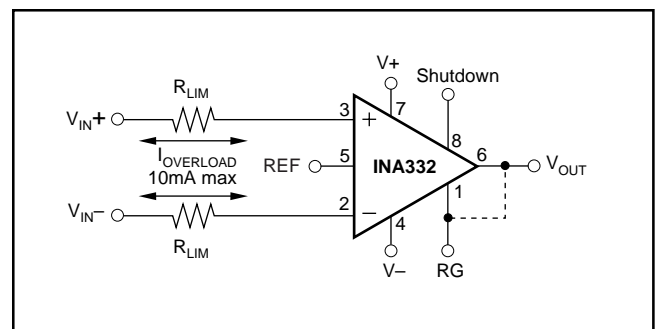


FIGURE 7. Sample Output Buffering Circuit.

## OFFSET VOLTAGE ERROR CALCULATION

The offset voltage ( $V_{OS}$ ) of the INA332AIDGK is specified at a maximum of  $500\mu\text{V}$  with a +5V power supply and the common-mode voltage at  $V_S/2$ . Additional specifications for power-supply rejection and common-mode rejection are provided to allow the user to easily calculate worst-case expected offset under the conditions of a given application.

Power-Supply Rejection Ratio (PSRR) is specified in  $\mu\text{V}/\text{V}$ . For the INA332, worst case PSRR is  $200\mu\text{V}/\text{V}$ , which means for each volt of change in power supply, the offset may shift up to  $200\mu\text{V}$ . Common-Mode Rejection Ratio (CMRR) is specified in dB, which can be converted to  $\mu\text{V}/\text{V}$  using the following equation:

$$\text{CMRR (in } \mu\text{V}/\text{V)} = 10^{[(\text{CMRR in dB})/-20]} \cdot 10^6$$

For the INA332, the worst case CMRR over the specified common-mode range is 60dB (at  $G = 25$ ) or about  $30\mu\text{V}/\text{V}$ . This means that for every volt of change in common-mode, the offset will shift less than  $30\mu\text{V}$ .

These numbers can be used to calculate excursions from the specified offset voltage under different application conditions. For example, an application might configure the amplifier with a 3.3V supply with 1V common-mode. This configuration varies from the specified configuration, representing a 1.7V variation in power supply (5V in the offset specification versus 3.3V in the application) and a 0.65V variation in common-mode voltage from the specified  $V_S/2$ .

Calculation of the worst-case expected offset would be as follows:

$$\begin{aligned} \text{Adjusted } V_{OS} = & \text{Maximum specified } V_{OS} + \\ & (\text{power-supply variation}) \cdot \text{PSRR} + \\ & (\text{common-mode variation}) \cdot \text{CMRR} \end{aligned}$$

$$\begin{aligned} V_{OS} = & 0.5\text{mV} + (1.7\text{V} \cdot 200\mu\text{V}) + (0.65\text{V} \cdot 30\mu\text{V}) \\ = & \pm 0.860\text{mV} \end{aligned}$$

However, the typical value will be smaller, as seen in the Typical Characteristics.

## FEEDBACK CAPACITOR IMPROVES RESPONSE

For optimum settling time and stability with high-impedance feedback networks, it may be necessary to add a feedback capacitor across the feedback resistor,  $R_F$ , as shown in Figure 8. This capacitor compensates for the zero created by the feedback network impedance and the INA332's RG-pin input capacitance (and any parasitic layout capacitance). The effect becomes more significant with higher impedance networks. Also,  $R_X$  and  $C_L$  can be added to reduce high-frequency noise.

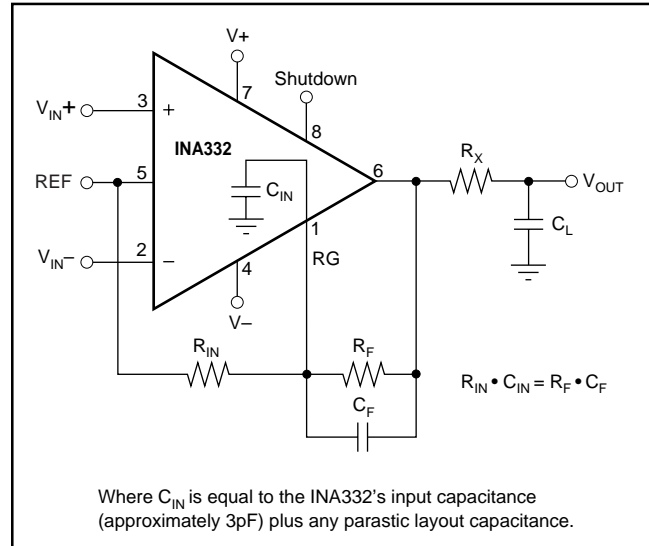


FIGURE 8. Feedback Capacitor Improves Dynamic Performance.

It is suggested that a variable capacitor be used for the feedback capacitor since input capacitance may vary between instrumentation amplifiers, and layout capacitance is difficult to determine. For the circuit shown in Figure 8, the value of the variable feedback capacitor should be chosen by the following equation:

$$R_{IN} \cdot C_{IN} = R_F \cdot C_F$$

Where  $C_{IN}$  is equal to the INA332's RG-pin input capacitance (typically 3pF) plus the layout capacitance. The capacitor can be varied until optimum performance is obtained.

# APPLICATION CIRCUITS

## MEDICAL ECG APPLICATIONS

Figure 9 shows the INA332 configured to serve as a low-cost ECG amplifier, suitable for moderate accuracy heart-rate applications such as fitness equipment. The input signals are obtained from the left and right arms of the patient. The common-mode voltage is set by two  $2M\Omega$  resistors. This potential through a buffer provides optional right leg drive.

Filtering can be modified to suit application needs by changing the capacitor value of the output filter.

## LOW-POWER, SINGLE-SUPPLY DATA ACQUISITION SYSTEMS

Refer to Figure 4 to see the INA332 configured to drive an ADS7818. Functioning at frequencies of up to 500kHz, the INA332 is ideal for low-power data acquisition.

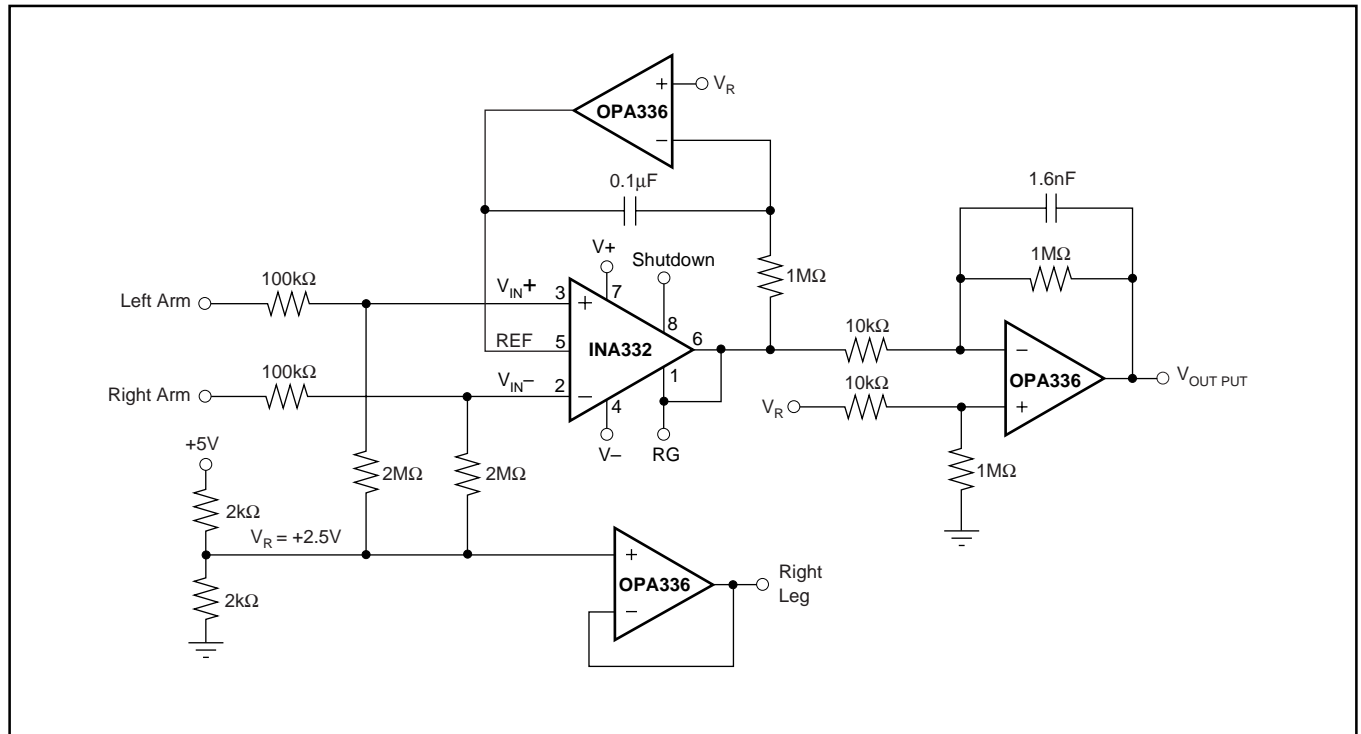
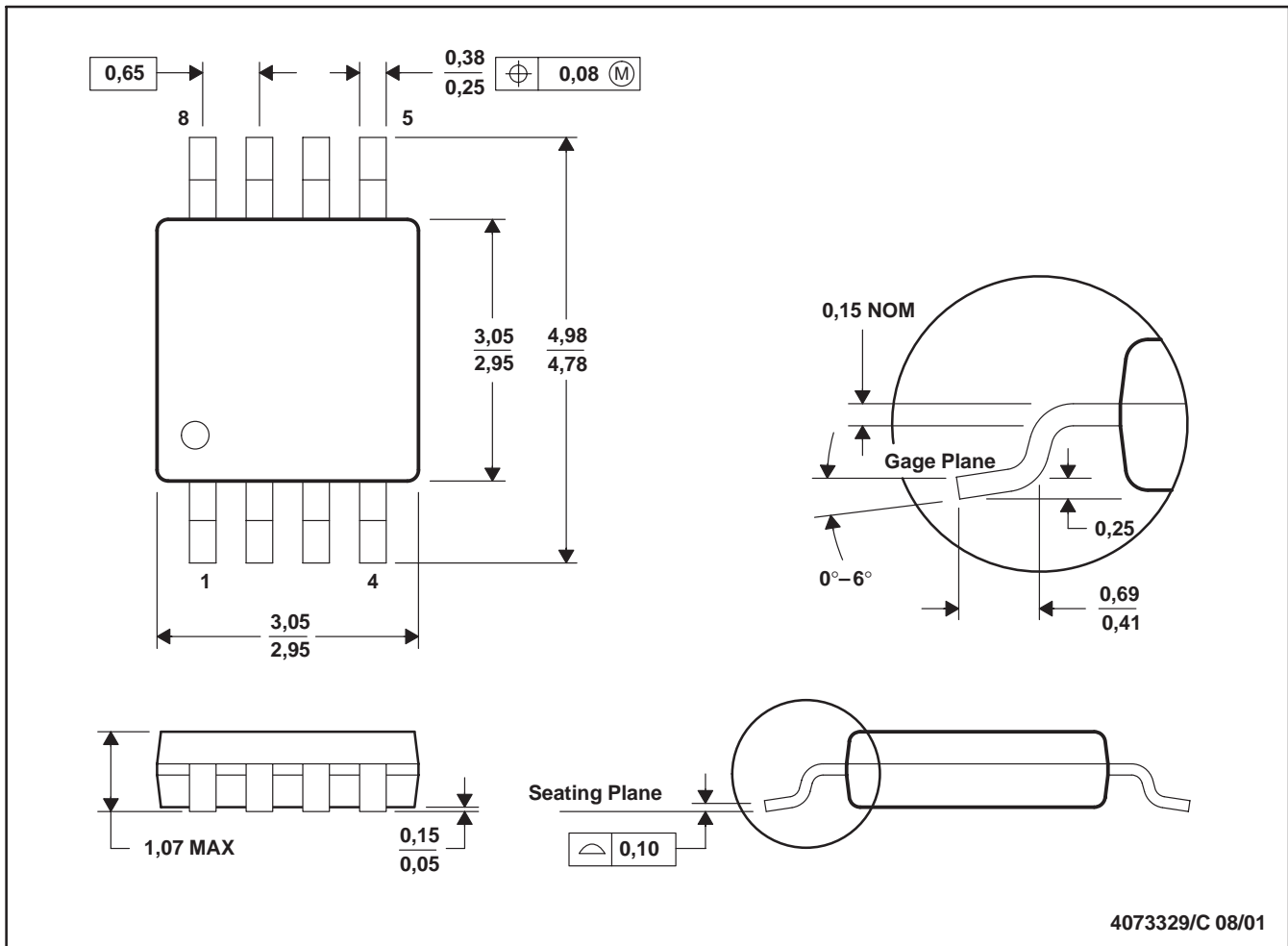


FIGURE 9. Simplified ECG Circuit for Medical Applications.

DGK (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE

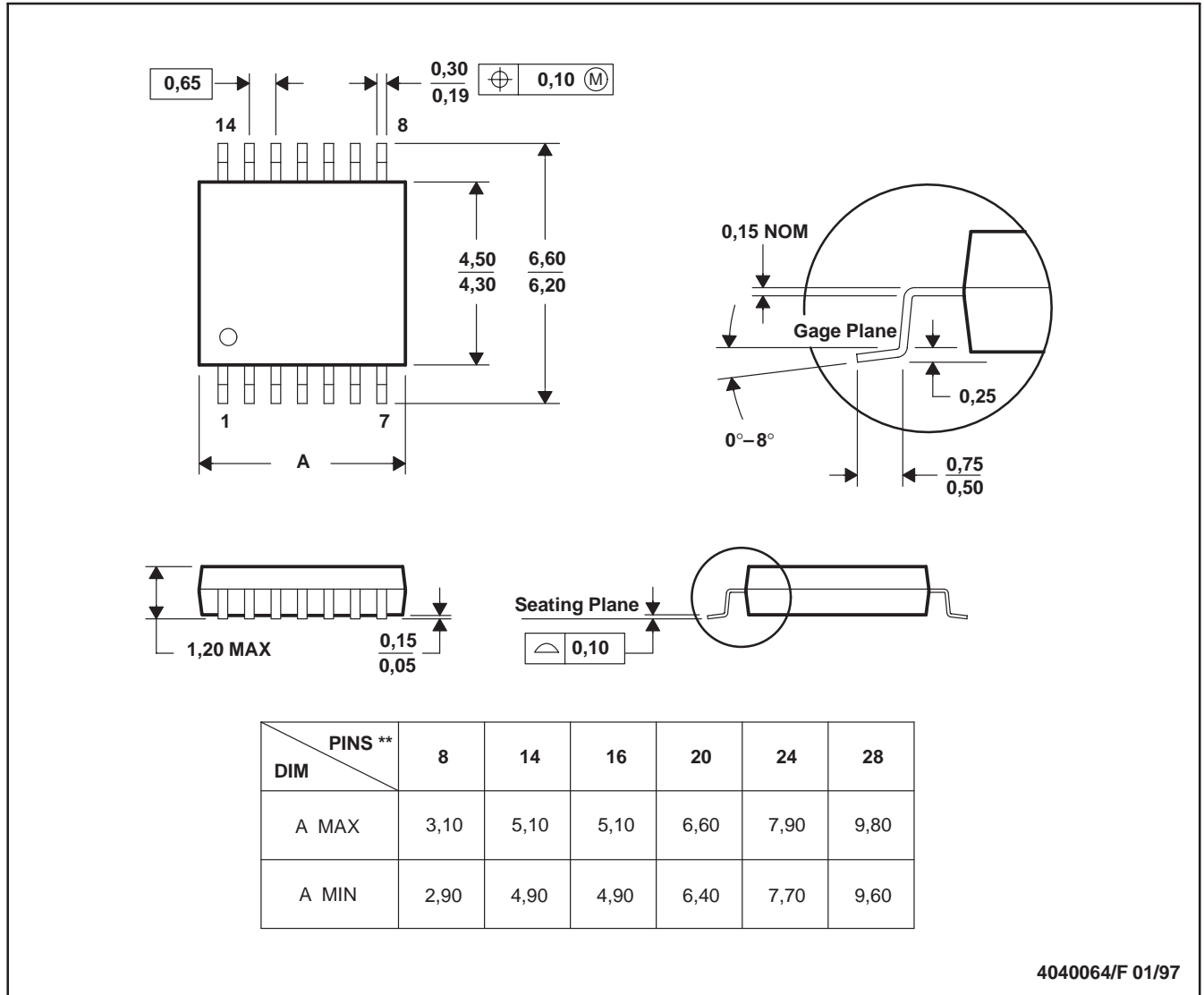


- NOTES: A. All linear dimensions are in millimeters.  
 B. This drawing is subject to change without notice.  
 C. Body dimensions do not include mold flash or protrusion.  
 D. Falls within JEDEC MO-187

PW (R-PDSO-G\*\*)

PLASTIC SMALL-OUTLINE PACKAGE

14 PINS SHOWN



- NOTES: A. All linear dimensions are in millimeters.  
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 C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.  
 D. Falls within JEDEC MO-153

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