

## INA1x8 高侧测量电流分流监视器

### 1 特性

- 完整的单极高侧电流测量电路
- 宽电源和共模范围
- INA138: 2.7V 至 36V
- INA168: 2.7V 至 60V
- 独立电源和输入共模电压
- 单电阻增益设定
- 低静态电流: 25 $\mu$ A (典型值)
- 宽温度范围: -40°C 至 +125°C
- 5 引脚小外形尺寸晶体管 (SOT)-23 封装

### 2 应用

- 分流测量:
  - 电话、计算机
- 便携式和备用电池系统
- 电池充电器
- 电源管理
- 手机
- 精密电流源

### 3 说明

INA138 和 INA168 (INA1x8) 是高侧单极电流分流监视器。此类器件兼具宽输入共模电压范围和低静态电流, 并且采用小型 SOT-23 封装, 广泛适用于各类应用而设计。

输入共模和电源电压相互独立, INA138 的电压范围为 2.7V 至 36V, INA168 的电压范围为 2.7V 至 60V。静态电流仅为 25 $\mu$ A, 允许电源连接到电流测量分流器的任一侧, 同时误差非常小。

该器件可将一个差分输入电压转换为电流输出。此电流使用外部负载电阻转换回电压, 该电阻可设置的增益范围为 1 至 100 以上。尽管该电路专为分流测量而设计, 但同时也非常适用于创造性应用中的测量和电平转换。

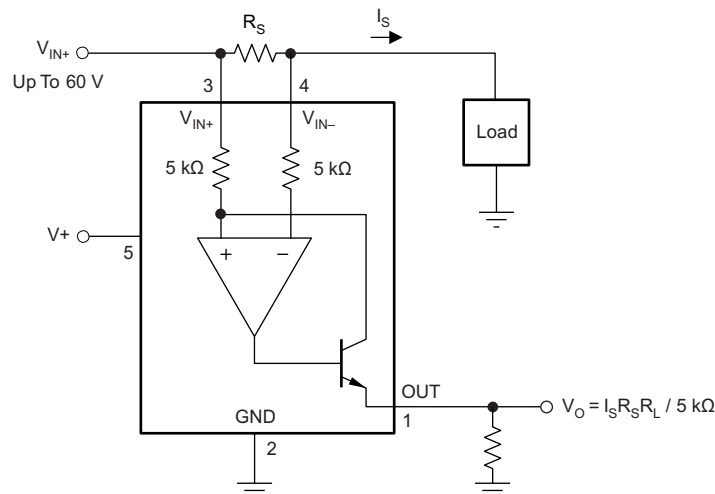
INA138 和 INA168 均采用 SOT23-5 封装, 额定温度范围为 -40°C 至 125°C。

器件信息<sup>(1)</sup>

| 器件型号   | 封装         | 封装尺寸 (标称值)      |
|--------|------------|-----------------|
| INA138 | SOT-23 (5) | 2.90mm × 1.60mm |
| INA168 |            |                 |

(1) 要了解所有可用封装, 请见数据表末尾的封装选项附录。

典型应用电路



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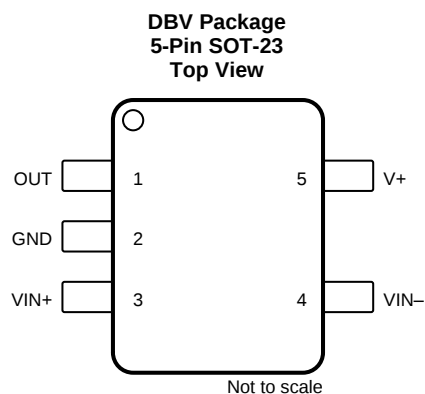
## 4 修订历史记录

注：之前版本的页码可能与当前版本有所不同。

| Changes from Revision D (December 2014) to Revision E                                                                                                                          | Page |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| • 已添加 在首页顶部导航栏添加了参考设计链接                                                                                                                                                        | 1    |
| • 已更改 在器件信息表中将封装尺寸从 18.00mm × 18.00mm 更改成了 2.90mm × 1.60mm                                                                                                                     | 1    |
| • Changed pin numbers in pin functions table to match pin configuration figure                                                                                                 | 3    |
| • Changed <i>Absolute Maximum Ratings</i> table for clarity; no values were changed                                                                                            | 4    |
| • Changed <i>Recommended Operating Conditions</i> table; moved some content from <i>Electrical Characteristics</i> table, but no values changed                                | 4    |
| • Changed all values in Thermal Information table                                                                                                                              | 5    |
| • Changed <i>Electrical Characteristics</i> table; reformatted for clarity; moved some content to <i>Recommended Operating Conditions</i> table, and deleted duplicate content | 5    |
| • Changed common-mode rejection test conditions to better highlight each device in <i>Electrical Characteristics</i> table                                                     | 5    |
| • Changed offset voltage vs temperature to offset voltage drift in <i>Electrical Characteristics</i> table                                                                     | 5    |
| • Changed offset voltage vs power supply test conditions to better highlight each device in <i>Electrical Characteristics</i> table                                            | 5    |
| • Changed reference in text from Figure 10 to Figure 11 in last paragraph of <i>Selecting the Shunt Resistor and <math>R_L</math></i> section                                  | 12   |

| Changes from Revision C (November 2005) to Revision D                                 | Page |
|---------------------------------------------------------------------------------------|------|
| • 已添加 <i>ESD</i> 额定值表，特性 描述 部分，器件功能模式，应用和实施部分，电源相关建议部分，布局部分，器件和文档支持部分以及机械、封装和可订购信息部分。 | 1    |

## 5 Pin Configuration and Functions



### Pin Functions

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

## 6 Specifications

### 6.1 Absolute Maximum Ratings

 over operating free-air temperature range (unless otherwise noted) <sup>(1)</sup>

|             |                                                   |        |                                                                            | MIN  | MAX | UNIT |
|-------------|---------------------------------------------------|--------|----------------------------------------------------------------------------|------|-----|------|
| Voltage     | Supply, V+                                        | INA138 |                                                                            | −0.3 | 60  | V    |
|             |                                                   | INA168 |                                                                            | −0.3 | 75  |      |
|             | Analog input, V <sub>IN+</sub> , V <sub>IN−</sub> | INA138 | Common mode <sup>(2)</sup>                                                 | −0.3 | 60  |      |
|             |                                                   |        | Sense voltage, V <sub>SENSE</sub> = (V <sub>IN+</sub> − V <sub>IN−</sub> ) | −40  | 2   |      |
|             |                                                   | INA168 | Common mode <sup>(2)</sup>                                                 | −0.3 | 75  |      |
|             |                                                   |        | Sense voltage, V <sub>SENSE</sub> = (V <sub>IN+</sub> − V <sub>IN−</sub> ) | −40  | 2   |      |
|             | Analog output, OUT pin <sup>(2)</sup>             |        |                                                                            | −0.3 | 40  |      |
| Current     | Input current into any pin                        |        |                                                                            | 10   | mA  |      |
| Temperature | Operating, T <sub>A</sub>                         |        |                                                                            | −55  | 150 | °C   |
|             | Junction, T <sub>J</sub>                          |        |                                                                            | 150  |     |      |
|             | Storage, T <sub>stg</sub>                         |        |                                                                            | −65  | 150 |      |

- (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 10 mA.

### 6.2 ESD Ratings

|                    |                         |                                                                                | VALUE | UNIT |
|--------------------|-------------------------|--------------------------------------------------------------------------------|-------|------|
| V <sub>(ESD)</sub> | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±1000 | V    |
|                    |                         | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±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 |
|--------------------|-----------------------------------------------------------------|-----|-----|-----|------|
| <b>INA138</b>      |                                                                 |     |     |     |      |
| V <sub>+</sub>     | Supply voltage                                                  | 2.7 | 5   | 36  | V    |
| V <sub>SENSE</sub> | Full-scale sense voltage (V <sub>IN+</sub> – V <sub>IN–</sub> ) |     | 100 | 500 | mV   |
|                    | Common-mode voltage                                             | 2.7 | 12  | 36  | V    |
| T <sub>A</sub>     | Operating temperature                                           | –40 | 25  | 125 | °C   |
| <b>INA168</b>      |                                                                 |     |     |     |      |
| V <sub>+</sub>     | Supply voltage                                                  | 2.7 | 5   | 60  | V    |
| V <sub>SENSE</sub> | Full-scale sense voltage (V <sub>IN+</sub> – V <sub>IN–</sub> ) |     | 100 | 500 | mV   |
|                    | Common-mode voltage                                             | 2.7 | 12  | 60  | V    |
| T <sub>A</sub>     | Operating temperature                                           | –40 | 25  | 125 | °C   |

## 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | INA1x8 | UNIT |
|-------------------------------|----------------------------------------------|--------|------|
|                               |                                              | DBV    |      |
|                               |                                              | 5 PINS |      |
| $R_{\theta JA}$               | 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 |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 2.5    | °C/W |
| $\Psi_{JB}$                   | 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.

## 6.5 Electrical Characteristics

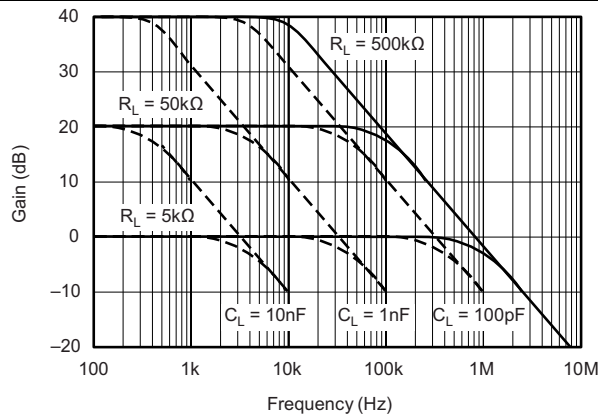
all other characteristics at  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{ V}$ ,  $V_{IN+} = 12\text{ V}$ , and  $R_{OUT} = 125\text{ k}\Omega$  (unless otherwise noted)

| PARAMETER                               | TEST CONDITIONS                                                                                   |                                                              | INA1x8 |                       |                       | UNIT                               |
|-----------------------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------|--------|-----------------------|-----------------------|------------------------------------|
|                                         |                                                                                                   |                                                              | MIN    | TYP                   | MAX                   |                                    |
| INPUT                                   |                                                                                                   |                                                              |        |                       |                       |                                    |
| Common-mode rejection                   | $V_{\text{SENSE}} = 50\text{ mV}$                                                                 | INA138, $V_{\text{IN}+} = 2.7\text{ V to }36\text{ V}$       | 100    | 120                   |                       | dB                                 |
|                                         |                                                                                                   | INA168, $V_{\text{IN}+} = 2.7\text{ V to }60\text{ V}$       | 100    | 120                   |                       |                                    |
| Offset voltage <sup>(1)</sup>           | $T_{\text{A}} = 25^{\circ}\text{C}$                                                               |                                                              |        | $\pm 0.2$             | $\pm 1$               | mV                                 |
|                                         | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$                                      |                                                              |        |                       | $\pm 2$               |                                    |
| Offset voltage drift <sup>(1)</sup>     | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$                                      |                                                              |        | 1                     |                       | $\mu\text{V}/^{\circ}\text{C}$     |
| Offset voltage vs power supply, $V_{+}$ | $V_{\text{SENSE}} = 50\text{ mV}$                                                                 | INA138, $V_{+} = 2.7\text{ V to }36\text{ V}$                |        | 0.1                   | 10                    | $\mu\text{V/V}$                    |
|                                         |                                                                                                   | INA168, $V_{+} = 2.7\text{ V to }60\text{ V}$                |        | 0.1                   | 10                    |                                    |
| Input bias current                      | $T_{\text{A}} = 25^{\circ}\text{C}$                                                               |                                                              |        | 2                     |                       | $\mu\text{A}$                      |
|                                         | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$ , INA138                             |                                                              |        |                       | 10                    |                                    |
| OUTPUT                                  |                                                                                                   |                                                              |        |                       |                       |                                    |
| Transconductance                        | $V_{\text{SENSE}} = 10\text{ mV to }150\text{ mV}$ , $T_{\text{A}} = 25^{\circ}\text{C}$          |                                                              | 198    | 200                   | 202                   | $\mu\text{A/V}$                    |
|                                         | $V_{\text{SENSE}} = 100\text{ mV}$ , $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$ |                                                              | 196    |                       | 204                   | $\mu\text{A/V}$                    |
| Transconductance drift                  | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$                                      |                                                              |        | 10                    |                       | $\text{nA}/^{\circ}\text{C}$       |
| Nonlinearity error                      | $V_{\text{SENSE}} = 10\text{ mV to }150\text{ mV}$                                                |                                                              |        | $\pm 0.01\%$          | $\pm 0.1\%$           |                                    |
| Total output error                      | $V_{\text{SENSE}} = 100\text{ mV}$                                                                | $T_{\text{A}} = 25^{\circ}\text{C}$                          |        | $\pm 0.5\%$           | $\pm 2\%$             |                                    |
|                                         |                                                                                                   | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$ |        | $\pm 2.5\%$           |                       |                                    |
| Output impedance                        |                                                                                                   |                                                              |        | $1\parallel 5$        |                       | $\text{G}\Omega\parallel\text{pF}$ |
| Voltage output swing                    | To power supply voltage, $V_{+}$                                                                  |                                                              |        | $(V_{+}) - 0.8$       | $(V_{+}) - 1.0$       | V                                  |
|                                         | To common-mode voltage, $V_{\text{CM}}$                                                           |                                                              |        | $V_{\text{CM}} - 0.5$ | $V_{\text{CM}} - 0.8$ | V                                  |
| FREQUENCY RESPONSE                      |                                                                                                   |                                                              |        |                       |                       |                                    |
| Bandwidth                               | $R_{\text{OUT}} = 5\text{ k}\Omega$                                                               |                                                              |        | 800                   |                       | kHz                                |
|                                         | $R_{\text{OUT}} = 125\text{ k}\Omega$                                                             |                                                              |        | 32                    |                       | kHz                                |
| Settling time                           | To 0.1%                                                                                           | 5-V step, $R_{\text{OUT}} = 5\text{ k}\Omega$                |        | 1.8                   |                       | $\mu\text{s}$                      |
|                                         |                                                                                                   | 5-V step, $R_{\text{OUT}} = 125\text{ k}\Omega$              |        | 30                    |                       | $\mu\text{s}$                      |
| NOISE                                   |                                                                                                   |                                                              |        |                       |                       |                                    |
| Output-current noise density            |                                                                                                   |                                                              |        | 9                     |                       | $\text{pA}/\sqrt{\text{Hz}}$       |
| Total output-current noise              | BW = 100 kHz                                                                                      |                                                              |        | 3                     |                       | nA RMS                             |
| POWER SUPPLY                            |                                                                                                   |                                                              |        |                       |                       |                                    |
| Quiescent current                       | $V_{\text{SENSE}} = 0\text{ V}$ ,<br>$I_{\text{O}} = 0\text{ mA}$                                 | $T_{\text{A}} = 25^{\circ}\text{C}$                          |        | 25                    | 45                    | $\mu\text{A}$                      |
|                                         |                                                                                                   | $T_{\text{A}} = -40^{\circ}\text{C to }+125^{\circ}\text{C}$ |        |                       | 60                    | $\mu\text{A}$                      |

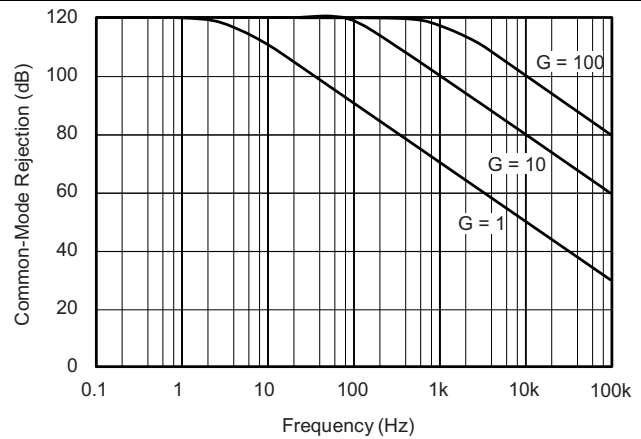
- (1) Defined as the amount of input voltage,  $V_{SENSE}$ , to drive the output to zero.

## 6.6 Typical Characteristics

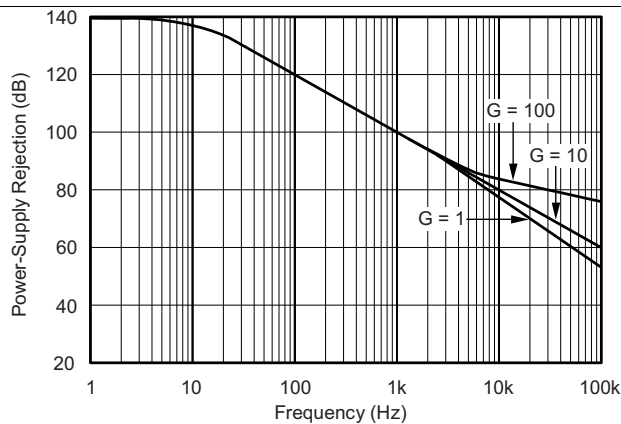
At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{ V}$ ,  $V_{IN+} = 12\text{ V}$ , and  $R_L = 125\text{ k}\Omega$ , unless otherwise noted.



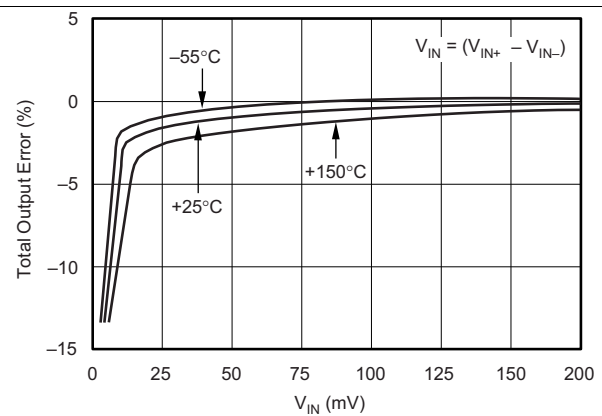
**Figure 1. Gain vs Frequency**



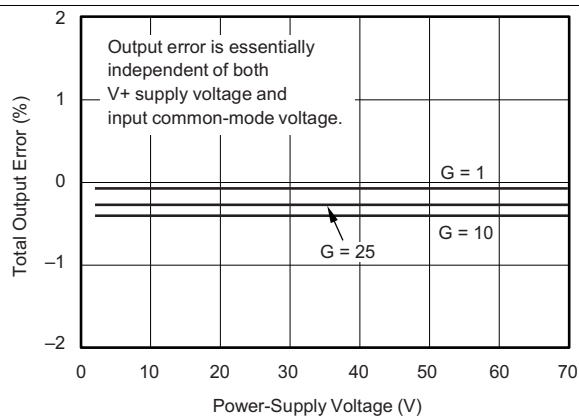
**Figure 2. Common-Mode Rejection vs Frequency**



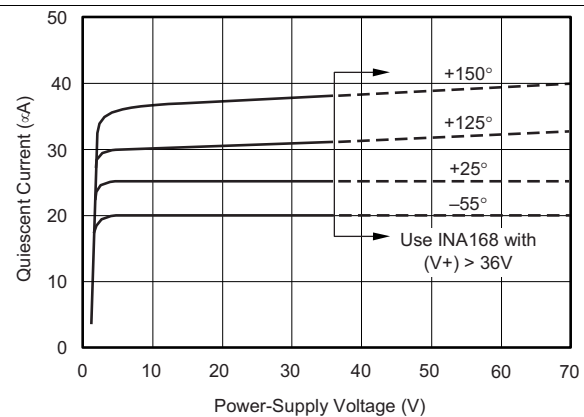
**Figure 3. Power-Supply Rejection vs Frequency**



**Figure 4. Total Output Error vs  $V_{IN}$**



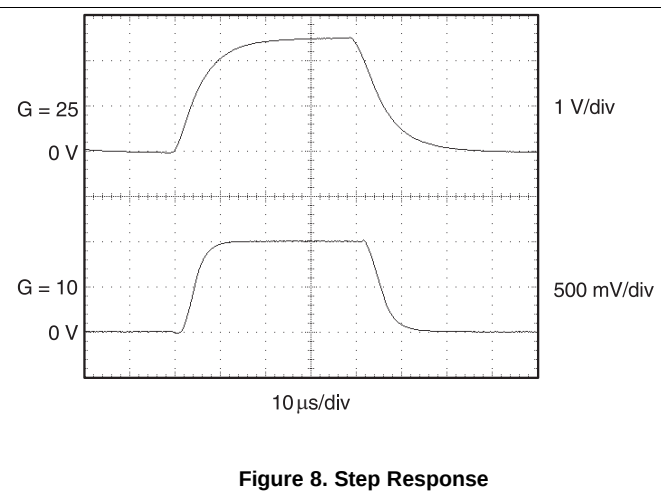
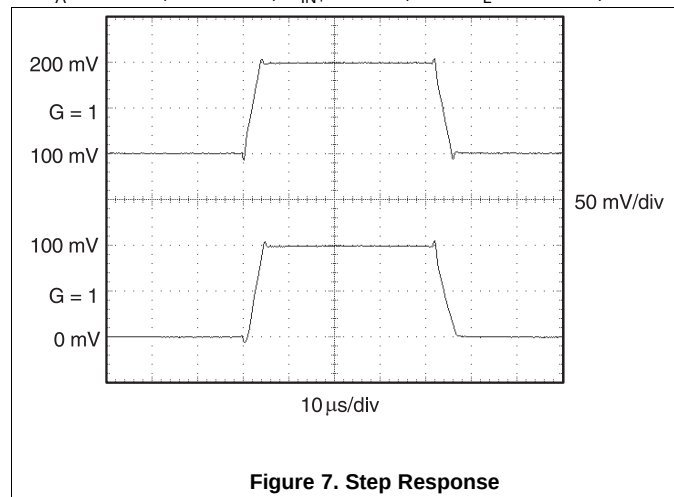
**Figure 5. Total Output Error vs Power-Supply Voltage**



**Figure 6. Quiescent Current vs Power-Supply Voltage**

## Typical Characteristics (continued)

At  $T_A = +25^\circ\text{C}$ ,  $V_+ = 5\text{ V}$ ,  $V_{IN+} = 12\text{ V}$ , and  $R_L = 125\text{ k}\Omega$ , unless otherwise noted.

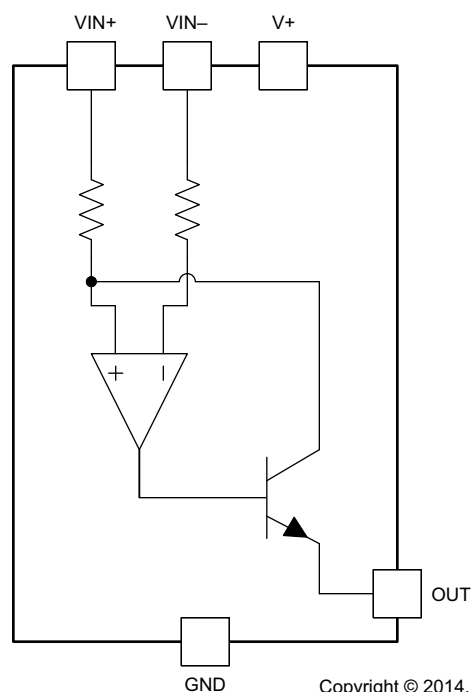


## 7 Detailed Description

### 7.1 Overview

The INA138 and INA168 devices (INA1x8) 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 INA1x8 devices can be powered from a single power supply and their input voltages can exceed the power supply voltage. The INA1x8 devices are ideal for measuring small differential voltages, such as those generated across a shunt resistor, in the presence of large common-mode voltages. Refer to [Functional Block Diagram](#) which illustrates the functional components within both INA1x8 devices.

### 7.2 Functional Block Diagram



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## 7.3 Feature Description

### 7.3.1 Output Voltage Range

The output of the INA1x8 device is a current that 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 ( $V_{out\ max}$ ) compliance is limited by either [Equation 1](#) or [Equation 2](#), whichever is lower:

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

or

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

### 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](#).

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 INA1x8 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. Refer to [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 INA138 and INA168 devices. 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 op amp, causing current to flow into the collector of Q1. External resistor  $R_L$  converts the output current to a voltage,  $V_{OUT}$ , at the OUT pin. The transfer function for the INA138 device is:

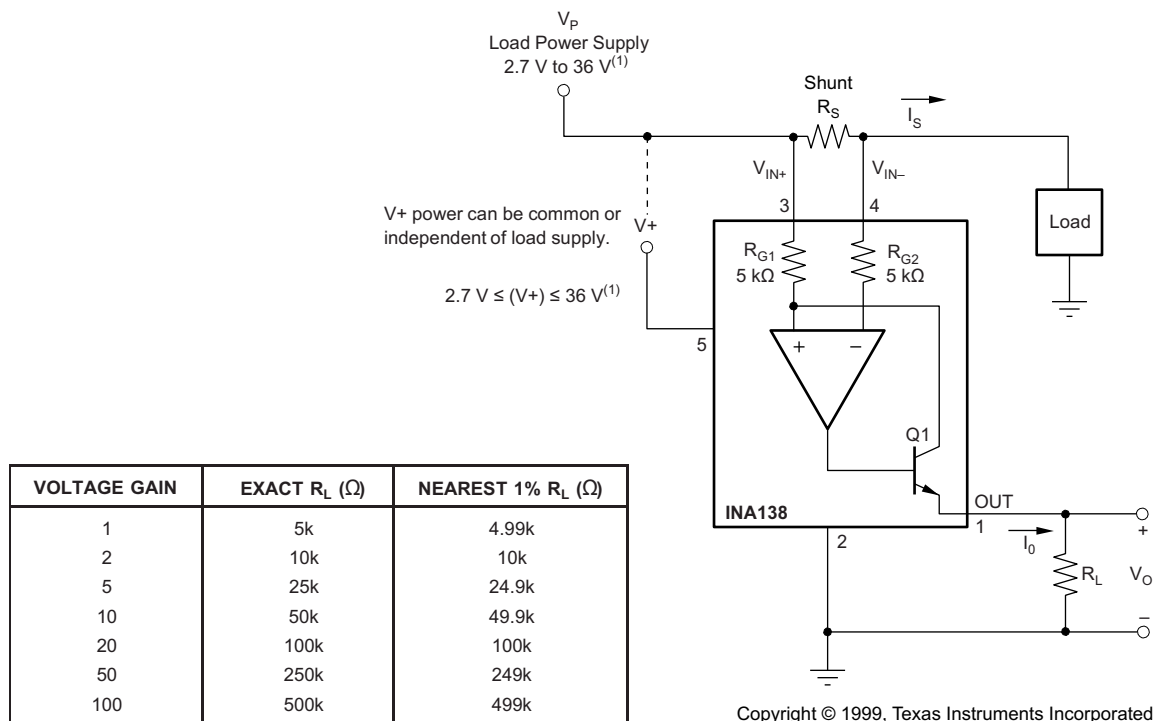
$$I_O = g_m(V_{IN+} - V_{IN-}) \quad (3)$$

where  $g_m = 200 \mu A/V$ .

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 INA138 device is  $200 \mu A/V$ . The complete transfer function for the current measurement amplifier in this application is:

$$V_{OUT} = (I_S) (R_S) (200 \mu A/V) (R_L) \quad (4)$$

The maximum differential input voltage for accurate measurements is 0.5 V, which produces a 100- $\mu A$  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,  $I_O$ , will be zero, but it will not cause damage.



(1) Maximum  $V_P$  and  $V+$  voltage is 60 V with INA168.

**Figure 9. Basic Circuit Connections**

## 8.2 Typical Applications

The INA1x8 devices are designed for current shunt measurement circuits, as shown in Figure 9, but basic device 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 10 through Figure 18.

### 8.2.1 Buffering Output to Drive an ADC

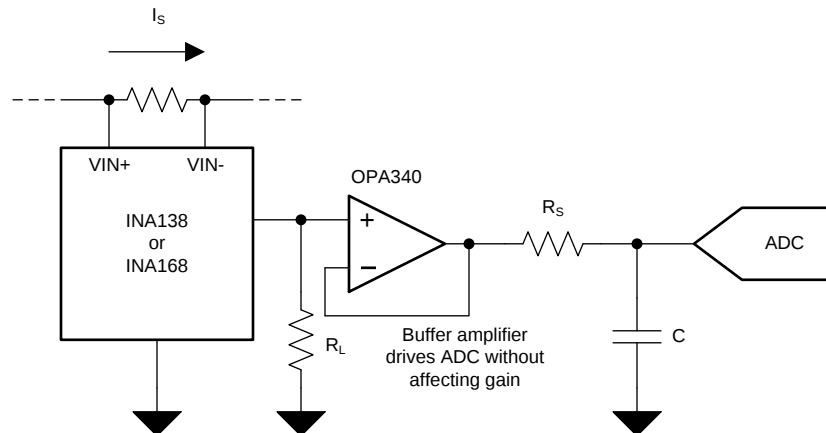


Figure 10. Buffering Output to Drive an ADC

#### 8.2.1.1 Design Requirements

Digitize the output of the INA1x8 devices using a 1-MSPS analog-to-digital converter (ADC).

#### 8.2.1.2 Detailed Design Procedure

##### 8.2.1.2.1 Selecting the Shunt Resistor and $R_L$

In Figure 9 the value chosen for the shunt resistor depends on the application and is a compromise between small-signal accuracy and maximum permissible voltage loss in the measurement line. High values of shunt resistor provide better accuracy at lower currents by minimizing the effects of offset, while low values of shunt resistor minimize voltage loss in the supply line. For most applications, best performance is attained with a shunt resistor value that provides a full-scale shunt voltage range of 50 mV to 100 mV. Maximum input voltage for accurate measurements is 500 mV.

The load resistor,  $R_L$ , is chosen to provide the desired full-scale output voltage. The output impedance of the INA1x8 OUT terminal is very high which permits using values of  $R_L$  up to 500 k $\Omega$  with excellent accuracy. The input impedance of any additional circuitry at the output should be much higher than the value of  $R_L$  to avoid degrading accuracy.

Some analog-to-digital converters (ADCs) have input impedances that 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 op amp can be used to buffer the ADC input. The INA1x8 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 via 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.

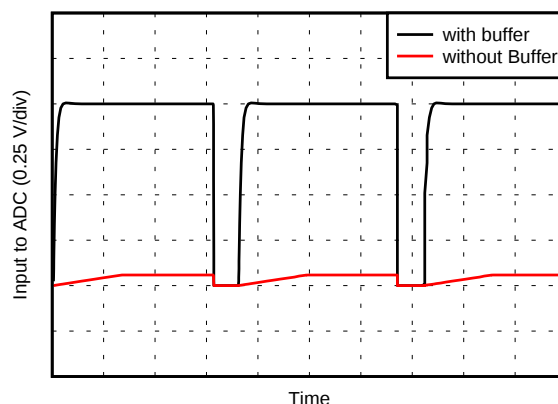
In many applications digitizing the output of the INA1x8 device is required, and can be accomplished by connecting the output of the amplifier to an ADC. It is very common for an ADC to have a dynamic input impedance. If the INA1x8 output is connected directly to an ADC input, the input impedance of 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 INA138 or INA168 device and the input to the ADC.

## Typical Applications (continued)

Figure 10 illustrates this concept. Notice that a low pass filter is 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 1MSPS Data Acquisition Reference Design for Single-Ended Multiplexed Applications \(TIPD173\)](#).

Figure 11 shows the expected results when driving an analog-to-digital converter at 1MSPS with and without buffering the INA1x8 output. Without the buffer, the high impedance of the INA1x8 reacts with the input capacitance and sample and hold (S/H) capacitance of the ADC, and does 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**

## Typical Applications (continued)

### 8.2.2 Output Filter

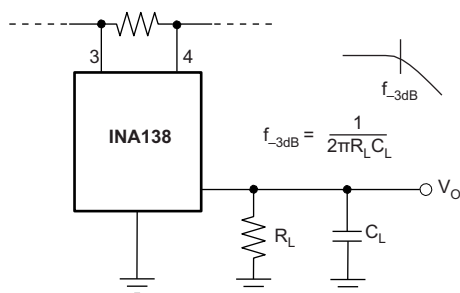


Figure 12. Output Filter

#### 8.2.2.1 Design Requirements

Filter the output of the INA1x8 devices.

#### 8.2.2.2 Detailed Design Procedure

A low-pass filter can be formed at the output of the INA1x8 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. Refer to 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.

#### 8.2.2.3 Application Curve

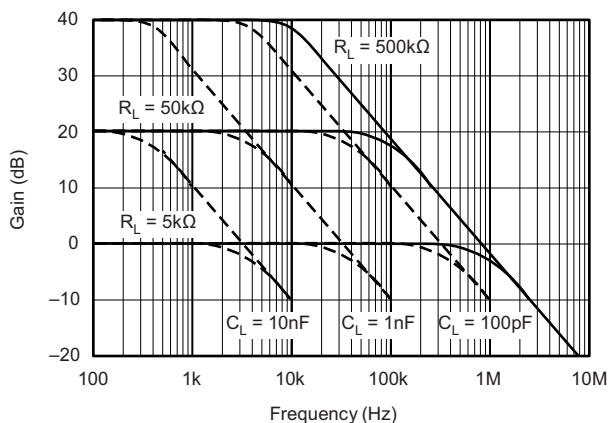
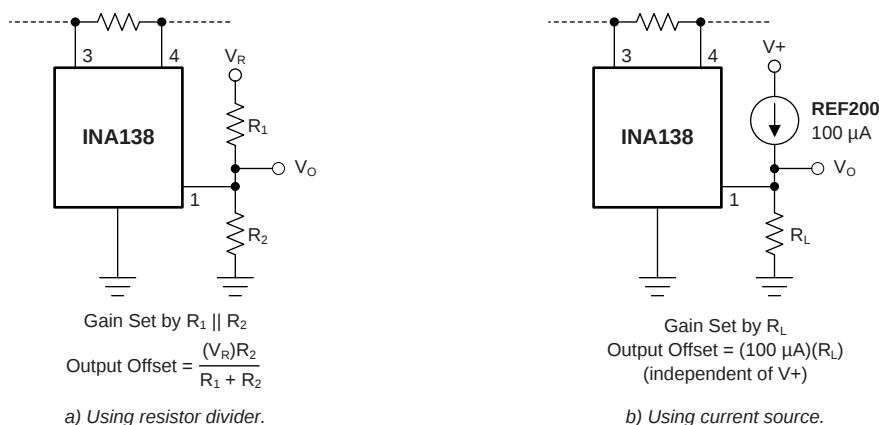


Figure 13. Gain vs Frequency

## Typical Applications (continued)

### 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 INA1x8 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 INA1x8 devices to remain centered with respect to the power supply at zero load current through the shunt resistor. Using this method the gain is determined 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 this 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 INA1x8 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 100-k $\Omega$  resistor results in a gain of 20 V/V. The 10-k $\Omega$  resistors connected in series with the INA1x8 output current are used to develop a voltage across the comparator inputs. Two diodes are required to prevent current flow into the INA1x8 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.

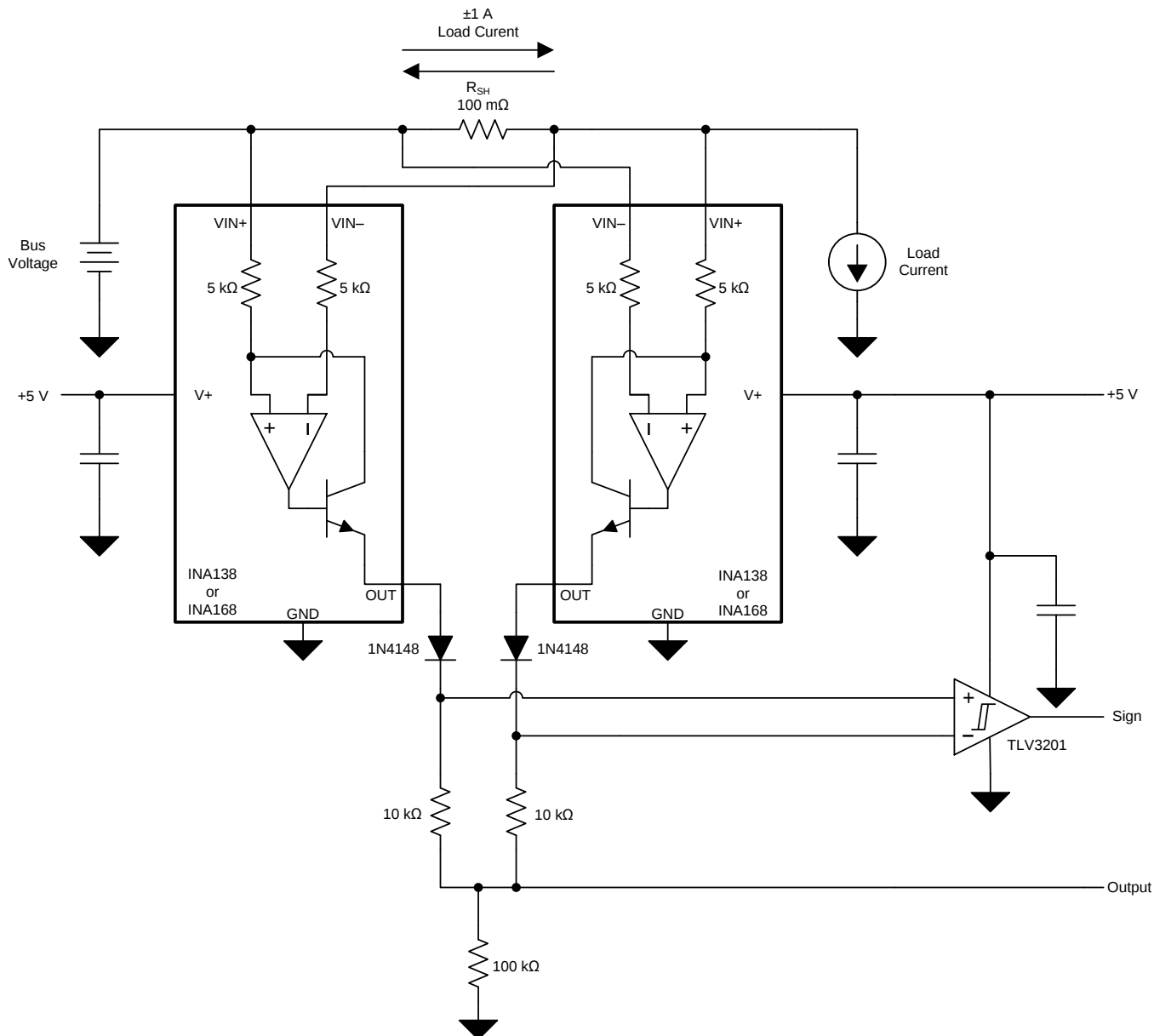
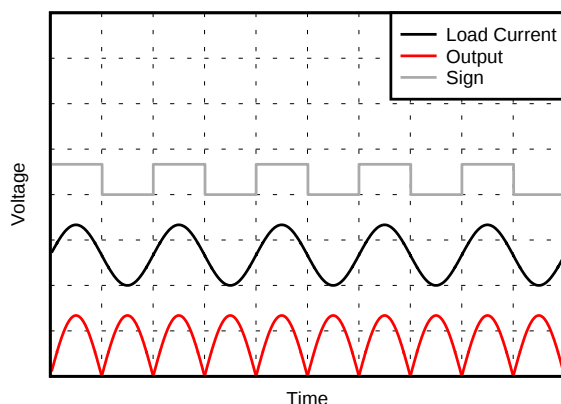


Figure 15. Bipolar Current Measurement

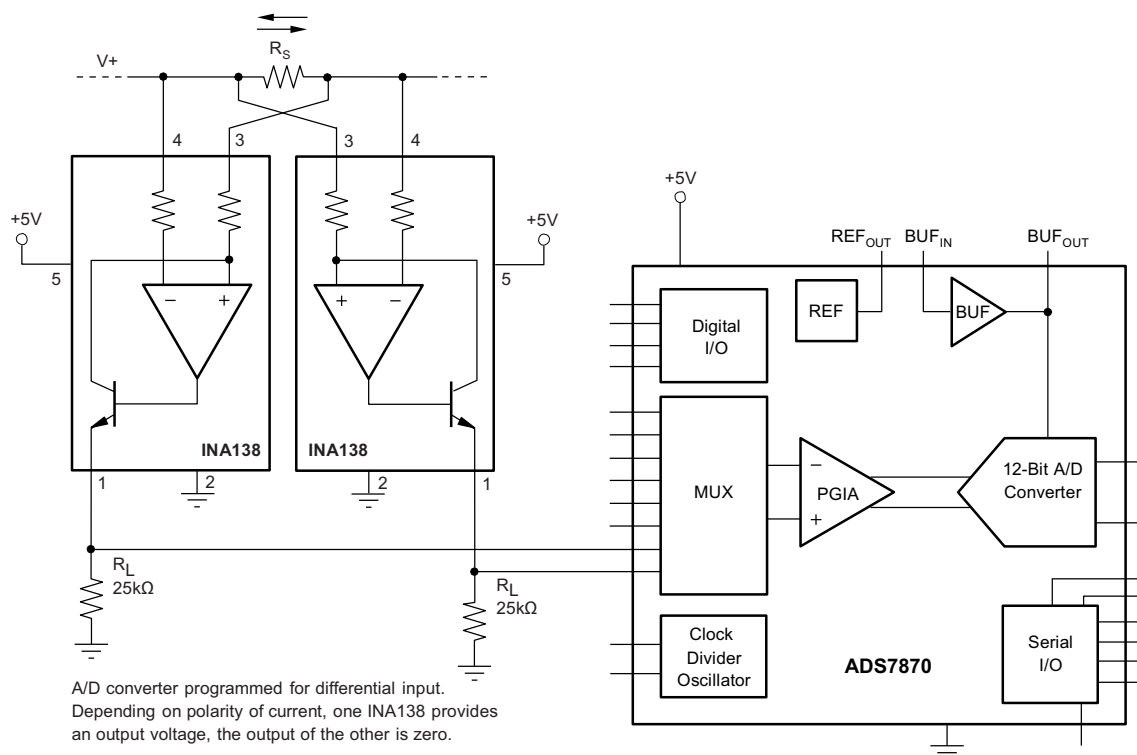
## Typical Applications (continued)



**Figure 16. Bipolar Current Measurements Results (arbitrary scale)**

### 8.2.5 Bipolar Current Measurement Using Differential Input of ADC

The INA1x8 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 bidirectional current measurement. Depending upon the polarity of the current, one of the INAs provides an output voltage, while the other output is zero. In this way the ADC reads the polarity of current directly, without the need for additional circuitry.



**Figure 17. Bipolar Current Measurement Using Differential Input of ADC**

## 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 INA1x8 device is powered by the digital I/O from the ADS7870. Multiplexing is achieved by switching on or off each the desired I/O.

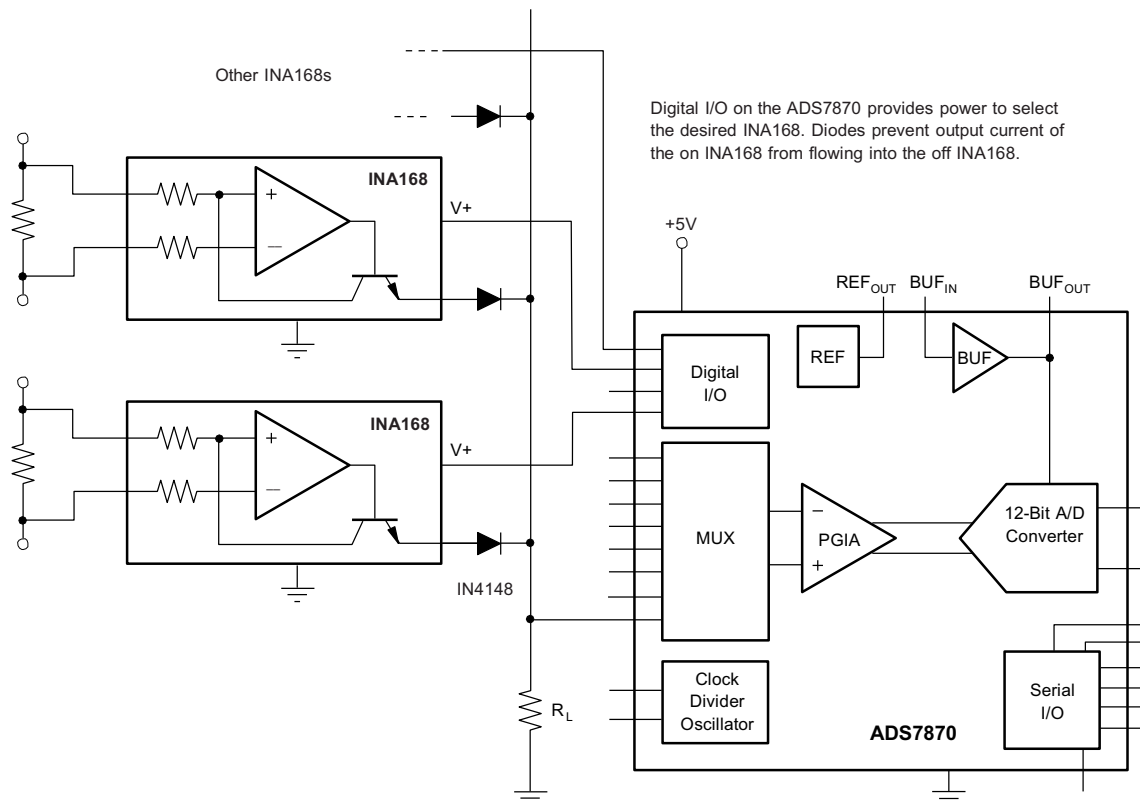


Figure 18. Multiplexed Measurement Using Logic Signal for Power

## 9 Power Supply Recommendations

The input circuitry of the INA138 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 36 V (or 60 V with the INA168). The output voltage range of the OUT terminal, however, is limited by the lesser of the two voltages (see [Output Voltage Range](#)). A 0.1- $\mu\text{F}$  capacitor is recommended to be placed near the power supply pin on the INA138 or INA168. Additional capacitance may be required for applications with noisy power supply voltages.

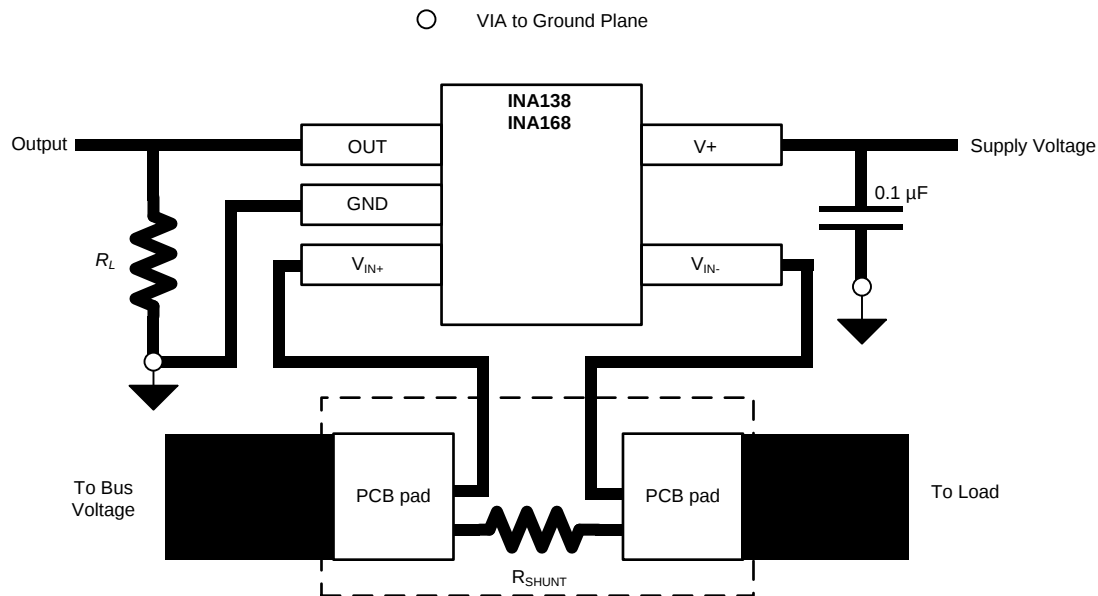
## 10 Layout

### 10.1 Layout Guidelines

[Figure 19](#) shows the basic connection of the INA138 device. The input pins,  $V_{\text{IN}+}$  and  $V_{\text{IN}-}$ , should 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 INA138. However, applications with noisy or high-impedance power supplies may require decoupling capacitors to reject power-supply noise. Connect bypass capacitors close to the device pins.

### 10.2 Layout Example



**Figure 19. Typical Layout Example**

## 11 器件和文档支持

### 11.1 文档支持

#### 11.1.1 相关文档

请参阅如下相关文档：

- 《用于单端多路复用应用的 16 位 1MSPS 数据采集 参考设计》
- 《ADS7870 12 位 ADC、MUX、PGA 和内部基准数据采集系统》
- 《TLV3201、TLV3202 40ns 低功耗推挽式输出比较器》
- 《REF200 双路拉电流/灌电流》

#### 11.2 相关链接

表 1 列出了快速访问链接。类别包括技术文档、支持与社区资源、工具和软件，以及申请样片或购买产品的快速链接。

表 1. 相关链接

| 器件     | 产品文件夹                 | 样片与购买                 | 技术文档                  | 工具和软件                 | 支持和社区                 |
|--------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| INA138 | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> |
| INA168 | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> | <a href="#">请单击此处</a> |

#### 11.3 接收文档更新通知

如需接收文档更新通知，请导航至 TI.com 上的器件产品文件夹。单击右上角的通知我 进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

#### 11.4 社区资源

下列链接提供到 TI 社区资源的连接。链接的内容由各个分销商“按照原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的《使用条款》。

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**设计支持** TI 参考设计支持 可帮助您快速查找有帮助的 E2E 论坛、设计支持工具以及技术支持的联系信息。

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

#### 11.7 Glossary

**SLYZ022** — TI Glossary.

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

## 12 机械、封装和可订购信息

以下页面包含机械、封装和可订购信息。这些信息是指定器件的最新可用数据。数据如有变更，恕不另行通知和修订此文档。如欲获取此数据表的浏览器版本，请参阅左侧的导航。

## PACKAGING INFORMATION

| Orderable part number        | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">INA138NA/250</a> | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | B38                 |
| INA138NA/250.A               | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | B38                 |
| <a href="#">INA138NA/3K</a>  | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | B38                 |
| INA138NA/3K.A                | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | B38                 |
| <a href="#">INA168NA/250</a> | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -            | A68                 |
| INA168NA/250.A               | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | A68                 |
| <a href="#">INA168NA/3K</a>  | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | A68                 |
| INA168NA/3K.A                | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | A68                 |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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**OTHER QUALIFIED VERSIONS OF INA138, INA168 :**

- Automotive : [INA138-Q1](#), [INA168-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| INA138NA/250 | SOT-23       | DBV             | 5    | 250  | 178.0              | 9.0                | 3.3     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| INA138NA/3K  | SOT-23       | DBV             | 5    | 3000 | 178.0              | 9.0                | 3.3     | 3.2     | 1.4     | 4.0     | 8.0    | Q3            |
| INA168NA/250 | SOT-23       | DBV             | 5    | 250  | 178.0              | 9.0                | 3.23    | 3.17    | 1.37    | 4.0     | 8.0    | Q3            |
| INA168NA/3K  | SOT-23       | DBV             | 5    | 3000 | 178.0              | 9.0                | 3.23    | 3.17    | 1.37    | 4.0     | 8.0    | Q3            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| INA138NA/250 | SOT-23       | DBV             | 5    | 250  | 180.0       | 180.0      | 18.0        |
| INA138NA/3K  | SOT-23       | DBV             | 5    | 3000 | 180.0       | 180.0      | 18.0        |
| INA168NA/250 | SOT-23       | DBV             | 5    | 250  | 180.0       | 180.0      | 18.0        |
| INA168NA/3K  | SOT-23       | DBV             | 5    | 3000 | 180.0       | 180.0      | 18.0        |



## SOT-23 - 1.45 mm max height

## SMALL OUTLINE TRANSISTOR



1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-178.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.

# EXAMPLE BOARD LAYOUT

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:15X



SOLDER MASK DETAILS

4214839/K 08/2024

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## EXAMPLE STENCIL DESIGN

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:15X

4214839/K 08/2024

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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