Current Sense Amplifiers

Introduction

What are Current Sense Amplifiers?
Current sense amplifiers, also called current shunt monitors, are specialized differential amplifiers with a precisely matched resistive gain network with the following characteristics:
- Designed to monitor the current flow by measuring the voltage drop across a sense element, typically a shunt resistor
- Tend to be easier to use, more precise and less prone to noise
- Support currents from 10s of µA to 100s of A
- Natively support common-mode voltages from -16 to +80 V and with additional circuitry up to 100s of volts

System benefits addressed by using current sense amplifiers:
- Real-time overcurrent protection
- Current and power monitoring for system optimization
- Current measurement for closed-loop feedback

Key Parameters

Common Mode Range:
This specification defines the DC voltage range at the input of an amplifier with respect to ground. Current sense amplifiers are typically designed to support common-mode voltages well beyond the chip supply voltage. For example, the INA240 is capable of supporting a common-mode voltages between -4 V to +80 V while running on a supply as low as 2.7 V.

Offset Voltage:
This is a differential DC error at the input of the amplifier. Historically, to reduce the impact of amplifiers with high offsets, larger value shunt resistors were used to increase the measured voltage drop. Today, TI is able to offer current sense amplifiers with offsets as low as 10µV, enabling higher precision measurements at low currents and allowing the use of smaller value shunt resistors for improved system efficiency.

Gain:
Current sense amplifiers come with various gain options that have robust performance over temperature and process variations by integrating a precisely matched resistive gain network. The gain options for fixed gain amplifiers vary from 0.125 V/V to 1000 V/V with gain errors as low as 0.01%.

Temperature Stability:
Current sense amplifiers integrate the amplifier along with all the gain-setting resistors which enables small and unified temperature drift. This allows for robust current measurements across the whole specified temperature range. The achieved temperature stability is one of the key advantages current sense amplifiers have over discrete implementations.
Current Sense Amplifiers
Key Design Considerations

High-Side Measurements
Current sensing techniques connect the current sense element between the supply bus and the load.

**System Advantages:**
- Able to detect load short to ground
- Current is monitored directly from the source
- High immunity to ground disturbance

**System Challenges:**
- High bus voltage limits the availability of high input common-mode voltage devices

**Advantages Over Discrete Current Sense Circuit:**
- Integrated gain resistors provide excellent matching to enable a higher performing and more stable platform
- Reduction in board space requirements
- High dynamic changes in the common-mode voltage are difficult to achieve with standard op amps
- Unique input architecture allows for the common-mode voltage to greatly exceed the device supply voltage

Low-Side Measurements
Current sensing techniques connect the current sense element between the load and ground.

**System Advantages:**
- Simple to implement and low-cost solution
- Wide range of available options

**System Challenges:**
- Difficult to detect load short to ground
- System ground disturbance by the shunt resistor

**Advantages Over Discrete Current Sense Circuit:**
- Integrated gain resistors provide excellent matching to enable a higher performing and more stable platform
- Reduction in board space requirements
- True differential measurement across the shunt resistor
- Lower $V_{OFFSET}$ saves system power by enabling the use of smaller value shunt resistors to achieve the same error level

Total Error
- For light loads with small current values that result in small differential voltage signals at the input, the total error will be dominated by the amplifier’s offset voltage. Low input offsets are critical to achieving accurate measurements at the low end of the dynamic range.
- For heavy loads with large current values that result in large differential voltage signals at the input, the total error will be dominated by the amplifier’s gain error.
## Current Sense Amplifiers

**Reference Designs**

Current sensing reference designs. See more designs online at [ti.com/referencedesigns](http://ti.com/referencedesigns).

<table>
<thead>
<tr>
<th>Design Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDA-00795</td>
<td><strong>Automotive Precision eFuse</strong>&lt;br&gt;One of the keys to preventing damage in automotive electronic systems is the ability to detect and react to potentially damaging conditions as rapidly as possible. This INA300-Q1 eFuse reference design is focused on providing high accuracy and fast response over-current protection at current levels as high as 30 A and scalable to &gt; 100 A.</td>
</tr>
<tr>
<td>TIDA-00528</td>
<td><strong>40 V to 400 V Unidirectional Current/Voltage/Power Monitoring</strong>&lt;br&gt;This reference design demonstrates a simple, non-isolated technique using a precision op amp and a high voltage P-FET to extend the common-mode voltage of a current sense amplifier up to 400 V. With minor component changes, this design can be optimized for any voltage ranging from 40 to 400 V.</td>
</tr>
<tr>
<td>TIDA-00753</td>
<td><strong>Three-phase Current Measurements for Motor</strong>&lt;br&gt;Maximizing motor control requires accurate current measurement. This reference design featuring the INA199 demonstrates a method for enhancing the signal chain on the output of a current transformer. In addition, this circuit offers significant power savings by lowering the burden resistor value.</td>
</tr>
</tbody>
</table>
## Current Sense Amplifiers

**Reference Designs**

Current sensing reference designs. See more designs online at [ti.com/referencedesigns](http://ti.com/referencedesigns).

<table>
<thead>
<tr>
<th>Design Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDA-00913</td>
<td><strong>48 V 3-Phase Inverter with Shunt-based In-line Motor Phase Current Sensing</strong>&lt;br&gt;This design realizes a 48 V/10A 3-phase GaN inverter with precision in-line shunt-based phase current sensing for accurate control of precision drives such as servo drives. One of the largest challenges with in-line shunt-based phase current sensing is the high common-mode voltage transients during PWM switching. The INA240 current sense amplifier overcomes this problem using enhanced PWM rejection.</td>
</tr>
<tr>
<td>TIDA-00440</td>
<td><strong>Leakage Current Measurement Reference Design for Determining Insulation Resistance</strong>&lt;br&gt;This design provides a reference solution to measure insulation resistance up to 100MΩ. It has an on-board isolated 500 V DC power supply and an isolated signal conditioning circuit to measure the leakage current. This design is useful to find leakage due to insulation breakdown in transformer and motor windings.</td>
</tr>
</tbody>
</table>

### Application Notes

Current and power measurement use cases in a short, easy-to-read format

[Browse now](http://ti.com/referencedesigns)
## Analog Output Current Sense Amplifiers

**Featured Products**

For more information see: [ti.com/currentsense](http://ti.com/currentsense).

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Available Bi-Directional</th>
<th>Low-Side Measurement Parameter Values</th>
<th>Description</th>
<th>Common Mode Voltage Range</th>
<th>Input Offset ±µ V Max</th>
<th>Input Offset Drift ±µ V/°C Typ</th>
<th>Gain Error % Typ</th>
<th>Package(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INA190</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>1.8 V, High-precision Current Sense Amplifier with Power Down</td>
<td>-0.1 to 40</td>
<td>10</td>
<td>0.1</td>
<td>0.1</td>
<td>10 UQFN, 6 WCSP, 6 SC70</td>
</tr>
<tr>
<td>INA210</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High performance, Zero-Drift Current Sense Amplifier</td>
<td>-0.3 to 26</td>
<td>35</td>
<td>0.1</td>
<td>0.02</td>
<td>10 UQFN, 6 SC70</td>
</tr>
<tr>
<td>INA240</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High AC CMRR High Common Mode Current Sense Amplifier for Motor &amp; Solenoid Control</td>
<td>-4 to 80</td>
<td>25</td>
<td>0.05</td>
<td>0.05</td>
<td>8 TSSOP, 8 SSIC</td>
</tr>
<tr>
<td>INA216</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Ultra-small, 5 V Current Sense Amplifier</td>
<td>1.8 to 5.5</td>
<td>100</td>
<td>0.06</td>
<td>0.01</td>
<td>10 UQFN, 4 WSCP</td>
</tr>
<tr>
<td>INA199</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Value line, Zero-Drift Current Sense Amplifier</td>
<td>-0.3 to 26</td>
<td>150</td>
<td>0.1</td>
<td>0.03</td>
<td>10 UQFN, 6 SC70</td>
</tr>
<tr>
<td>INAx180</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>350kHz Bandwidth, Unidirectional Current Sense Amplifier for Cost-sensitive Applications (Single, Dual, &amp; Quad Options)</td>
<td>-0.2 to 26</td>
<td>150</td>
<td>0.2</td>
<td>0.1</td>
<td>5 SOT-23, 8 VSSOP, 14 TSSOP</td>
</tr>
<tr>
<td>INAx181</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>350kHz Bandwidth, Bidirectional Current Sense Amplifier for Cost-sensitive Applications (Single, Dual, &amp; Quad Options)</td>
<td>-0.2 to 26</td>
<td>150</td>
<td>0.2</td>
<td>0.1</td>
<td>6 SOT-23, 10 VSSOP, 20 TSSOP</td>
</tr>
<tr>
<td>INA226</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>40 V Bidirectional, Precision Current Sense Amplifier</td>
<td>-0.1 to 40</td>
<td>50</td>
<td>0.05</td>
<td>0.02</td>
<td>6 SC70</td>
</tr>
<tr>
<td>INA293</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>110 V High Voltage, High Bandwidth, Unidirectional Current Sense Amplifier</td>
<td>-4 to 110</td>
<td>100</td>
<td>0.2</td>
<td>0.02</td>
<td>5 SOT-23</td>
</tr>
<tr>
<td>INA290</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>120 V High Voltage, High Bandwidth, High-side Current Sense Amplifier</td>
<td>2.7 to 120</td>
<td>100</td>
<td>0.2</td>
<td>0.02</td>
<td>5 SC70</td>
</tr>
<tr>
<td>INA185</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>350kHz Bandwidth, High-Precision, Bidirectional Current Sense Amplifier in SOT-563 Package</td>
<td>-0.2 to 26</td>
<td>55</td>
<td>0.2</td>
<td>0.05</td>
<td>6 SOT-563</td>
</tr>
<tr>
<td>INA225</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Programmable-Gain, Zero-Drift, High Accuracy</td>
<td>0 to 36</td>
<td>150</td>
<td>0.2</td>
<td>0.05</td>
<td>8 MSOP</td>
</tr>
<tr>
<td>LMP8481</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High Common Mode, High-Speed Current Sense Amplifier</td>
<td>4.5 to 76</td>
<td>265</td>
<td>6</td>
<td>0.6</td>
<td>8 VSSOP</td>
</tr>
<tr>
<td>LMP8640</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High-Speed Current Sense Amplifier</td>
<td>-2 to 42</td>
<td>900</td>
<td>2.6</td>
<td>0.25</td>
<td>6 SOT-23</td>
</tr>
<tr>
<td>INA250</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High Accuracy, Zero-Drift Current Sense Amplifier with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt</td>
<td>0 to 36</td>
<td>50mA</td>
<td>25µA/°C</td>
<td>0.3</td>
<td>16 TSSOP</td>
</tr>
<tr>
<td>INA253</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High AC CMRR High Common Mode Current Sense Amplifier Solenoid Control with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt</td>
<td>-4 to 80</td>
<td>12.5mA</td>
<td>25µA/°C</td>
<td>0.25</td>
<td>20 TSSOP</td>
</tr>
<tr>
<td>INA301</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Comparator</td>
<td>0 to 36</td>
<td>35</td>
<td>0.1</td>
<td>0.03</td>
<td>8 VSSOP</td>
</tr>
<tr>
<td>INA302</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Dual Comparators</td>
<td>0 to 36</td>
<td>30</td>
<td>0.02</td>
<td>0.02</td>
<td>14 TSSOP</td>
</tr>
<tr>
<td>INA303</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Window Comparator</td>
<td>0 to 36</td>
<td>30</td>
<td>0.02</td>
<td>0.02</td>
<td>14 TSSOP</td>
</tr>
<tr>
<td>INA381</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Cost-efficient Current Sense Amplifier with Integrated Standalone Comparator</td>
<td>-0.2 to 26</td>
<td>150</td>
<td>0.1</td>
<td>0.1</td>
<td>8 UQFN</td>
</tr>
</tbody>
</table>

## Digital Output Power Monitors

**Featured Products**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Available Bi-Directional</th>
<th>Low-Side Measurement Parameter Values</th>
<th>Description</th>
<th>Common Mode Voltage Range</th>
<th>Input Offset ±µ V Max</th>
<th>Input Offset Drift ±µV/°C Typ</th>
<th>Gain Error % Typ</th>
<th>Package(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INA226</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Ultra-High Accuracy, Current, Voltage, &amp; Power</td>
<td>0 to 36</td>
<td>10</td>
<td>0.02</td>
<td>0.02</td>
<td>10 VSSOP</td>
</tr>
<tr>
<td>INA260</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>Ultra-High Accuracy, Current, Voltage, &amp; Power Monitor with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt</td>
<td>0 to 36</td>
<td>5mA</td>
<td>1µA/°C</td>
<td>0.02</td>
<td>16 TSSOP</td>
</tr>
<tr>
<td>INA233</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>High Accuracy, Current, Voltage, Power, &amp; Energy Monitor with 1.8 V/°C/PMBus</td>
<td>0 to 36</td>
<td>10</td>
<td>0.02</td>
<td>0.02</td>
<td>10 VSSOP</td>
</tr>
<tr>
<td>INA229</td>
<td>✓ ✓ ✓</td>
<td>I, V, P</td>
<td>85 V Current/Voltage/Power/Energy/Charge Monitoring Device with SPI Interface with Internal Temperature Sensor</td>
<td>0 to 85</td>
<td>10</td>
<td>0.01</td>
<td>0.02</td>
<td>10 VSSOP, 16 UQFN</td>
</tr>
<tr>
<td>INA3221</td>
<td>✓ ✓ ✓</td>
<td>I, V</td>
<td>Triple-channel, Current &amp; Voltage Monitor with Alert</td>
<td>0 to 26</td>
<td>80</td>
<td>0.1</td>
<td>0.1</td>
<td>16 UQFN</td>
</tr>
</tbody>
</table>

Preview devices as of Q2 2019
Measuring current or power in your design?

Browse a series of short training videos to get started.

ti.com/currentsensestaining

TI Worldwide Technical Support

Internet
TI Semiconductor Product Information Center Home Page
support.ti.com
TI E2E™ Community Home Page
e2e.ti.com

Product Information Centers

Americas
Phone +1(512) 434-1560
Mexico
Phone 0800-670-7544
Internet/Email ti.com/sds/ti/csc/support_Americas.page

Europe, Middle East, and Africa
Phone
European Free Call 00800-ASK-TEXAS
(00800 275 83927)
International +49 (0) 8161 80 2121
Russian Support +7 (4) 95 98 10 701
Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Asia
Phone
Note: Toll-free numbers may not support mobile and IP phones.
Australia 1-800-999-084
China 800-820-8882
Hong Kong 800-96-5941
India 000-800-100-8888
Indonesia 001-803-8861-1006
Korea 080-551-2804
Malaysia 1-800-80-3973
New Zealand 0800-446-934
Philippines 1-800-765-7404
Singapore 800-886-1028
Taiwan 0800-006800
Thailand 001-800-886-0010
International +86-21-23073444
Fax +86-21-23073686
Email tiasia@ti.com or ti-china@ti.com
Internet support.ti.com/sc/pc/pic/asia.htm
Technical forums www.deysupport.com

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI’s standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer’s applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company’s products or services does not constitute TI’s approval, warranty or endorsement thereof.

© 2019 Texas Instruments Incorporated
Printed in U.S.A.
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2019, Texas Instruments Incorporated