Current Sense Amplifiers

Texas Instruments

ti.com/currentsense

2021

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

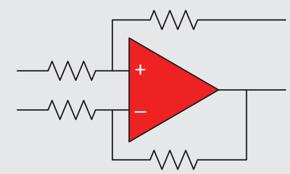
Common Mode Range:
This specification defines the DC voltage range at the input of an amplifier with respect to ground. Current sense amplifiers are typically designed to support common-mode voltages well beyond the chip supply voltage. For example, the INA240 is capable of supporting a common-mode voltages 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%.

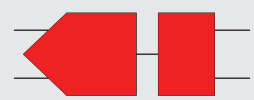
Temperature Stability:
Current sense amplifiers integrate the amplifier along with all the gain-setting resistors which enables small and unified temperature drift. This allows for robust current measurements across the whole specified temperature range. The achieved temperature stability is one of the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

Analog output



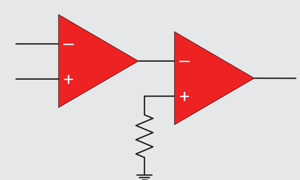
Integrates the full analog signal processing and provides a voltage or current output.

Digital output



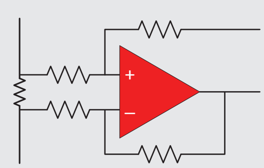
Integrates the full signal conditioning path and utilizes a standard 2-wire digital interface.

Comparator output



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

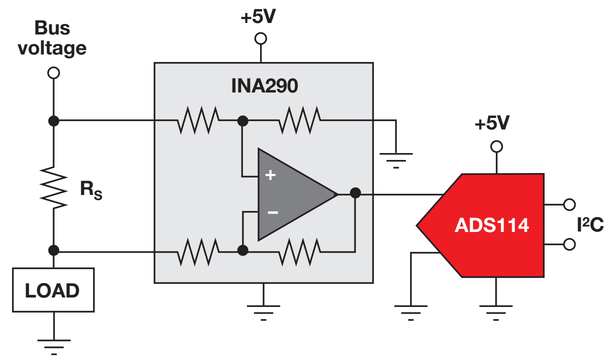
Integrated shunt



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.

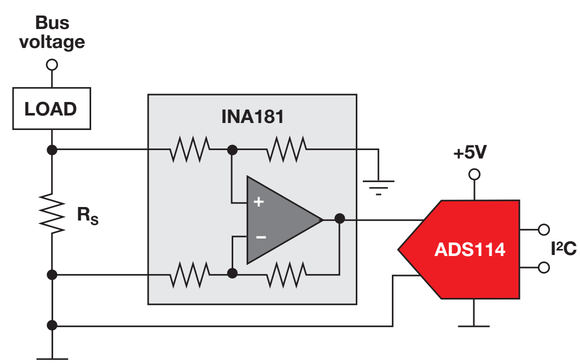


System Advantages:
- Able to detect load short to ground
- Current is monitored directly from the source
- High immunity to ground disturbance

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.



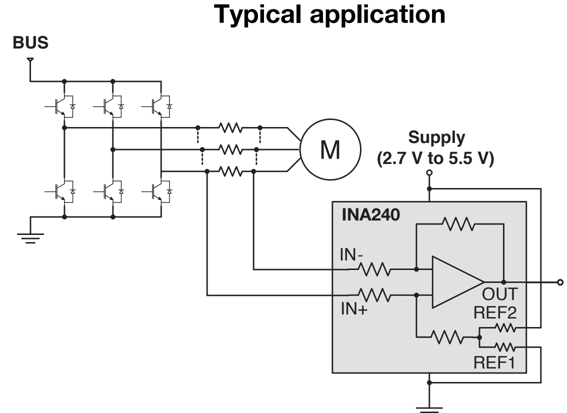
System Advantages:
- Simple to implement and low-cost solution
- Wide range of available options

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_{OFFSET} saves system power by enabling the use of smaller value shunt resistors to achieve the same error level

In-line Measurements
Current sensing techniques connect the current sense element in-line to the load.

Typical application



System advantages:
- True phase current at all times reduces phase to phase errors
- Best current feedback for greatest accuracy

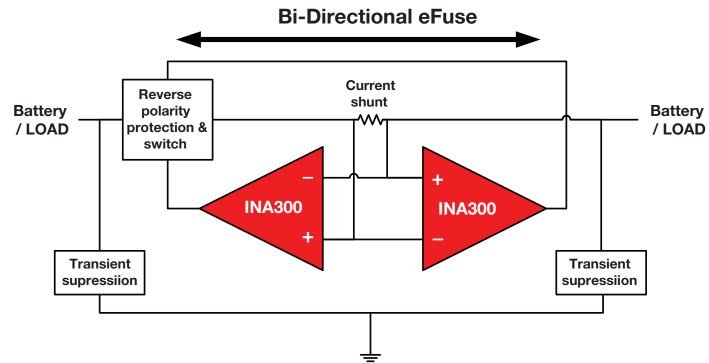
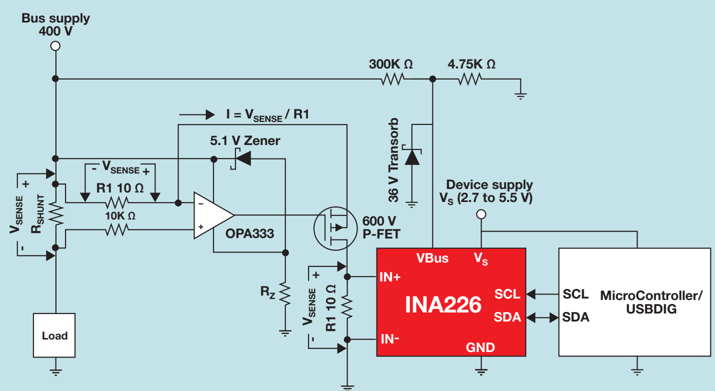
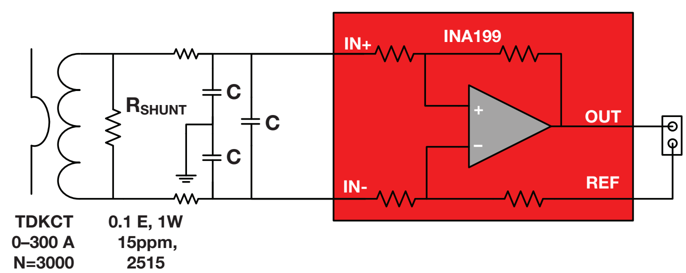
System Challenges:
- PWM common-mode voltage seen by amplifier
- High common-mode voltage combined with high dV/dT poses steep challenge to many amplifiers

INA240 advantages over discrete current sense circuit
- Enhanced PWM rejection provides high levels of suppression for large common-mode transients (dV/dT) in systems that use PWM signals

Current Sense Amplifiers

Reference Designs

Current sensing reference designs. See more designs online at **ti.com/referencedesigns**.

Design Number	Description	
TIDA-00795	**Automotive Precision eFuse** 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 > 100 A.	
TIDA-00528	**40 V to 400 V Unidirectional Current/ Voltage/Power Monitoring** 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.	
TIDA-00753	**Three-phase Current Measurements for Motor** 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.	

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Reference Designs

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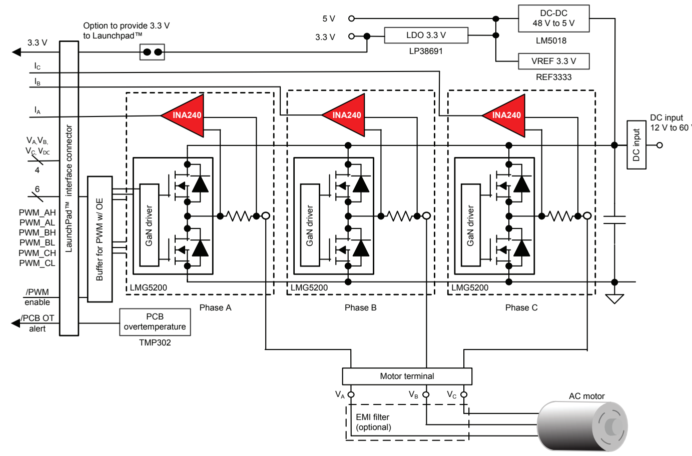
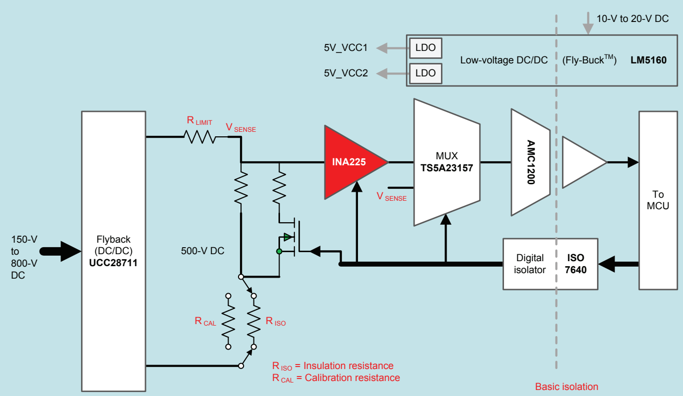
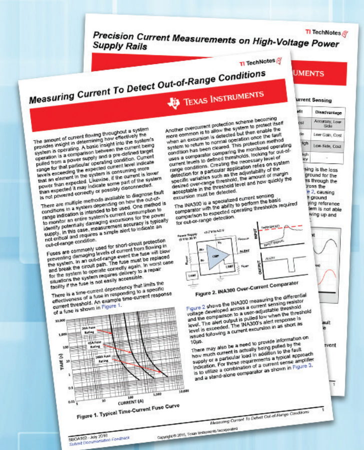
Design Number	Description	
TIDA-00913	**48 V 3-Phase Inverter with Shunt-based In-line Motor Phase Current Sensing** This design realizes a 48 V/10A 3-phase GaN inverter with precision in-line shunt-based phase current sensing for accurate control of precision drives such as servo drives. One of the 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.	
TIDA-00440	**Leakage Current Measurement Reference Design for Determining Insulation Resistance** 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.	

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**.

Part Number	AEC-Q100 Available	Bi-Directional	Low-Side	Description	Common Mode Voltage Range	Input Offset ±µ V Max	Input Offset Drift ±µ V/°C Typ	Gain Error % Typ	Package(s)
INA190 Family	✔	✔	✔	1.8 V, High-precision Current Sense Amplifier with Power Down	-0.1 to 40	10	0.1	0.1	10 UQFN, 6 WCSP, 6 SC70
INA210 Family	✔	✔	✔	High performance, Zero-Drift Current Sense Amplifier	-0.3 to 26	35	0.1	0.02	10 UQFN, 6 SC70
INA240 Family	✔	✔	✔	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
INA216 Family				Ultra-small, 5 V Current Sense Amplifier	1.8 to 5.5	100	0.06	0.01	10 UQFN, 4 WSCP
INA199 Family	✔	✔	✔	Value line, Zero-Drift Current Sense Amplifier	-0.3 to 26	150	0.1	0.03	10 UQFN, 6 SC70
INAx180 Family	✔		✔	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
INAx181 Family	✔	✔	✔	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
INA186 Family	✔	✔	✔	40 V Bidirectional, Precision Current Sense Amplifier	-0.1 to 40	50	0.05	0.02	6 SC70
INA293 Family	✔		✔	110 V High Voltage, High Bandwidth, Unidirectional Current Sense Amplifier	-4 to 110	100	0.2	0.02	5 SOT-23
INA290 Family	✔			120 V High Voltage, High Bandwidth, High-side Current Sense Amplifier	2.7 to 120	100	0.2	0.02	5 SC70
INA185 Family		✔	✔	350kHz Bandwidth, High-Precision, Bidirectional Current Sense Amplifier in SOT-563 Package	-0.2 to 26	55	0.2	0.05	6 SOT-563
INA225	✔	✔	✔	Programmable-Gain, Zero-Drift, High Accuracy	0 to 36	150	0.2	0.05	8 MSOP
LMP8481 Family	✔	✔		High Common Mode, High-Speed Current Sense Amplifier	4.5 to 76	265	6	0.6	8 VSSOP
LMP8640 Family	✔		✔	High-Speed Current Sense Amplifier	-2 to 42	900	2.6	0.25	6 SOT-23
INA250 Family	✔	✔	✔	High Accuracy, Zero-Drift Current Sense Amplifier with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt	0 to 36	50mA	25µA/°C	0.3	16 TSSOP
INA253 Family	✔	✔	✔	High AC CMRR High Common Mode Current Sense Amplifier Solenoid Control with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt	-4 to 80	12.5mA	25µA/°C	0.25	20 TSSOP
INA301 Family	✔		✔	Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Comparator	0 to 36	35	0.1	0.03	8 VSSOP
INA302 Family	✔	✔	✔	Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Dual Comparators	0 to 36	30	0.02	0.02	14 TSSOP
INA303 Family	✔	✔	✔	Overcurrent Protection High-Speed, Precision Current Sense Amplifier with Integrated Window Comparator	0 to 36	30	0.02	0.02	14 TSSOP
INA381 Family	✔		✔	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 2021

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 ±µ V Max	Input Offset Drift ±µ V/°C Typ	Gain Error % Typ	Package(s)
INA226	✔	✔	✔	I, V, P	Ultra-High Accuracy, Current, Voltage, & Power	0 to 36	10	0.02	0.02	10 VSSOP
INA260		✔	✔	I, V, P	Ultra-High Accuracy, Current, Voltage, & Power Monitor with 0.1%, 15 PPM/°C 2mΩ Integrated Shunt	0 to 36	5mA	1µA/°C	0.02	16 TSSOP
INA233		✔	✔	I, V, P, E	High Accuracy, Current, Voltage, Power, & Energy Monitor with 1.8 V I^2C/PMBus	0 to 36	10	0.02	0.02	10 VSSOP
INA229	✔	✔	✔	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
INA3221	✔	✔	✔	I, V	Triple-channel, Current & Voltage Monitor with Alert	0 to 26	80	0.1	0.1	16 VQFN

Preview devices as of Q2 2021

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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/lsds/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.

Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

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	Domestic	0120-81-0036
Internet/Email	International	ti.com/lsds/ti.csc/support_Japan.page
	Domestic	www.tij.co.jp/pic

Asia

Phone — Toll-Free Number

Note: Toll-free numbers may not support mobile and IP phones.

Australia	1-800-999-084
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
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Thailand	001-800-886-0010

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