INA901-SP Radiation Hardened, –15-V to 80-V Common Mode, Unidirectional Current-Shunt Monitor

1 Features

- 5962-1821001
  - Radiation Hardness Assured (RHA)
  - 100 krad(Si) at Low Dose Rate
  - Single Event Latch-up (SEL)
  - Immune to 93 MeV·cm²/mg at 125°C
  - See Radiation Reports
  - Qualified Over the Military Temperature Range (–55°C to 125°C)
  - High-Performance 8-Pin Ceramic Flat Pack Package (HKX)
- Wide Common-Mode Range: –15 V to 80 V
- CMRR: 120 dB
- Accuracy:
  - ±0.5-mV Offset
  - ±0.2% Gain Error
  - 2.5-μV/°C Offset Drift
  - 50-ppm/°C Gain Drift
- Bandwidth: Up to 130 kHz
- Gain: 20 V/V
- Quiescent Current: 700 μA
- Power Supply: 2.7 V to 16 V
- Provision for Filtering

2 Applications

- Power Supervision
- Overcurrent and Undercurrent Detection
- Satellites Telemetry
- Space Signal Conditioning
- Motor Control Loops

3 Description

The INA901-SP is a voltage-output, current-sense amplifier that can sense drops across shunt resistors at common-mode voltages from –15 V to 80 V, independent of the supply voltage. The INA901-SP operates from a single 2.7-V to 16-V supply, drawing 700 μA (typical) of supply current.

The gain of the INA901-SP is 20 V/V. The 130-kHz bandwidth simplifies use in current-control loops. The pinouts readily enable filtering.

The device is specified over the extended operating temperature range of –55°C to 125°C and is offered in an 8-pin CFP package.

Device Information

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>GRADE</th>
<th>PACKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5962R1821001VXC</td>
<td>QMLV RHA [100 krad(Si)]</td>
<td>8-lead CFP (HKX)</td>
</tr>
<tr>
<td>5962-1821001VXC</td>
<td>QMLV</td>
<td>8-lead CFP (HKX)</td>
</tr>
<tr>
<td>INA901HKX/EM</td>
<td>Engineering Samples</td>
<td>6.48 × 6.48 mm Weight: 0.39 g</td>
</tr>
<tr>
<td>INA901EVM-CVAL</td>
<td>Ceramic Evaluation Board</td>
<td>—</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum at the end of the data sheet.
(2) These units are intended for engineering evaluation only. They are processed to a noncompliant flow. These units are not suitable for qualification, production, radiation testing or flight use. Parts are not warranted for performance over the full MIL specified temperature range of –55°C to 125°C or operating life.
(3) Weight is accurate to ±10%.

Simplified Schematic
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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 A (December 2018) to Revision B Page

- Changed the device status from Advance Information to Production Data .......................................................... 1
5 Pin Configuration and Functions

NOTE (1): NC denotes no internal connection.

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>TYPE(1)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUF IN</td>
<td>4</td>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>GND</td>
<td>2</td>
<td>—</td>
<td>GND</td>
</tr>
<tr>
<td>IN–</td>
<td>1</td>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>IN+</td>
<td>8</td>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>NC</td>
<td>7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>OUT</td>
<td>5</td>
<td>O</td>
<td>A</td>
</tr>
<tr>
<td>PRE OUT</td>
<td>3</td>
<td>O</td>
<td>A</td>
</tr>
<tr>
<td>V+</td>
<td>6</td>
<td>—</td>
<td>P</td>
</tr>
</tbody>
</table>

(1) A = analog, P = power, GND = ground

6 Specifications

6.1 Absolute Maximum Ratings(1)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage (Vs)</td>
<td></td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Analog inputs, Vin+, Vin–</td>
<td>18</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Analog output: OUT and PRE OUT pins</td>
<td>GND – 0.3</td>
<td>(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>Operating temperature</td>
<td>–55</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Junction temperature</td>
<td>150</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage temperature, Tstg</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.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(ESD) Electrostatic discharge</td>
<td>Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)</td>
<td>±3000</td>
</tr>
<tr>
<td>Charged-device model (CDM), per JEDEC specification JESD22-C101(2)</td>
<td>±1000</td>
<td>V</td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{CM}}$</td>
<td>–15</td>
<td>80</td>
<td>V</td>
</tr>
<tr>
<td>$V_S$</td>
<td>2.7</td>
<td>16</td>
<td>V</td>
</tr>
<tr>
<td>$T_A$</td>
<td>–55</td>
<td>125</td>
<td>°C</td>
</tr>
</tbody>
</table>

6.4  Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>INA901-SP</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{\text{JA}}$ Junction-to-ambient thermal resistance</td>
<td></td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\text{JC(top)}}$ Junction-to-case (top) thermal resistance</td>
<td></td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\text{JB}}$ Junction-to-board thermal resistance</td>
<td>98.8</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{\text{JT}}$ Junction-to-top characterization parameter</td>
<td>32.5</td>
<td>°C/W</td>
</tr>
<tr>
<td>$\psi_{\text{JB}}$ Junction-to-board characterization parameter</td>
<td>93.1</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\text{JC(bot)}}$ Junction-to-case (bottom) thermal resistance</td>
<td>26.5</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.
### 6.5 Electrical Characteristics

$V_S = 2.7$ V and 16 V, $V_{CM} = -15$ V, 12 V and 80 V, $V_{SENSE} = 100$ mV, and PRE OUT connected to BUF IN, unless otherwise noted. $T_A$ is as shown in SUBGROUP column.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>SUBGROUP(1)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{SENSE}$ Full-scale input voltage</td>
<td>$V_{SENSE} = (V_{IN+}) – (V_{IN–})$</td>
<td>[1, 2, 3]</td>
<td>0.15</td>
<td>(V $S$ – 0.2) / Gain</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{CM}$ Common-mode input range</td>
<td></td>
<td>[1, 2, 3]</td>
<td>–16</td>
<td>80</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>CMRR Common-mode rejection ratio</td>
<td>$V_{IN+} = -15$ V to 80 V</td>
<td>[1]</td>
<td>80</td>
<td>120</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>$V_{OS}$ Offset voltage, RTI</td>
<td></td>
<td>[2, 3]</td>
<td>70</td>
<td>120</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>$dV_{OS}/dT$</td>
<td></td>
<td>[1, 2, 3]</td>
<td>2.5</td>
<td>5</td>
<td>250</td>
<td>μV/°C</td>
</tr>
<tr>
<td>PSR $V_{OS}$ vs power-supply</td>
<td></td>
<td>[1, 2, 3]</td>
<td>5</td>
<td>250</td>
<td></td>
<td>μV/V</td>
</tr>
<tr>
<td>$I_b$ Input bias current, $V_{IN–}$ pin</td>
<td></td>
<td>[1]</td>
<td>±8</td>
<td>±16</td>
<td>±19</td>
<td>μA</td>
</tr>
<tr>
<td>PRE OUT output impedance</td>
<td></td>
<td>[2, 3]</td>
<td>96</td>
<td>6</td>
<td></td>
<td>kΩ</td>
</tr>
<tr>
<td>Buffer input bias current</td>
<td></td>
<td></td>
<td>–50</td>
<td>0</td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td>Buffer input bias current temperature coefficient</td>
<td></td>
<td>±0.03</td>
<td></td>
<td></td>
<td>nA/°C</td>
<td></td>
</tr>
</tbody>
</table>

### OUTPUT ($V_{SENSE} ≥ 20$ mV)(2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>SUBGROUP(1)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G$ Gain</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td>V/V</td>
</tr>
<tr>
<td>$G_{BUF}$ Output buffer gain</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>V/V</td>
</tr>
<tr>
<td>Total gain error $V_{SENSE} = 20$ mV to 100 mV</td>
<td>[4, 5, 6]</td>
<td>±0.2%</td>
<td>±1.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total gain error vs temperature $T_A = -55°C$ to 125°C</td>
<td></td>
<td>50</td>
<td>ppm/°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total output error(3)</td>
<td></td>
<td>[4]</td>
<td>±0.75%</td>
<td>±2%</td>
<td>±3%</td>
<td></td>
</tr>
<tr>
<td>Nonlinearity error $V_{SENSE} = 20$ mV to 100 mV</td>
<td>[5, 6]</td>
<td>±0.002%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_O$ Output impedance, pin 5</td>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Maximum capacitive load</td>
<td></td>
<td></td>
<td>No sustained oscillation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### VOLTAGE OUTPUT ($R_L = 10$ kΩ to GND)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>SUBGROUP(1)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swing to $V+$ power-supply rail</td>
<td>$V_{SENSE} = 20$ mV to 100 mV</td>
<td>[1, 2, 3]</td>
<td>(V $+$) – 0.05</td>
<td>(V $+$) – 0.2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Swing to GND</td>
<td></td>
<td>[1, 2, 3]</td>
<td>$V_{GND} + 0.003$</td>
<td>$V_{GND} + 0.05$</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

### FREQUENCY RESPONSE

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>SUBGROUP(1)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW Bandwidth</td>
<td>$C_{LOAD} = 5$ pF</td>
<td></td>
<td>130</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Phase margin</td>
<td>$C_{LOAD} &lt; 10$ nF</td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td>°</td>
</tr>
<tr>
<td>Slew rate</td>
<td>$1$</td>
<td>$V_{PSS}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_s$ Settling time (1%)</td>
<td>$V_{SENSE} = 10$ mV to 100 mV$_{PP}$,</td>
<td>$C_{LOAD} = 5$ pF</td>
<td>2</td>
<td></td>
<td>μs</td>
<td></td>
</tr>
</tbody>
</table>

---

(1) For subgroup definitions, please see Quality Conformance Inspection table.
(2) For output behavior when $V_{SENSE} < 20$ mV, see the Accuracy Variations as a Result of $V_{SENSE}$ and Common-Mode Voltage section.
(3) Total output error includes effects of gain error and $V_{OS}$. 
Electrical Characteristics (continued)

\( V_S = 2.7 \text{ V and } 16 \text{ V, } V_{CM} = -15 \text{ V, } 12 \text{ V and } 80 \text{ V, } V_{\text{SENSE}} = 100 \text{ mV, and PRE OUT connected to BUF IN, unless otherwise noted. } T_A \text{ is as shown in SUBGROUP column.} \)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>SUBGROUP((1))</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e_n)</td>
<td>Volge noise density</td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td>nV/√Hz</td>
</tr>
</tbody>
</table>

**POWER SUPPLY**

\( V_S \) Operating range

\( V_{\text{OUT}} = 2 \text{ V} \)

\( V_{\text{SENSE}} = 0 \text{ mV} \)

(4) RTI means Referred-to-Input.

6.6 Quality Conformance Inspection

MIL-STD-883, Method 5005 - Group A

<table>
<thead>
<tr>
<th>SUBGROUP</th>
<th>DESCRIPTION</th>
<th>TEMP (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Static tests at</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Static tests at</td>
<td>125</td>
</tr>
<tr>
<td>3</td>
<td>Static tests at</td>
<td>–55</td>
</tr>
<tr>
<td>4</td>
<td>Dynamic tests at</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>Dynamic tests at</td>
<td>125</td>
</tr>
<tr>
<td>6</td>
<td>Dynamic tests at</td>
<td>–55</td>
</tr>
<tr>
<td>7</td>
<td>Functional tests at</td>
<td>25</td>
</tr>
<tr>
<td>8A</td>
<td>Functional tests at</td>
<td>125</td>
</tr>
<tr>
<td>8B</td>
<td>Functional tests at</td>
<td>–55</td>
</tr>
<tr>
<td>9</td>
<td>Switching tests at</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>Switching tests at</td>
<td>125</td>
</tr>
<tr>
<td>11</td>
<td>Switching tests at</td>
<td>–55</td>
</tr>
<tr>
<td>12</td>
<td>Setting time at</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>Setting time at</td>
<td>125</td>
</tr>
<tr>
<td>14</td>
<td>Setting time at</td>
<td>–55</td>
</tr>
</tbody>
</table>
6.7 Typical Characteristics

At $T_A = 25^\circ\text{C}$, $V_S = 12\text{ V}$, $V_{\text{CM}} = 12\text{ V}$, and $V_{\text{SENSE}} = 100\text{ mV}$, unless otherwise noted.
Typical Characteristics (continued)

At $T_A = 25^\circ C$, $V_S = 12$ V, $V_{CM} = 12$ V, and $V_{SENSE} = 100$ mV, unless otherwise noted.

---

Figure 7. Positive Output Voltage Swing vs Output Current

Figure 8. Quiescent Current vs Output Voltage

Figure 9. Quiescent Current vs Common-Mode Voltage

Figure 10. Output Short-Circuit Current vs Supply Voltage

Figure 11. PRE OUT Output Resistance Production Distribution

Figure 12. Buffer Gain vs Frequency
Typical Characteristics (continued)

At $T_A = 25°C$, $V_S = 12\, V$, $V_{CM} = 12\, V$, and $V_{SENSE} = 100\, mV$, unless otherwise noted.

Figure 13. Small-Signal Step Response
(10-mV to 20-mV Input)

Figure 14. Large-Signal Step Response
(10-mV to 100-mV Input)
7 Detailed Description

7.1 Overview

The INA901-SP current-shunt monitor with voltage output can sense drops across current shunts at common-mode voltages from –16 V to 80 V, independent of the supply voltage. The INA901-SP pinouts readily enable filtering.

The INA901-SP is available with a 20-V/V output voltage scale. The 130-kHz bandwidth simplifies use in current-control loops.

The INA901-SP operates from a single 2.7-V to 18-V supply, drawing a maximum of 900 μA of supply current. The devices are specified over the extended operating temperature range of –55°C to 125°C and are offered in an 8-pin CFP package.

7.2 Functional Block Diagram
7.3 Feature Description

7.3.1 Basic Connection

Figure 15 shows the basic connection of the INA901-SP. Connect the input pins (IN+ and IN–) 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. Place minimum bypass capacitors of 0.01 μF and 0.1 μF in value close to the supply pins. Although not mandatory, an additional 10-mF electrolytic capacitor placed in parallel with the other bypass capacitors may be useful in applications with particularly noisy supplies.

![INA901-SP Basic Connections](image)

Figure 15. INA901-SP Basic Connections

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 (V_S – 0.2) / Gain.

7.3.3 Transient Protection

The –16-V to 80-V common-mode range of INA901-SP is ideal for withstanding 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 INA901-SP exposed to transients on the inputs in excess of their ratings, external transient absorption with semiconductor transient absorbers (Zeners or Transzorbs) are necessary.
Feature Description (continued)

Use of MOVs or VDRs is not recommended except when they are used in addition to a semiconductor transient absorber. Select the transient absorber such that it never allows the INA901-SP to be exposed to transients greater than 80 V (that is, allow for transient absorber tolerance, as well as additional voltage because of transient absorber dynamic impedance). Despite the use of internal Zener-type ESD protection, the INA901-SP is not suited to using external resistors in series with the inputs because the internal gain resistors can vary up to ±30%, but are tightly matched (if gain accuracy is not important, then resistors can be added in series with the INA901-SP inputs with two equal resistors on each input).
7.4 Device Functional Modes

7.4.1 First- or Second-Order Filtering

The output of the INA901-SP is accurate within the output voltage swing range set by the power-supply pin, V+.

The INA901-SP readily enables the inclusion of filtering between the preamp output and buffer input. Single-pole filtering can be accomplished with a single capacitor because of the 96-kΩ output impedance at PRE OUT on pin 3, as shown in Figure 16a.

The INA901-SP readily lends to second-order Sallen-Key configurations, as shown in Figure 16b. When designing these configurations consider that the PRE OUT 96-kΩ output impedance exhibits an initial variation of ±30% with the addition of a –2200-ppm/°C temperature coefficient.

NOTE: Remember to use the appropriate buffer gain = 2 when designing Sallen-Key configurations.

Figure 16. The INA901-SP Can Be Easily Connected for First- or Second-Order Filtering

7.4.2 Accuracy Variations as a Result of $V_{\text{SENSE}}$ and Common-Mode Voltage

The accuracy of the INA901-SP 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 used 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:
  - $V_{\text{SENSE}} < 20 \text{ mV}, 0 \text{ V} \leq V_{\text{CM}} \leq V_S$
Device Functional Modes (continued)

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 1.

\[
G = \frac{V_{\text{OUT1}} - V_{\text{OUT2}}}{100\text{mV} - 20\text{mV}}
\]

where
- \( V_{\text{OUT1}} \) = Output voltage with \( V_{\text{SENSE}} = 100 \text{ mV} \) and
- \( V_{\text{OUT2}} \) = Output voltage with \( V_{\text{SENSE}} = 20 \text{ mV} \). 

Equation 1

Then the offset voltage is measured at \( V_{\text{SENSE}} = 100 \text{ mV} \) and referred to the input (RTI) of the current shunt monitor, as shown in Equation 2.

\[
V_{\text{OS RTI}} \ (\text{Referred-To-Input}) = \left( \frac{V_{\text{OUT1}}}{G} \right) - 100\text{mV}
\]

Equation 2

In the Typical Characteristics section, the Output Error vs Common-Mode Voltage curve (Figure 6) 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 device functions, as illustrated in the Output Error vs Common-Mode Voltage curve (Figure 6). As noted, for this graph \( V_S = 12 \text{ V} \); for \( V_{\text{CM}} < 12 \text{ V} \), the output error increases when \( V_{\text{CM}} \) 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 INA901-SP is 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 INA901-SP, knowing what the behavior of the devices is in these regions is important.
Device Functional Modes (continued)

When $V_{\text{SENSE}}$ 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 $V_{\text{OUT}} = 60$ mV for $V_{\text{SENSE}} = 0$ mV. When $V_{\text{SENSE}}$ approaches 20 mV, $V_{\text{OUT}}$ returns to the expected output value with accuracy as specified in the Electrical Characteristics table. Figure 17 shows this effect using the INA901-SP (gain = 20).

![Figure 17. Example For Low $V_{\text{SENSE}}$ Cases 1 and 3 (INA901-SP Gain = 20)](image)

### 7.4.2.4 Low $V_{\text{SENSE}}$ Case 2: $V_{\text{SENSE}} < 20$ mV, $0 \leq V_{\text{CM}} \leq V_{S}$

This region of operation is the least accurate for the INA901-SP. To achieve the wide input common-mode voltage range, these devices use two op amp front ends in parallel. One op amp 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, $V_{\text{OUT}}$ approaches voltages close to linear operation levels for Normal Case 2.

This deviation from linear operation becomes greatest the closer $V_{\text{SENSE}}$ approaches 0 V. Within this region, when $V_{\text{SENSE}}$ approaches 20 mV, device operation is closer to that described by Normal Case 2. Figure 18 shows this behavior for the INA901-SP. The $V_{\text{OUT}}$ maximum peak for this case is determined by maintaining a constant $V_{S}$, setting $V_{\text{SENSE}} = 0$ mV, and sweeping $V_{\text{CM}}$ from 0 V to $V_{S}$. The exact $V_{\text{CM}}$ at which $V_{\text{OUT}}$ peaks during this case varies from device to device. The maximum peak voltage for the INA901-SP is 0.4 V.

![Figure 18. Example for Low $V_{\text{SENSE}}$ Case 2 (INA901-SP, Gain = 20)](image)
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
The INA901-SP measures the voltage developed across a current-sensing resistor when current passes through it. There is also a filtering feature to remove unwanted transients and smooth the output voltage.

8.2 Typical Application

![Circuit Diagram](image)

**Figure 19. Filtering Configuration**

8.2.1 Design Requirements
In this application, the device is configured to measure a triangular periodic current at 10 kHz with filtering. The average current through the shunt is the information that is desired. This current can be either solenoid current or inductor current where current is being pulsed through.

Selecting the capacitor size is based on the lowest frequency component to be filtered out. The amount of signal that is filtered out is dependant on this cutoff frequency. From the cutoff frequency, the attenuation is 20 dB per decade.
Typical Application (continued)

8.2.2 Detailed Design Procedure

Without this filtering capability, an input filter must be used. When series resistance is added to the input, large errors also come into play because the resistance must be large to create a low cutoff frequency. By using a 10-nF capacitor for the single-pole filter capacitor, the 10-kHz signal is averaged. The cutoff frequency made by the capacitor is set at 166-Hz frequency. This frequency is well below the periodic frequency and reduces the ripple on the output and the average current can easily be measured.

8.2.3 Application Curves

Figure 20 shows the output waveform without filtering. The output signal tracks the input signal with a large ripple. If this current is sampled by an ADC, many samples must be taken to average the current digitally. This process requires additional time for sampling or operating at a higher sampling rate, which may be undesirable for the application.

Figure 21 shows the output waveform with filtering. The average value of the current with a small ripple can now be easily sampled by the converter without the need for digital averaging.

![Figure 20. Without Filtering](image1)

![Figure 21. With Filtering](image2)
9 Power Supply Recommendations

The input circuitry of the INA901-SP 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

- Connect the input pins to the sensing resistor using a Kelvin or 4-wire connection. This connection technique ensures that only the current-sensing resistor impedance is detected between the input pins. Poor routing of the current-sensing resistor commonly results in additional resistance present between the input pins. Given the very low ohmic value of the current resistor, any additional high-current carrying impedance can cause significant measurement errors.

- Place the power-supply bypass capacitor as closely as possible to the supply and ground pins. The recommended value of this bypass capacitor is 0.1 μF. Additional decoupling capacitance can be added to compensate for noisy or high-impedance power supplies.

10.1.1 RFI and EMI

Attention to good layout practices is always recommended. 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 and EMI sensitivity. PCB layout must 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.

10.2 Layout Example

![Example Layout Diagram]

**Figure 22. Example Layout**
11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation
Refer to the INA901-SP product folder on ti.com for links to technical documents and tools and software.

11.2 Receiving Notification of Documentation Updates
To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on Alert me 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.

11.3 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.

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

11.4 Trademarks
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11.5 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.

11.6 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.
## PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status (1)</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan (2)</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp (3)</th>
<th>Op Temp (°C)</th>
<th>Device Marking (4/5)</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
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<td>HKX</td>
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<td>1</td>
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<td>NIAU</td>
<td>N / A for Pkg Type</td>
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<tr>
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<tr>
<td>INA901HKX/EM</td>
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<td>CFP</td>
<td>HKX</td>
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<td>TBD</td>
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<td>N / A for Pkg Type</td>
<td>25 to 25</td>
<td>INA901HKX/EM</td>
<td>Samples</td>
</tr>
</tbody>
</table>

(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 substances 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/Ball Finish** - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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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.
3. This package is hermetically sealed with a metal lid. The lid is not connected to any lead.
4. The leads are gold plated.
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