



## microPower, Single-Supply, CMOS INSTRUMENTATION AMPLIFIER

### FEATURES

- **LOW QUIESCENT CURRENT:** 40 $\mu$ A/channel  
Shut Down: < 1 $\mu$ A
- **HIGH GAIN ACCURACY:** G = 5, 0.02%, 2ppm/ $^{\circ}$ C
- **GAIN SET WITH EXTERNAL RESISTORS**
- **LOW OFFSET VOLTAGE:**  $\pm$ 200 $\mu$ V
- **HIGH CMRR:** 94dB
- **LOW BIAS CURRENT:** 10pA
- **BANDWIDTH:** 500kHz, G = 5V/V
- **RAIL-TO-RAIL OUTPUT SWING:** (V+) – 0.02V
- **WIDE TEMPERATURE RANGE:**  
–55 $^{\circ}$ C to +125 $^{\circ}$ C
- **SINGLE VERSION IN MSOP-8 PACKAGE AND  
DUAL VERSION IN TSSOP-14 PACKAGE**

### APPLICATIONS

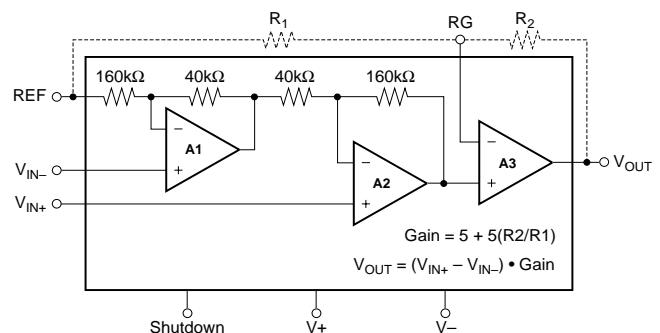
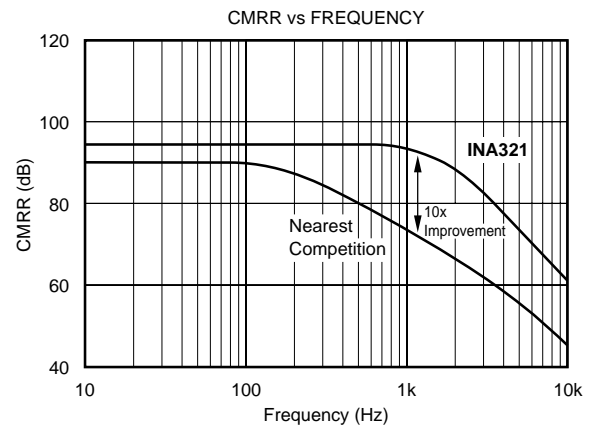
- **INDUSTRIAL SENSOR AMPLIFIERS:**  
Bridge, RTD, Thermistor, Position
- **PHYSIOLOGICAL AMPLIFIERS:**  
ECG, EEG, EMG
- **A/D CONVERTER SIGNAL CONDITIONING**
- **DIFFERENTIAL LINE RECEIVERS WITH GAIN**
- **FIELD UTILITY METERS**
- **PCMCIA CARDS**
- **COMMUNICATION SYSTEMS**
- **TEST EQUIPMENT**
-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

### DESCRIPTION

The INA321 family is a series of rail-to-rail output, micropower CMOS instrumentation amplifiers that offer wide-range, single-supply, as well as bipolar-supply operation. The INA321 family provides low-cost, low-noise amplification of differential signals with micropower current consumption of 40 $\mu$ A. When shutdown the INA321 has a quiescent current of less than 1 $\mu$ A. Returning to normal operations within nanoseconds, the shutdown feature makes the INA321 optimal for low-power battery or multiplexing applications.

Configured internally for 5V/V gain, the INA321 offers exceptional flexibility with user-programmable external gain resistors. The INA321 reduces common-mode error over frequency and with CMRR remaining high up to 3kHz, line noise and line harmonics are rejected.

The low-power design does not compromise on bandwidth or slew rate, making the INA321 ideal for driving sampling Analog-to-Digital (A/D) converters as well as general-purpose applications. With high precision, low cost, and small packaging, the INA321 outperforms discrete designs, while offering reliability and performance.



# SPECIFICATIONS: $V_S = +2.7V$ TO $+5.5V$

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

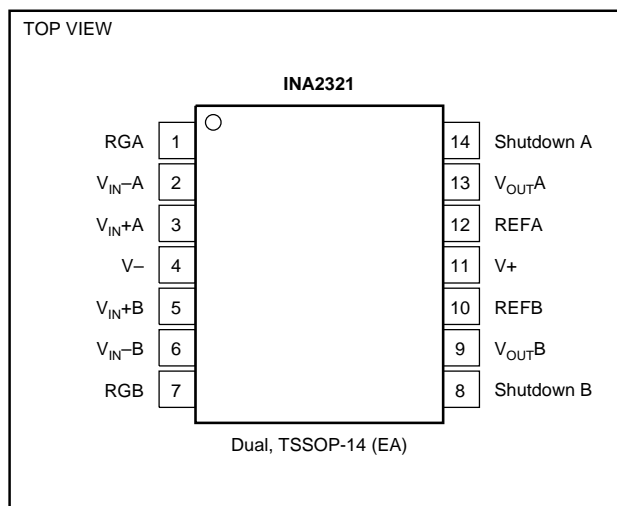
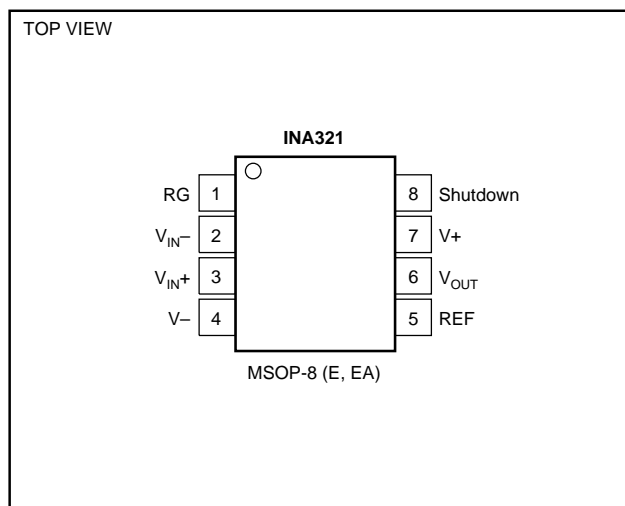
At  $T_A = +25^{\circ}C$ ,  $R_L = 25k\Omega$ ,  $G = 25$ , and  $I_A$  common =  $V_S/2$ , unless otherwise noted.

PARAMETER	CONDITION	INA321E			INA321EA INA2321EA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
<b>INPUT</b>								
Input Offset Voltage, RTI	$V_S = +5V$		$\pm 0.2$	$\pm 0.5$		*	1	mV
<b>Over Temperature</b>				<b><math>\pm 2.2</math></b>		*	<b>2.5</b>	mV
<b>vs Temperature</b>			$\pm 7$			*		$\mu V/^{\circ}C$
<b>vs Power Supply</b>	$V_S = +2.7V$ to $+5.5V$		$\pm 50$	$\pm 200$		*	*	$\mu V/V$
<b>Over Temperature</b>				<b><math>\pm 220</math></b>		*	*	$\mu V/V$
Long-Term Stability			$\pm 0.4$			*		$\mu V/month$
Input Impedance			$10^{13} \parallel 3$			*		$\Omega \parallel pF$
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 $3.8V$	90	94		80	*		dB
<b>Over Temperature</b>	<b><math>V_S = 5V, V_{CM} = 0.55V</math> to <math>3.8V</math></b>	<b>77</b>			<b>75</b>			dB
	$V_S = 2.7V, V_{CM} = 0.35V$ to $1.5V$		94			*		dB
Crosstalk, Dual			110			*		dB
<b>INPUT BIAS CURRENT</b>								
Bias Current			$\pm 0.5$	$\pm 10$		*	*	pA
Offset Current			$\pm 0.5$	$\pm 10$		*	*	pA
<b>NOISE, RTI</b>								
Voltage Noise: $f = 10Hz$	$R_S = 0\Omega$		500			*		$nV/\sqrt{Hz}$
$f = 100Hz$			190			*		$nV/\sqrt{Hz}$
$f = 1kHz$			100			*		$nV/\sqrt{Hz}$
$f = 0.1Hz$ to $10Hz$			20			*		$\mu Vp-p$
Current Noise: $f = 1kHz$			3			*		$fA/\sqrt{Hz}$
<b>GAIN<sup>(1)</sup></b>								
Gain Equation, Externally Set	$G > 5$		$G = 5 + 5(R2/R1)$			*	*	V/V
Range of Gain		5		1000		*	*	%
Gain Error			$\pm 0.02$	$\pm 0.1$		*	*	ppm/ $^{\circ}C$
<b>vs Temperature</b>	<b><math>G = 5</math></b>		<b><math>\pm 0.02</math></b>	<b><math>\pm 0.1</math></b>		*	*	% of FS
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>		*	*	% of FS
<b>OUTPUT</b>								
Output Voltage Swing from Rail <sup>(2, 5)</sup>	$G \geq 10$	50	25		*	*		mV
<b>Over Temperature</b>		<b>50</b>			*	*		mV
Capacitance Load Drive		See Typical Curve <sup>(3)</sup>				*		pF
Short-Circuit Current			8			*		mA
			16			*		mA
<b>FREQUENCY RESPONSE</b>								
Bandwidth, -3dB	$G = 5$		500			*		kHz
Slew Rate	$V_S = 5V, G = 25$		0.4			*		V/ $\mu s$
Settling Time, 0.1%	$G = 5, C_L = 50pF, V_O = 2V$ step		8			*		$\mu s$
0.01%			12			*		$\mu s$
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	$V_{SD} > 2.5^{(4)}$		40	60		*	*	$\mu A$
<b>Over Temperature</b>				<b>70</b>	*		*	$\mu A$
Shutdown Quiescent Current/Chan	$V_{SD} < 0.8^{(4)}$		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			*		$^{\circ}C/W$

\*Specifications same as INA321E

NOTES: (1) Does not include errors from external gain setting resistors (2) Output voltage swings are measured between the output and power-supply rails. (3) See typical performance curve "Percent Overshoot vs Load Capacitance." (4) See typical performance curve "Shutdown Voltage vs Supply Voltage." (5) Output does not swing to positive rail if gain is less than 10.

## PIN CONFIGURATION



## 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	-65°C to +150°C
Storage Temperature	-65°C to +150°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C

NOTE: (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied. (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. 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.

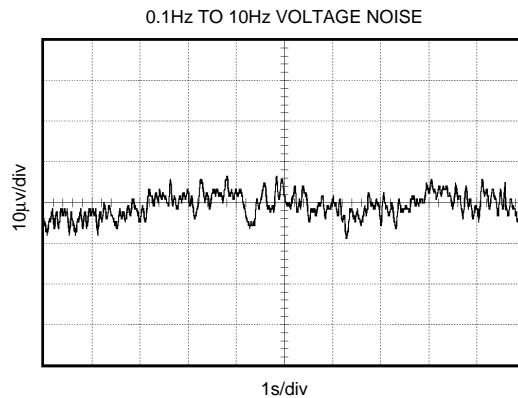
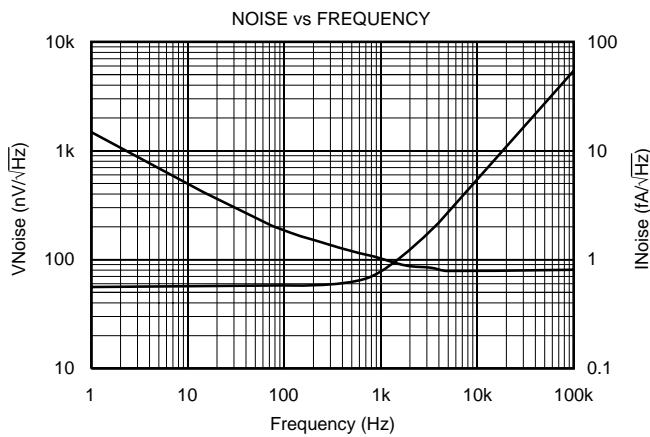
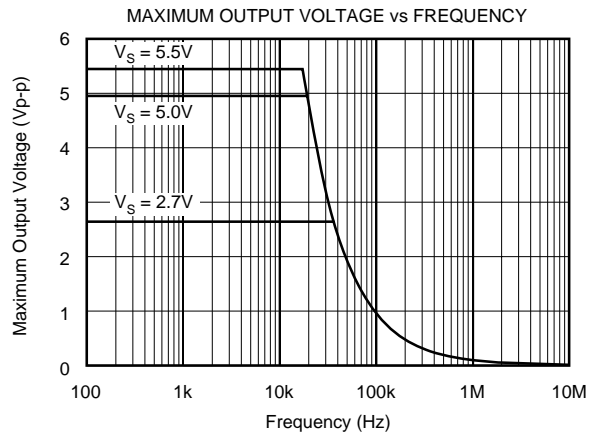
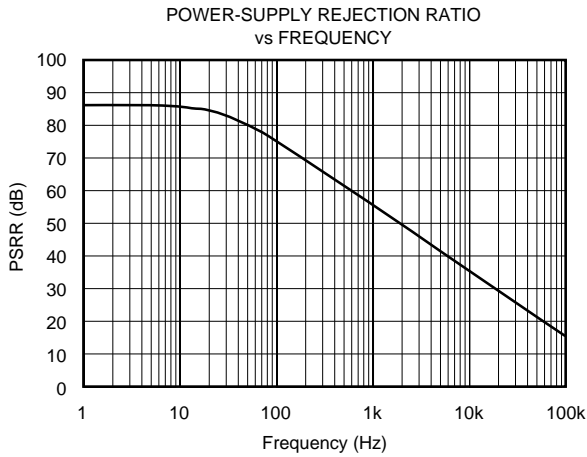
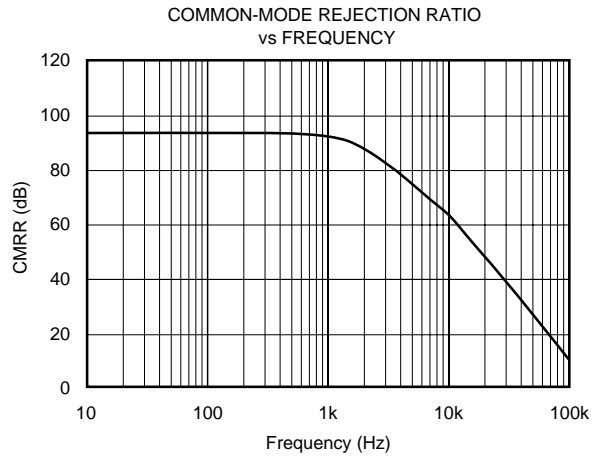
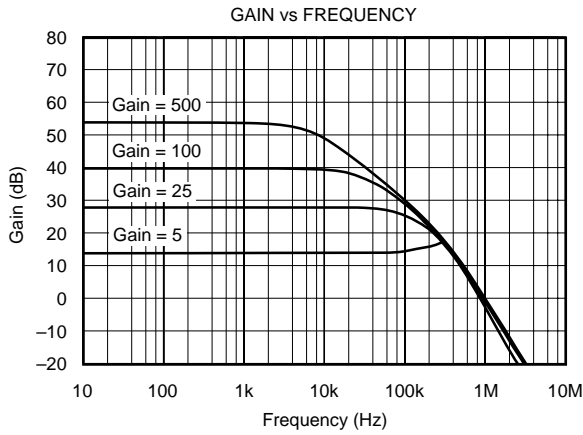
## PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER <sup>(1)</sup>	TRANSPORT MEDIA
<b>SINGLE</b>						
INA321E	MSOP-8	337	-55°C to +125°C	C21	INA321E/250	Tape and Reel
"	"	"	"	"	INA321E/2K5	Tape and Reel
INA321EA	MSOP-8	337	-55°C to +125°C	C21	INA321EA/250	Tape and Reel
"	"	"	"	"	INA321EA/2K5	Tape and Reel
<b>DUAL</b>						
INA2321EA	TSSOP-14	357	-55°C to +125°C	INA2321EA	INA2321EA/250	Tape and Reel
"	"	"	"	"	INA2321EA/2K5	Tape and Reel

NOTES: (1) Models with a slash (/) are available only in Tape and Reel in the quantities indicated (e.g., /2K5 indicates 2500 devices per reel). Ordering 2500 pieces of "INA321E/2K5" will get a single 2500-piece Tape and Reel.

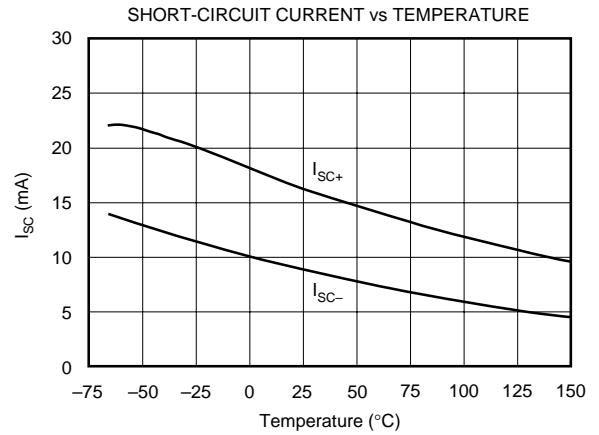
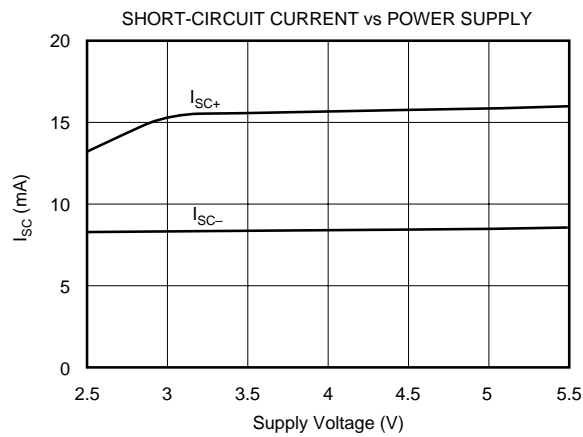
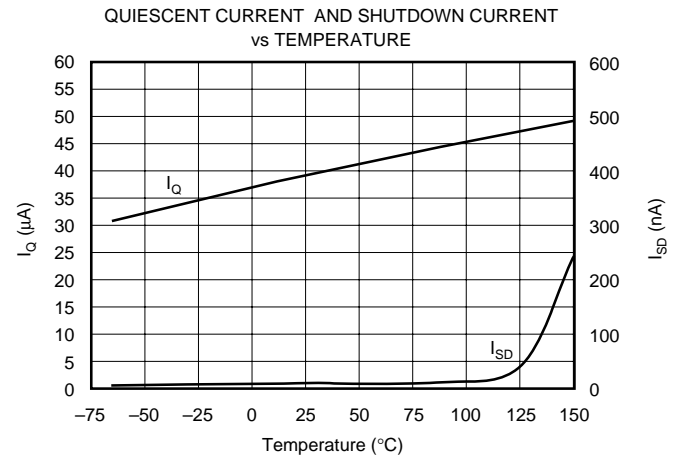
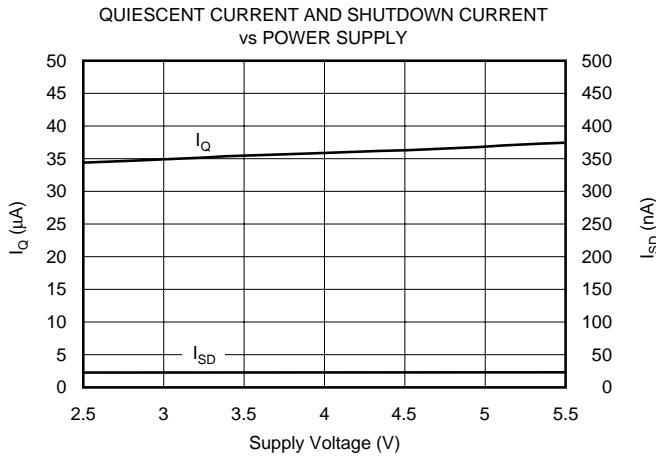
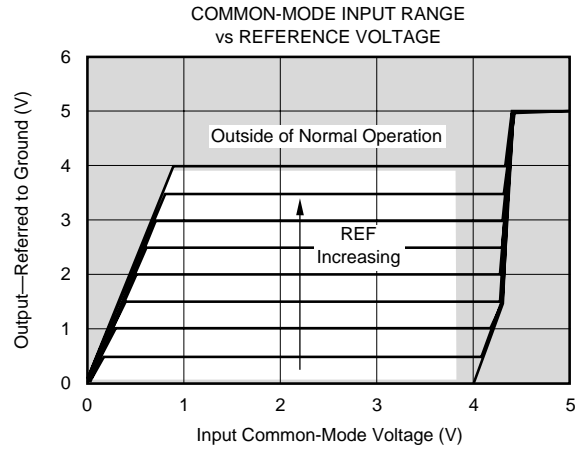
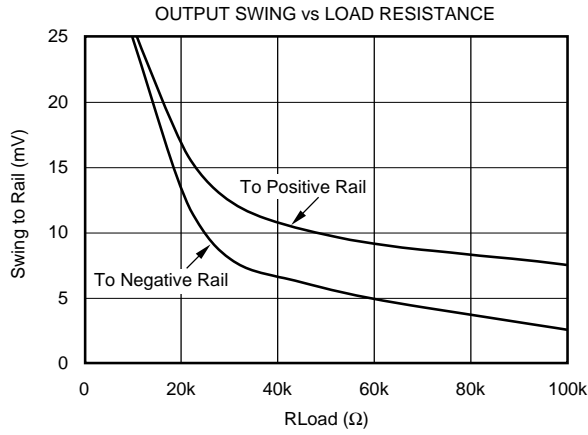
# TYPICAL PERFORMANCE CURVES

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = 1/2V_S$ ,  $R_L = 25\text{k}\Omega$ ,  $C_L = 50\text{pF}$ , unless otherwise noted.



# TYPICAL PERFORMANCE CURVES (Cont.)

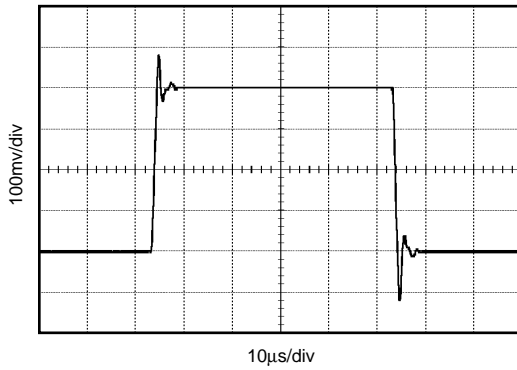
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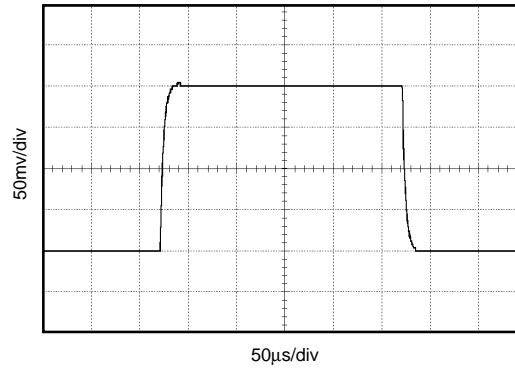
# TYPICAL PERFORMANCE CURVES (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = 1/2V_S$ ,  $R_L = 25\text{k}\Omega$ ,  $C_L = 50\text{pF}$ , unless otherwise noted.

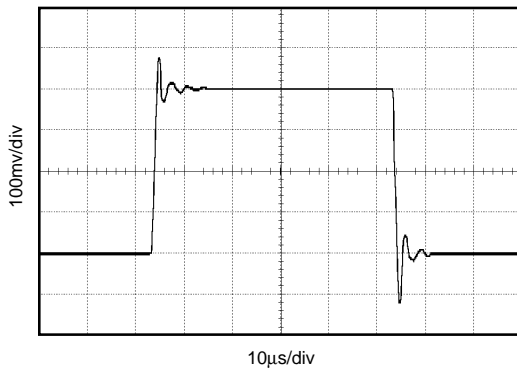
SMALL-SIGNAL STEP RESPONSE ( $G = 5$ )



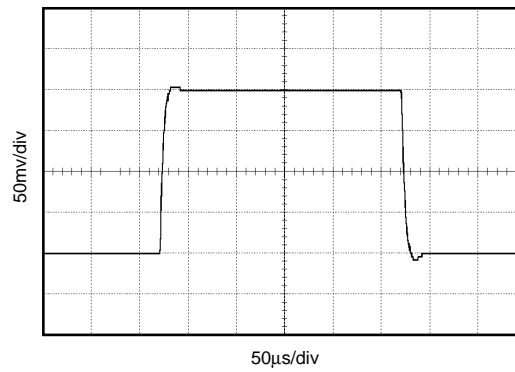
SMALL-SIGNAL STEP RESPONSE ( $G = 100$ )



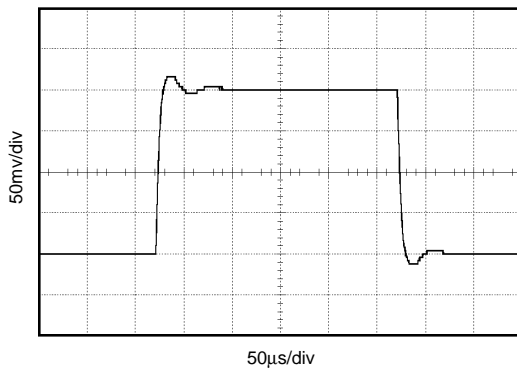
SMALL-SIGNAL STEP RESPONSE  
( $G = 5$ ,  $C_L = 1000\text{pF}$ )



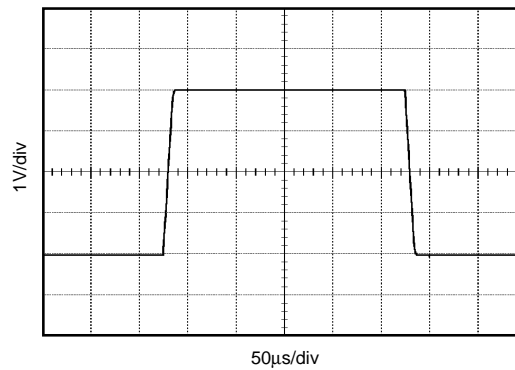
SMALL-SIGNAL STEP RESPONSE  
( $G = 100$ ,  $C_L = 1000\text{pF}$ )



SMALL-SIGNAL STEP RESPONSE  
( $G = 100$ ,  $C_L = 5000\text{pF}$ )

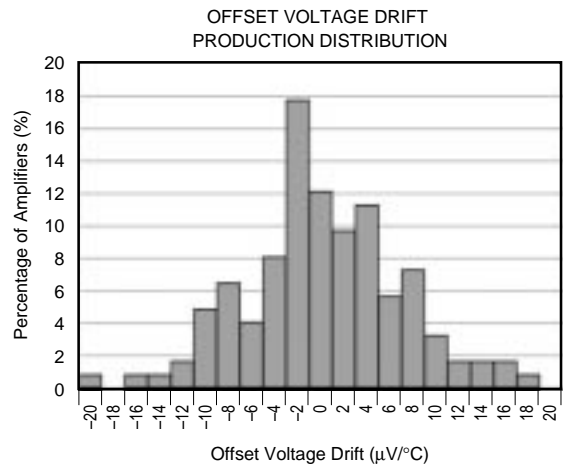
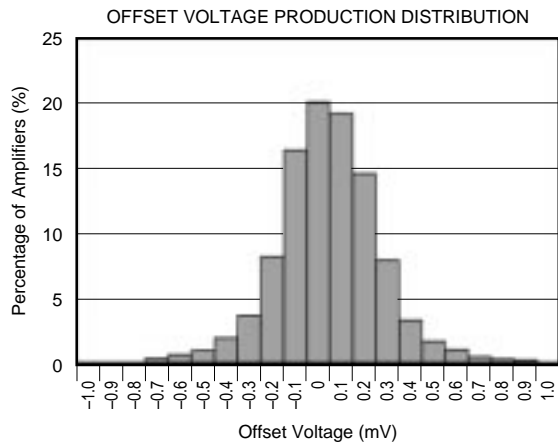
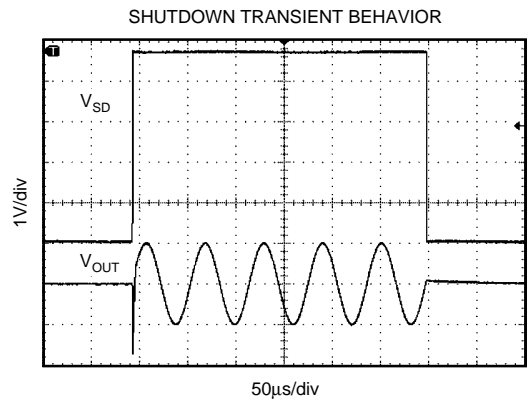
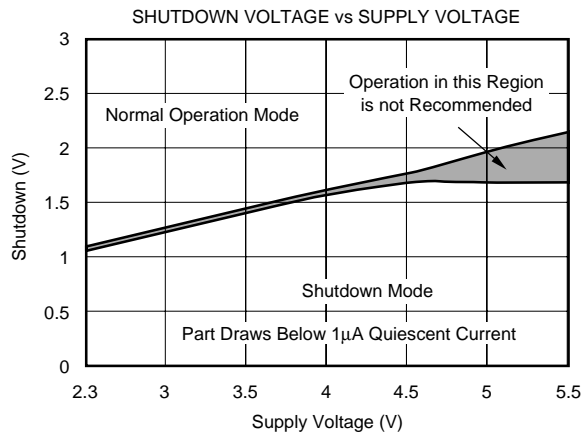
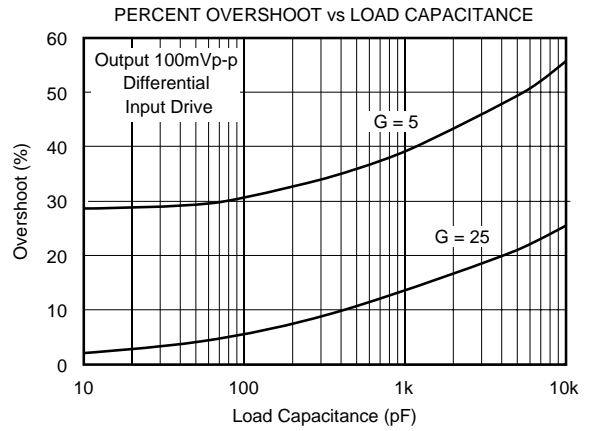
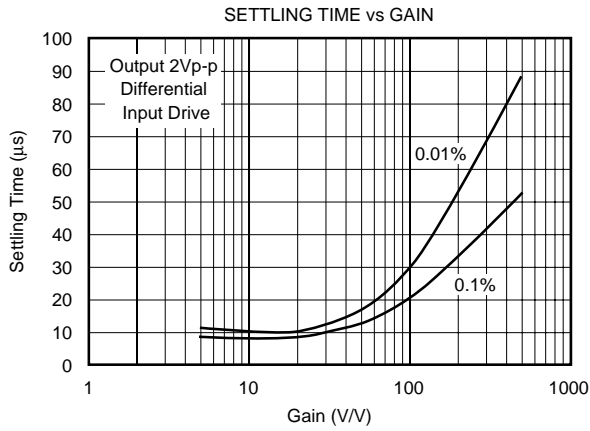


LARGE-SIGNAL STEP RESPONSE  
( $G = 25$ ,  $C_L = 50\text{pF}$ )



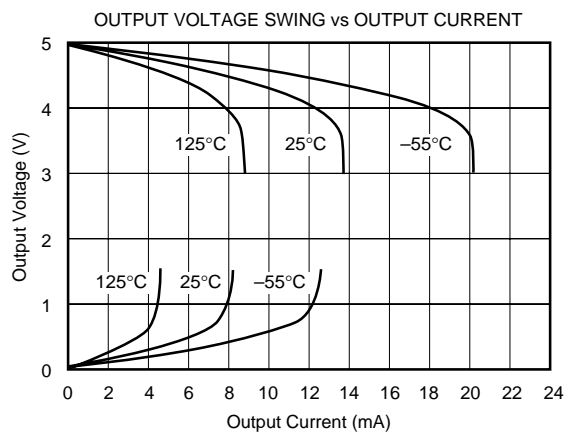
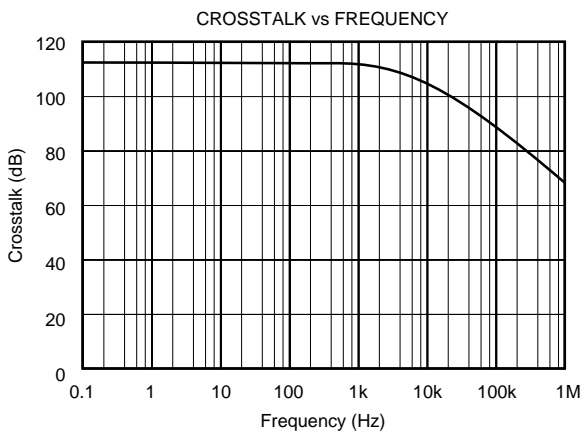
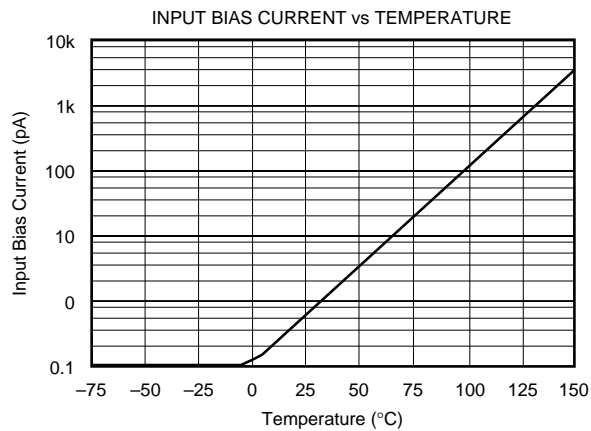
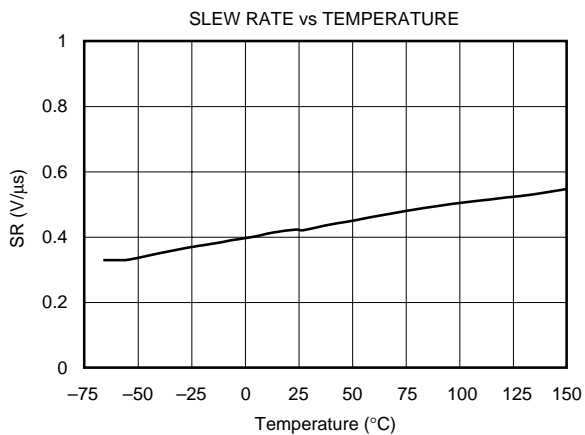
# TYPICAL PERFORMANCE CURVES (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = 1/2 V_S$ ,  $R_L = 25\text{k}\Omega$ ,  $C_L = 50\text{pF}$ , unless otherwise noted.



# TYPICAL PERFORMANCE CURVES (Cont.)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ ,  $V_{CM} = 1/2V_S$ ,  $R_L = 25\text{k}\Omega$ ,  $C_L = 50\text{pF}$ , unless otherwise noted.





# APPLICATIONS INFORMATION

The INA321 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 INA321 and INA2321. The power supply should be capacitively decoupled with 0.1µF capacitors as close to the INA321 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 INA321 family is fully specified and guaranteed over a supply range of +2.7V to +5.5V, with key parameters guaranteed 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 Performance Curves.

The INA321 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.

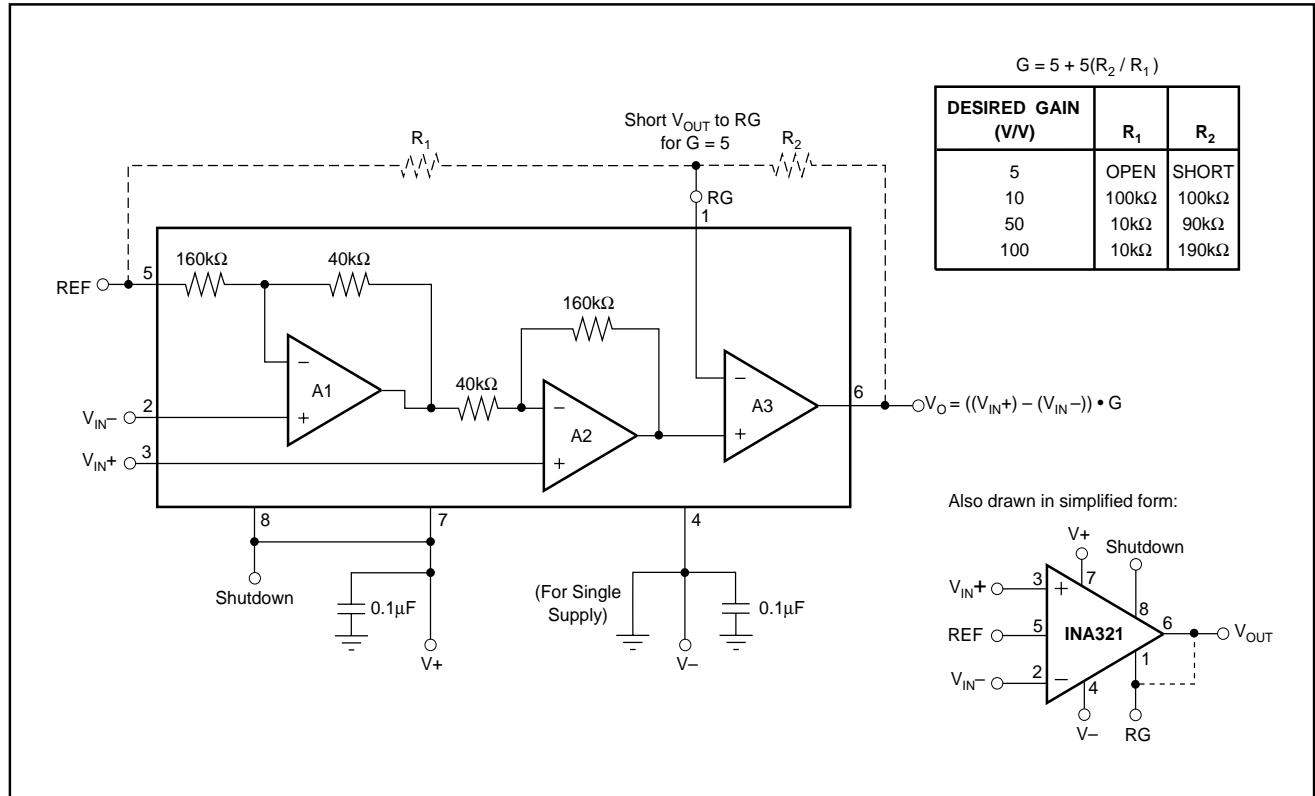


FIGURE 1. Basic Connections.

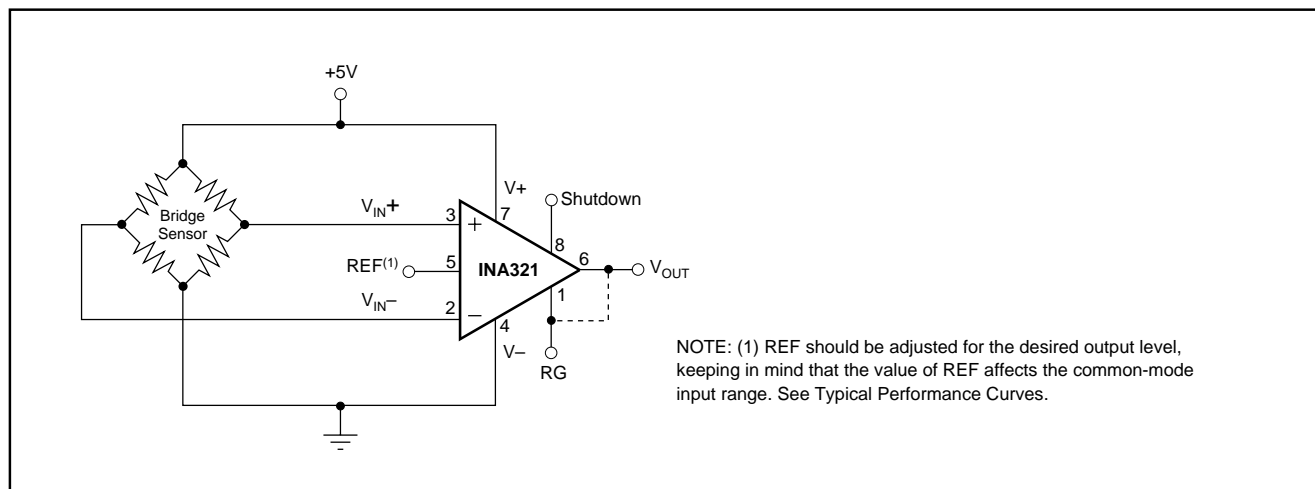


FIGURE 2. Bridge Amplifier of the INA321.

## 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 INA321. With an internally set gain of 5, the INA321 can be programmed for gains greater than 5 according to the following equation:

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

The INA321 is designed to provide accurate gain, with gain error guaranteed to be less than 0.1%. Setting gain with matching TC resistors will minimize gain drift. Errors from external resistors will add directly to the guaranteed error, and may become dominant error sources.

## INPUT COMMON-MODE 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 Performance Curves for Input Common-Mode 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 guaranteed operation,  $V_{OA2}$  should be less than  $V_{DD} - 1.2V$ .

The reference pin requires a low-impedance connection. As little as  $160\Omega$  in series with the reference pin will degrade the CMRR to 80dB. 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 INA321 is ideal for use with high-impedance sources. The input bias current of less than 10pA makes the INA321 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.

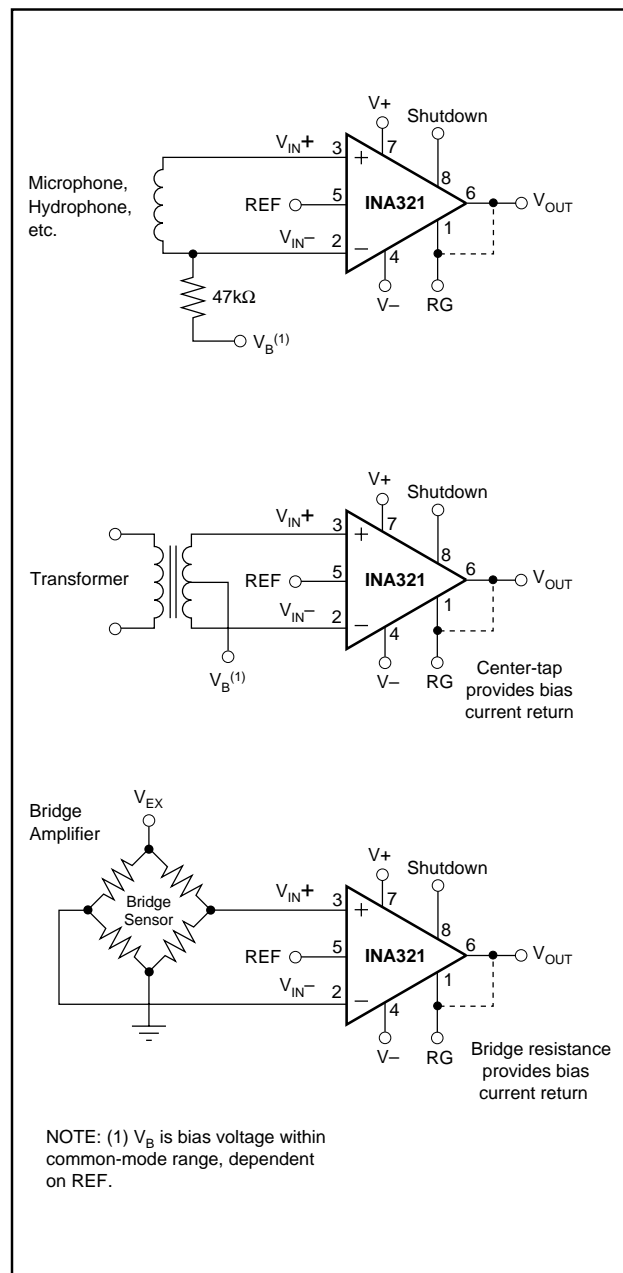


FIGURE 3. Providing an Input Common-Mode Path.

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.

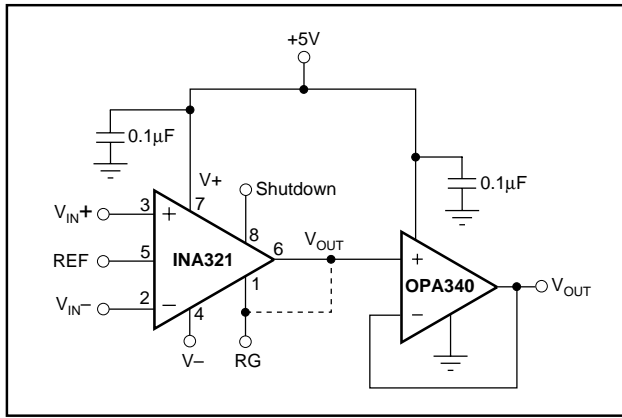


FIGURE 4. Output Buffering Circuit. Able to drive loads as low as 600Ω.

### SHUTDOWN MODE

The shutdown pin of the INA321 is nominally connected to V+. When the pin is pulled below 0.8V on a 5V supply, the INA321 goes into sleep mode within nanoseconds. For actual shutdown threshold, see typical performance curve “Shutdown Voltage vs Supply Voltage”. Drawing less than 1µA 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 INA321 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 25kΩ, the output voltage can swing to within a few millivolts of the supply rail while maintaining low gain error. For heavier loads and over temperature, see the typical performance curve “Output Voltage Swing vs Output Current.” The INA321’s low output impedance at high frequencies makes it suitable for directly driving Capacitive Digital-to-Analog (CDAC) input A/D converters, as shown in Figure 5.

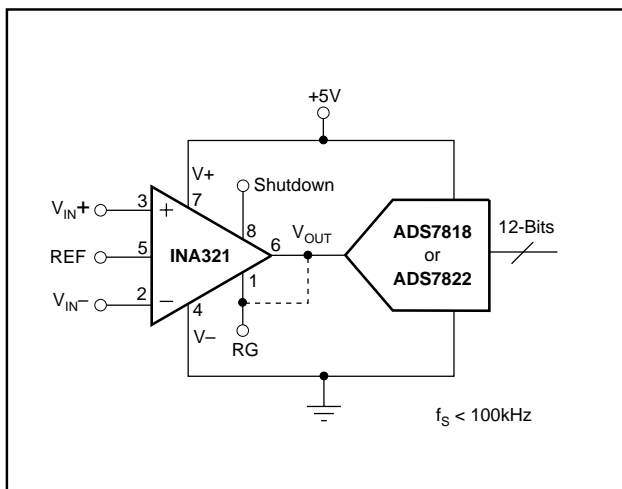


FIGURE 5. INA321 Directly Drives a Capacitive-Input, A/D Converter.

### OUTPUT BUFFERING

The INA321 is optimized for a load impedance of 10kΩ or greater. For higher output current the INA321 can be buffered using the OPA340, as shown in Figure 4. The OPA340 can swing within 50mV of the supply rail, driving a 600Ω load. The OPA340 is available in the tiny MSOP-8 package.

### OFFSET TRIMMING

The INA321 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\_OUT is +1. An op-amp buffer is used to provide low impedance at the REF terminal to preserve good common-mode rejection.

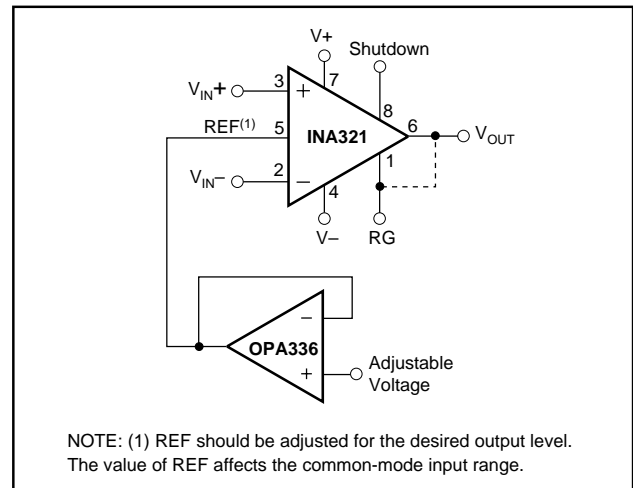


FIGURE 6. Optional Offset Trimming Voltage.

### 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\_LIM, as shown in Figure 7. Many input signals are inherently current-limited to less than 10mA, therefore, a limiting resistor is not required.

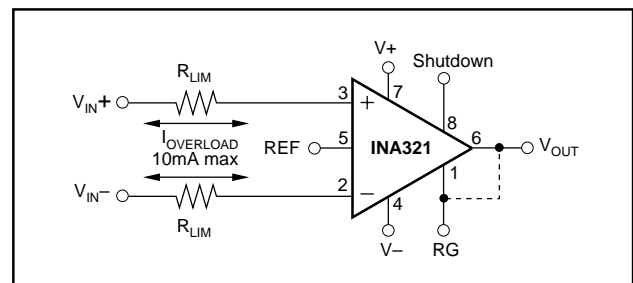


FIGURE 7. Input Protection.

## OFFSET VOLTAGE ERROR CALCULATION

The offset voltage ( $V_{OS}$ ) of the INA321E is specified at a maximum of  $500\mu\text{V}$  with a  $+5\text{V}$  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 INA321, 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:

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

For the INA321, the worst case CMRR over the specified common-mode range is 90dB (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 Performance Curves.

## 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 INA321's  $R_G$ -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.

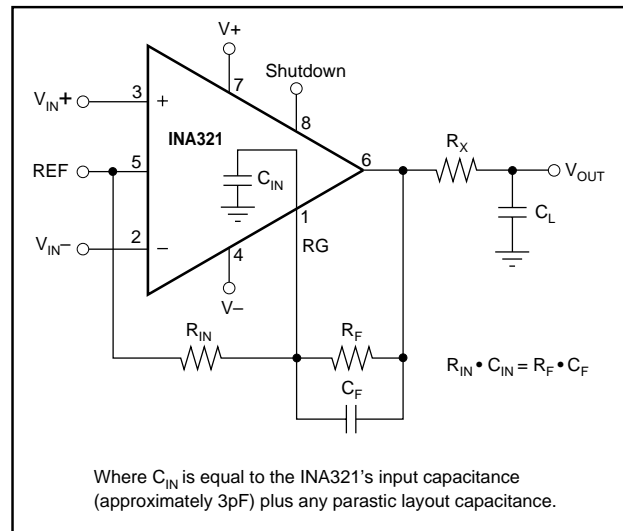


FIGURE 8. Feedback Capacitor Improves Dynamic Performance.

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 INA321's  $R_G$ -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 INA321 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  $2\text{M}\Omega$  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 5 to see the INA321 configured to drive an ADS7818. Functioning at frequencies of up to  $500\text{kHz}$ , the INA321 is ideal for low-power data acquisition.

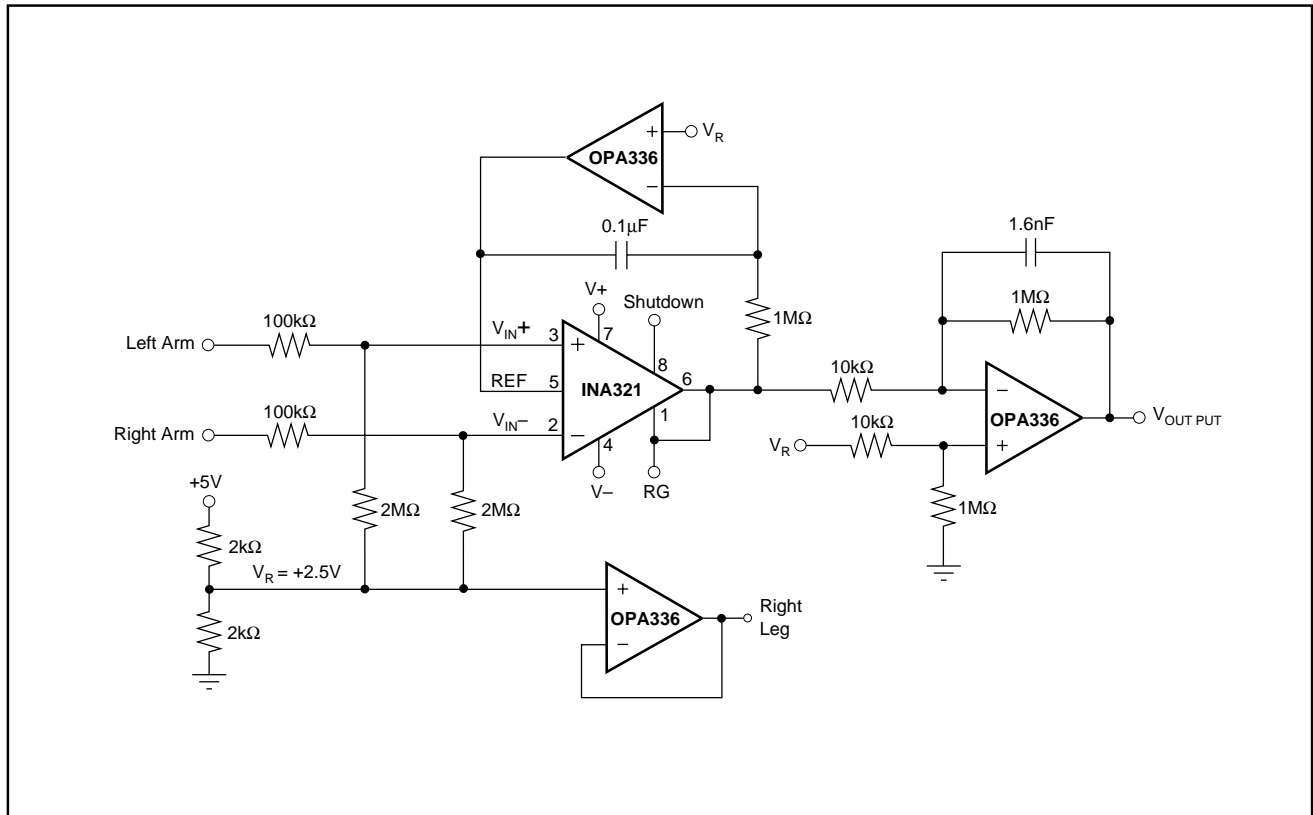


FIGURE 9. Simplified ECG Circuit for Medical Applications.

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**PACKAGING INFORMATION**

ORDERABLE DEVICE	STATUS(1)	PACKAGE TYPE	PACKAGE DRAWING	PINS	PACKAGE QTY
INA2321EA/250	ACTIVE	TSSOP	PW	14	250
INA2321EA/2K5	ACTIVE	TSSOP	PW	14	2500
INA321E/250	ACTIVE	VSSOP	DGK	8	250
INA321E/2K5	ACTIVE	VSSOP	DGK	8	2500
INA321EA/250	ACTIVE	VSSOP	DGK	8	250
INA321EA/2K5	ACTIVE	VSSOP	DGK	8	2500

(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.

**OBSELETE:** TI has discontinued the production of the device.

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