CURRENT SHUNT MONITORS
–16-V to +80-V Common-Mode Range

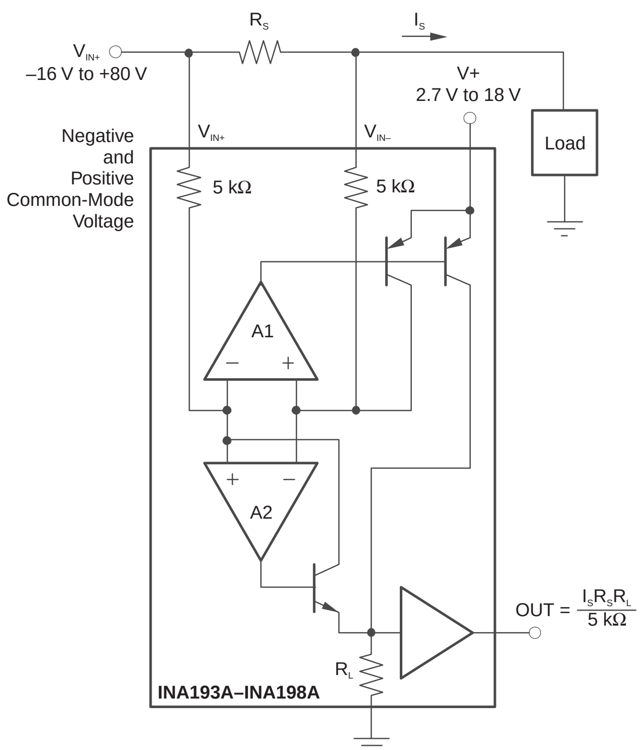
FEATURES

- **Qualified for Automotive Applications**
- **Customer-Specific Configuration Control Can Be Supported Along With Major-Change Approval**
- **Wide Common-Mode Voltage: –16 V to +80 V**
- **Low Error: 3.0% Over Temperature (Max)**
- **Bandwidth: Up to 500 kHz**
- **Three Transfer Functions Available: 20 V/V, 50 V/V, and 100 V/V**
- **Complete Current-Sense Solution**

DESCRIPTION

The INA193A–INA198A family of current shunt monitors with voltage output can sense drops across shunts at common-mode voltages from –16 V to +80 V, independent of the INA19xA supply voltage. They are available with three output voltage scales: 20 V/V, 50 V/V, and 100 V/V. The 500-kHz bandwidth simplifies use in current control loops. The INA193A–INA195A provide identical functions but alternative pin configurations to the INA196A–INA198A, respectively.

The INA193A–INA198A operate from a single 2.7-V to 18-V supply. They are specified over the extended operating temperature range (–40°C to 125°C), and are offered in a space-saving SOT-23 package.



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.

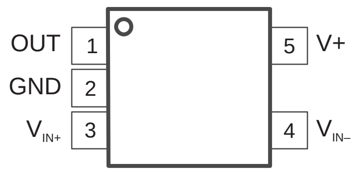
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION(1)

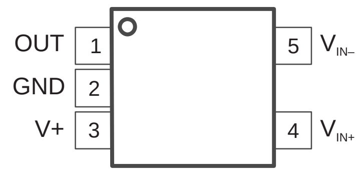
T_A	PACKAGE(2)		ORDERABLE PART NUMBER	TOP-SIDE MARKING
–40°C to 125°C	SOT-23 – DBV	Reel of 3000	INA193AQDBVRQ1	BOG
			INA194AQDBVRQ1	BOH
			INA195AQDBVRQ1	BOI
			INA196AQDBVRQ1	BOJ
			INA197AQDBVRQ1	BOK
			INA198AQDBVRQ1	BOL

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the website at www.ti.com.
(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

INA193A
INA194A
INA195A
DBV PACKAGE
(TOP VIEW)



INA196A
INA197A
INA198A
DBV PACKAGE
(TOP VIEW)



ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Supply voltage			18	V
Differential input voltage range, analog inputs ($V_{IN+} – V_{IN–}$)		–18	18	V
Common-mode voltage range(2)		–16	80	V
Analog output voltage range(2)	OUT	GND – 0.3	(V+) + 0.3	V
Input current into any pin(2)			5	mA
Storage temperature range		–65	150	°C
Junction temperature			150	°C
ESD qualification ratings	Human-Body Model		4000	V
	Machine Model		200	
	Charged-Device Model		1000	

(1) Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 5 mA.

ELECTRICAL CHARACTERISTICS

V_S = 12 V, V_{IN+} = 12 V, V_{SENSE} = 100 mV (unless otherwise noted)
Full range T_A = –40°C to 125°C

PARAMETER		TEST CONDITIONS	T_A	MIN	TYP	MAX	UNIT
INPUT							
V_{SENSE}	Full-scale input voltage	$V_{SENSE} = V_{IN+} – V_{IN–}$	25°C		0.15	(V_S – 0.2)/ Gain	V
VCM	Common-mode input		Full range	–16		80	V
CMR	Common-mode rejection	V_{IN+} = –16 V to +80 V	25°C	80	94		dB
		V_{IN+} = 12 V to 80 V	Full range	100	120		
V_{OS}	Offset voltage, RTI		25°C		±0.5	2	mV
			Full range		0.5	3	
dV_{OS}/dT	Offset voltage vs temperature		Full range		2.5		µV/°C
PSR	Offset voltage vs power supply	V_S = 2.7 V to 18 V, V_{IN+} = 18 V	Full range		5	100	µV/V
I_B	Input bias current	$V_{IN–}$ pin	Full range		±8	±23	µA
OUTPUT							
G	Gain	INA193A, INA196A	25°C		20		V/V
		INA194A, INA197A			50		
		INA195A, INA198A			100		
	Gain error	V_{SENSE} = 20 mV to 100 mV	25°C		±0.2	±1	%
			Full range			±2	
	Total output error(1)		25°C		±0.75	±2.2	%
			Full range		±1	±3	
	Nonlinearity error	V_{SENSE} = 20 mV to 100 mV	25°C		±0.002	±0.1	%
R_O	Output impedance		25°C		1.5		Ω
	Maximum capacitive load	No sustained oscillation	25°C		10		pF
VOLTAGE OUTPUT(2)							
	Swing to V+ power-supply rail	R_L = 100 kΩ to GND	Full range		V+ – 0.1	V+ – 0.2	V
	Swing to GND(3)	R_L = 100 kΩ to GND	Full range		V_{GND} + 3	V_{GND} + 50	mV
FREQUENCY RESPONSE							
BW	Bandwidth	INA193A, INA196A; C_{LOAD} = 5 pF	25°C		500		kHz
		INA194A, INA197A; C_{LOAD} = 5 pF			300		
		INA195A, INA198A; C_{LOAD} = 5 pF			200		
	Phase margin	C_{LOAD} < 10 nF	25°C		40		°
t_s	Settling time (1%)	V_{SENSE} = 10 mV to 100 mV_{PP}, C_{LOAD} = 5 pF	25°C		2		µs
NOISE, RTI							
	Voltage noise density		25°C		40		$nV/\sqrt{Hz}$

(1) Total output error includes effects of gain error and V_{OS}.
(2) See Typical Characteristics curve Output Swing vs Output Current.
(3) Specified by design

ELECTRICAL CHARACTERISTICS (continued)

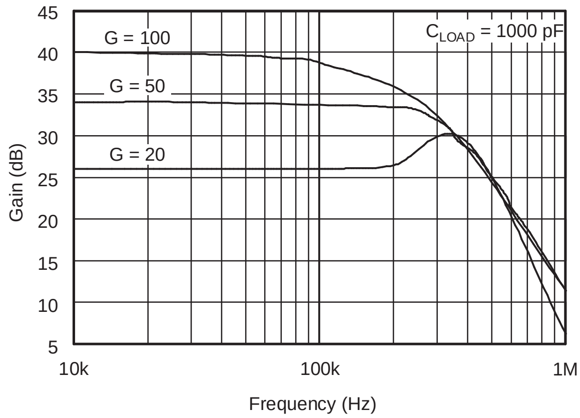
V_S = 12 V, V_{IN+} = 12 V, V_{SENSE} = 100 mV (unless otherwise noted)
Full range T_A = –40°C to 125°C

PARAMETER		TEST CONDITIONS		T_A	MIN	TYP	MAX	UNIT
POWER SUPPLY								
V_S	Operating voltage			Full range	2.7		18	V
I_Q	Quiescent current	V_{OUT} = 2 V		Full range		700	1250	µA
		INA193A, INA194A, INA196A, INA197A	V_{SENSE} = 0 mV	Full range		370	950	µA
		INA195A, INA198A	V_{SENSE} = 0 mV	Full range		370	1050	µA
TEMPERATURE RANGE								
	Operating temperature				–40		125	°C
	Storage temperature				–65		150	°C
θ_{JA}	Thermal resistance					200		°C/W

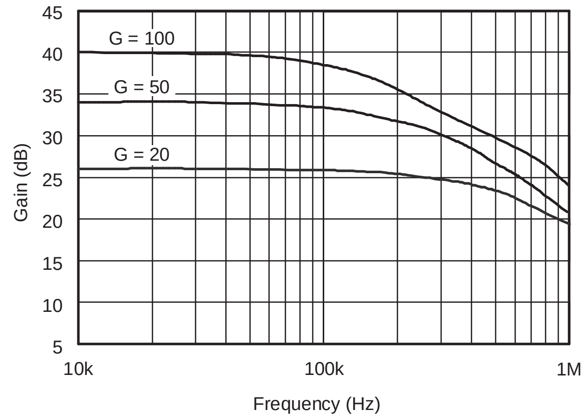
TYPICAL CHARACTERISTICS

T_A = 25°C, V_S = 12 V, V_{IN+} = 12 V, and V_{SENSE} = 100 mV (unless otherwise noted)

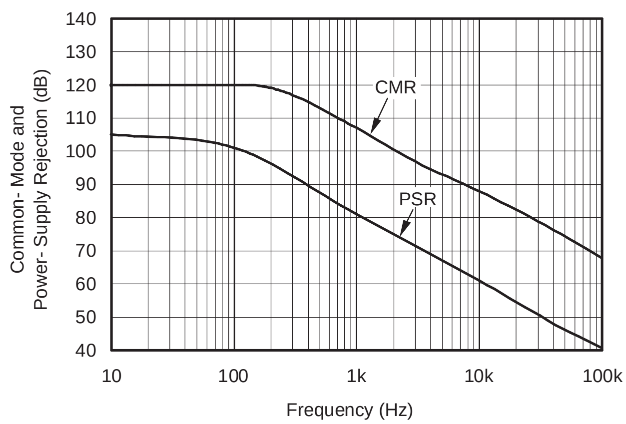
GAIN vs FREQUENCY



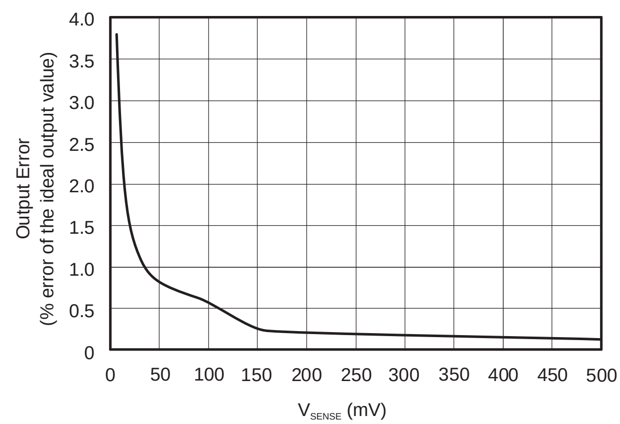
GAIN vs FREQUENCY



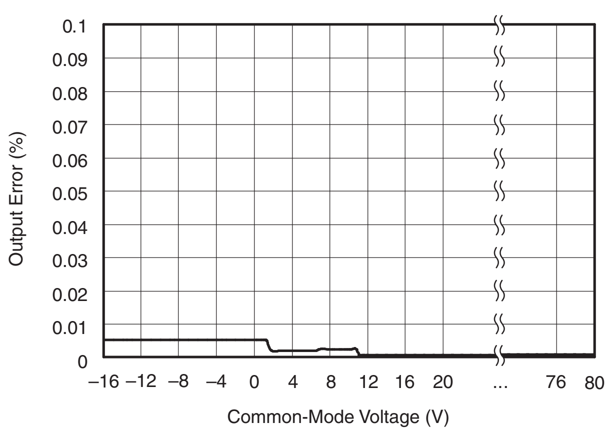
COMMON-MODE and POWER-SUPPLY REJECTION vs FREQUENCY



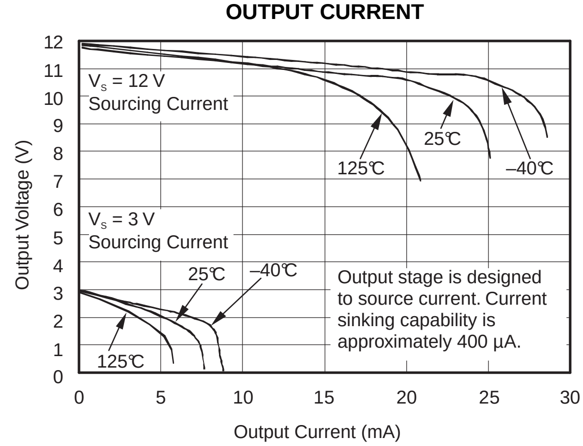
OUTPUT ERROR vs V_{SENSE}



OUTPUT ERROR vs COMMON-MODE VOLTAGE



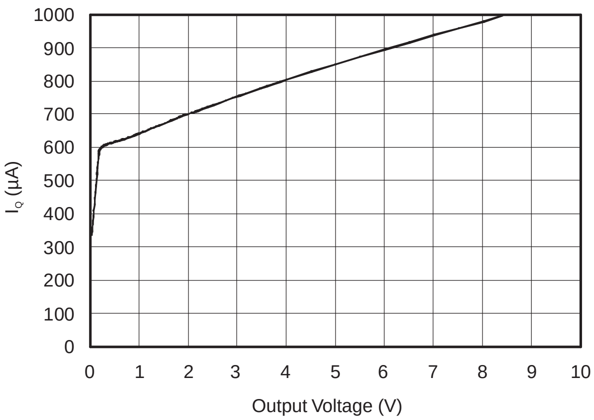
POSITIVE OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



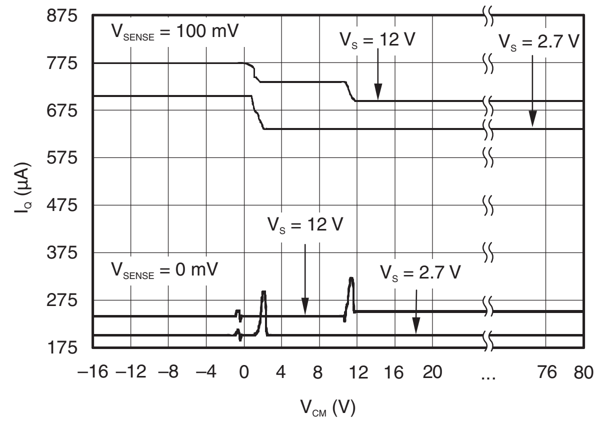
TYPICAL CHARACTERISTICS (continued)

T_A = 25°C, V_S = 12 V, V_{IN+} = 12 V, and V_{SENSE} = 100 mV (unless otherwise noted)

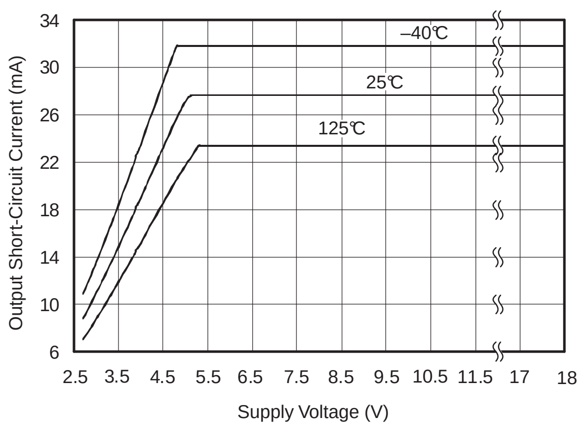
QUIESCENT CURRENT vs OUTPUT VOLTAGE



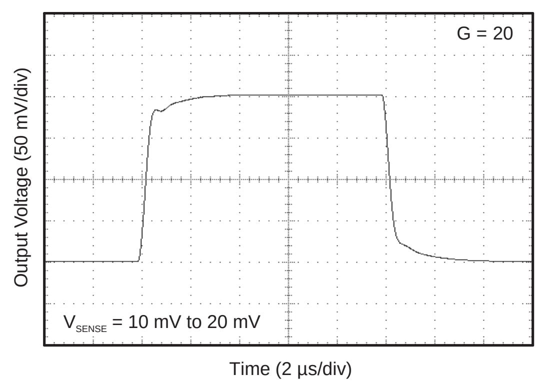
QUIESCENT CURRENT vs COMMON-MODE VOLTAGE



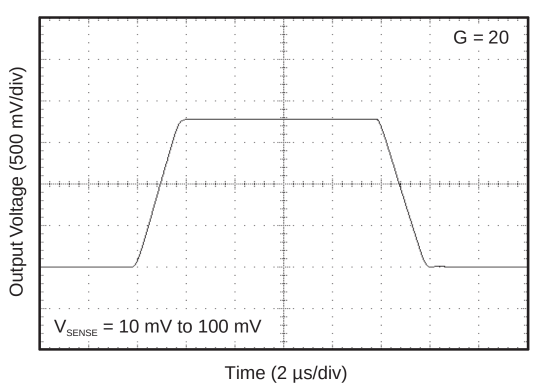
OUTPUT SHORT-CIRCUIT CURRENT vs SUPPLY VOLTAGE



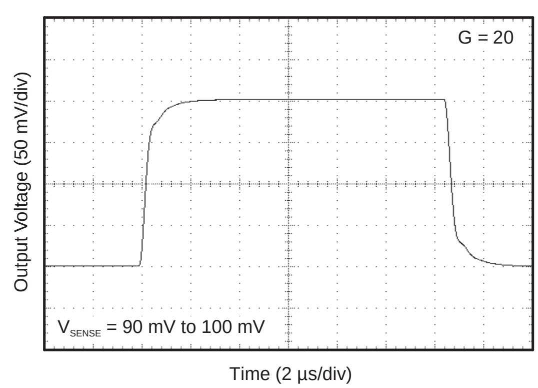
STEP RESPONSE



STEP RESPONSE

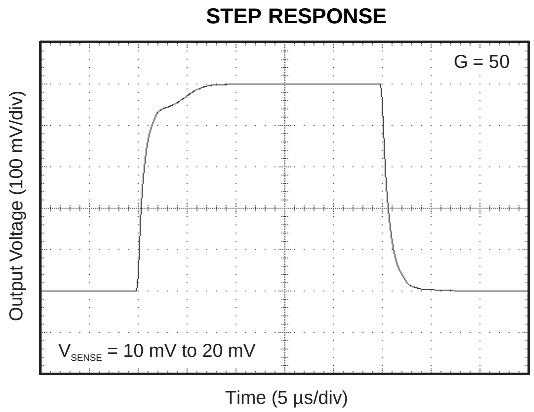


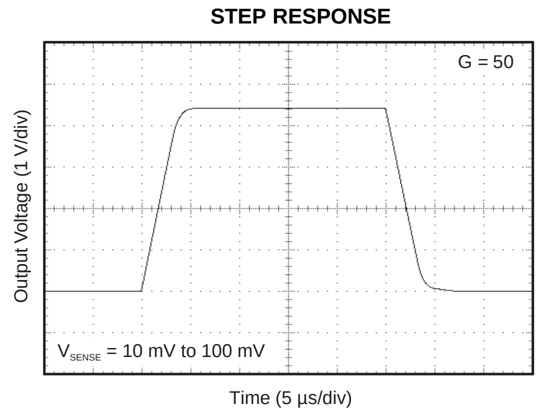
STEP RESPONSE

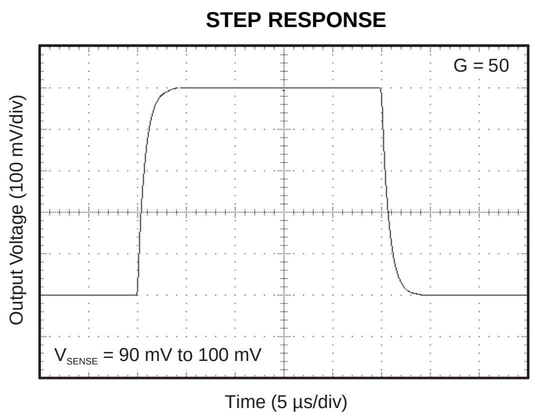


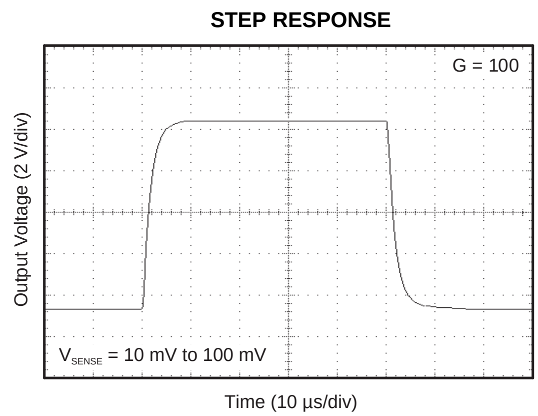
TYPICAL CHARACTERISTICS (continued)

T_A = 25°C, V_S = 12 V, V_{IN+} = 12 V, and V_{SENSE} = 100 mV (unless otherwise noted)









APPLICATION INFORMATION

Basic Connection

Figure 1 shows the basic connection of the INA19xA. The input pins, V_{IN+} and V_{IN-}, should be connected as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistance.

Power-supply bypass capacitors are required for stability. Applications with noisy or high-impedance power supplies may require additional decoupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

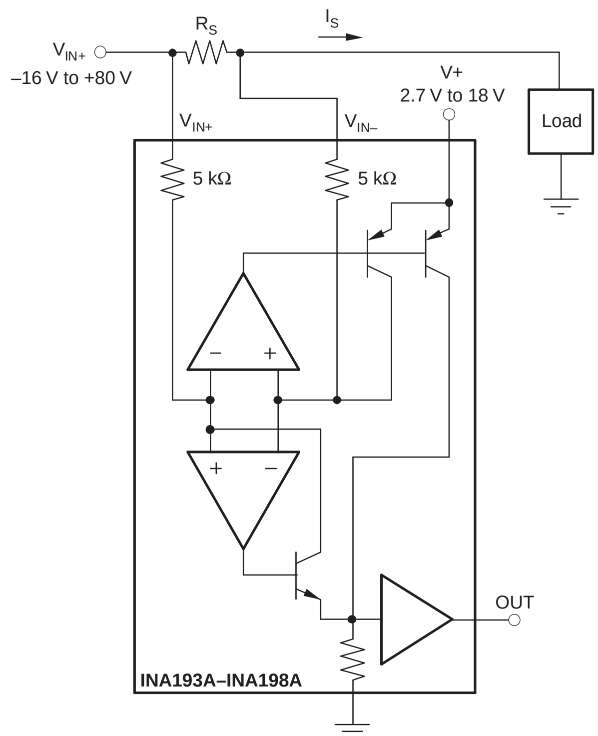


Figure 1. INA19xA Basic Connection

Power Supply

The input circuitry of the INA19xA can accurately measure beyond its power-supply voltage, V+. For example, the V+ power supply can be 5 V, whereas the load power-supply voltage is up to 80 V. The output voltage range of the OUT terminal, however, is limited by the voltages on the power-supply pin.

Selecting R_S

The value chosen for the shunt resistor, R_S, depends on the application and is a compromise between small-signal accuracy and maximum permissible voltage loss in the measurement line. High values of R_S provide better accuracy at lower currents by minimizing the effects of offset, while low values of R_S minimize voltage loss in the supply line. For most applications, best performance is attained with an R_S value that provides a full-scale shunt voltage range of 50 mV to 100 mV. Maximum input voltage for accurate measurements is 500 mV.

APPLICATION INFORMATION (continued)

Transient Protection

The –16-V to +80-V common-mode range of the INA19xA is ideal for withstanding automotive fault conditions ranging from 12 V battery reversal up to 80-V transients, since no additional protective components are needed up to those levels. In the event that the INA19xA is exposed to transients on the inputs in excess of its ratings, then external transient absorption with semiconductor transient absorbers (zeners or Transzorbs) are necessary. Use of MOVs or VDRs is not recommended except when they are used in addition to a semiconductor transient absorber. Select the transient absorber such that it never allows the INA19xA to be exposed to transients greater than 80 V (that is, allow for transient absorber tolerance, as well as additional voltage due to transient absorber dynamic impedance). Despite the use of internal zener-type ESD protection, the INA19xA does not lend itself to using external resistors in series with the inputs since the internal gain resistors can vary up to ±30%. (If gain accuracy is not important, then resistors can be added in series with the INA19xA inputs with two equal resistors on each input.)

Output Voltage Range

The output of the INA19xA is accurate within the output voltage swing range set by the power supply pin, V+. This is best illustrated when using the INA195A or INA198A (which are both versions using a gain of 100), where a 100-mV full-scale input from the shunt resistor requires an output voltage swing of 10 V, and a power-supply voltage sufficient to achieve 10 V on the output.

Input Filtering

An obvious and straightforward location for filtering is at the output of the INA19xA series; however, this location negates the advantage of the low output impedance of the internal buffer. The only other option for filtering is at the input pins of the INA19xA, which is complicated by the internal 5-kΩ ± 30% input impedance (see Figure 2). Using the lowest possible resistor values minimizes both the initial shift in gain and effects of tolerance. The effect on initial gain is given by:

$$\text{Gain Error \%} = 100 - \left(100 \times \frac{5\ \text{k}\Omega}{5\ \text{k}\Omega + R_{FILT}}\right) \tag{1}$$

Total effect on gain error can be calculated by replacing the 5-kΩ term with 5 kΩ – 30% (or 3.5 kΩ) or 5 kΩ + 30% (or 6.5 kΩ). The tolerance extremes of R_{FILT} can also be inserted into the equation. If a pair of 100-Ω 1% resistors are used on the inputs, the initial gain error is 1.96%. Worst-case tolerance conditions always occur at the lower excursion of the internal 5-kΩ resistor (3.5 kΩ), and the higher excursion of R_{FILT}, 3% in this case.

Note that the specified accuracy of the INA19xA must then be combined in addition to these tolerances. While this discussion treats accuracy worst-case conditions by combining the extremes of the resistor values, it is appropriate to use geometric mean or root sum square calculations to total the effects of accuracy variations.

APPLICATION INFORMATION (continued)

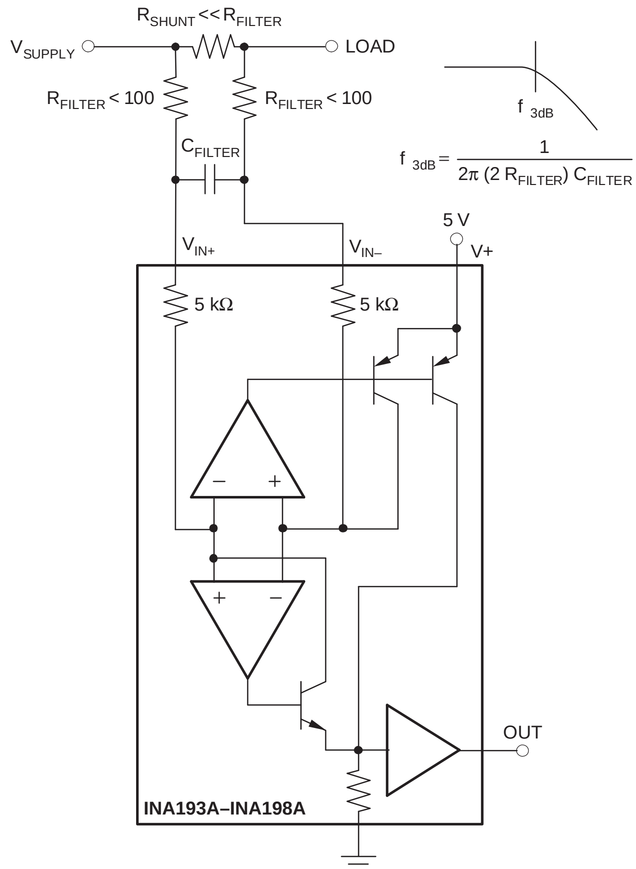


Figure 2. Input Filter (Gain Error = 1.5% to –2.2%)

APPLICATION INFORMATION (continued)

Inside the INA19xA

The INA19xA uses a new, unique, internal circuit topology that provides common-mode range extending from –16 V to +80 V while operating from a single power supply. The common-mode rejection in a classic instrumentation amplifier approach is limited by the requirement for accurate resistor matching. By converting the induced input voltage to a current, the INA19xA provides common-mode rejection that is no longer a function of closely matched resistor values, providing the enhanced performance necessary for such a wide common-mode range. A simplified diagram (see Figure 3) shows the basic circuit function. When the common-mode voltage is positive, amplifier A2 is active.

The differential input voltage, $V_{IN+} – V_{IN–}$ applied across R_S, is converted to a current through a 5-kΩ resistor. This current is converted back to a voltage through R_L, and then amplified by the output buffer amplifier. When the common-mode voltage is negative, amplifier A1 is active. The differential input voltage, $V_{IN+} – V_{IN–}$ applied across R_S, is converted to a current through a 5-kΩ resistor. This current is sourced from a precision current mirror whose output is directed into R_L, converting the signal back into a voltage and amplified by the output buffer amplifier. Patent-pending circuit architecture ensures smooth device operation, even during the transition period where both amplifiers A1 and A2 are active.

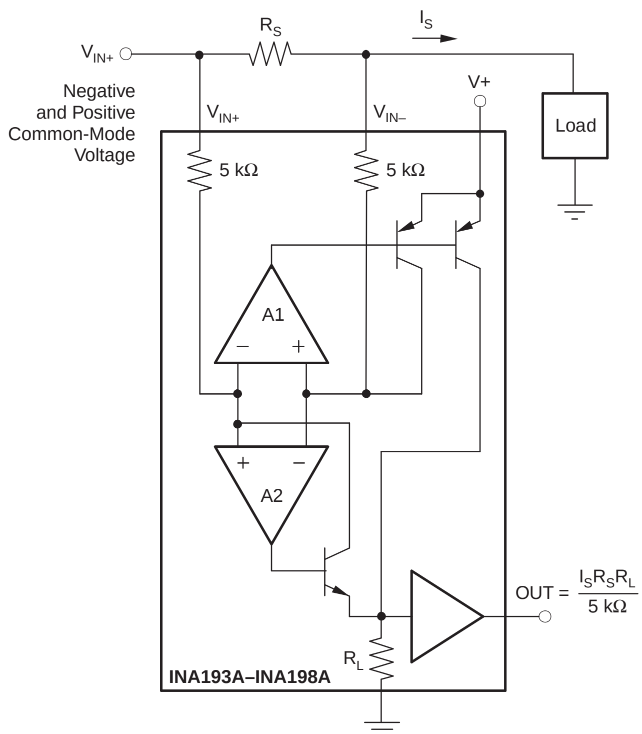


Figure 3. INA19xA Simplified Circuit Diagram

APPLICATION INFORMATION (continued)

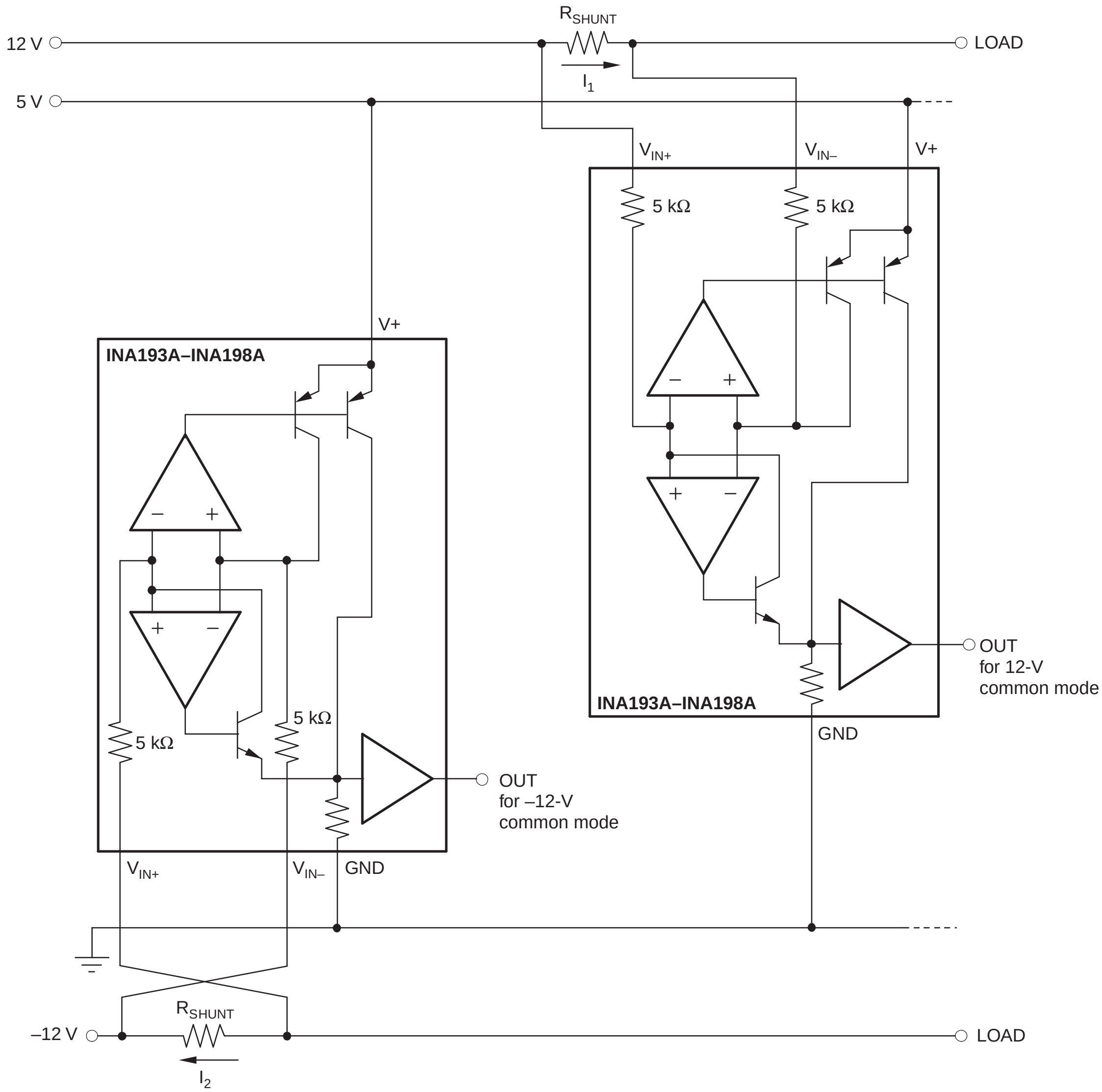


Figure 4. Monitor Bipolar Output Power-Supply Current

APPLICATION INFORMATION (continued)

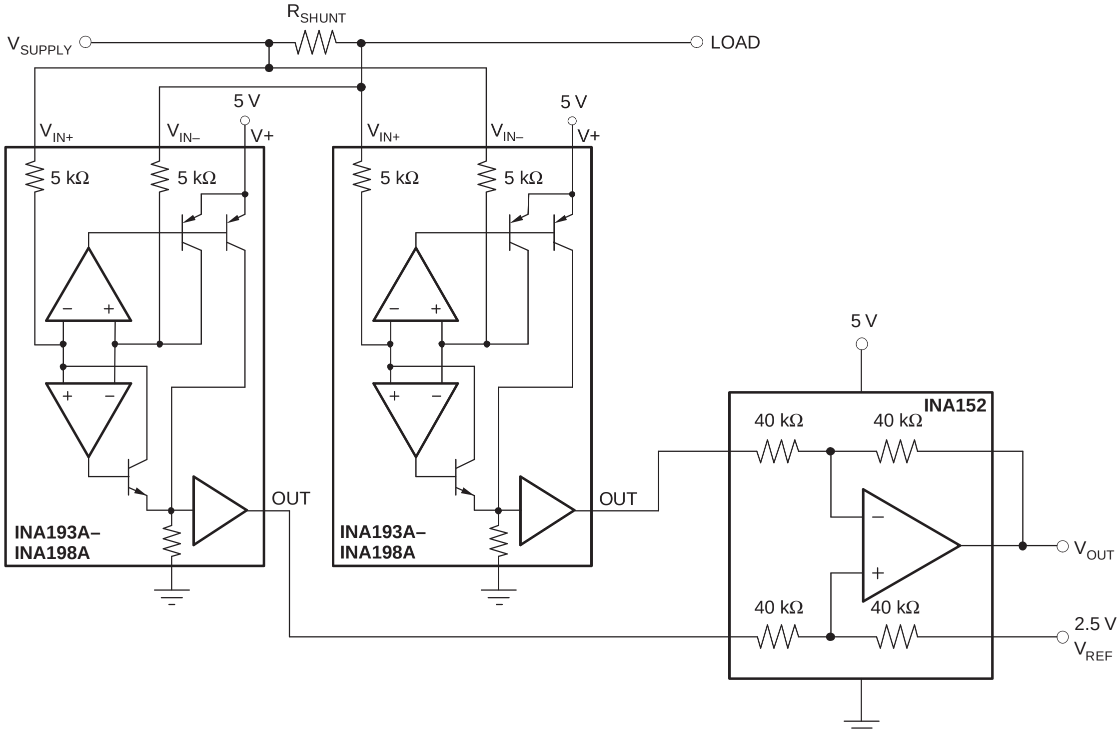


Figure 5. Bidirectional Current Monitoring

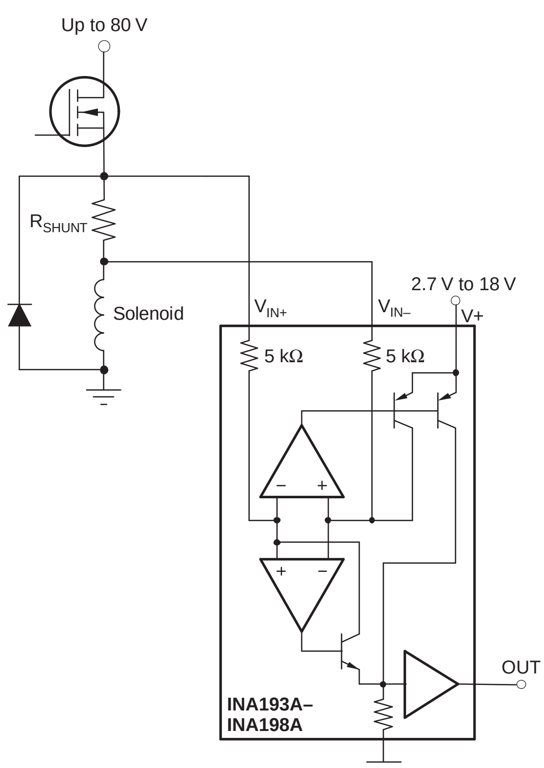
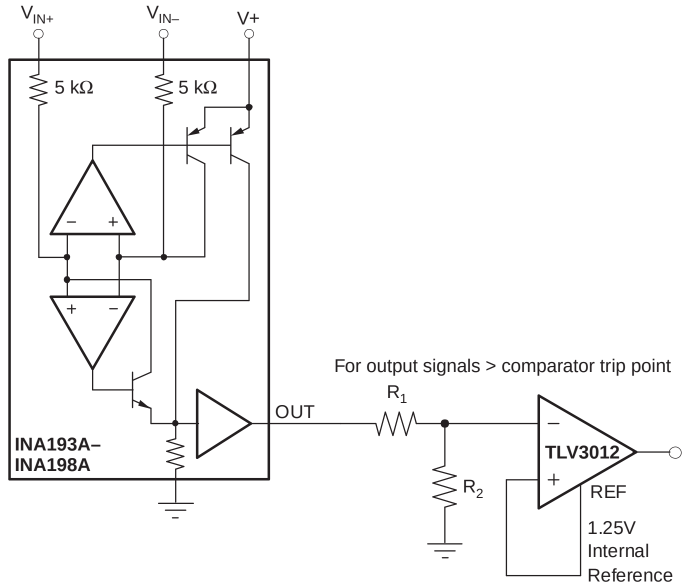
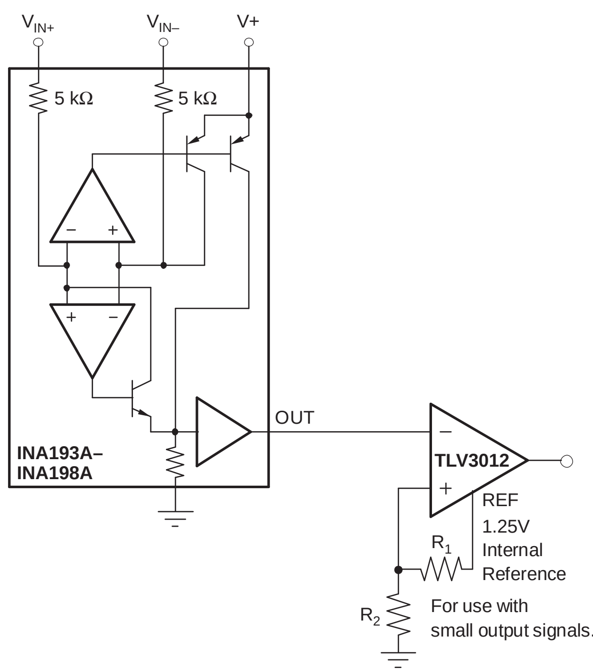


Figure 6. Inductive Current Monitor Including Flyback

APPLICATION INFORMATION (continued)



(a) INA19xA Output Adjusted by Voltage Divider



(b) Comparator Reference Voltage Adjusted by Voltage Divider

Figure 7. INA19xA With Comparator

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
INA193AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA194AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA195AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA196AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA197AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
INA198AQDBVRQ1	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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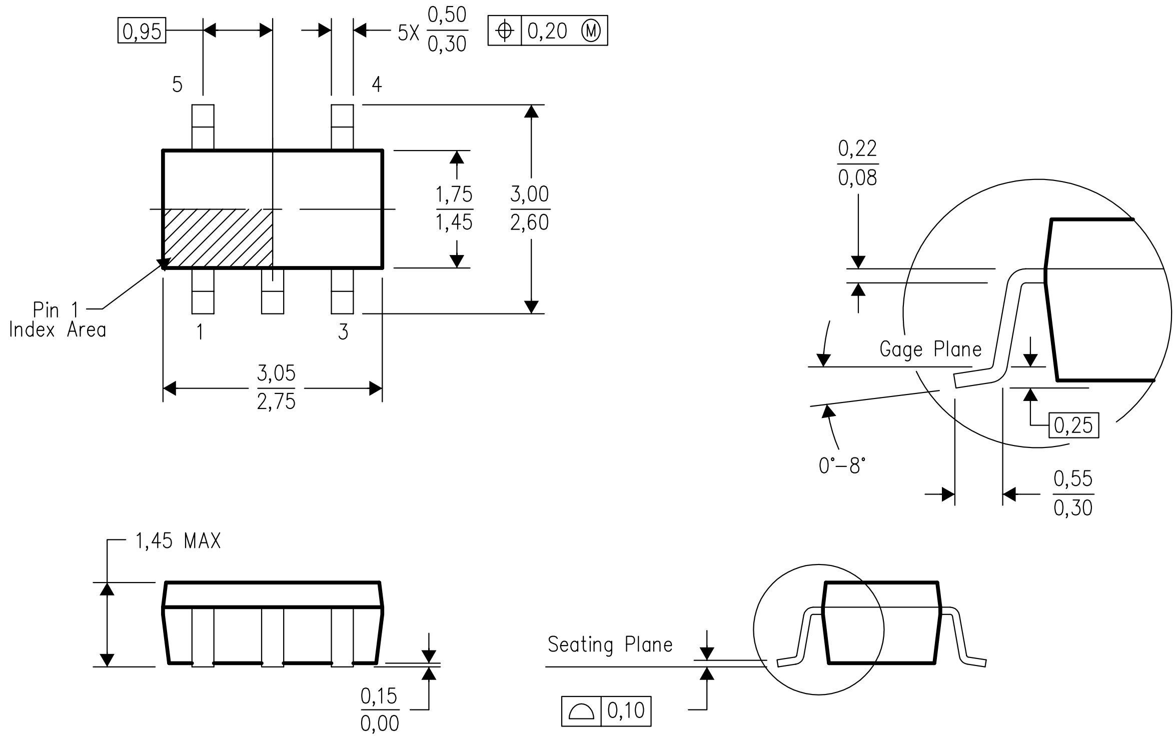
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

DBV (R–PDSO–G5) PLASTIC SMALL–OUTLINE PACKAGE



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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. Mold flash and protrusion shall not exceed 0.15 per side.
- D. Falls within JEDEC MO–178 Variation AA.

IMPORTANT NOTICE

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
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