INA19xA-Q1 Current Shunt Monitors –16-V to 80-V Common-Mode Range

1 Features
• Qualified for Automotive Applications
• Functional Safety-Capable
  – Documentation available to aid functional safety system design
• Wide Common-Mode Voltage: –16 V to 80 V
• Low Error: 3% Overtemperature (Maximum)
• Bandwidth: Up to 500 kHz
• Three Transfer Functions Available: 20 V/V, 50 V/V, and 100 V/V
• Complete Current-Sense Solution

2 Applications
• Welding Equipment
• Body Control Modules
• Load Health Monitoring
• Telecom Equipment
• HEV/EV Powertrain
• Power Management
• Battery Chargers

3 Description
The INA19xA-Q1 family of current shunt monitors with voltage output can sense drops across shunts at common-mode voltages from –16 V to 80 V, independent of the INA19xA supply voltage. They are available with three output voltage scales: 20 V/V, 50 V/V, and 100 V/V. The 500-kHz bandwidth simplifies use in current control loops and monitoring DC motor health. The INA193A–INA195A provide identical functions but alternative pin configurations to the INA196A–INA198A, respectively.

The INA19xA-Q1 operate from a single 2.7-V to 18-V supply. They are specified over the extended operating temperature range (–40°C to 125°C), and are offered in a space-saving SOT-23 package.

Device Information

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INA19xA-Q1</td>
<td>SOT-23 (5)</td>
<td>2.90 mm × 1.60 mm</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the package option addendum at the end of the data sheet.
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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 (July 2015) to Revision E (January 2021) ........................................ 1
   • Updated the numbering format for tables, figures, and cross-references throughout the document........ 1
   • Added Functional Safety bullets.................................. 1

Changes from Revision C (October 2008) to Revision D (July 2015) ........................................ 1
   • Added 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
   • Added Input Bias Current vs Common Mode Voltage Vs=5 V graph to Typical Characteristics ............ 7
   • Added Input Bias Current vs Common Mode Voltage Vs=12 V graph to Typical Characteristics .......... 7
5 Pin Configuration and Functions

![Diagram of 5-pin configuration and functions](image)

**Figure 5-1. DBV Package 5-Pin SOT-23 INA193A-Q1, INA194A-Q1, INA195A-Q1 Top View**

![Diagram of 5-pin configuration and functions](image)

**Figure 5-2. DBV Package 5-Pin SOT-23 INA196A-Q1, INA197A-Q1, INA198A-Q1 Top View**

**Table 5-1. Pin Functions**

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>GND</td>
<td>2</td>
<td>2</td>
<td>GND Ground</td>
</tr>
<tr>
<td>OUT</td>
<td>1</td>
<td>1</td>
<td>O Output voltage</td>
</tr>
<tr>
<td>V+</td>
<td>5</td>
<td>3</td>
<td>Analog Power supply, 2.7 to 18 V</td>
</tr>
<tr>
<td>V_IN+</td>
<td>3</td>
<td>4</td>
<td>I Connect to supply side of shunt resistor</td>
</tr>
<tr>
<td>V_IN-</td>
<td>4</td>
<td>5</td>
<td>I Connect to load side of shunt resistor</td>
</tr>
</tbody>
</table>
6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)\(^{(1)}\)

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td></td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Differential input voltage</td>
<td>–18</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Common-mode voltage range</td>
<td>–16</td>
<td>80</td>
<td>V</td>
</tr>
<tr>
<td>Analog output voltage range</td>
<td>OUT</td>
<td>GND – 0.3 ((V^+)+0.3)</td>
<td>V</td>
</tr>
<tr>
<td>Input current into any pin</td>
<td>5</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Junction temperature</td>
<td></td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature, (T_{stg})</td>
<td>–65</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

\(^{(1)}\) 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.

\(^{(2)}\) Input voltage at any pin may exceed the voltage shown if the current at that pin is limited to 5 mA.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th>(V_{(ESD)})</th>
<th>Electrostatic discharge</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human-body model (HBM), per AEC Q100-002(^{(1)})</td>
<td>(\pm 4000)</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Charged-device model (CDM), per AEC Q100-011</td>
<td>(\pm 1000)</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Machine model</td>
<td>(\pm 200)</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

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

| \(V_{CM}\) | Common-mode input voltage | MIN | NOM | MAX | UNIT |
| V+          | Operating supply voltage  | 12  |     |     | V    |
| \(T_A\)     | Operating free-air temperature | –40 | 125 | °C  |

6.4 Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(^{(1)})</th>
<th>INA19xA-Q1 DBV (SOT-23)</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{JA}) Junction-to-ambient thermal resistance</td>
<td>221.7</td>
<td>°C/W</td>
</tr>
<tr>
<td>(R_{JC(top)}) Junction-to-case (top) thermal resistance</td>
<td>144.7</td>
<td>°C/W</td>
</tr>
<tr>
<td>(R_{JB}) Junction-to-board thermal resistance</td>
<td>49.7</td>
<td>°C/W</td>
</tr>
<tr>
<td>(\psi_{JT}) Junction-to-top characterization parameter</td>
<td>26.1</td>
<td>°C/W</td>
</tr>
<tr>
<td>(\psi_{JB}) Junction-to-board characterization parameter</td>
<td>49</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

\(^{(1)}\) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report, SPRA953.
6.5 Electrical Characteristics

\( V_S = 12 \text{ V}, V_{IN+} = 12 \text{ V}, V_{SENSE} = 100 \text{ mV} \) (unless otherwise noted) Full range \( T_A = -40^\circ \text{C} \) to \( 125^\circ \text{C} \)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>( T_A )</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{SENSE} )</td>
<td>Full-scale input voltage ( V_{SENSE} = V_{IN+} - V_{IN-} )</td>
<td>25°C</td>
<td>0.15</td>
<td>(( V_S - 0.2 ))/Gain</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VCM</td>
<td>Common-mode input</td>
<td>Full range</td>
<td>-16</td>
<td>80</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>CMR</td>
<td>Common-mode rejection ( V_{IN+} = -16 \text{ V} ) to ( 80 \text{ V} )</td>
<td>25°C</td>
<td>80</td>
<td>94</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>( V_{IN+} = 12 \text{ V} ) to ( 80 \text{ V} )</td>
<td>Full range</td>
<td>100</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_{OS} )</td>
<td>Offset voltage, RTI</td>
<td>25°C</td>
<td>±0.5</td>
<td>2</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>( dV_{OS}/dT )</td>
<td>Offset voltage vs temperature</td>
<td>Full range</td>
<td>0.5</td>
<td>3</td>
<td></td>
<td>μV/°C</td>
</tr>
<tr>
<td>PSR</td>
<td>Offset voltage vs power supply ( V_S = 2.7 \text{ V} ) to ( 18 \text{ V} ), ( V_{IN+} = 18 \text{ V} )</td>
<td>Full range</td>
<td>5</td>
<td>100</td>
<td></td>
<td>μV/V</td>
</tr>
<tr>
<td>( I_B )</td>
<td>Input bias current ( V_{IN-} ) pin</td>
<td>Full range</td>
<td>±8</td>
<td>±23</td>
<td></td>
<td>μA</td>
</tr>
</tbody>
</table>

**OUTPUT (\( V_{SENSE} \geq 20 \text{ mV} \))**

<table>
<thead>
<tr>
<th>( G )</th>
<th>Gain</th>
<th>INA193A, INA196A</th>
<th>25°C</th>
<th>20</th>
<th>V/V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>INA194A, INA197A</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INA195A, INA198A</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Gain error</td>
<td>( V_{SENSE} = 20 \text{ mV} ) to ( 100 \text{ mV} )</td>
<td>25°C</td>
<td>±0.2%</td>
<td>±1%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±2%</td>
<td></td>
</tr>
<tr>
<td>Total output error(1)</td>
<td>( V_{SENSE} = 20 \text{ mV} ) to ( 100 \text{ mV} )</td>
<td>25°C</td>
<td>±0.75%</td>
<td>±2.2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±1%</td>
<td>±3%</td>
</tr>
<tr>
<td>Nonlinearity error</td>
<td>( V_{SENSE} = 20 \text{ mV} ) to ( 100 \text{ mV} )</td>
<td>25°C</td>
<td>±0.002%</td>
<td>±0.1%</td>
<td></td>
</tr>
<tr>
<td>( R_O )</td>
<td>Output impedance</td>
<td>25°C</td>
<td>1.5</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>Maximum capacitive load</td>
<td>No sustained oscillation</td>
<td>25°C</td>
<td>10</td>
<td>nF</td>
<td></td>
</tr>
</tbody>
</table>

**OUTPUT (\( V_{SENSE} < 20 \text{ mV} \))** (4)

| \( V_{OUT} \) | Output voltage | All devices \( -16 \text{ V} \leq V_{CM} < 0 \) \( V_S < V_{CM} \leq 80 \text{ V} \) | 25°C | 300 | mV |
|               |                | INA193A, INA196A |      | 300 |     |
|               |                | INA194A, INA197A |      | 0.4 | V   |
|               |                | INA195A, INA198A |      | 1   |     |
|               |                | \( 0 \text{ V} \leq V_{CM} \leq V_S, \) \( V_S = 5 \text{ V} \) |      | 2   |     |

**VOLTAGE OUTPUT(2)**

| \( V_{OUT} \) | Output voltage | Swing to \( V^+ \) power-supply rail \( R_L = 100 \text{ kΩ} \) to GND | Full range | \( V^+ - 0.1 \) | \( V^+ - 0.2 \) | \( V \) |
|               |                | Swing to GND(3) \( R_L = 100 \text{ kΩ} \) to GND | Full range | \( V_{GND} + 3 \) | \( V_{GND} + 50 \) | mV |
\( V_S = 12 \, V, \, V_{IN+} = 12 \, V, \, V_{SENSE} = 100 \, mV \) (unless otherwise noted) Full range \( T_A = -40^\circ \text{C} \) to \( 125^\circ \text{C} \)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>( T_A )</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY RESPONSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW Bandwidth</td>
<td>INA193A, INA196A</td>
<td>C(_{LOAD}) = 5 , pF</td>
<td>25°C</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td>INA194A, INA197A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>INA195A, INA198A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase margin</td>
<td>C(_{LOAD}) &lt; 10 , nF</td>
<td>25°C</td>
<td></td>
<td></td>
<td>°</td>
</tr>
<tr>
<td></td>
<td>Slew rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V/\mu s</td>
</tr>
<tr>
<td></td>
<td>Settling time (1%)</td>
<td>V(<em>{SENSE}) = 10 mV to 100 mV(</em>{PP}), C(_{LOAD}) = 5 , pF</td>
<td>25°C</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>NOISE, RTI Voltage noise density</td>
<td></td>
<td>25°C</td>
<td>40</td>
<td></td>
<td></td>
<td>nV/\sqrt{\text{Hz}}</td>
</tr>
<tr>
<td>POWER SUPPLY V(_S) Operating voltage</td>
<td></td>
<td>Full range</td>
<td>2.7</td>
<td>18</td>
<td>\text{V}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V(_{OUT}) = 2 , V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>\mu A</td>
</tr>
<tr>
<td></td>
<td>INA193A, INA194A, INA196A, INA197A</td>
<td>V(_{SENSE}) = 0 mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>INA195A, INA198A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMPERATURE RANGE Operating temperature</td>
<td></td>
<td></td>
<td>\text{–40}</td>
<td>125</td>
<td>°\text{C}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storage temperature</td>
<td></td>
<td>\text{–65}</td>
<td>150</td>
<td>°\text{C}</td>
<td></td>
</tr>
</tbody>
</table>

(1) Total output error includes effects of gain error and \( V_{OS} \).
(2) See Figure 6-7.
(3) Specified by design
(4) For details on this region of operation, see Section 7.4.2.
6.6 Typical Characteristics

\[ T_A = 25^\circ C, V_S = 12 \, V, \, V_{IN+} = 12 \, V, \text{ and } V_{SENSE} = 100 \, mV \text{ (unless otherwise noted)} \]

**Figure 6-1. Gain vs Frequency**

**Figure 6-2. Gain vs Frequency**

**Figure 6-3. Gain Plot**

**Figure 6-4. Common-Mode and Power-Supply Rejection vs Frequency**

**Figure 6-5. Output Error vs Vsense**

**Figure 6-6. Output Error vs Common-Mode Voltage**
Output stage is designed to source current. Current sinking capability is approximately 400 µA.

Figure 6-7. Positive Output Voltage Swing vs Output Current

Figure 6-8. Quiescent Current vs Output Voltage

Figure 6-9. Input Bias Current vs Common Mode Voltage

Figure 6-10. Input Bias Current vs Common Mode Voltage

Figure 6-11. Quiescent Current vs Common Mode Voltage

Figure 6-12. Output Short Circuit Current vs Supply Voltage
Figure 6-13. Step Response

Figure 6-14. Step Response

Figure 6-15. Step Response

Figure 6-16. Step Response

Figure 6-17. Step Response

Figure 6-18. Step Response
Figure 6-19. Step Response
7 Detailed Description

7.1 Overview

The INA193A–INA198A family of current shunt monitors with voltage output can sense drops across shunts at common mode voltages from −16 V to 80 V, independent of the INA19x supply voltage. They are available with three output voltage scales: 20 V/V, 50 V/V, and 100 V/V. The 500-kHz bandwidth simplifies use in current control loops. The INA193A–INA195A devices provide identical functions but alternative pin configurations to the INA196A–INA198A, respectively.

The INA193A–INA198A devices operate from a single 2.7-V to 18-V supply, drawing a maximum of 900 μA of supply current. They are specified over the extended operating temperature range (−40°C to 125°C), and are offered in a space-saving SOT-23 package.

7.2 Functional Block Diagram

7.3 Feature Description

7.3.1 Basic Connection

Figure 7-1 shows the basic connection of the INA19xA. The input pins, \( V_{IN+} \) and \( V_{IN-} \), should be connected as closely as possible to the shunt resistor to minimize any resistance in series with the shunt resistance.

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

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

7.3.3 Inside the INA19xA

The INA19xA uses a new, unique, internal circuit topology that provides common mode range extending from –16 V to 80 V while operating from a single power supply. The common mode rejection in a classic instrumentation amplifier approach is limited by the requirement for accurate resistor matching. By converting the induced input voltage to a current, the INA19xA provides common mode rejection that is no longer a function of closely matched resistor values, providing the enhanced performance necessary for such a wide common mode range. A simplified diagram (see Figure 7-1) shows the basic circuit function. When the common mode voltage is positive, amplifier A2 is active.

The differential input voltage, $V_{IN+} - V_{IN-}$, applied across $R_S$, is converted to a current through a 5-kΩ resistor. This current is converted back to a voltage through $R_L$, and then amplified by the output buffer amplifier. When the common mode voltage is negative, amplifier A1 is active. The differential input voltage, $V_{IN+} - V_{IN-}$, applied across $R_S$, is converted to a current through a 5-kΩ resistor. This current is sourced from a precision current mirror whose output is directed into $R_L$, converting the signal back into a voltage and amplified by the output buffer amplifier. Patent-pending circuit architecture ensures smooth device operation, even during the transition period where both amplifiers A1 and A2 are active.
Figure 7-2. Monitor Bipolar Output Power-Supply Current
Figure 7-3. Bidirectional Current Monitoring

Figure 7-4. Inductive Current Monitor Including Flyback
7.3.4 Power Supply

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

7.4.1 Input Filtering

An obvious and straightforward location for filtering is at the output of the INA19xA series; however, this location negates the advantage of the low output impedance of the internal buffer. The only other option for filtering is at the input pins of the INA19xA, which is complicated by the internal 5-kΩ ± 30% input impedance (see Figure 7-6). Using the lowest possible resistor values minimizes both the initial shift in gain and effects of tolerance. The effect on initial gain is given by:

\[
\text{Gain Error \%} = 100 - \left( 100 \times \frac{5 \, \text{k}\Omega}{5 \, \text{k}\Omega + R_{\text{FILT}}} \right)
\]

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

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

\[
f_{3\text{dB}} = \frac{1}{2 x \left( 2 R_{\text{FILTER}} \right) C_{\text{FILTER}}}
\]

\[\text{LOADV} = \text{SUPPLY}
\]

\[
\text{f}_{3\text{dB}} = \frac{1}{2 x \left( 2 R_{\text{FILTER}} \right) C_{\text{FILTER}}}
\]

\[
\text{V}_{\text{IN+}} \quad \text{V}_{\text{IN–}}
\]

\[
\text{5 kΩ} \quad \text{5 kΩ}
\]

\[
\text{OUT}
\]

\[
\text{INA193A–INA198A}
\]

Figure 7-6. Input Filter (Gain Error = 1.5% to –2.2%)

7.4.2 Accuracy Variations as a Result Of \( V_{\text{SENSE}} \) and Common Mode Voltage

The accuracy of the INA19xA-Q1 current shunt monitors is a function of two main variables:
$V_{\text{SENSE}}$ ($V_{\text{IN}+} - V_{\text{IN}-}$) and common mode voltage, $V_{\text{CM}}$, relative to the supply voltage, $V_S$. $V_{\text{CM}}$ is expressed as $(V_{\text{IN}+} + V_{\text{IN}-})/2$; however, in practice, $V_{\text{CM}}$ is seen as the voltage at $V_{\text{IN}+}$ because the voltage drop across $V_{\text{SENSE}}$ is usually small.

This section addresses the accuracy of these specific operating regions:

- **Normal Case 1**: $V_{\text{SENSE}} \geq 20 \text{ mV}$, $V_{\text{CM}} \geq V_S$
- **Normal Case 2**: $V_{\text{SENSE}} \geq 20 \text{ mV}$, $V_{\text{CM}} < V_S$
- **Low $V_{\text{SENSE}}$ Case 1**: $V_{\text{SENSE}} < 20 \text{ mV}$, $-16 \text{ V} \leq V_{\text{CM}} < 0$
- **Low $V_{\text{SENSE}}$ Case 2**: $V_{\text{SENSE}} < 20 \text{ mV}$, $0 \text{ V} \leq V_{\text{CM}} \leq V_S$
- **Low $V_{\text{SENSE}}$ Case 3**: $V_{\text{SENSE}} < 20 \text{ mV}$, $V_S < V_{\text{CM}} \leq 80 \text{ V}$

### 7.4.2.1 Normal Case 1: $V_{\text{SENSE}} \geq 20 \text{ mV}$, $V_{\text{CM}} \geq V_S$

This region of operation provides the highest accuracy. Here, the input offset voltage is characterized and measured using a two-step method. First, the gain is determined by (Equation 2).

$$G = \frac{V_{\text{OUT}1} - V_{\text{OUT}2}}{100 \text{ mV} - 20 \text{ mV}}$$

(2)

where

- $V_{\text{OUT}1}$ = Output voltage with $V_{\text{SENSE}} = 100 \text{ mV}$
- $V_{\text{OUT}2}$ = Output voltage with $V_{\text{SENSE}} = 20 \text{ mV}$

The offset voltage is then measured at $V_{\text{SENSE}} = 100 \text{ mV}$ and referred to the input (RTI) of the current shunt monitor, as shown in (Equation 3).

$$V_{\text{OS,RTI}} \text{ (Referred To Input)} = \left( \frac{V_{\text{OUT}1}}{G} \right) - 100 \text{ mV}$$

(3)

In Section 6.6, the *Output Error vs Common Mode Voltage* curve shows the highest accuracy for this region of operation. In this plot, $V_S = 12 \text{ V}$; for $V_{\text{CM}} \geq 12 \text{ V}$, the output error is at its minimum. This case is also used to create the $V_{\text{SENSE}} \geq 20 \text{ mV}$ output specifications in the *Electrical Characteristics* table.

### 7.4.2.2 Normal Case 2: $V_{\text{SENSE}} \geq 20 \text{ mV}$, $V_{\text{CM}} < V_S$

This region of operation has slightly less accuracy than Normal Case 1 as a result of the common mode operating area in which the part functions, as seen in Figure 6-6. As noted, for this graph $V_S = 12 \text{ V}$; for $V_{\text{CM}} < 12 \text{ V}$, the Output Error increases as $V_{\text{CM}}$ becomes less than 12 V, with a typical maximum error of 0.005% at the most negative $V_{\text{CM}} = -16 \text{ V}$.

### 7.4.2.3 Low $V_{\text{SENSE}}$ Case 1: $V_{\text{SENSE}} < 20 \text{ mV}$, $-16 \text{ V} \leq V_{\text{CM}} < 0$; and Low $V_{\text{SENSE}}$ Case 3: $V_{\text{SENSE}} < 20 \text{ mV}$, $V_S < V_{\text{CM}} \leq 80 \text{ V}$

Although the INA19xA-Q1 family of devices are not designed for accurate operation in either of these regions, some applications are exposed to these conditions; for example, when monitoring power supplies that are switched on and off while $V_S$ is still applied to the INA19xA-Q1. It is important to know what the behavior of the devices will be in these regions.

As $V_{\text{SENSE}}$ approaches 0 mV, in these $V_{\text{CM}}$ regions, the device output accuracy degrades. A larger-than-normal offset can appear at the current shunt monitor output with a typical maximum value of $V_{\text{OUT}} = 300 \text{ mV}$ for $V_{\text{SENSE}} = 0 \text{ mV}$. As $V_{\text{SENSE}}$ approaches 20 mV, $V_{\text{OUT}}$ returns to the expected output value with accuracy as specified in *Electrical Characteristics*. Figure 7-7 illustrates this effect using the INA195A and INA198A (Gain = 100).
7.4.2.4 Low V\textsubscript{SENSE} Case 2: V\textsubscript{SENSE} < 20 mV, 0 V ≤ V\textsubscript{CM} ≤ V\textsubscript{S}

This region of operation is the least accurate for the INA19xA-Q1 family. To achieve the wide input common mode voltage range, these devices use two operational amplifier front ends in parallel. One operational amplifier front end operates in the positive input common mode voltage range, and the other in the negative input region. For this case, neither of these two internal amplifiers dominates and overall loop gain is very low. Within this region, V\textsubscript{OUT} approaches voltages close to linear operation levels for Normal Case 2. This deviation from linear operation becomes greatest the closer V\textsubscript{SENSE} approaches 0 V. Within this region, as V\textsubscript{SENSE} approaches 20 mV, device operation is closer to that described by Normal Case 2. Figure 7-8 illustrates this behavior for the INA195A. The V\textsubscript{OUT} maximum peak for this case is tested by maintaining a constant V\textsubscript{S}, setting V\textsubscript{SENSE} = 0 mV and sweeping V\textsubscript{CM} from 0 V to V\textsubscript{S}. The exact V\textsubscript{CM} at which V\textsubscript{OUT} peaks during this test varies from part to part, but the V\textsubscript{OUT} maximum peak is tested to be less than the specified V\textsubscript{OUT} tested limit.

A. INA193, INA196 V\textsubscript{OUT} Tested Limit = 0.4 V
INA194, INA197 V\textsubscript{OUT} Tested Limit = 1 V
V\textsubscript{OUT} tested limit at V\textsubscript{SENSE} = 0 mV, 0 ≤ V\textsubscript{CM1} ≤ V\textsubscript{S}.
V\textsubscript{CM2}, V\textsubscript{CM3}, and V\textsubscript{CM4} illustrate the variance from part to part of the V\textsubscript{CM} that can cause maximum V\textsubscript{OUT} with V\textsubscript{SENSE} < 20 mV.

7.4.3 Shutdown

Because the INA19xA-Q1 consume a quiescent current less than 1 mA, they can be powered by either the output of logic gates or by transistor switches to supply power. Use a totem pole output buffer or gate that can provide sufficient drive along with 0.1 μF bypass capacitor, preferably ceramic with good high frequency characteristics. This gate should have a supply voltage of 3 V or greater because the INA19xA-Q1 requires a minimum supply greater than 2.7 V. In addition to eliminating quiescent current, this gate also turns off the 10 μA bias current present at each of the inputs. An example shutdown circuit is shown in Figure 7-9.
7.4.4 Transient Protection

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

7.4.5 Output Voltage Range

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

8.1 Application Information

The INA193A-IN198A devices measure the voltage developed across a current-sensing resistor when current passes through it. The ability to have shunt common mode voltages from −16-V to 80-V drive and control the output signal with Vs offers multiple configurations, as discussed throughout this section.

8.2 Typical Application

The device is a unidirectional, current-sense amplifier capable of measuring currents through a resistive shunt with shunt common mode voltages from −16 V to 80 V. Two devices can be configured for bidirectional monitoring and is common in applications that include charging and discharging operations where the current flow-through resistor can change directions.

![Diagram of INA193A-IN198A with shunt resistors and supply voltage](image)

Figure 8-1. Bidirectional Current Monitoring

8.2.1 Design Requirements

Vsupply is set to 12 V, Vref at 2.5 V and a 10-mΩ shunt. The accuracy of the current will typically be less than 0.5% for current greater than ±2 A. For current lower than ±2 A, the accuracy will vary; use Section 7.4.2 for accuracy considerations.

8.2.2 Detailed Design Procedure

The ability to measure this current flowing in both directions is enabled by adding a unity gain amplifier with a Vref, as shown in Figure 8-1. The output then responds by increasing above VREF for positive differential signals (relative to the IN – pin) and responds by decreasing below VREF for negative differential signals. This
reference voltage applied to the REF pin can be set anywhere from 0 V to V+. For bidirectional applications, VREF is typically set at mid-scale for equal signal range in both current directions. In some cases, however, VREF is set at a voltage other than mid-scale when the bidirectional current and corresponding output signal are not required to be symmetrical.

8.2.3 Application Curve

An example output response of a bidirectional configuration is shown in Figure 8-2. With the REF pin connected to a reference voltage, 2.5 V in this case, the output voltage is biased upwards by this reference level. The output rises above the reference voltage for positive differential input signals and falls below the reference voltage for negative differential input signals.

![Figure 8-2. Output Voltage vs Shunt Input Current](image)

9 Power Supply Recommendations

The input circuitry of the INA193A-INA198A devices can accurately measure beyond its power-supply voltage, V+. For example, the V+ power supply can be 5 V, whereas the load power-supply voltage is up to 80 V. The output voltage range of the OUT terminal, however, is limited by the voltages on the power-supply pin.
10 Layout

10.1 Layout Guidelines

10.1.1 RFI/EMI

TI always recommends adhering to good layout practices. Keep traces short and, when possible, use a printed-circuit-board (PCB) ground plane with surface-mount components placed as close to the device pins as possible. Small ceramic capacitors placed directly across amplifier inputs can reduce RFI/EMI sensitivity. PCB layout should locate the amplifier as far away as possible from RFI sources. Sources can include other components in the same system as the amplifier itself, such as inductors (particularly switched inductors handling a lot of current and at high frequencies). RFI can generally be identified as a variation in offset voltage or dc signal levels with changes in the interfering RF signal. If the amplifier cannot be located away from sources of radiation, shielding may be needed. Twisting wire input leads makes them more resistant to RF fields. The difference in input pin location of the INA193A–INA195A versus the INA196A–INA198A may provide different EMI performance.

10.2 Layout Example

![Recommended Layout Diagram]

Figure 10-1. Recommended Layout
11 Device and Documentation Support

11.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on Subscribe to updates to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.2 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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11.3 Trademarks

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

11.4 Electrostatic Discharge Caution

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.

11.5 Glossary

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 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.
## PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead finish/Ball material</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Device Marking</th>
<th>Samples</th>
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(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

(2) **RoHS**: TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
- **RoHS Exempt**: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
- **Green**: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices 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.
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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF INA193A-Q1:


NOTE: Qualified Version Definitions:

- Enhanced Product - Supports Defense, Aerospace and Medical Applications
## TAPE AND REEL INFORMATION

### TAPE DIMENSIONS

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<td>B0</td>
<td>Dimension designed to accommodate the component length</td>
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<tr>
<td>K0</td>
<td>Dimension designed to accommodate the component thickness</td>
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### REEL DIMENSIONS

*All dimensions are nominal.

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### TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal*

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NOTES:

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.
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.
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.
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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