



# CURRENT SHUNT MONITOR

## –16V to 36V Common-Mode Range

### FEATURES

- **WIDE COMMON-MODE VOLTAGE:**  
–16V to 36V
- **LOW ERROR: 3.0% Over Temp (max)**
- **BANDWIDTH: Up to 500kHz**
- **THREE TRANSFER FUNCTIONS AVAILABLE:**  
20V/V, 50V/V, and 100V/V
- **QUIESCENT CURRENT: 900µA (max)**
- **COMPLETE CURRENT SENSE SOLUTION**

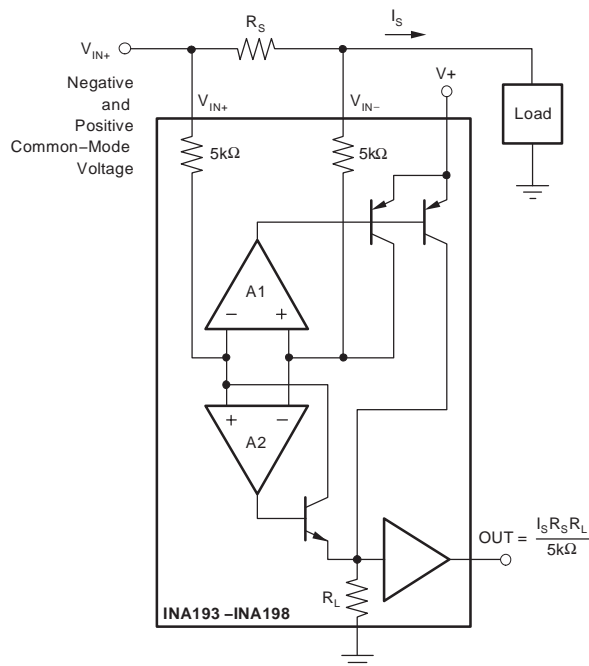
### APPLICATIONS

- WELDING EQUIPMENT
- NOTEBOOK COMPUTERS
- CELL PHONES
- TELECOM EQUIPMENT
- AUTOMOTIVE
- POWER MANAGEMENT
- BATTERY CHARGERS

### DESCRIPTION

The INA193—INA198 family of current shunt monitors with voltage output can sense drops across shunts at common-mode voltages from –16V to +36V, independent of the INA19x supply voltage. They are available with three output voltage scales: 20V/V, 50V/V, and 100V/V. The 500kHz bandwidth simplifies use in current control loops. The INA193—INA195 provide identical functions but alternative pin configurations to the INA196—INA198 (respectively).

The INA193—INA198 operate from a single +2.7V to +13.5V supply, drawing a maximum of 900µA of supply current. They are specified over the extended operating temperature range (–40°C to +125°C), and are offered in a space-saving SOT23 package.



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.

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**ABSOLUTE MAXIMUM RATINGS(1)**

Supply Voltage	+18V
Analog Inputs, $V_{IN+}$ , $V_{IN-}$	
Differential ( $V_{IN+}$ ) – ( $V_{IN-}$ )	-2V to +2V
Common-Mode(2)	-16V to +36V
Analog Output, Out(2)	GND – 0.3V to (V+) + 0.3V
Input Current Into Any Pin(2)	5mA
Operating Temperature	-55°C to +150°C
Storage Temperature	-65°C to +150°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C
ESD Ratings	
Human Body Model	4000V
Charged-Device Model	1000V

- (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 supported.
- (2) Input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 5mA.



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.

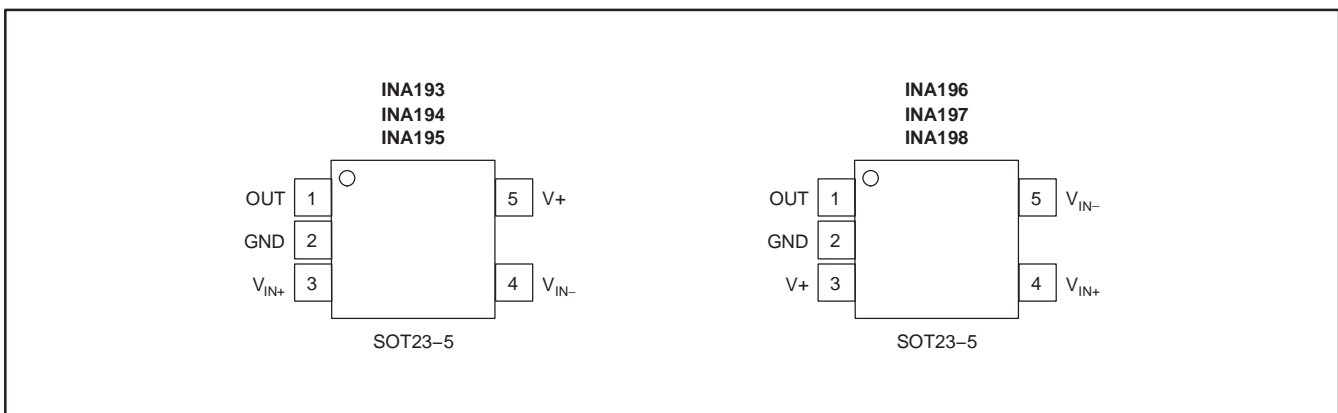
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

**ORDERING INFORMATION**

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR(1)	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
INA193	SOT23-5	DBV	-40°C to +125°C	BJJ	INA193AIDBVT	Tape and Reel, 250
					INA193AIDBVR	Tape and Reel, 3000
INA194	SOT23-5	DBV	-40°C to +125°C	BJI	INA194AIDBVT	Tape and Reel, 250
					INA194AIDBVR	Tape and Reel, 3000
INA195	SOT23-5	DBV	-40°C to +125°C	BJK	INA195AIDBVT	Tape and Reel, 250
					INA195AIDBVR	Tape and Reel, 3000
INA196	SOT23-5	DBV	-40°C to +125°C	BJE	INA196AIDBVT	Tape and Reel, 250
					INA196AIDBVR	Tape and Reel, 3000
INA197	SOT23-5	DBV	-40°C to +125°C	BJH	INA197AIDBVT	Tape and Reel, 250
					INA197AIDBVR	Tape and Reel, 3000
INA198	SOT23-5	DBV	-40°C to +125°C	BJL	INA198AIDBVT	Tape and Reel, 250
					INA198AIDBVR	Tape and Reel, 3000

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

**PIN ASSIGNMENTS**



**ELECTRICAL CHARACTERISTICS:  $V_S = +12V$**

**Boldface** limits apply over the specified temperature range,  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ .

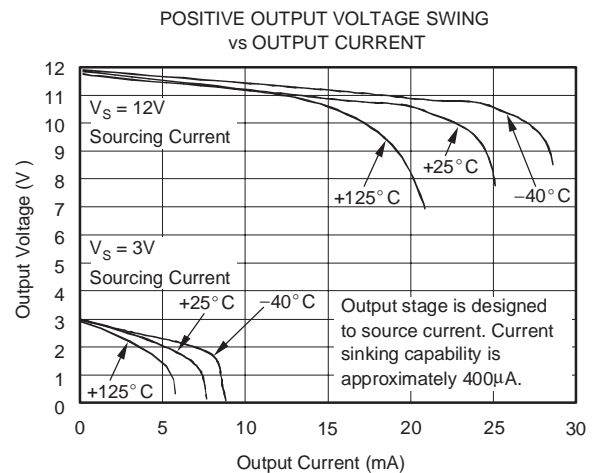
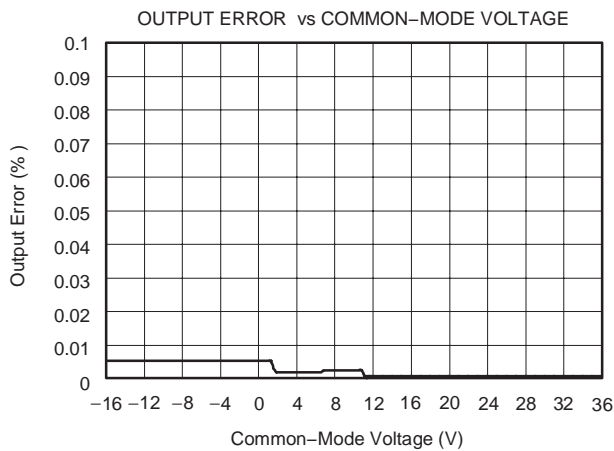
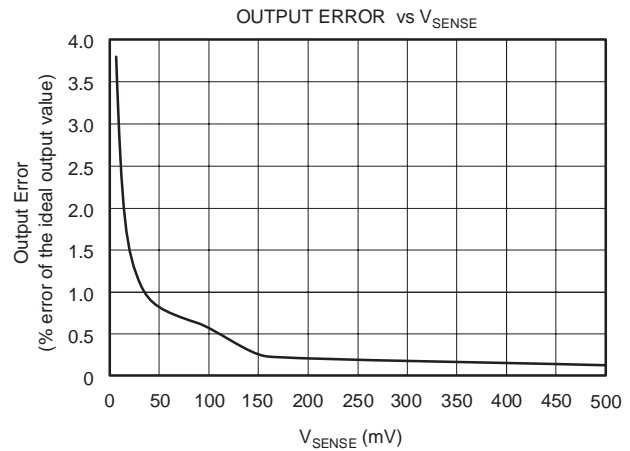
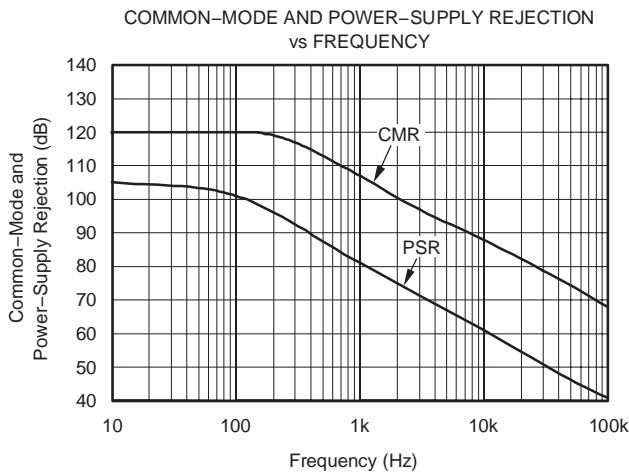
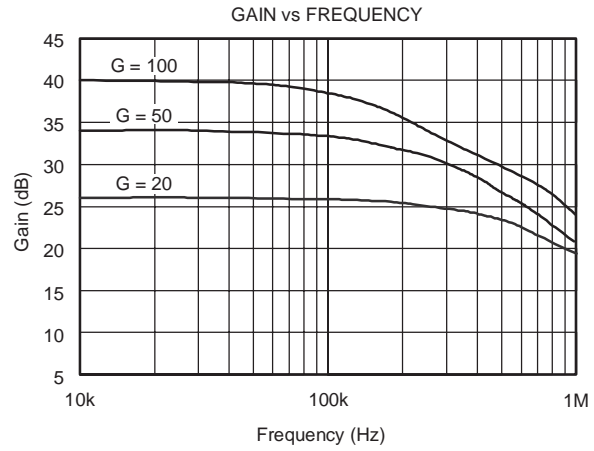
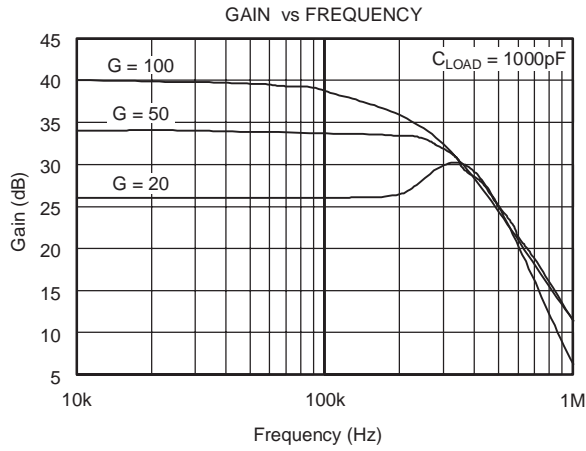
All specifications at  $T_A = +25^\circ\text{C}$ ,  $V_S = +12V$ ,  $V_{IN+} = 12V$ , and  $V_{SENSE} = 100\text{mV}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	INA193, INA194, INA195 INA196, INA197, INA198			UNIT
		MIN	TYP	MAX	
<b>INPUT</b>					
Full-Scale Input Voltage	$V_{SENSE}$		0.15	$(V_S - 0.2)/\text{Gain}$	V
<b>Common-Mode Input Range</b>	$V_{CM}$	<b>-16</b>		<b>36</b>	V
Common-Mode Rejection	CMR	80	94		dB
<b>Over Temperature</b>		<b>100</b>	<b>120</b>		dB
Offset Voltage, RTI	$V_{OS}$		$\pm 0.5$	2	mV
<b>Over Temperature</b>			<b>0.5</b>	<b>3</b>	mV
<b>vs Temperature</b>	$dV_{OS}/dT$		<b>2.5</b>		$\mu\text{V}/^\circ\text{C}$
<b>vs Power Supply</b>	PSR	$V_S = +2.7V$ to $+13.5V$ , $V_{IN+} = +13.5V$	5	<b>100</b>	$\mu\text{V}/V$
Input Bias Current, $V_{IN-}$ pin	$I_B$		$\pm 8$	$\pm 16$	$\mu\text{A}$
<b>OUTPUT</b>					
Gain: INA193, INA196	G		20		V/V
INA194, INA197			50		V/V
INA195, INA198			100		V/V
Gain Error		$V_{SENSE} = 20\text{mV}$ to $100\text{mV}$ , $T_A = 25^\circ\text{C}$	$\pm 0.2$	$\pm 1$	%
<b>Over Temperature</b>		<b><math>V_{SENSE} = 20\text{mV}</math> to <math>100\text{mV}</math></b>		<b><math>\pm 2</math></b>	%
Total Output Error(1)			$\pm 0.75$	$\pm 2.2$	%
<b>Over Temperature</b>			$\pm 1$	<b><math>\pm 3</math></b>	%
Nonlinearity Error		$V_{SENSE} = 20\text{mV}$ to $100\text{mV}$	$\pm 0.002$	$\pm 0.1$	%
Output Impedance	$R_O$		1.5		$\Omega$
Maximum Capacitive Load		No Sustained Oscillation	10		nF
<b>VOLTAGE OUTPUT(2)</b>					
<b>Swing to <math>V_+</math> Power Supply Rail</b>		$R_L = 100\text{k}\Omega$ to GND			
<b>Swing to GND(3)</b>			$(V_+) - 0.1$ $(V_{GND}) + 3$	$(V_+) - 0.2$ $(V_{GND}) + 50$	V mV
<b>FREQUENCY RESPONSE</b>					
Bandwidth, INA193, INA196	BW	$C_{LOAD} = 5\text{pF}$	500		kHz
INA194, INA197		$C_{LOAD} = 5\text{pF}$	300		kHz
INA195, INA198		$C_{LOAD} = 5\text{pF}$	200		kHz
Phase Margin		$C_{LOAD} < 10\text{nF}$	40		degrees
Settling Time (1%)	$t_S$	$V_{SENSE} = 10\text{mV}$ to $100\text{mV}_{PP}$ , $C_{LOAD} = 5\text{pF}$	2		$\mu\text{s}$
<b>NOISE, RTI</b>					
Voltage Noise Density			40		$\text{nV}/\sqrt{\text{Hz}}$
<b>POWER SUPPLY</b>					
<b>Operating Range</b>	$V_S$		<b>+2.7</b>	<b>+13.5</b>	V
Quiescent Current	$I_Q$	$V_{OUT} = 2V$	700	900	$\mu\text{A}$
<b>Over Temperature</b>		<b><math>V_{SENSE} = 0\text{mV}</math></b>	<b>370</b>	<b>950</b>	$\mu\text{A}$
<b>TEMPERATURE RANGE</b>					
Specified Temperature Range			-40	+125	$^\circ\text{C}$
Operating Temperature Range			-55	+150	$^\circ\text{C}$
Storage Temperature Range			-65	+150	$^\circ\text{C}$
Thermal Resistance, SOT23	$\theta_{JA}$		200		$^\circ\text{C}/W$

- (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.

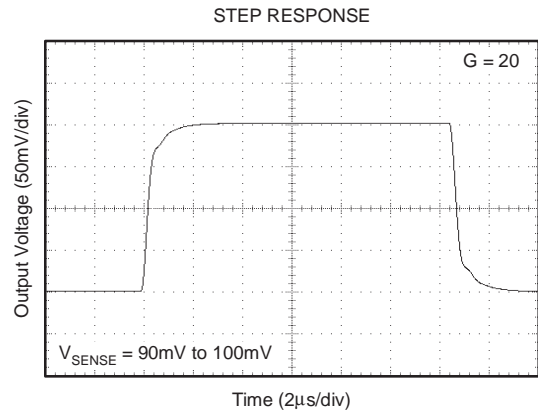
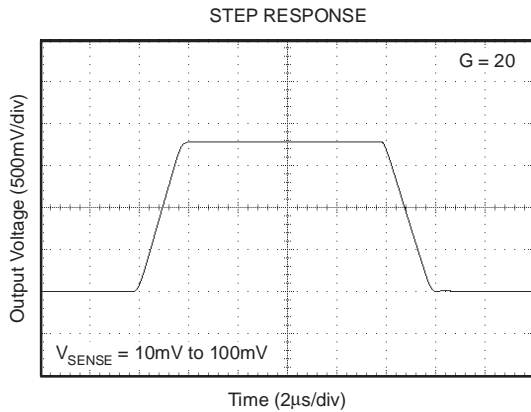
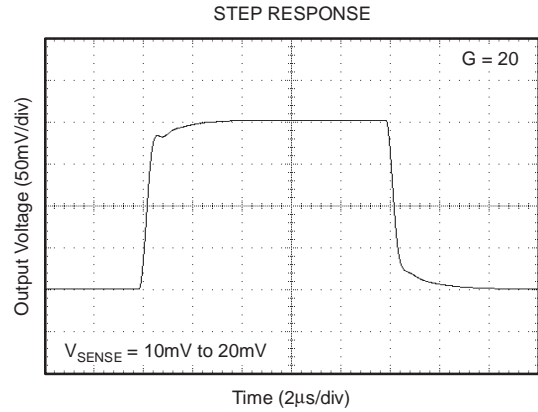
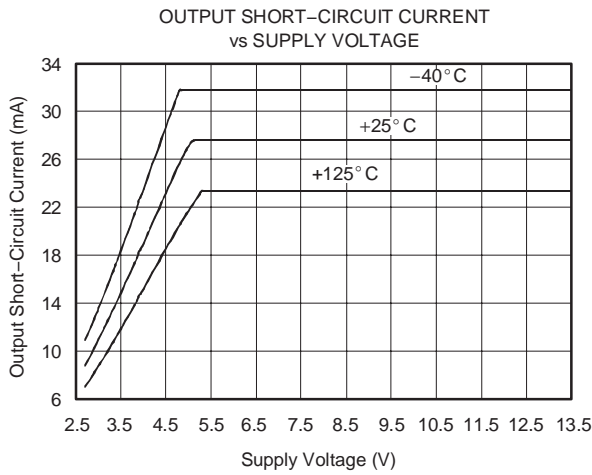
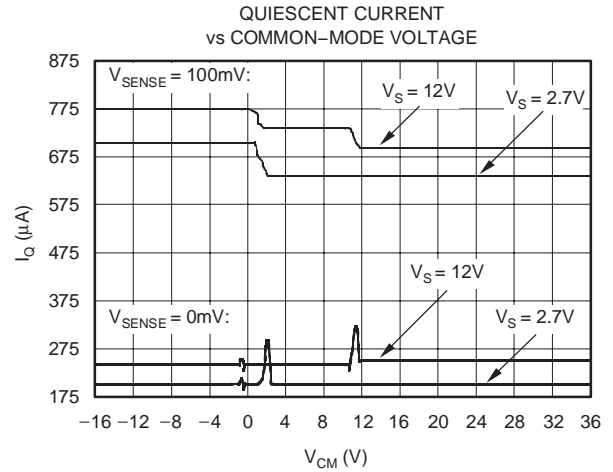
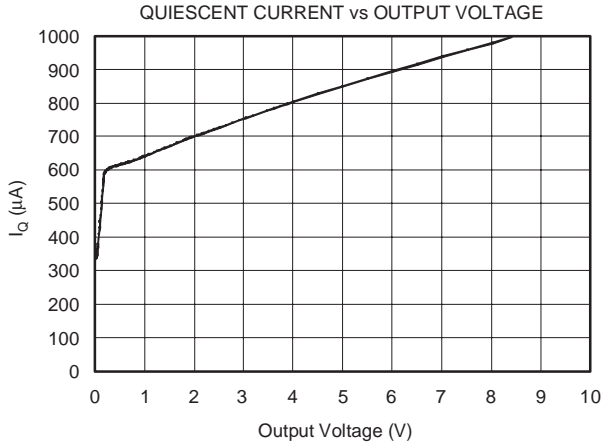
**TYPICAL CHARACTERISTICS**

All specifications at  $T_A = +25^\circ\text{C}$ ,  $V_S = +12$ , and  $V_{IN+} = 12\text{V}$ , and  $V_{SENSE} = 100\text{mV}$ , unless otherwise noted.



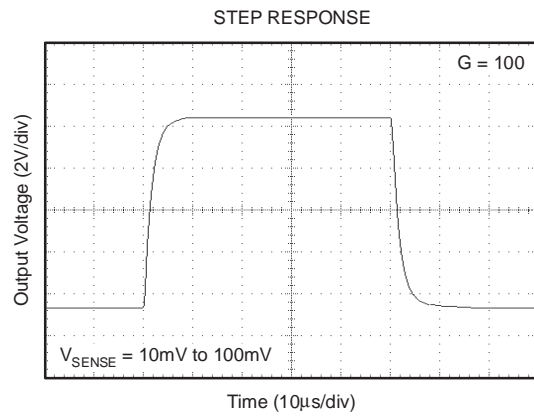
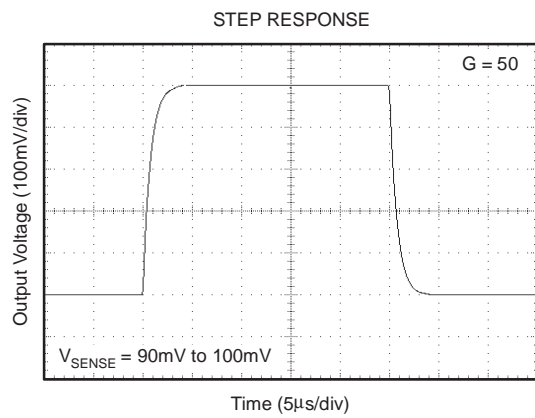
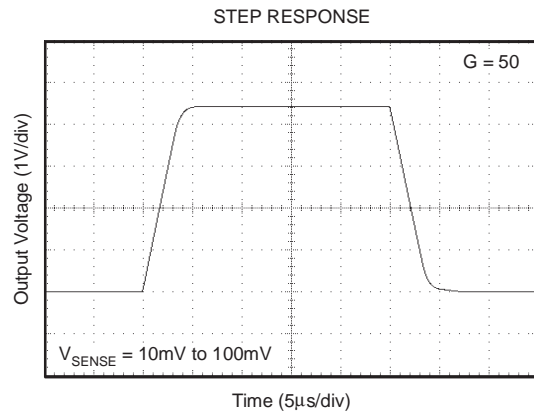
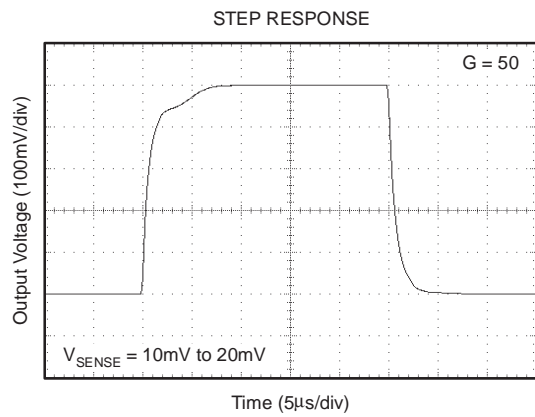
## TYPICAL CHARACTERISTICS (continued)

All specifications at  $T_A = +25^\circ\text{C}$ ,  $V_S = +12$ , and  $V_{IN+} = 12\text{V}$ , and  $V_{SENSE} = 100\text{mV}$ , unless otherwise noted.



### TYPICAL CHARACTERISTICS (continued)

All specifications at  $T_A = +25^\circ\text{C}$ ,  $V_S = +12$ , and  $V_{IN+} = 12\text{V}$ , and  $V_{SENSE} = 100\text{mV}$ , unless otherwise noted.



## APPLICATIONS INFORMATION

### BASIC CONNECTION

Figure 1 shows the basic connection of the INA19x. 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.

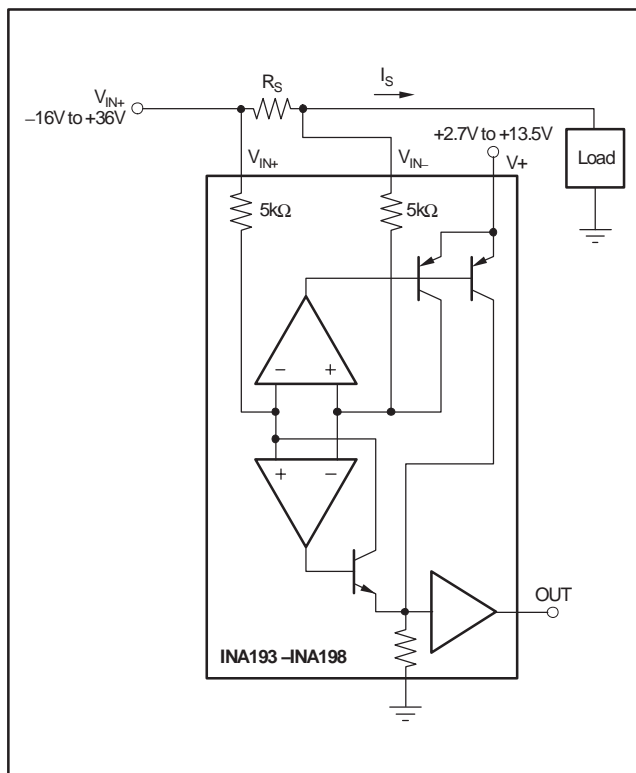


Figure 1. INA19x Basic Connection

### POWER SUPPLY

The input circuitry of the INA19x can accurately measure beyond its power-supply voltage,  $V+$ . For example, the  $V+$  power supply can be 5V, whereas the load power-supply

voltage is up to +36V. 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 50mV to 100mV. Maximum input voltage for accurate measurements is 500mV.

### TRANSIENT PROTECTION

The  $-16V$  to  $+36V$  common-mode range of the INA19x is ideal for withstanding automotive fault conditions ranging from 12V battery reversal up to +36V transients, since no additional protective components are needed up to those levels. In the event that the INA19x is exposed to transients on the inputs in excess of its ratings, then external transient absorption with semiconductor transient absorbers (zeners or *Transzorbs*) will be 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 will never allow the INA19x to be exposed to transients greater than +36V (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 INA19x does not lend itself to using external resistors in series with the inputs since the internal gain resistors can vary up to  $\pm 30\%$ . (If gain accuracy is not important, then resistors can be added in series with the INA19x inputs with two equal resistors on each input.)

### OUTPUT VOLTAGE RANGE

The output of the INA19x is accurate within the output voltage swing range set by the power supply pin,  $V+$ . This is best illustrated when using the INA195 or INA198 (which are both versions using a gain of 100), where a 100mV full-scale input from the shunt resistor requires an output voltage swing of +10V, and a power-supply voltage sufficient to achieve +10V on the output.

## INPUT FILTERING

An obvious and straightforward location for filtering is at the output of the INA19x 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 INA19x, which is complicated by the internal  $5\text{k}\Omega + 30\%$  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:

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

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

Note that the specified accuracy of the INA19x must then be combined in addition to these tolerances. While this discussion treated 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.

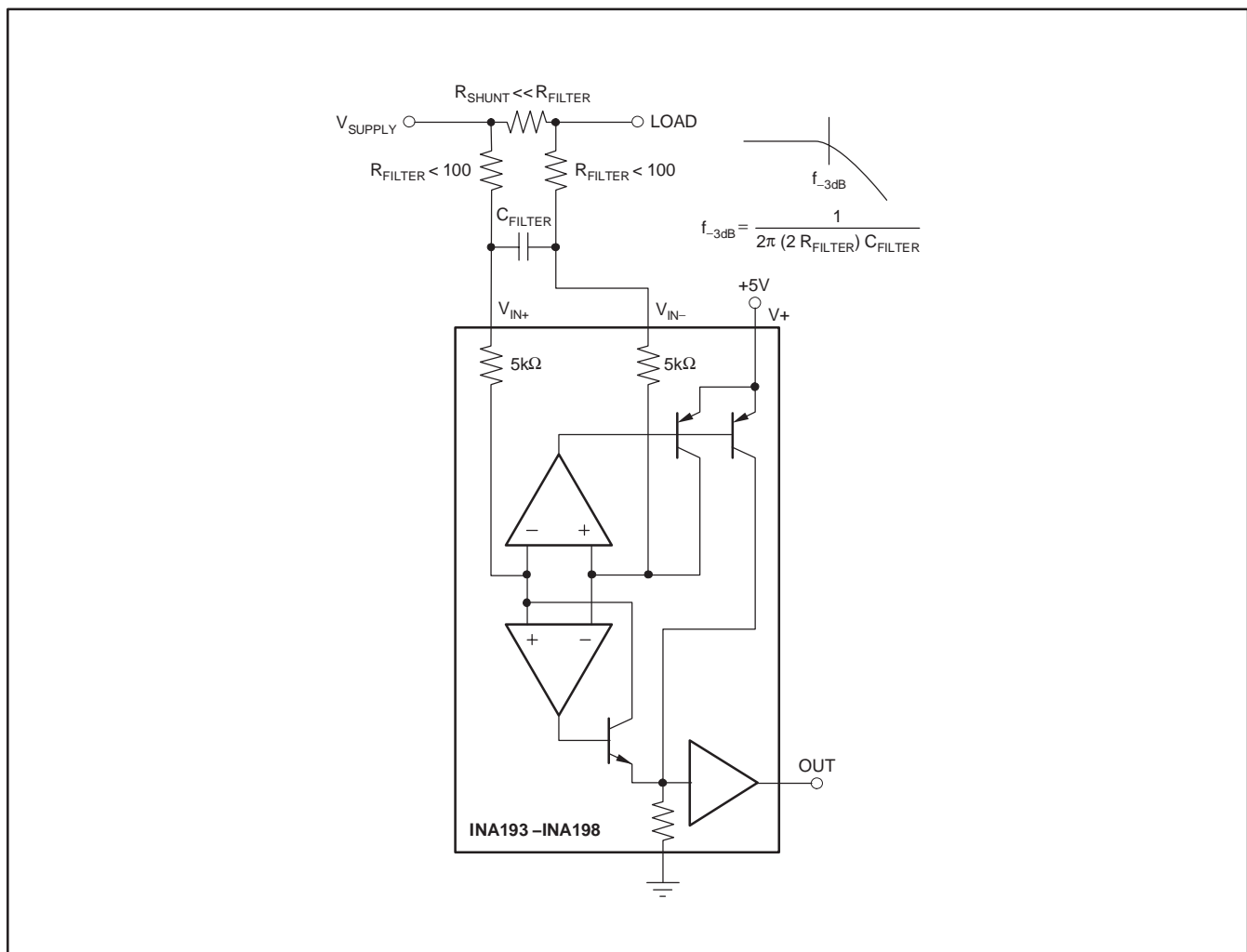


Figure 2. Input Filter (Gain Error – 1.5% to –2.2%)



### INSIDE THE INA19x

The INA19x uses a new, unique internal circuit topology that provides common-mode range extending from  $-16V$  to  $+36V$  while operating from a single power supply. The common-mode rejection in a classic instrumentation amp approach is limited by the requirement for accurate resistor matching. By converting the induced input voltage to a current, the INA19x 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  $5k\Omega$  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  $5k\Omega$  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.

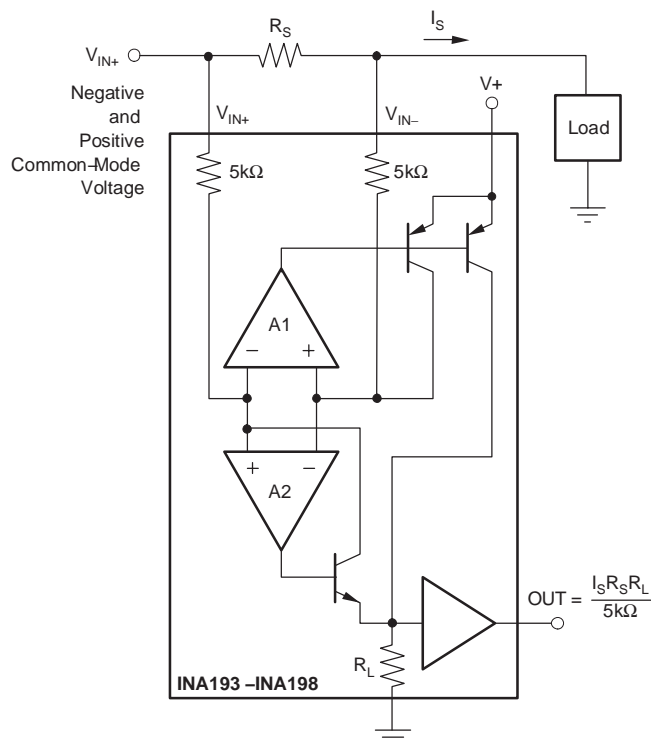


Figure 3. INA19x Simplified Circuit Diagram

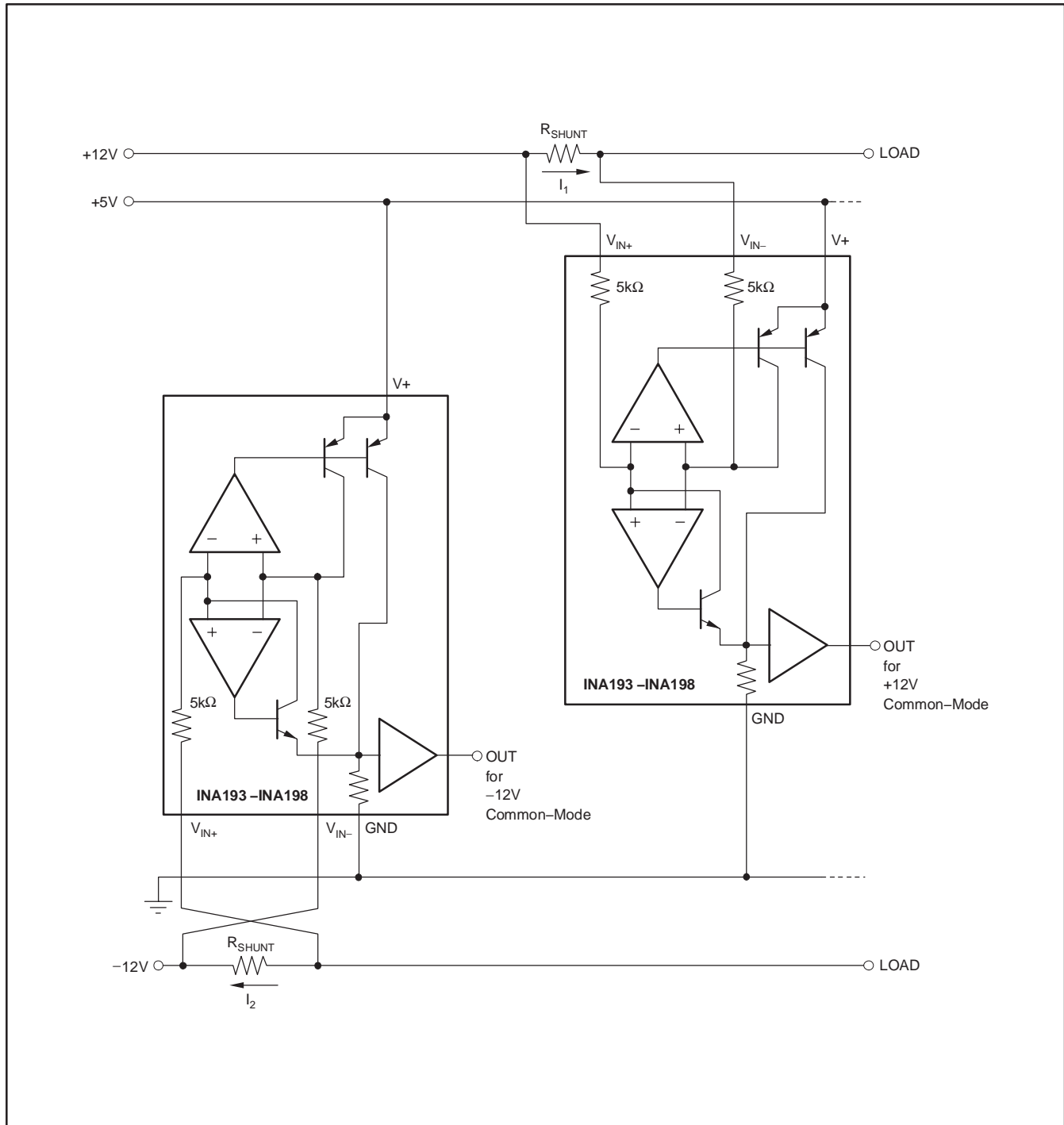
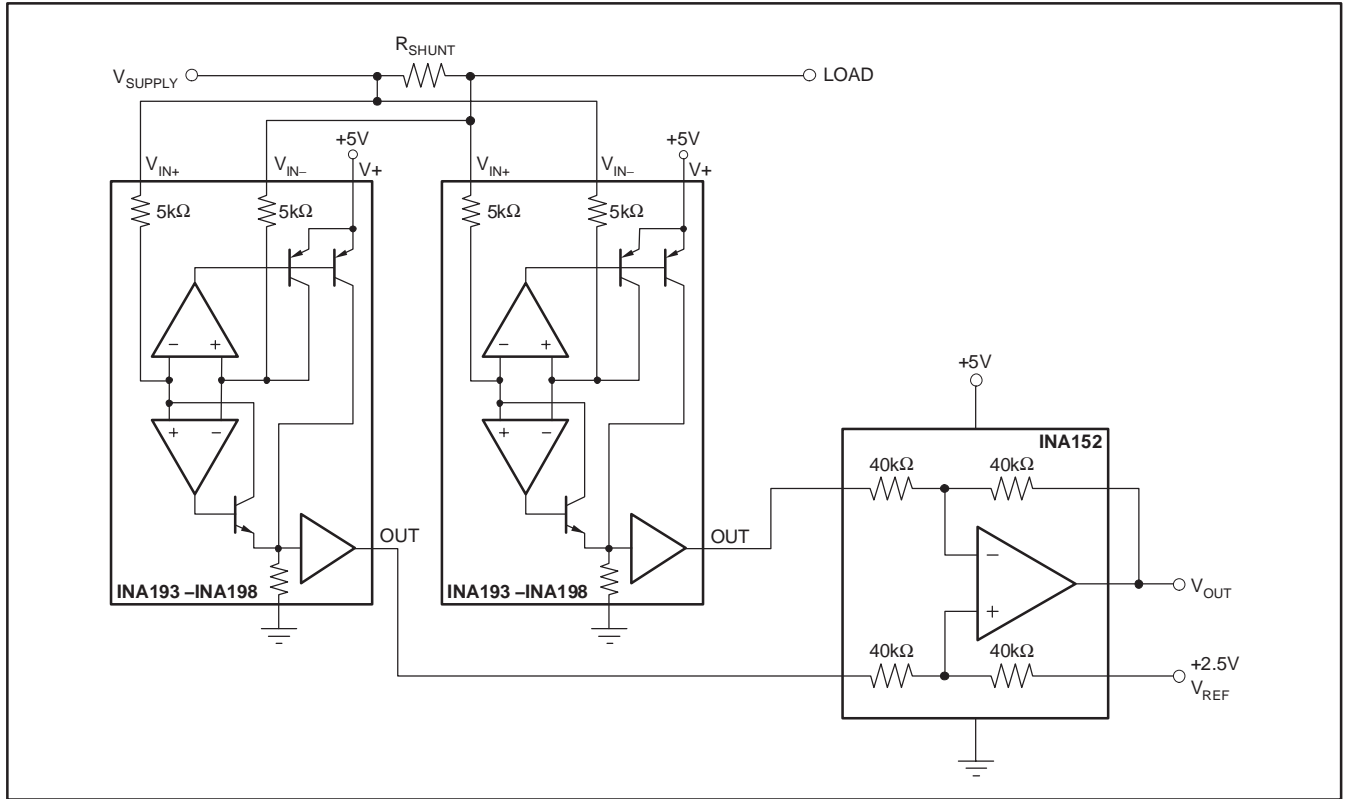
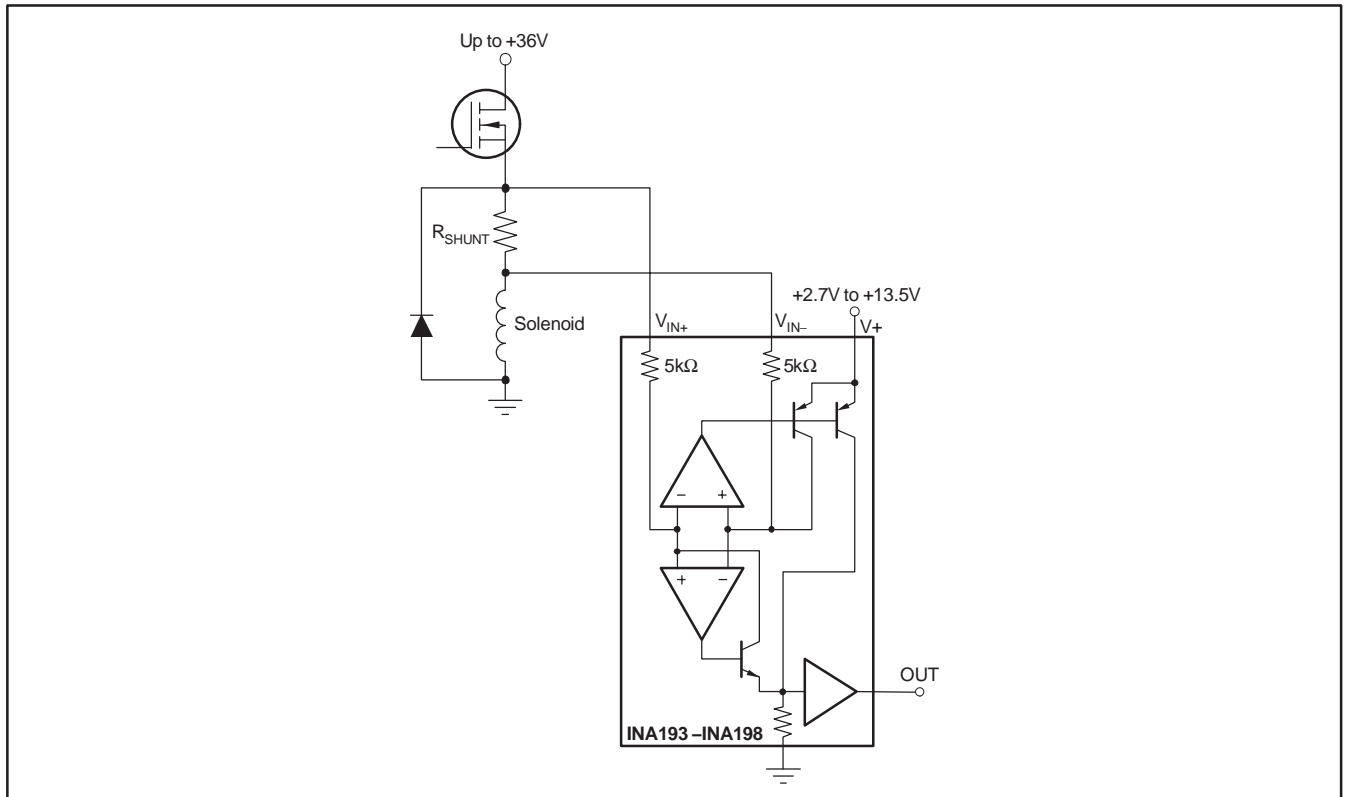


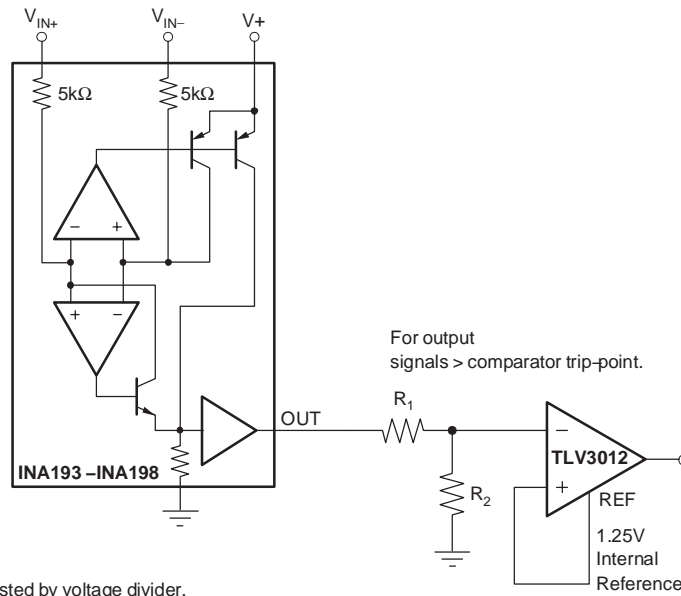
Figure 4. Monitor Bipolar Output Power-Supply Current



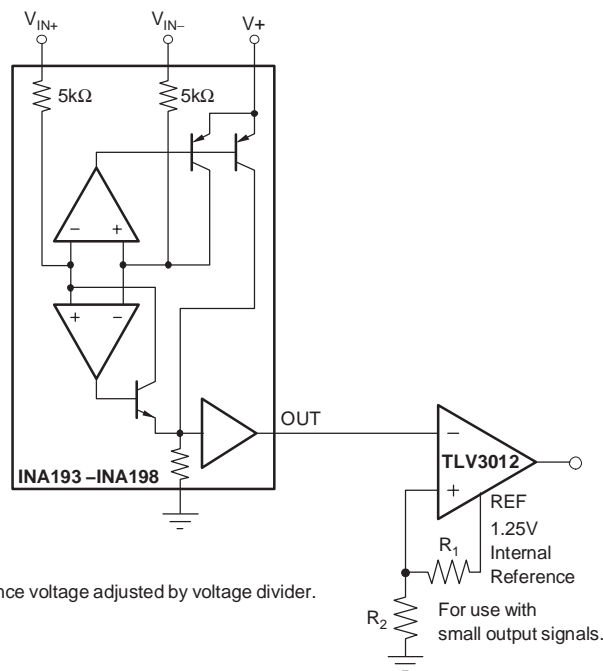
**Figure 5. Bi-directional Current Monitoring**



**Figure 6. Inductive Current Monitor Including Flyback**



(a) INA19x output adjusted by voltage divider.



(b) Comparator reference voltage adjusted by voltage divider.

Figure 7. INA19x With Comparator

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
INA193AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU NIPDAU	Level-3-260C-168 HR
INA193AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU NIPDAU	Level-3-260C-168 HR
INA194AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU	Level-3-260C-168 HR
INA194AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU	Level-3-260C-168 HR
INA195AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU	Level-3-260C-168 HR
INA195AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU	Level-3-260C-168 HR
INA196AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU NIPDAU	Level-3-260C-168 HR
INA196AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU NIPDAU	Level-3-260C-168 HR
INA197AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU NIPDAU	Level-3-260C-168 HR
INA197AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU NIPDAU	Level-3-260C-168 HR
INA198AIDBVR	ACTIVE	SOT-23	DBV	5	3000	None	CU NIPDAU	Level-3-260C-168 HR
INA198AIDBVT	ACTIVE	SOT-23	DBV	5	250	None	CU NIPDAU	Level-3-260C-168 HR

<sup>(1)</sup> 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.

<sup>(2)</sup> Eco Plan - May not be currently available - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**None:** Not yet available Lead (Pb-Free).

**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.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean "Pb-Free" and in addition, uses package materials that do not contain halogens, including bromine (Br) or antimony (Sb) above 0.1% of total product weight.

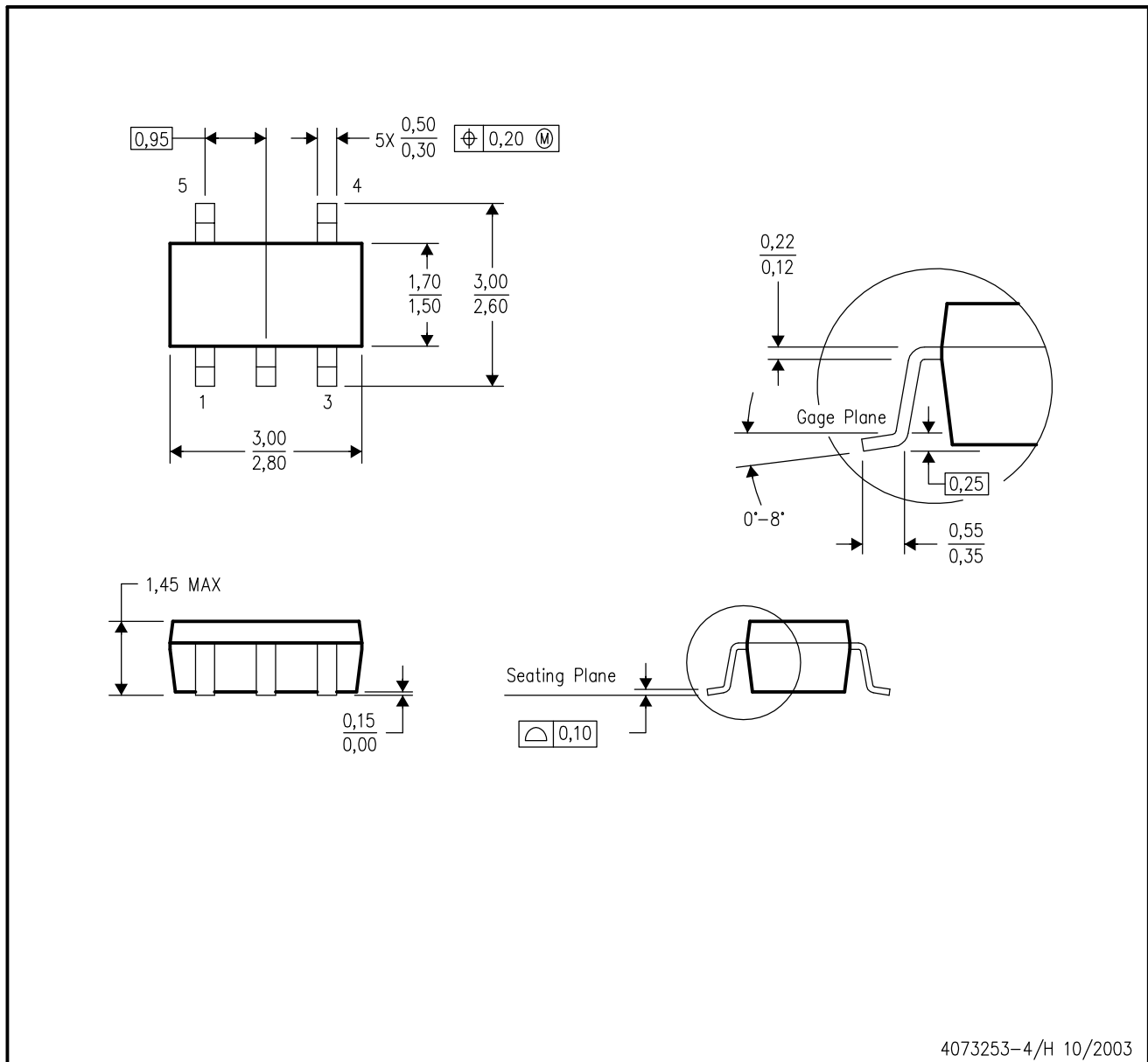
<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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DBV (R-PDSO-G5)

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-178 Variation AA.

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