

# Current Sense Amplifiers



Monitoring

Feedback



Feedback

Protection

# 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  $\mu\text{A}$  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  $10\mu\text{V}$ , enabling higher precision measurements at low currents and allowing the use of smaller value shunt resistors for improved system efficiency.

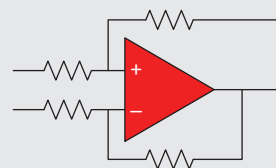
#### Gain:

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.

### Analog Output



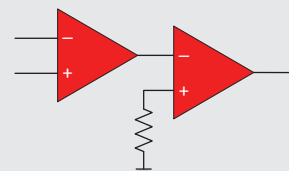
Integrates the full analog signal processing and provides a voltage or current output.

### Digital Output



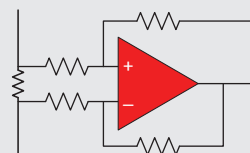
Integrates the full signal conditioning path and utilizes a standard 2-wire digital interface.

### Comparator Output



Provides a simple ALERT signal when the load current exceeds a threshold.

### Integrated Shunt



Offers a low-drift, precision integrated sense element.

# 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:

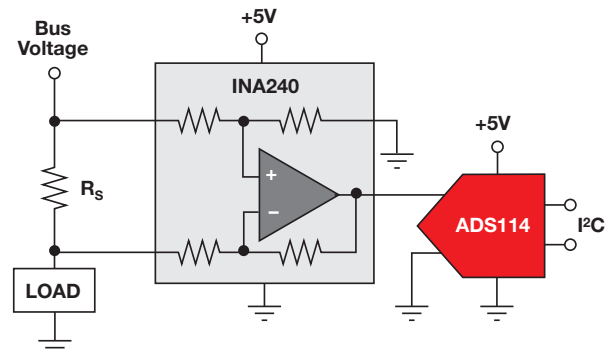
- Able to detect load short to ground
- Current is monitored directly from the source
- High immunity to ground disturbance

#### 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:

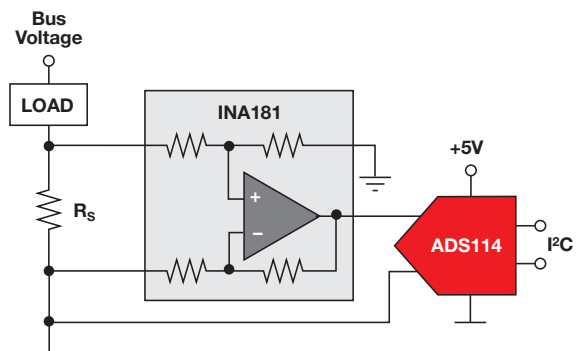
- Simple to implement and low-cost solution
- Wide range of available options

#### System Challenges:

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

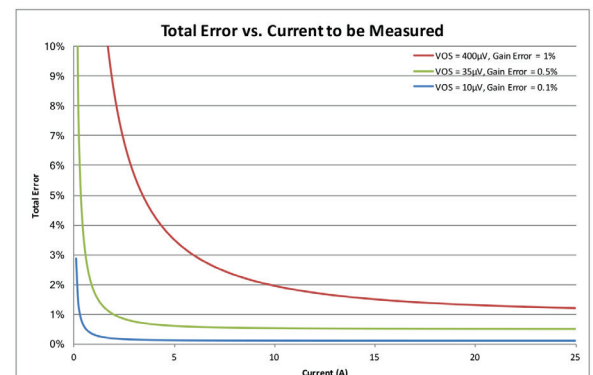
#### Advantages Over Discrete Current Sense Circuit:

- 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  $V_{\text{OFFSET}}$  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

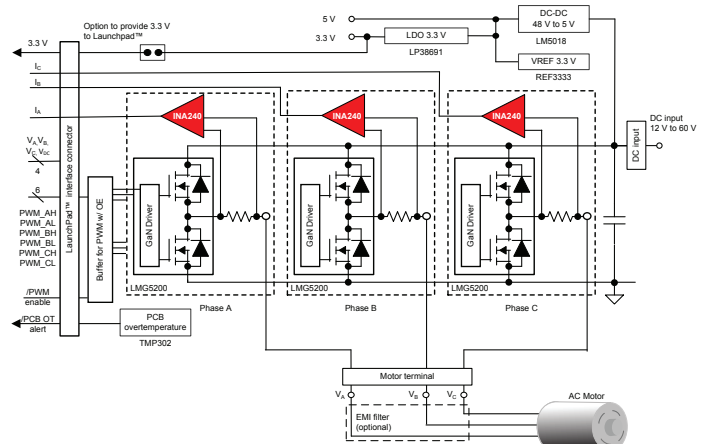
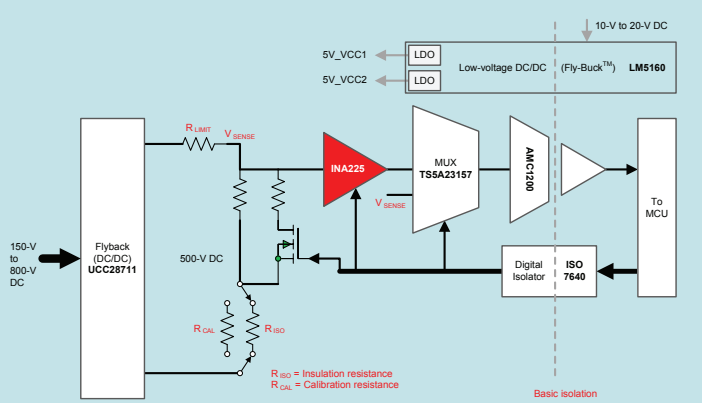
Current sensing reference designs. See more designs online at [ti.com/referencedesigns](https://ti.com/referencedesigns).

| Design Number | Description                                                                                                                                                                                                                                                                                                                                                                                             |  |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| TIDA-00795    | <p><b>Automotive Precision eFuse</b></p> <p>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.</p> |  |
| TIDA-00528    | <p><b>40 V to 400 V Unidirectional Current/Voltage/Power Monitoring</b></p> <p>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.</p>               |  |
| TIDA-00753    | <p><b>Three-phase Current Measurements for Motor</b></p> <p>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.</p>                               |  |

# Current Sense Amplifiers

## Reference Designs

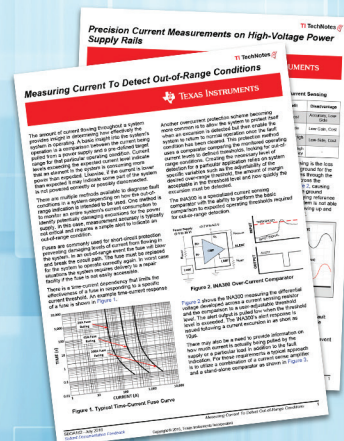
Current sensing reference designs. See more designs online at [ti.com/referencedesigns](https://ti.com/referencedesigns).

| Design Number | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TIDA-00913    | <p><b>48 V 3-Phase Inverter with Shunt-based In-line Motor Phase Current Sensing</b></p> <p>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.</p>  |
| TIDA-00440    | <p><b>Leakage Current Measurement Reference Design for Determining Insulation Resistance</b></p> <p>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.</p>                                                                                 |

## Application Notes

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

[Browse now](#)





# Analog Output Current Sense Amplifiers

## Featured Products

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

| Part Number                    | AEC-Q100 Available | Bi-Directional | Low-Side | Description                                                                                                                             | Common Mode Voltage Range | Input Offset $\pm \mu\text{V}$ Max | Input Offset Drift $\pm \mu\text{V}/^\circ\text{C}$ Typ | Gain Error % Typ | Package(s)                   |
|--------------------------------|--------------------|----------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------|------------------------------------|---------------------------------------------------------|------------------|------------------------------|
| <a href="#">INA190 Family</a>  | ✓                  | ✓              | ✓        | 1.8 V, High-precision Current Sense Amplifier with Power Down                                                                           | -0.1 to 40                | 10                                 | 0.1                                                     | 0.1              | 10 UQFN, 6 WSCP, 6 SC70      |
| <a href="#">INA210 Family</a>  | ✓                  | ✓              | ✓        | High performance, Zero-Drift Current Sense Amplifier                                                                                    | -0.3 to 26                | 35                                 | 0.1                                                     | 0.02             | 10 UQFN, 6 SC70              |
| <a href="#">INA240 Family</a>  | ✓                  | ✓              | ✓        | High AC CMRR High Common Mode Current Sense Amplifier for Motor & Solenoid Control                                                      | -4 to 80                  | 25                                 | 0.05                                                    | 0.05             | 8 TSSOP, 8 SOIC              |
| <a href="#">INA216 Family</a>  |                    |                |          | Ultra-small, 5 V Current Sense Amplifier                                                                                                | 1.8 to 5.5                | 100                                | 0.06                                                    | 0.01             | 10 UQFN, 4 WSCP              |
| <a href="#">INA199 Family</a>  | ✓                  | ✓              | ✓        | Value line, Zero-Drift Current Sense Amplifier                                                                                          | -0.3 to 26                | 150                                | 0.1                                                     | 0.03             | 10 UQFN, 6 SC70              |
| <a href="#">INAx180 Family</a> | ✓                  |                | ✓        | 350kHz Bandwidth, Unidirectional Current Sense Amplifier for Cost-sensitive Applications (Single, Dual, & Quad Options)                 | -0.2 to 26                | 150                                | 0.2                                                     | 0.1              | 5 SOT-23, 8 VSSOP, 14 TSSOP  |
| <a href="#">INAx181 Family</a> | ✓                  | ✓              | ✓        | 350kHz Bandwidth, Bidirectional Current Sense Amplifier for Cost-sensitive Applications (Single, Dual, & Quad Options)                  | -0.2 to 26                | 150                                | 0.2                                                     | 0.1              | 6 SOT-23, 10 VSSOP, 20 TSSOP |
| <a href="#">INA186 Family</a>  | ✓                  | ✓              | ✓        | 40 V Bidirectional, Precision Current Sense Amplifier                                                                                   | -0.1 to 40                | 50                                 | 0.05                                                    | 0.02             | 6 SC70                       |
| <a href="#">INA293 Family</a>  | ✓                  |                | ✓        | 110 V High Voltage, High Bandwidth, Unidirectional Current Sense Amplifier                                                              | -4 to 110                 | 100                                | 0.2                                                     | 0.02             | 5 SOT-23                     |
| <a href="#">INA290 Family</a>  | ✓                  |                |          | 120 V High Voltage, High Bandwidth, High-side Current Sense Amplifier                                                                   | 2.7 to 120                | 100                                | 0.2                                                     | 0.02             | 5 SC70                       |
| <a href="#">INA185 Family</a>  |                    | ✓              | ✓        | 350kHz Bandwidth, High-Precision, Bidirectional Current Sense Amplifier in SOT-563 Package                                              | -0.2 to 26                | 55                                 | 0.2                                                     | 0.05             | 6 SOT-563                    |
| <a href="#">INA225</a>         | ✓                  | ✓              | ✓        | Programmable-Gain, Zero-Drift, High Accuracy                                                                                            | 0 to 36                   | 150                                | 0.2                                                     | 0.05             | 8 MSOP                       |
| <a href="#">LMP8481 Family</a> | ✓                  | ✓              |          | High Common Mode, High-Speed Current Sense Amplifier                                                                                    | 4.5 to 76                 | 265                                | 6                                                       | 0.6              | 8 VSSOP                      |
| <a href="#">LMP8640 Family</a> | ✓                  |                | ✓        | High-Speed Current Sense Amplifier                                                                                                      | -2 to 42                  | 900                                | 2.6                                                     | 0.25             | 6 SOT-23                     |
| <a href="#">INA250 Family</a>  | ✓                  | ✓              | ✓        | High Accuracy, Zero-Drift Current Sense Amplifier with 0.1%, 15 PPM/ $^\circ\text{C}$ 2m $\Omega$ Integrated Shunt                      | 0 to 36                   | 50mA                               | 25 $\mu\text{A}/^\circ\text{C}$                         | 0.3              | 16 TSSOP                     |
| <a href="#">INA253 Family</a>  | ✓                  | ✓              | ✓        | High AC CMRR High Common Mode Current Sense Amplifier Solenoid Control with 0.1%, 15 PPM/ $^\circ\text{C}$ 2m $\Omega$ Integrated Shunt | -4 to 80                  | 12.5mA                             | 25 $\mu\text{A}/^\circ\text{C}$                         | 0.25             | 20 TSSOP                     |
| <a href="#">INA301 Family</a>  | ✓                  |                | ✓        | Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Comparator                                         | 0 to 36                   | 35                                 | 0.1                                                     | 0.03             | 8 VSSOP                      |
| <a href="#">INA302 Family</a>  | ✓                  | ✓              | ✓        | Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Dual Comparators                                   | 0 to 36                   | 30                                 | 0.02                                                    | 0.02             | 14 TSSOP                     |
| <a href="#">INA303 Family</a>  | ✓                  | ✓              | ✓        | Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Window Comparator                                  | 0 to 36                   | 30                                 | 0.02                                                    | 0.02             | 14 TSSOP                     |
| <a href="#">INA381 Family</a>  | ✓                  |                | ✓        | Cost-efficient Current Sense Amplifier with Integrated Standalone Comparator                                                            | -0.2 to 26                | 150                                | 0.1                                                     | 0.1              | 8 UQFN                       |

*Preview devices as of Q2 2019*

# Digital Output Power Monitors

## Featured Products

| Part Number             | AEC-Q100 Available | Bi-Directional | Low-Side | Measurement Parameter Values | Description                                                                                                             | Common Mode Voltage Range | Input Offset $\pm \mu\text{V}$ Max | Input Offset Drift $\pm \mu\text{V}/^\circ\text{C}$ Typ | Gain Error % Typ | Package(s)        |
|-------------------------|--------------------|----------------|----------|------------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------|------------------------------------|---------------------------------------------------------|------------------|-------------------|
| <a href="#">INA226</a>  | ✓                  | ✓              | ✓        | I, V, P                      | Ultra-High Accuracy, Current, Voltage, & Power                                                                          | 0 to 36                   | 10                                 | 0.02                                                    | 0.02             | 10 VSSOP          |
| <a href="#">INA260</a>  |                    | ✓              | ✓        | I, V, P                      | Ultra-High Accuracy, Current, Voltage, & Power Monitor with 0.1%, 15 PPM/ $^\circ\text{C}$ 2m $\Omega$ Integrated Shunt | 0 to 36                   | 5mA                                | 1 $\mu\text{A}/^\circ\text{C}$                          | 0.02             | 16 TSSOP          |
| <a href="#">INA233</a>  |                    | ✓              | ✓        | I, V, P, E                   | High Accuracy, Current, Voltage, Power, & Energy Monitor with 1.8 V I <sup>2</sup> C/PMBus                              | 0 to 36                   | 10                                 | 0.02                                                    | 0.02             | 10 VSSOP          |
| <a href="#">INA229</a>  | ✓                  | ✓              | ✓        | I, V, P, E                   | 85 V Current/Voltage/Power/Energy/Charge Monitoring Device with SPI Interface with Internal Temperature Sensor          | 0 to 85                   | 10                                 | 0.01                                                    | 0.02             | 10 VSSOP, 16 VQFN |
| <a href="#">INA3221</a> | ✓                  | ✓              | ✓        | I, V                         | Triple-channel, Current & Voltage Monitor with Alert                                                                    | 0 to 26                   | 80                                 | 0.1                                                     | 0.1              | 16 VQFN           |

*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/currentsensetraining](http://ti.com/currentsensetraining)



**Sensing** Innovation

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### Internet

**TI Semiconductor Product Information Center Home Page**

[support.ti.com](http://support.ti.com)

**TI E2E™ Community Home Page**

[e2e.ti.com](http://e2e.ti.com)

### Product Information Centers

|                 |                |                                                                                                          |
|-----------------|----------------|----------------------------------------------------------------------------------------------------------|
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| <b>Mexico</b>   | Phone          | 0800-670-7544                                                                                            |
|                 | Internet/Email | <a href="http://ti.com/lstds/ti/csc/support_Americas.page">ti.com/lstds/ti/csc/support_Americas.page</a> |

### Europe, Middle East, and Africa

|                    |                                      |
|--------------------|--------------------------------------|
| Phone              |                                      |
| European Free Call | 00800-ASK-TEXAS<br>(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.

|              |                                                              |
|--------------|--------------------------------------------------------------|
| Internet     | <a href="http://www.ti.com/asktexas">www.ti.com/asktexas</a> |
| Direct Email | <a href="mailto:asktexas@ti.com">asktexas@ti.com</a>         |

### Japan

|                |               |                                                                                                    |
|----------------|---------------|----------------------------------------------------------------------------------------------------|
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|                | Domestic      | 0120-81-0036                                                                                       |
| Internet/Email | International | <a href="http://ti.com/lstds/ti/csc/support_Japan.page">ti.com/lstds/ti/csc/support_Japan.page</a> |
|                | Domestic      | <a href="http://www.tij.co.jp/pic">www.tij.co.jp/pic</a>                                           |

### Asia

|                                                                      |                   |
|----------------------------------------------------------------------|-------------------|
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| <b>Note:</b> Toll-free numbers may not support mobile and IP phones. |                   |
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| China                                                                | 800-820-8682      |
| 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            | <a href="mailto:tiasia@ti.com">tiasia@ti.com</a> or <a href="mailto:ti-china@ti.com">ti-china@ti.com</a> |
| Internet         | <a href="http://support.ti.com/sc/pic/asia.htm">support.ti.com/sc/pic/asia.htm</a>                       |
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