INA1x9 High-Side Measurement Current Shunt Monitor

1 Features

- Complete Unipolar High-side Current Measurement Circuit
- Wide Supply and Common-Mode Range
- INA139: 2.7 V to 40 V
- INA169: 2.7 V to 60 V
- Independent Supply and Input Common-Mode Voltages
- Single Resistor Gain Set
- Low Quiescent Current: 60 µA (Typical)
- 5-Pin, SOT-23 Packages

2 Applications

- Current Shunt Measurement:
  - Automotive, Telephone, Computers
- Portable and Battery-Backup Systems
- Battery Chargers
- Power Management
- Cell Phones
- Precision Current Source

3 Description

The INA139 and INA169 are high-side, unipolar, current shunt monitors. Wide input common-mode voltage range, high-speed, low quiescent current, and tiny SOT-23 packaging enable use in a variety of applications.

Input common-mode and power-supply voltages are independent and can range from 2.7 V to 40 V for the INA139 and 2.7 V to 60 V for the INA169. Quiescent current is only 60 µA, which permits connecting the power supply to either side of the current measurement shunt with minimal error.

The device converts a differential input voltage to a current output. This current is converted back to a voltage with an external load resistor that sets any gain from 1 to over 100. Although designed for current shunt measurement, the circuit invites creative applications in measurement and level shifting.

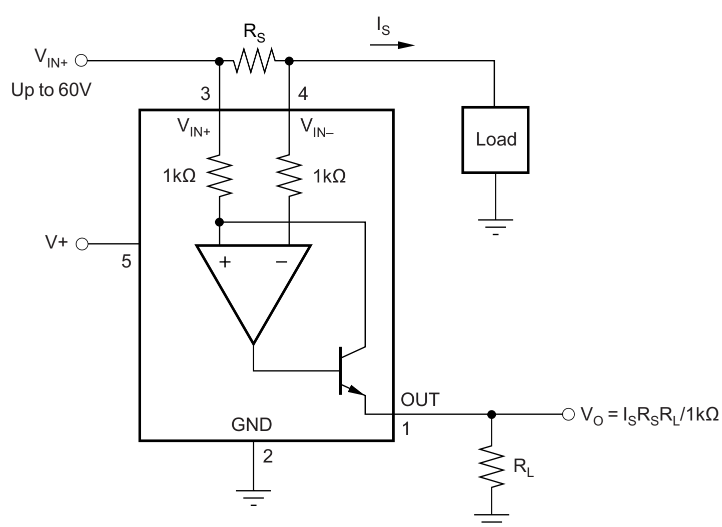
Both the INA139 and INA169 are available in 5-pin SOT-23 packages, and are specified for the –40°C to 85°C temperature range.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA139	SOT-23 (5)	2.90 mm × 1.60 mm
INA169		

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application Circuit



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4 Revision History

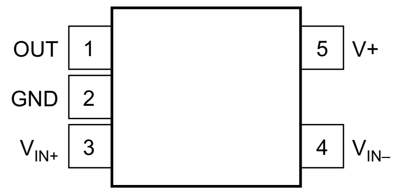
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision D (November 2005) to Revision E **Page**

- Changed *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1

5 Pin Configuration and Functions

DBV Package
5-Pin SOT-23
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
OUT	1	O	Output current
GND	2	—	Ground
VIN+	3	I	Positive input voltage
VIN-	4	I	Negative input voltage
V+	5	I	Power supply voltage

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

			MIN	MAX	UNIT
V+	Supply voltage	INA139	–0.3	60	V
		INA169	–0.3	75	V
V_{IN+}, $V_{IN–}$	Analog inputs, INA139	Common mode[2]	–0.3	60	V
		Differential (V_{IN+}) – ($V_{IN–}$)	–40	2	
	Analog inputs, INA169	Common mode[2]	–0.3	75	V
		Differential (V_{IN+}) – ($V_{IN–}$)	–40	2	
	Analog output, Out[2]		–0.3	40	V
	Input current into any pin			10	mA
	Operating temperature		–55	125	°C
T_J	Junction temperature			150	°C
T_{stg}	Storage temperature		–65	125	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) The input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 10mA.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[1]	±1000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins[2]	±500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

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

	MIN	NOM	MAX	UNIT
INA139				
V+	2.7	5	40	V
Common mode voltage	2.7	12	40	V
INA169				
V+	2.7	5	60	V
Common mode voltage	2.7	12	60	V

6.4 Thermal Information

THERMAL METRIC[1]		INA1x9 DBV (SOT-23) 5 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	168.3	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	73.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	28.1	°C/W
ψ_{JT}	Junction-to-top characterization parameter	2.5	°C/W
ψ_{JB}	Junction-to-board characterization parameter	27.6	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics

All other characteristics at T_A = –40°C to 85°C, V_+ = 5 V, V_{IN+} = 12 V, and R_{OUT} = 25 kΩ, unless otherwise noted.

PARAMETER		TEST CONDITIONS	INA139NA			INA169NA			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
INPUT									
Full-Scale Sense Voltage		$V_{SENSE} = V_{IN+} – V_{IN–}$		100	500		100	500	mV
Common-Mode Input Range			2.7		40	2.7		60	V
Common-Mode Rejection		V_{IN+} = 2.7 V to 40 V, V_{SENSE} = 50 mV V_{IN+} = 2.7 V to 60 V, V_{SENSE} = 50 mV	100	115					dB
Offset Voltage(1) RTI						100	120		dB
				±0.2	±1		±0.2	±1	mV
vs Temperature		T_{MIN} to T_{MAX}		1			1		µV/°C
vs Power Supply, V+		V+ = 2.7 V to 40 V, V_{SENSE} = 50 mV		0.5	10				µV/V
		V+ = 2.7 V to 60 V, V_{SENSE} = 50 mV					0.1	10	
Input Bias Current				10			10		µA
OUTPUT									
Transconductance vs Temperature		V_{SENSE} = 10 mV – 150 mV	990	1000	1010	990	1000	1010	µA/V
		V_{SENSE} = 10 mV,		10			10		nA/°C
Nonlinearity Error		V_{SENSE} = 10 mV to 150 mV		±0.01%	±0.1%		±0.01%	±0.1%	
Total Output Error		V_{SENSE} = 100 mV		±0.5%	±2%		±0.5%	±2%	
Output Impedance				1 || 5			1 || 5		GΩ || pF
Voltage Output	Swing to Power Supply, V+			(V+) – 0.9	(V+) – 1.2		(V+) – 0.9	(V+) – 1.2	V
	Swing to Common Mode, V_{CM}			V_{CM} – 0.6	V_{CM} –1		V_{CM} – 0.6	V_{CM} – 1	V
FREQUENCY RESPONSE									
Bandwidth		R_{OUT} = 10 kΩ		440			440		kHz
		R_{OUT} = 20 kΩ		220			220		kHz
Settling Time (0.1%)		5-V Step, R_{OUT} = 10 kΩ		2.5			2.5		µs
		5-V Step, R_{OUT} = 20 kΩ		5			5		µs
NOISE									
Output-Current Noise Density				20			20		pA/√Hz
Total Output-Current Noise		BW = 100 kHz		7			7		nA RMS
POWER SUPPLY									
Operating Range, V+			2.7		40	2.7		60	V
Quiescent Current		$V_{SENSE} = 0$, $I_O = 0$		60	125		60	125	µA
TEMPERATURE RANGE									
Specification, T_{MIN} to T_{MAX}			–40		85	–40		85	°C
Operating			–55		125	–55		125	°C
Storage			–65		150	–65		150	°C
Thermal Resistance, θ_{JA}				200			200		°C/W

(1) Defined as the amount of input voltage, V_{SENSE}, to drive the output to zero.

6.6 Typical Characteristics

At T_A = 25°C, V+ = 5 V, V_{IN+} = 12 V, and R_L = 125 kΩ, unless otherwise noted.

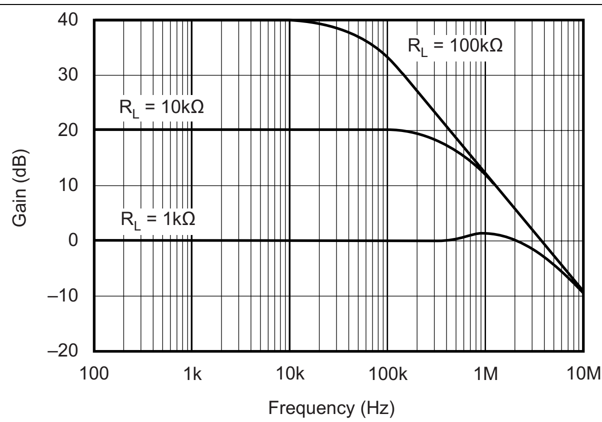


Figure 1. Gain vs Frequency

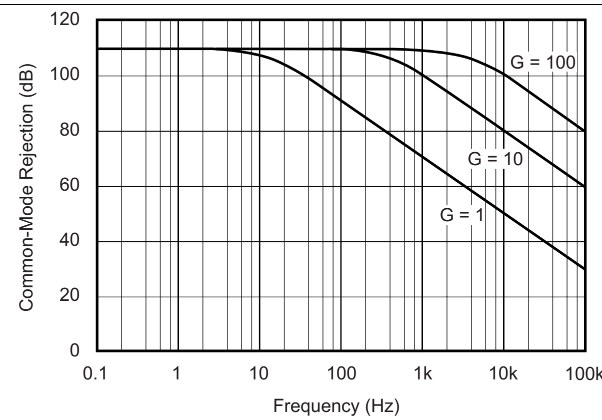


Figure 2. Common-Mode Rejection vs Frequency

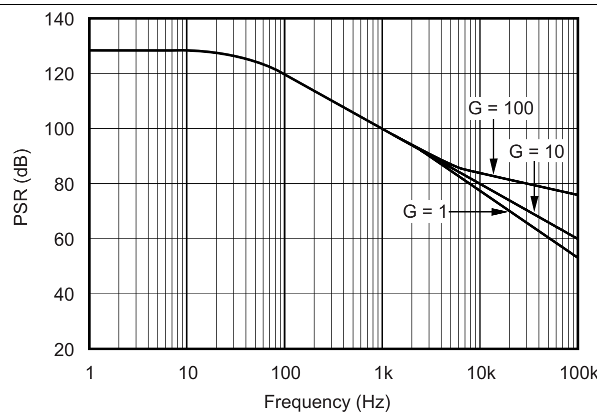


Figure 3. Power-Supply Rejection vs Frequency

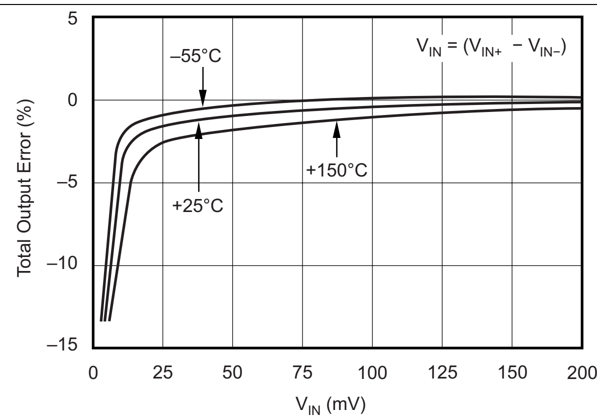


Figure 4. Total Output Error vs V_{IN}

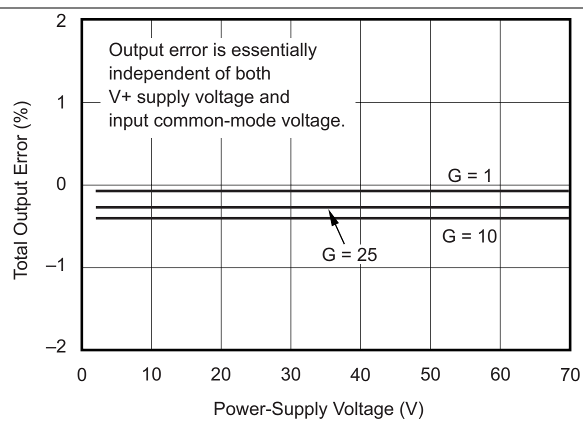


Figure 5. Total Output Error vs Power-Supply Voltage

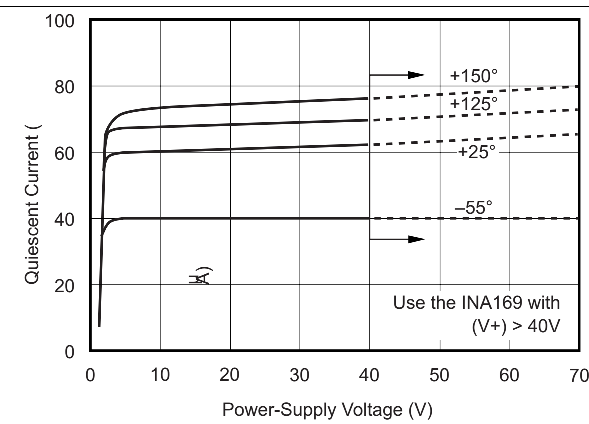


Figure 6. Quiescent Current vs Power-Supply Voltage

Typical Characteristics (continued)

At T_A = 25°C, V+ = 5 V, V_{IN+} = 12 V, and R_L = 125 kΩ, unless otherwise noted.

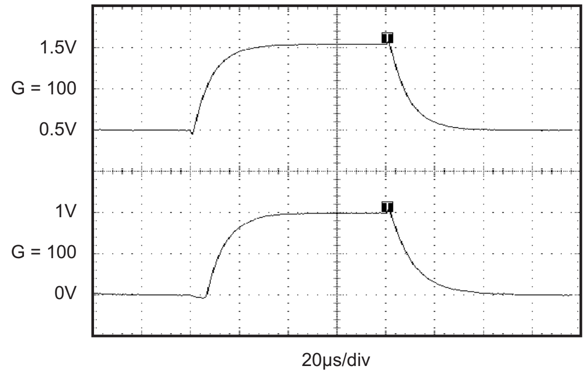


Figure 7. Step Response

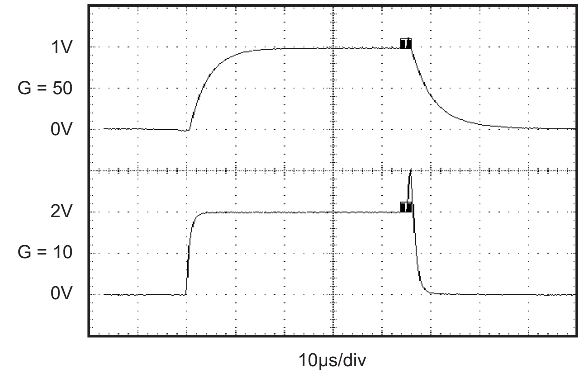


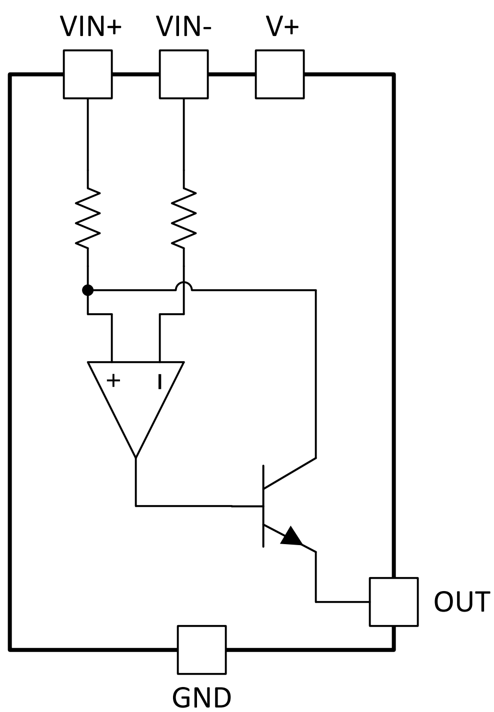
Figure 8. Step Response

7 Detailed Description

7.1 Overview

The INA139 and INA169 devices are comprised of a high voltage, precision operational amplifier, precision thin film resistors trimmed in production to an absolute tolerance and a low noise output transistor. The INA139 and INA169 devices can be powered from a single power supply and their input voltages can exceed the power supply voltage. The INA139 and INA169 devices are ideal for measuring small differential voltages, such as those generated across a shunt resistor in the presence of large, common-mode voltages. See *Functional Block Diagram*, which illustrates the functional components within both the INA139 and INA169 devices.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Output Voltage Range

The output of the INA139 is a current, which is converted to a voltage by the load resistor, R_L. The output current remains accurate within the *compliance voltage range* of the output circuitry. The shunt voltage and the input common-mode and power-supply voltages limit the maximum possible output swing. The maximum output voltage compliance is limited by the lower of Equation 1 and Equation 2.

$$V_{out\ max} = (V+) - 0.7\ V - (V_{IN+} - V_{IN-}) \quad (1)$$

or

$$V_{out\ max} = V_{IN-} - 0.5\ V \quad (2)$$

(whichever is lower)

7.3.2 Bandwidth

Measurement bandwidth is affected by the value of the load resistor, R_L. High gain produced by high values of R_L will yield a narrower measurement bandwidth (see *Typical Characteristics*). For widest possible bandwidth, keep the capacitive load on the output to a minimum. Reduction in bandwidth due to capacitive load is shown in the *Typical Characteristics*.

Feature Description (continued)

If bandwidth limiting (filtering) is desired, a capacitor can be added to the output (see Figure 12). This will not cause instability.

7.4 Device Functional Modes

For proper operation the INA139 and INA169 devices must operate within their specified limits. Operating either device outside of their specified power supply voltage range or their specified common-mode range will result in unexpected behavior and is not recommended. Additionally operating the output beyond their specified limits with respect to power supply voltage and input common-mode voltage will also produce unexpected results. See *Electrical Characteristics* for the device specifications.

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

8.1.1 Operation

Figure 9 illustrates the basic circuit diagram for both the INA139 and INA169. Load current I_S is drawn from supply V_S through shunt resistor R_S. The voltage drop in shunt resistor V_S is forced across R_{G1} by the internal operational amplifier, causing current to flow into the collector of Q1. The external resistor R_L converts the output current to a voltage, V_{OUT}, at the OUT pin.

The transfer function for the INA139 is given by Equation 3:

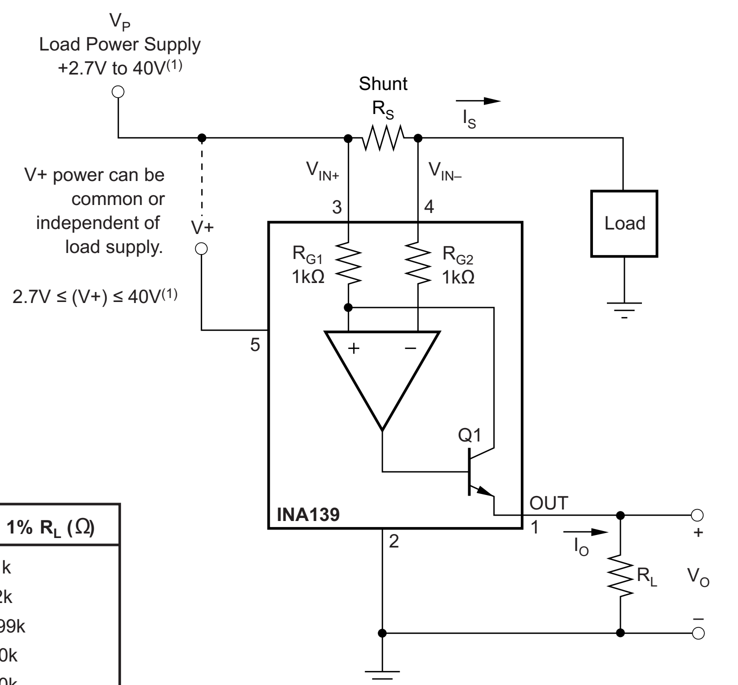
$$I_O = g_m(V_{IN+} - V_{IN-}) \quad (3)$$

where g_m = 1000 µA/V.

In the circuit of Figure 9, the input voltage, ($V_{IN+} - V_{IN-}$), is equal to $I_S \times R_S$ and the output voltage, V_{OUT}, is equal to $I_O \times R_L$. The transconductance, g_m, of the INA139 is 1000 µA/V. The complete transfer function for the current measurement amplifier in this application is given by Equation 4:

$$V_{OUT} = (I_S)\,(R_S)\,(1000\ \mu A/V)\,(R_L) \quad (4)$$

The maximum differential input voltage for accurate measurements is 0.5 V, which produces a 500-µA output current. A differential input voltage of up to 2 V will not cause damage. Differential measurements (pins 3 and 4) must be unipolar with a more-positive voltage applied to pin 3. If a more-negative voltage is applied to pin 3, the output current, I_O, is zero, but it will not cause damage.



VOLTAGE GAIN	EXACT R_L (Ω)	NEAREST 1% R_L (Ω)
1	1k	1k
2	2k	2k
5	5k	4.99k
10	10k	10k
20	20k	20k
50	50k	49k
100	100k	100k

NOTE: (1) Maximum V_P and V+ voltage is 60V with the INA169.

Figure 9. Basic Circuit Connections

8.2 Typical Applications

The INA139 is designed for current shunt measurement circuits, as shown in Figure 9, but its basic function is useful in a wide range of circuitry. A creative engineer will find many unforeseen uses in measurement and level shifting circuits. A few ideas are illustrated in Figure 14 through Figure 18.

8.2.1 Buffering Output to Drive an ADC

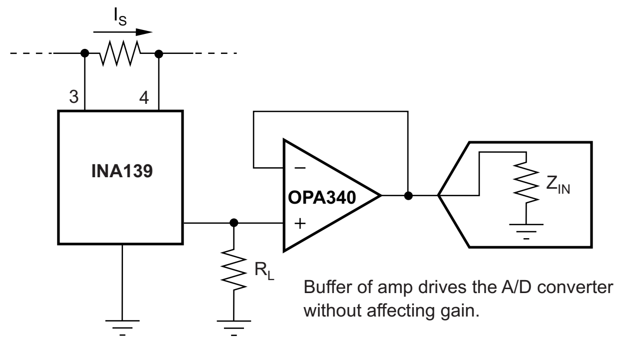


Figure 10. Buffering Output to Drive the A/D Converter

8.2.1.1 Design Requirements

Digitize the output of the INA139 or INA169 devices using a 1-MSPS analog-to-digital converter (ADC).

8.2.1.2 Detailed Design Procedure

8.2.1.2.1 Selecting R_S and R_L

In Figure 9 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 of 50 mV to 100 mV; maximum input voltage for accurate measurements is 500 mV.

R_L is chosen to provide the desired full-scale output voltage. The output impedance of the INA139 and INA169 OUT terminal is very high, which permits using values of R_L up to 100 kΩ with excellent accuracy. The input impedance of any additional circuitry at the output must be much higher than the value of RL to avoid degrading accuracy.

Some Analog-to-Digital converters (ADC) have input impedances that will significantly affect measurement gain. The input impedance of the ADC can be included as part of the effective R_L if its input can be modeled as a resistor to ground. Alternatively, an operational amplifier can be used to buffer the ADC input, as shown in Figure 10. The INA139 and INA169 are current output devices, and as such have an inherently large output impedance. The output currents from the amplifier are converted to an output voltage through the load resistor, R_L, connected from the amplifier output to ground. The ratio of the load resistor value to that of the internal resistor value determines the voltage gain of the system.

In many applications digitizing the output of the INA139 or INA169 devices is required. This is accomplished by connecting the output of the amplifier to an ADC. It is very common for an ADC to have a dynamic input impedance. If the INA139 or INA169 output is connected directly to an ADC input, the input impedance of the ADC is effectively connected in parallel with the gain setting resistor R_L. This parallel impedance combination will affect the gain of the system and the impact on the gain is difficult to estimate accurately. A simple solution that eliminates the paralleling of impedances, simplifying the gain of the circuit is to place a buffer amplifier, such as the OPA340, between the output of the INA139 or INA169 devices and the input to the ADC.

Typical Applications (continued)

Figure 10 illustrates this concept. A low pass filter can be placed between the OPA340 output and the input to the ADC. The filter capacitor is required to provide any instantaneous demand for current required by the input stage of the ADC. The filter resistor is required to isolate the OPA340 output from the filter capacitor to maintain circuit stability. The values for the filter components will vary according to the operational amplifier used for the buffer and the particular ADC selected. More information can be found regarding the design of the low pass filter in the TI Precision Design *16-bit 1-MSPS Data Acquisition Reference Design for Single-Ended Multiplexed Applications*, TIPD173.

Figure 11 shows the expected results when driving an analog-to-digital converter at 1 MSPS with and without buffering the INA139 or INA169 output. Without the buffer, the high impedance of the INA139 or INA169 will react with the input capacitance and sample and hold (S/H) capacitance of the analog-to-digital converter and will not allow the S/H to reach the correct final value before it is reset and the next conversion starts. Adding the buffer amplifier significantly reduces the output impedance driving the S/H and allows for higher conversion rates than can be achieved without adding the buffer.

8.2.1.3 Application Curve

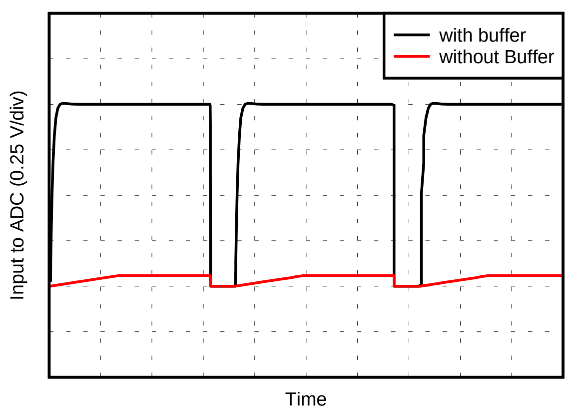


Figure 11. Driving an ADC With and Without a Buffer

8.2.2 Output Filter

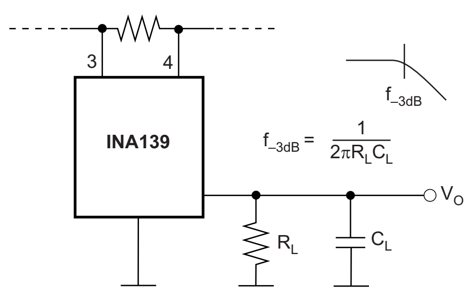


Figure 12. Output Filter

8.2.2.1 Design Requirements

Filter the output of the INA139 or INA169 devices.

8.2.2.2 Detailed Design Procedure

A low-pass filter can be formed at the output of the INA139 or INA169 devices simply by placing a capacitor of the desired value in parallel with the load resistor. First determine the value of the load resistor needed to achieve the desired gain. See the table in Figure 9. Next, determine the capacitor value that will result in the desired cutoff frequency according to the equation shown in Figure 12. Figure 13 illustrates various combinations of gain settings (determined by R_L) and filter capacitors.

Typical Applications (continued)

8.2.2.3 Application Curve

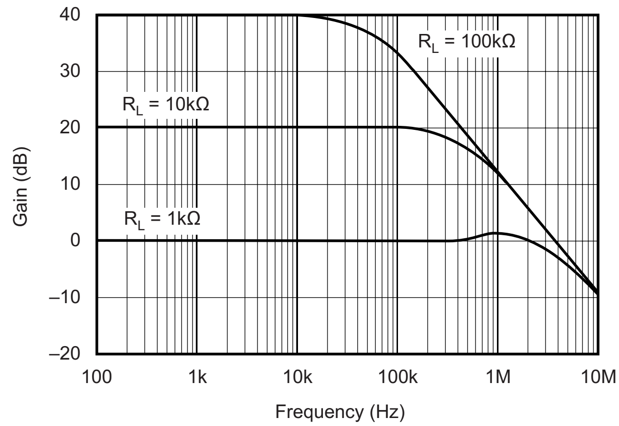


Figure 13. Gain vs Frequency

8.2.3 Offsetting the Output Voltage

For many applications using only a single power supply it may be required to level shift the output voltage away from ground when there is no load current flowing in the shunt resistor. Level shifting the output of the INA139 or INA169 devices is easily accomplished by one of two simple methods shown in Figure 14. The method on the left hand side of Figure 14 illustrates a simple voltage divider method. This method is useful for applications that require the output of the INA138 or INA168 devices to remain centered with respect to the power supply at zero load current through the shunt resistor. Using this method the gain is determine by the parallel combination of R_1 and R_2 while the output offset is determined by the voltage divider ratio R_1 and R_2. For applications that may require a fixed value of output offset, independent of the power supply voltage, the current source method shown on the right-hand side of Figure 14 is recommended. With this method a REF200 constant current source is used to generate a constant output offset. Using his method the gain is determined by R_L and the offset is determined by the product of the value of the current source and R_L.

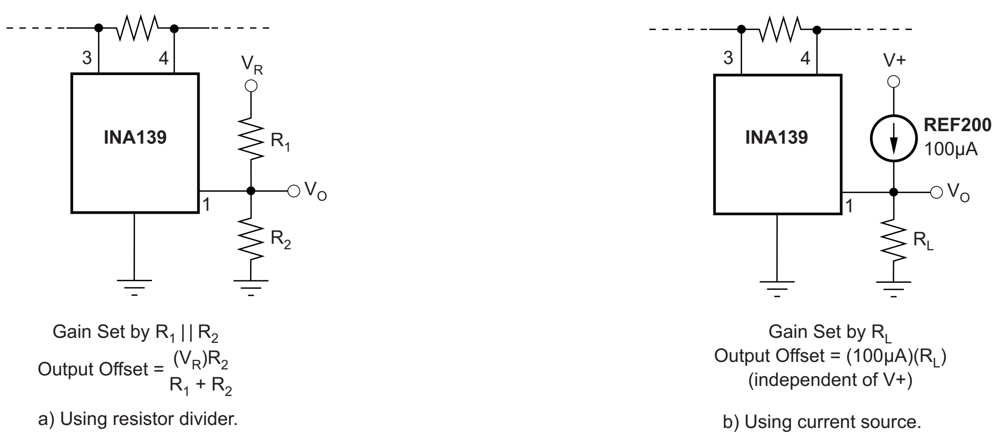


Figure 14. Offsetting the Output Voltage

Typical Applications (continued)

8.2.4 Bipolar Current Measurement

The INA139 or INA169 devices can be configured as shown in Figure 15 in applications where measuring current bi-directionally is required. Two INA devices are required connecting their inputs across the shunt resistor as shown in Figure 15. A comparator, such as the TLV3201, is used to detect the polarity of the load current. The magnitude of the load current is monitored across the resistor connected between ground and the connection labeled *Output*. In this example the 20-kΩ resistor results in a gain of 20 V/V. The 10-kΩ resistors connected in series with the INA139 or INA169 output current are used to develop a voltage across the comparator inputs. Two diodes are required to prevent current flow into the INA139 or INA169 output, as only one device at a time is providing current to the *Output* connection of the circuit. The circuit functionality is illustrated in Figure 16.

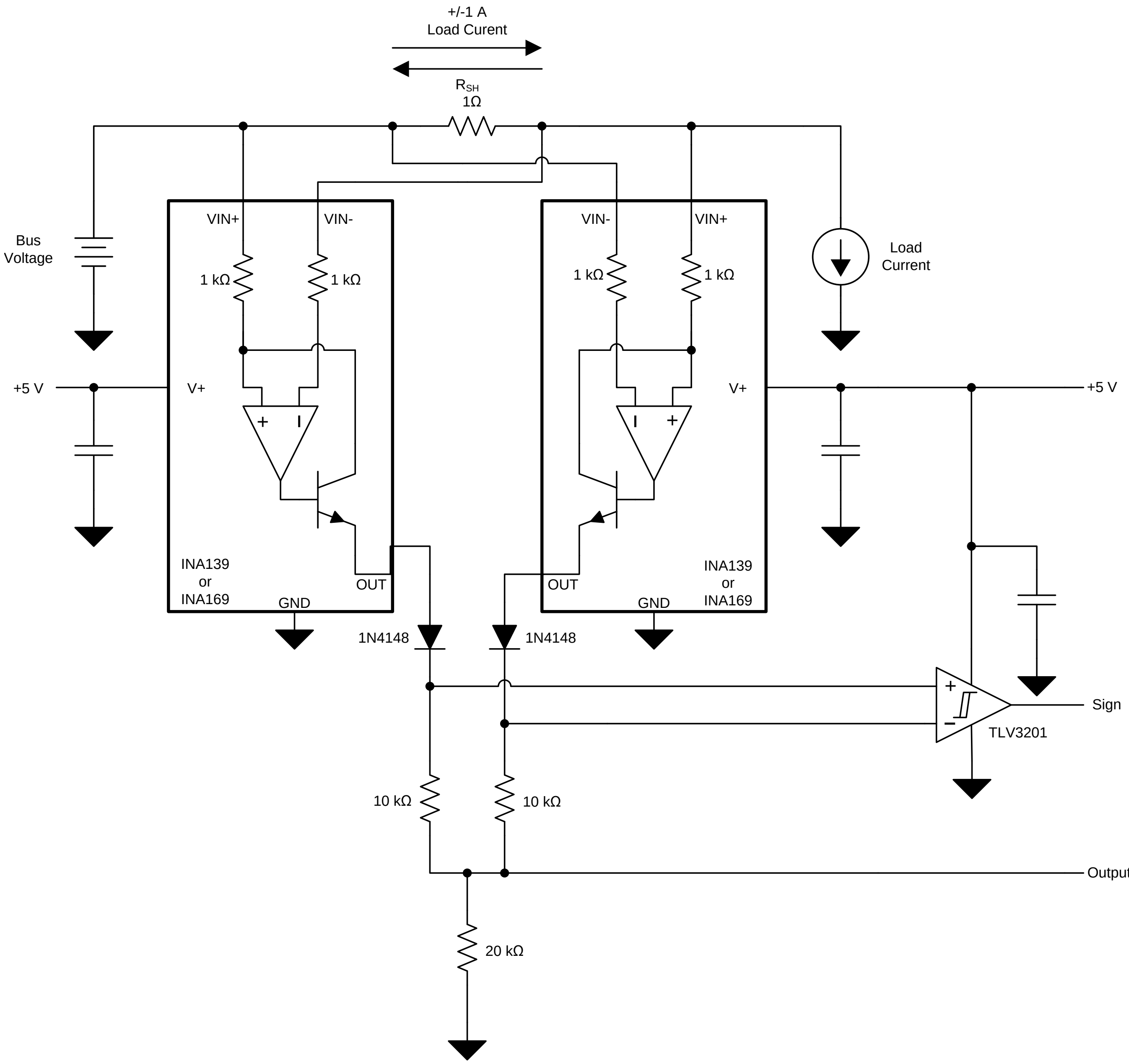


Figure 15. Bipolar Current Measurement

Typical Applications (continued)

8.2.4.1 Application Curve

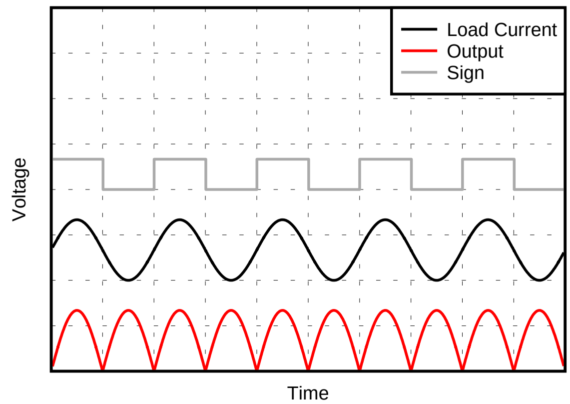


Figure 16. Bipolar Current Measurement Results (Arbitrary Scale)

8.2.5 Bipolar Current Measurement Using a Differential Input of the A/D Converter

The INA139 or INA169 devices can be used with an ADC such as the ADS7870 programmed for differential mode operation. Figure 17 illustrates this configuration. In this configuration, the use of two INAs allows for bi-directional current measurement. Depending upon the polarity of the current, one of the INAs will provide an output voltage while the other output is zero. In this way the ADC will read the polarity of current directly, without the need for additional circuitry.

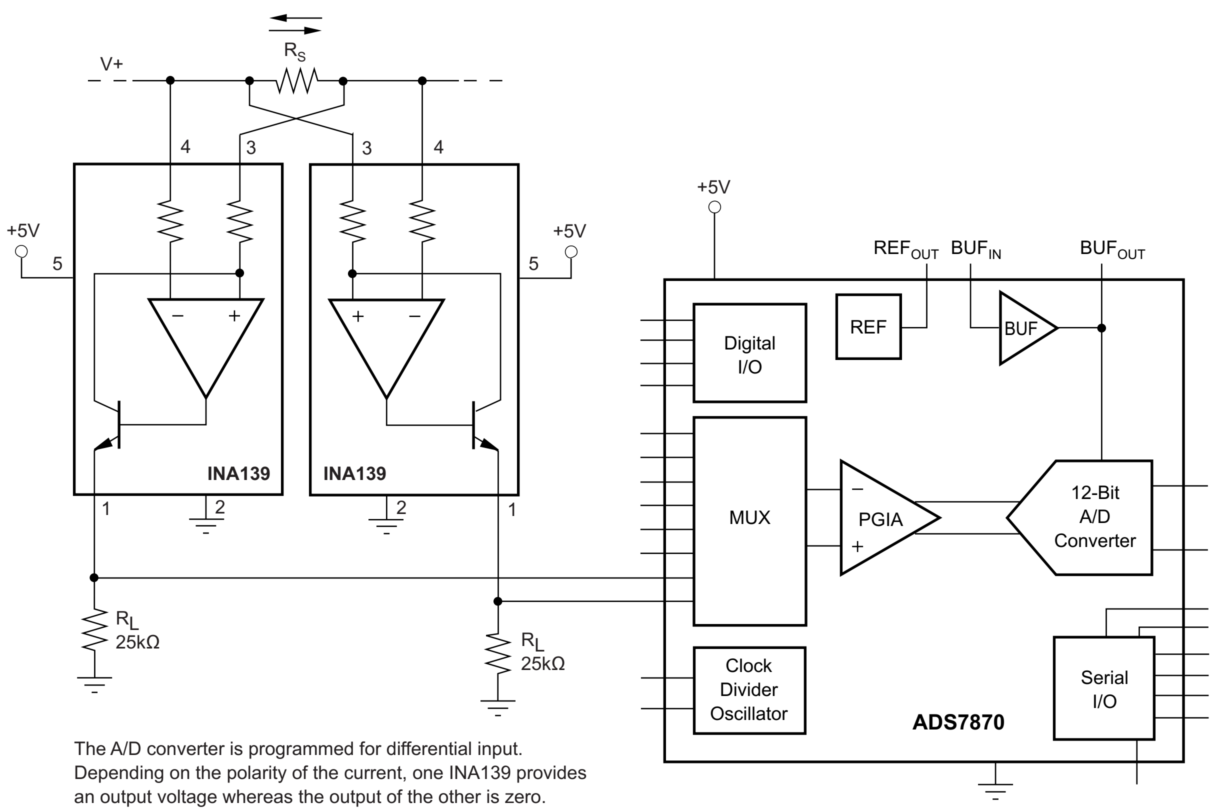


Figure 17. Bipolar Current Measurement Using a Differential Input of the A/D Converter

Typical Applications (continued)

8.2.6 Multiplexed Measurement Using Logic Signal for Power

Multiple loads can be measured as illustrated in Figure 18. In this configuration each INA139 or INA169 device is powered by the Digital I/O from the ADS7870. Multiplexing is achieved by switching on or off each the desired I/O.

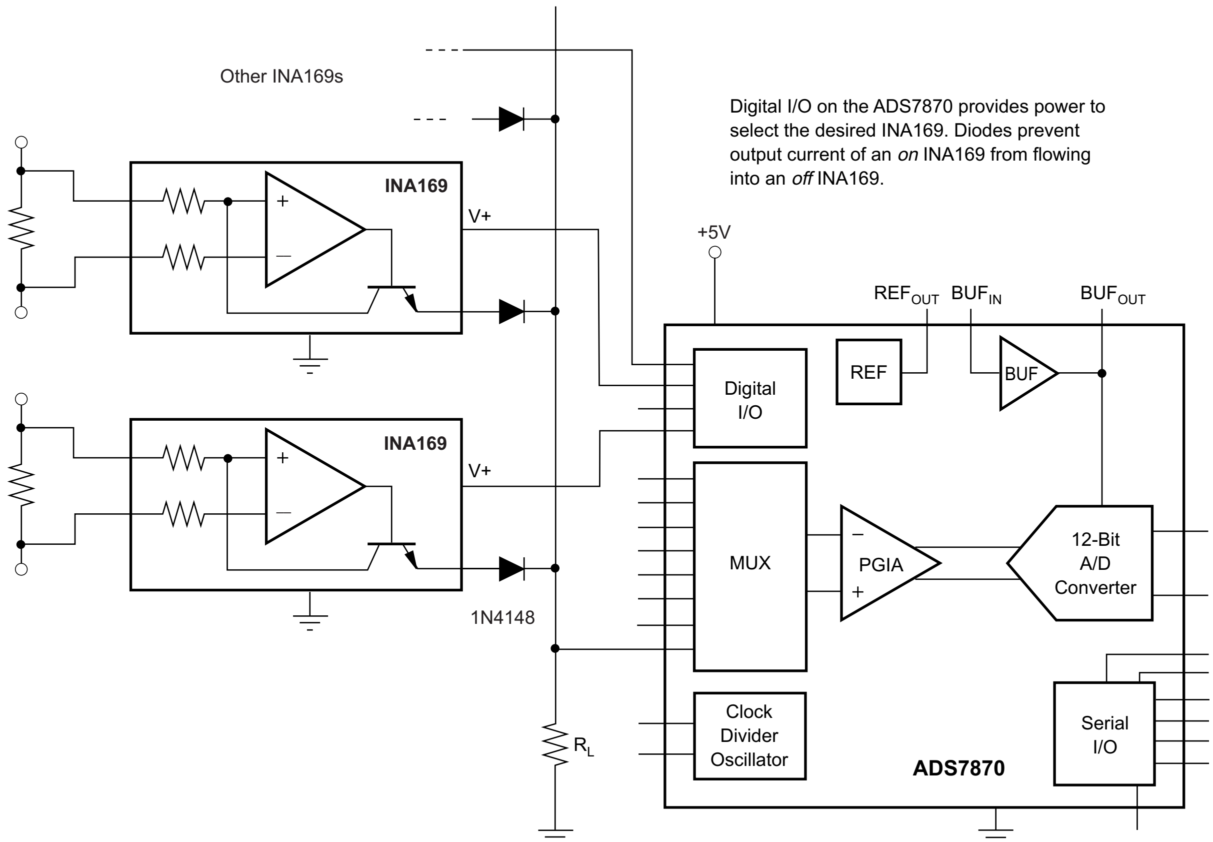


Figure 18. Multiplexed Measurement Using Logic Signal for Power

9 Power Supply Recommendations

The input circuitry of the INA139 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 40 V (or 60 V with the INA169). However, the output voltage range of the OUT terminal is limited by the lesser of the two voltages (see *Output Voltage Range*). TI recommends placing a 0.1-µF capacitor near the V+ pin on the INA139 or INA169. Additional capacitance may be required for applications with noisy supply voltages.

10 Layout

10.1 Layout Guidelines

Figure 19 shows the basic connection of the INA139. The input pins, V_{IN+} and $V_{IN–}$, must be connected as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistance. The output resistor, R_L, is shown connected between pin 1 and ground. Best accuracy is achieved with the output voltage measured directly across R_L. This is especially important in high-current systems where load current could flow in the ground connections, affecting the measurement accuracy.

No power-supply bypass capacitors are required for stability of the INA139. However, applications with noisy or high-impedance power supplies may require decoupling capacitors to reject power-supply noise; connect the bypass capacitors close to the device pins.

10.2 Layout Example

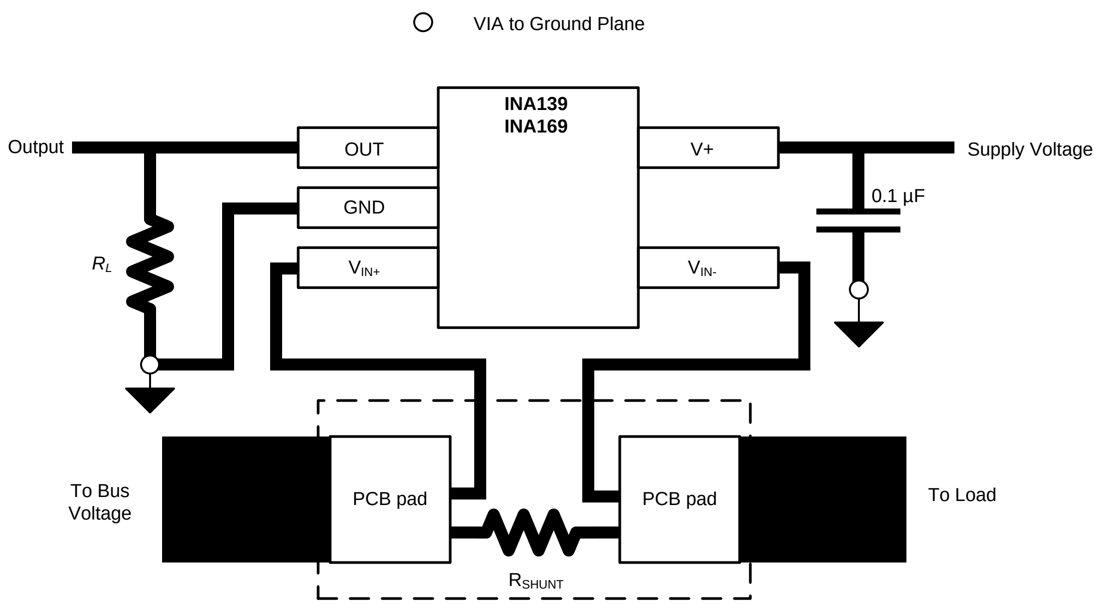


Figure 19. Typical Layout Example

11 Device and Documentation Support

11.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 1. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
INA139	Click here	Click here	Click here	Click here	Click here
INA169	Click here	Click here	Click here	Click here	Click here

11.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.3 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.4 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

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DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
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