

Current and voltage sensing in EVSE and solar

Bart Basile

SEM – Grid Infrastructure – Renewable Energy

Asia FAE Summit - 2018

Additional resources

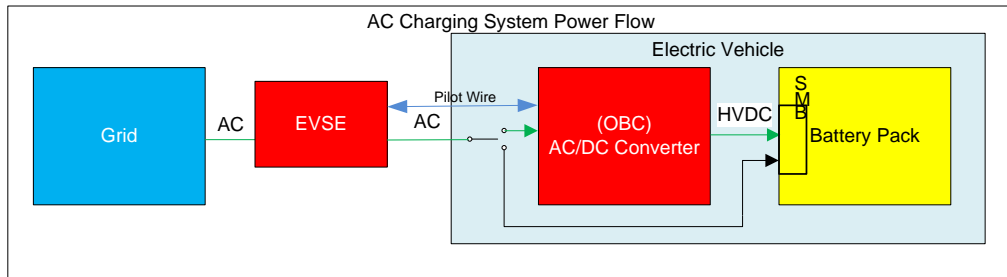


- [AC charging station system resources](#)
- [DC charging station system resources](#)
- [Solar inverter system resources](#)
- [TI.com training portal](#)
- [TI reference designs library](#)

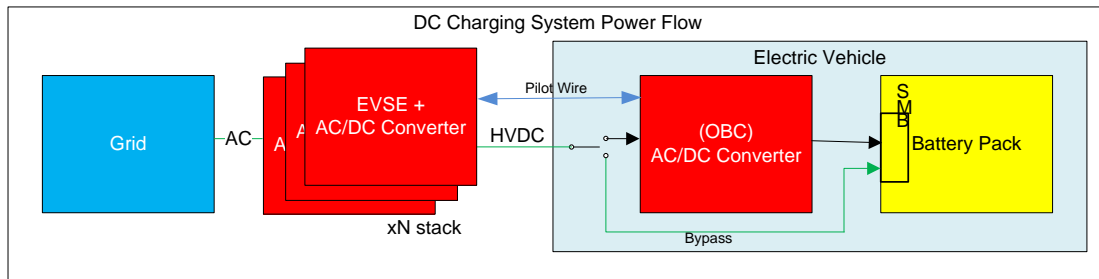
Overview

- **System overview**
- Overview current sensing
 - Shunt based measurement
 - Isolated current sensing
 - Magnetic measurement
- Overview voltage sensing
 - Non-isolated measurement
 - Isolated voltage sensing
- Additional information / Q&A

Levels in EV charging stations



AC charging station: Level 1 & 2

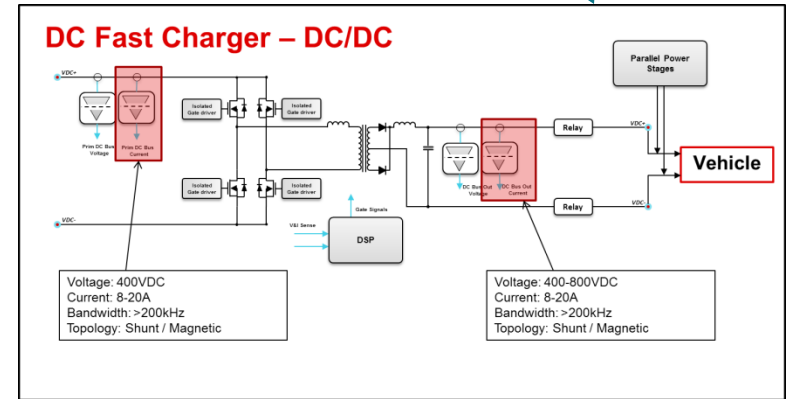
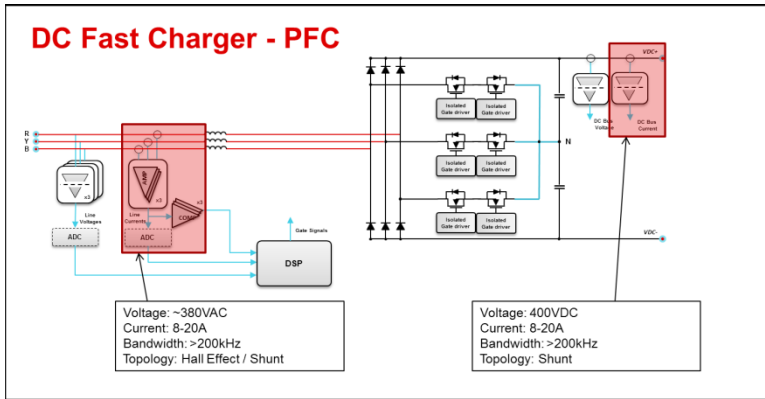
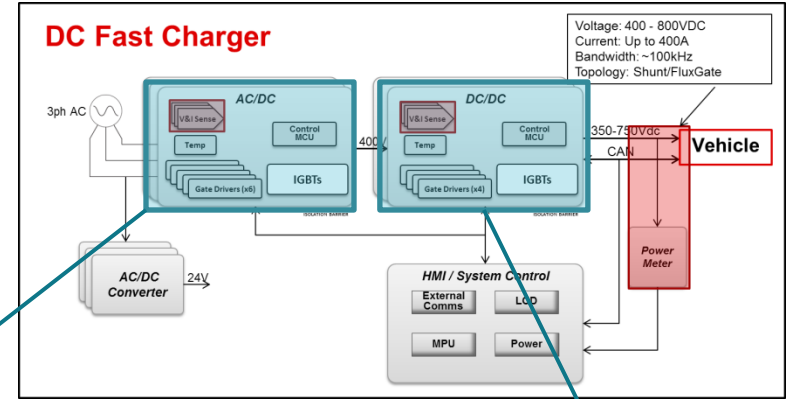
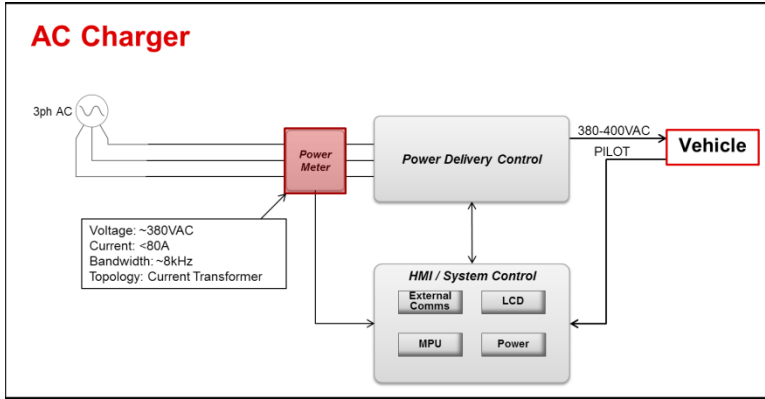


DC charging station: Level 3

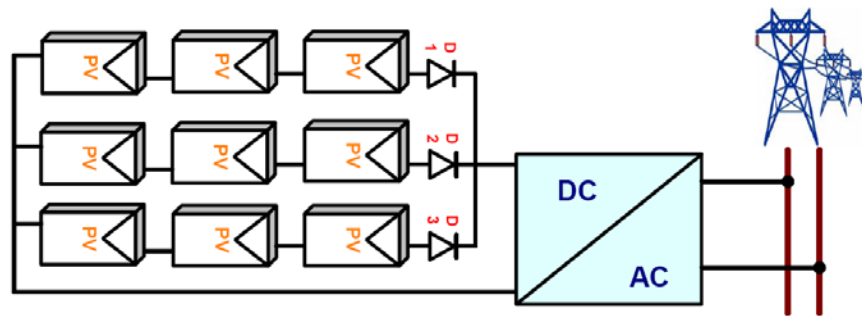
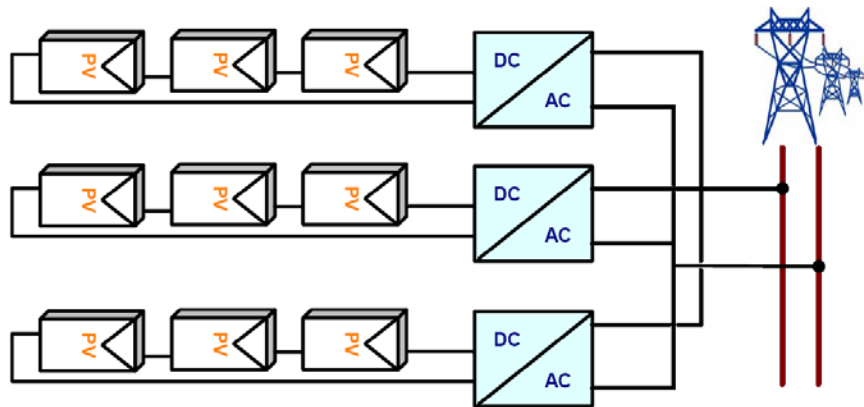
EVSE Type	Power Supply	Charger Power	Charging time* (Approx.) for a 24kWh Battery
AC Charging Station: L1 Residential	120/230VAC & 12 A to 16A (Single Phase)	~1.44kW to ~1.92kW	~17 Hours
AC Charging Station: L2 Commercial	208 ~ 240VAC & 15 A ~ 80A (Single/ Split Phase)	~ 3.1kW to ~19.2kW	~8 Hours
DC Charging Station: L3 Fast Chargers	300 to 600VDC & (Max 400A) (Poly Phase)	From 120kW up to 240kW	~ 30 Minutes

* Charging time does NOT scale linearly with EVSE charge capacity

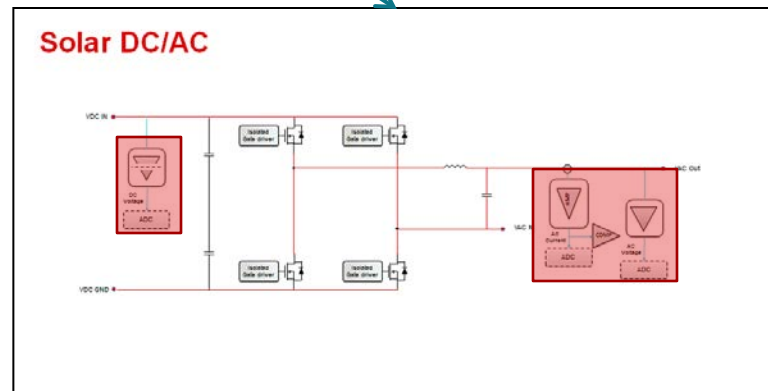
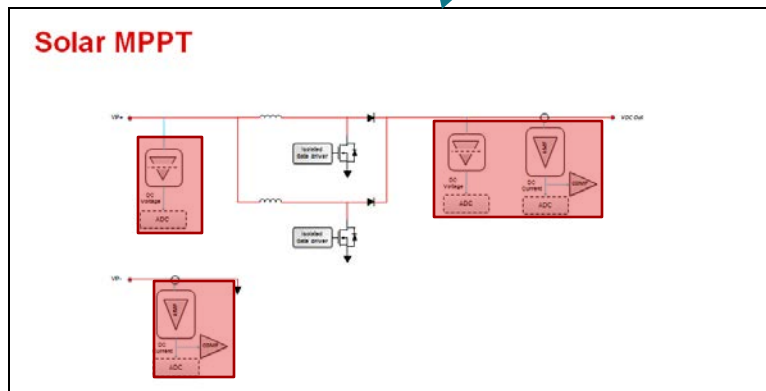
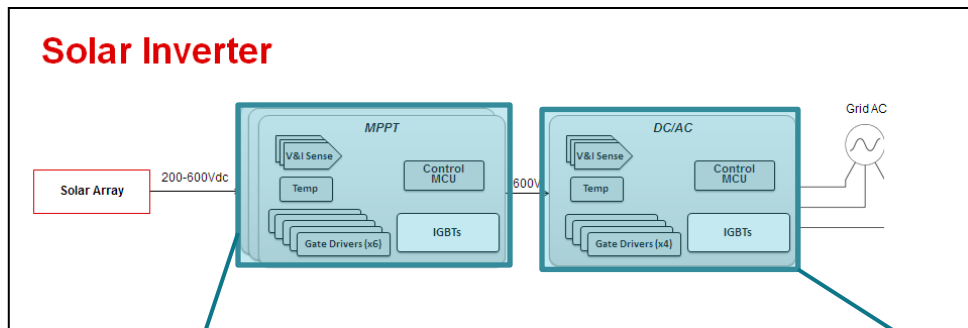
Charging station topology



Solar system overview



Solar inverter topology



Overview

- System overview
- Overview current sensing
 - **Shunt based measurement**
 - Isolated current sensing
 - Magnetic measurement
- Overview voltage sensing
 - Non-isolated measurement
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- Additional information / Q&A

Current sensor key parameters

Configuration

Common mode

Bandwidth

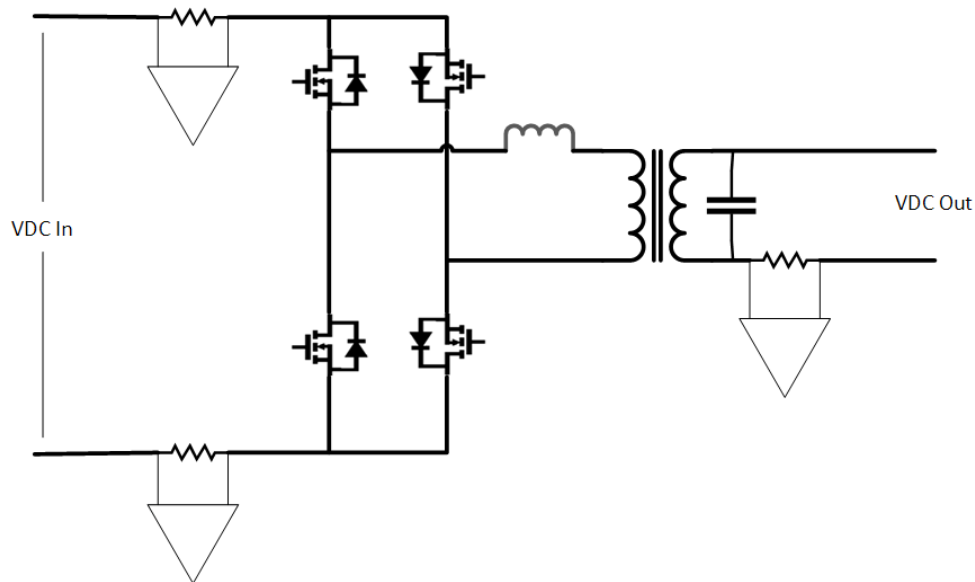
Directionality

Offset

Gain

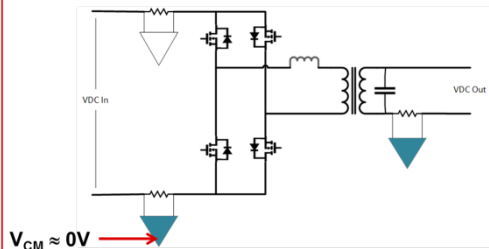
Output

- What are the key parameters when selecting a **current sense amplifier**?

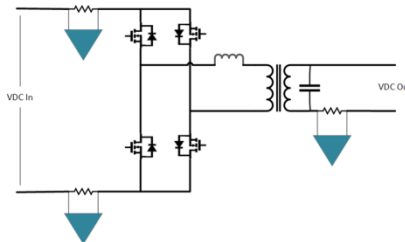


Current sensor key parameters

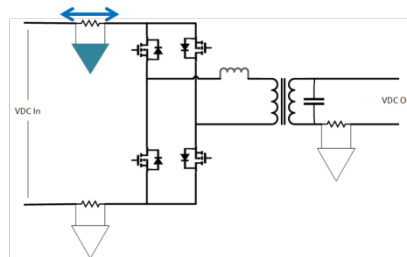
- **Low-side sensing:** shunt resistor placed between the system load & ground



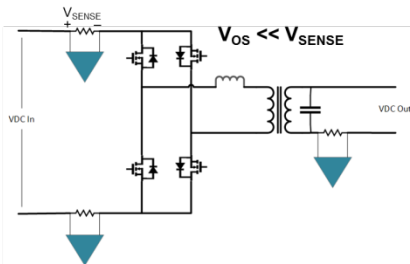
- **Bandwidth** depends on the application



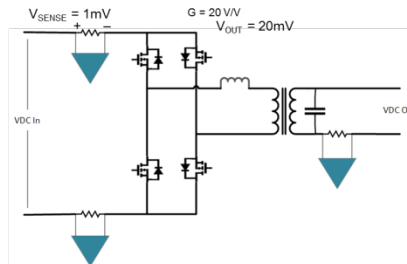
- **Directionality:** Can the sensor measure current in both directions?



- Amplifier's **OFFSET** (V_{OS}) is important because V_{OS} cannot be bigger than the sense voltage, V_{SENSE}

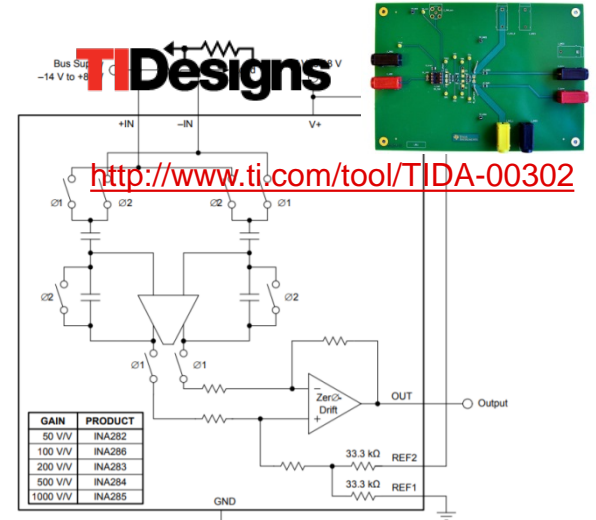


- The **GAIN** amplifies the small signal V_{SENSE} .



How to size the shunt resistor

- We need the following to size the shunt resistor
 - Load current range
 - Available supply voltage
- Obtain output voltage range from CSM datasheet
 - INA282 Input and Output Range:
 - For this example, $V_s = 5V$, therefore:
- Refer it back to the input by dividing by the device's gain
 - INA282 Gain = 50 V/V
- Now use the I_{load} range to calculate the maximum and minimum values for the shunt resistance:
 - Using $5A < I_{load} < 10A$ for this example
- Note: Rshunt value is directly related to both power and accuracy
- Resistor power dissipation results in self heating (drift) and system power losses
- So, use the largest Rshunt that your system can tolerate



TIDesigns

<http://www.ti.com/tool/TIDA-00302>

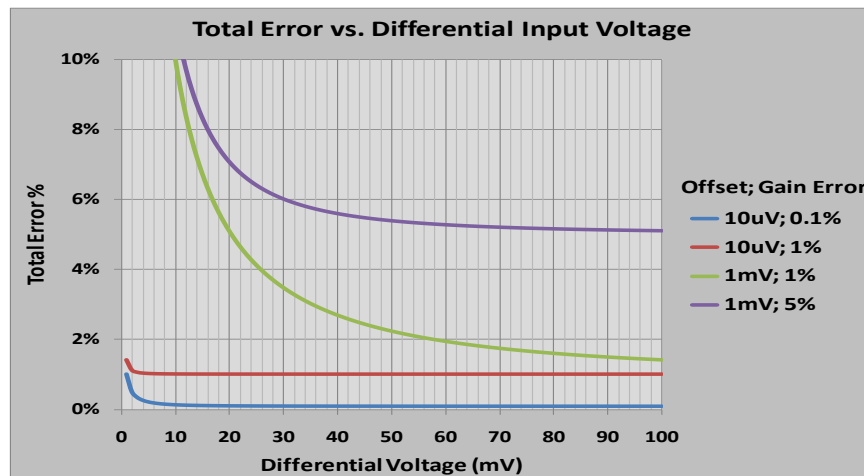
INA28x Block Diagram

- 16V to 80V Input Common Mode
 - ±5V Analog Supply Range
 - Multiple Gain Configurations
- $P = \text{Input Range} \times \text{Current}$
 $P = 92\text{mV} \times 10\text{A} = \mathbf{0.92W}$

Accuracy is the key

- Worst case accuracy vs.
- Probable accuracy (Root-mean-square)
- Error sources:

Description	Referred to
Input offset voltage (V_{OS})	Input
Offset voltage drift ($\frac{\Delta V_{OS}}{\Delta T}$)	Input
Offset voltage shift ($\frac{\Delta V_{OS}}{\Delta t}$)	Input
Gain error (%)	Output
Common-mode rejection (dB)	Input
Power supply rejection (dB)	Input
Input offset current (I_{OS})	Input
Shunt resistor tolerance (%)	Input

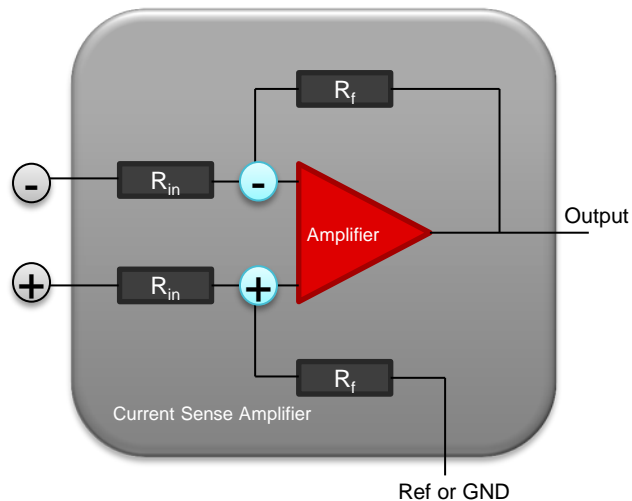


Offset dominates error at
small signal inputs

Gain error dominates error at
large signal inputs

General purpose op-amp vs. current sense amplifier

General purpose op-amp	Current sense amplifier
<ul style="list-style-type: none"> Bandwidth is usually specified with unity 	<ul style="list-style-type: none"> Usually specified at a fixed gain
<ul style="list-style-type: none"> V_{offset} is measured at the input of the op-amp as shown in the graphic with blue circles 	<ul style="list-style-type: none"> V_{offset} is measured at the input resistors as shown in the graphic with gray circles
<ul style="list-style-type: none"> Needs a larger PCB footprint as at least two gain resistors and an op-amp are needed 	<ul style="list-style-type: none"> Smaller PCB footprint as the amplifier, gain resistors and compensation capacitors are all integrated in the same package
<ul style="list-style-type: none"> Offset voltage temperature drift is given for the op-amp alone 	<ul style="list-style-type: none"> Offset voltage temperature drift takes into account the amplifier and gain resistors' variations
<ul style="list-style-type: none"> CMRR specification is only for the op-amp 	<ul style="list-style-type: none"> CMRR specification takes into account the amplifier and gain resistors' variations
<ul style="list-style-type: none"> Gain error and its temperature drift are determined by the tolerance of the external resistor network 	<ul style="list-style-type: none"> Gain error and its temperature drift are specified as the resistors are integrated
<ul style="list-style-type: none"> Common mode voltage is limited by the supply rail 	<ul style="list-style-type: none"> Common mode voltage is independent of the supply rail and can go up to 80V
<ul style="list-style-type: none"> System error typically ~10%, even with precision passives 	<ul style="list-style-type: none"> System error <1% possible

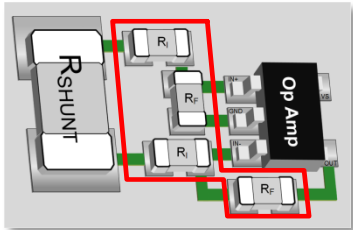


Typical current measurement circuit

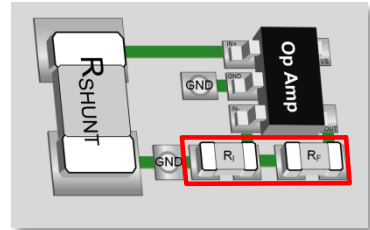
- General purpose op-amp (red)
- Current sense amplifier (gray)

Integrated current sensing benefits vs. discrete solutions

Discrete current sensing circuits approach



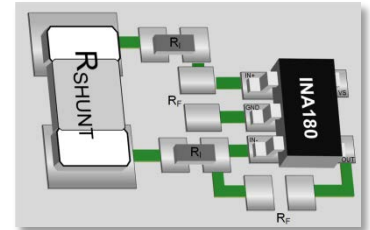
Differential measurement



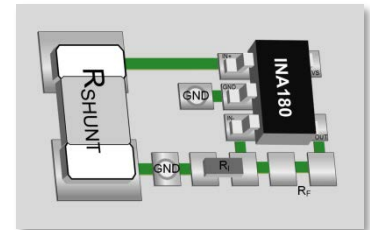
Single-ended measurement



Integrated current sensing approach



Differential measurement



Single-ended measurement

Typical considerations

- Op-amp
 - Low cost
- Gain resistors
 - Low cost

Average measurements accuracy with large temperature variations

- Integrates the op-amp and all the gain resistances
- Stable over the entire temperature range
 - Integrated gain resistors
 - V_{OS} ($1\mu V/^\circ C$ Drift)
- Low-side & high-side capable

Result: Accurate measurements with low temperature variations

Shunt-Based, <1% Accurate, $\pm 100\text{A}$, High-Side, Bi-directional Current Measurement Reference Design

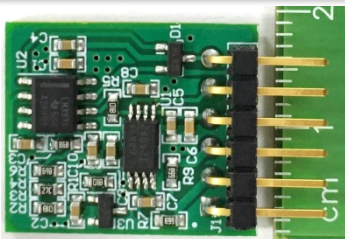
Features

- Shunt-based $\pm 100\text{A}$ continuous bi-directional current measurement solution
- **Maximum shunt voltage limited to $\pm 25\text{ mV}$** to reduce power dissipation
- High-side current sense circuit with common-mode voltage of 80V , supporting batteries ranging from 6V to 60V
- Calibrated **DC accuracy of <1% across temperatures -25°C to 85°C**
- Can interface directly with differential or single-ended ADC
- Fast over-current **fault alert in either direction** for system safety
- **Adaptable for current sensing even close to fast switching nodes** without any external common-mode filtering

Target applications

- Battery chargers
- Uninterruptable Power Supplies (UPS)
- Energy storage systems
- Battery management systems
- AC-DC power supplies

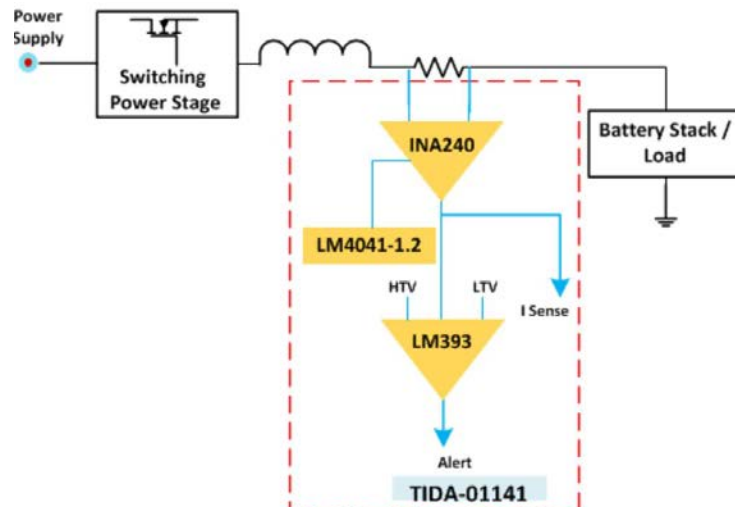
Tools & resources



- [TIDA-01141 and tools folder](#)
- [Design guide](#)
- **Design files:** Schematics, BOM, gerbers, and more
- **Device datasheets:**
 - [INA240](#), [LM2903/393](#), [LM4041](#)

Benefits

- High current measurement using shunts in a small form-factor, addresses space sensitive and high power density needs.
- High accuracy with low shunt resistance value, reduces power loss and hence shunt sizing
- Scalable solution to measure low and high currents
- Common design for DC and low frequency pulse current sensing
- Ideal fit for $12\text{V}/24\text{V}/36\text{V}/48\text{V}$ battery current sensing applications



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Additional shunt resources

- Tech notes
- Online training series
- Error estimation tool

Current Mode Control in Switching Power Supplies

Problem Statement

Current mode control is used in switching power supplies to improve performance. Peak and average current are discussed in order to provide immunity to performance degradation.

- Lead solution: SBOA168
- TI TechNote: SBOA168

High Common-Mode Rejection

High common-mode rejection is required to reject common-mode noise from the current sense signal.

Switching Power Supply Current Measurements

Problem Statement

The location of the current sense resistor is critical for accurate measurement. Informative data is utilized to address the challenges of current sense resistor placement in switching power supplies.

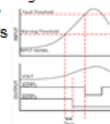
- Lead solution: SBOA168
- TI TechNote: SBOA168

Monitoring Current for Multiple Out-of-Range Conditions

Problem Statement

Proper system operation is frequently evaluated based on maintaining expected operating current levels. Out-of-range conditions may require different handling procedures based on how far beyond the limits the system is operating.

- Lead solution: INA302/3
- TI TechNote: SBOA168



Applicable End Equipments

- Industrial
- Automotive
- Personal Electronics
- Communication Equipment
- Enterprise Computing

Simplicity of design

The INA302 & INA303 are optimized for handling out-of-range conditions with independent threshold settings reducing the complexity of the over-current protection (OCP) design.

Zero-drift, High Accuracy

Excellent measurement accuracy (V_{OS} : 35 μ V & 0.5 μ V/°C drift; Gain Error: 0.1% & 10ppm/°C drift) enables stable measurements over the full temperature range.

Fast on-chip Comparators

The bi-directional INA302/INA303 offer both dual over-current and windowed alert capability with fast over-current detection & programmable threshold limits.

TI Training

1.1 Getting Started with Current Sense Amplifiers, Session 1: When to choose a Current Sense Amp with Dan Harmon

When to choose a Current Sense Amp

- Based on Ohm's Law
- Shunt resistor in series with load
- Invasive
- Power dissipated by R_{SHUNT}
- Sensing circuit not isolated from system load

Direct Sensing

Part Number	SubFamily	Common Mode Voltage (Max) (V)	Input Offset (Max) (mV)	Input Offset Drift (Typ) (mV/°C)	Gain (V/V)	Gain Error (%)	CMRR (Min) (dB)	Bandwidth (kHz)	Iq (Max) (nA)	Supply Voltage (Max) (V)	Supply Voltage (Min) (V)	Features	Rating
INA260 - High/Low-Side Digital Current/Power Monitor with Integrated 2m Ω Shunt Resistor	Current Sense Power / Current Monitor, Current Sensing With Integrated Shunt	36	10	1	0.15	130	3.5	0.42	5.5	2.7		Alert Function, Bidirectional, I2C, Integrated Shunt, Low-side Capable	Catalog

INA260 (ACTIVE)

- Order Now
- Online datasheet
- Download datasheet
- Description & parameters
- Technical documents
- Tools & software
- Quality & packaging
- Support & training

Error Analysis Tool

Year Error (%) vs. Sense Current (A)

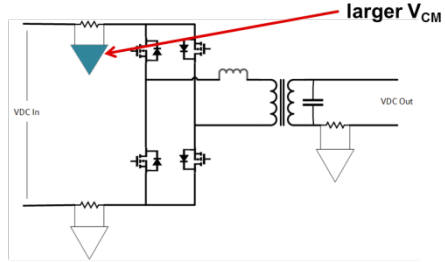
Functional diagram

Overview

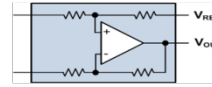
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Current sensor key parameters

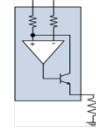
- **High-Side Sensing:** shunt resistor placed between the supply and load.



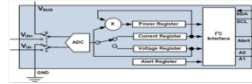
Voltage Output



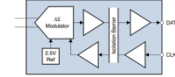
Current Output



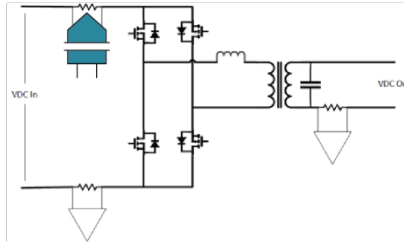
Digital Output



Bit-stream Output

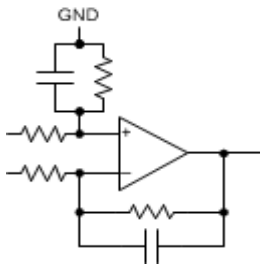
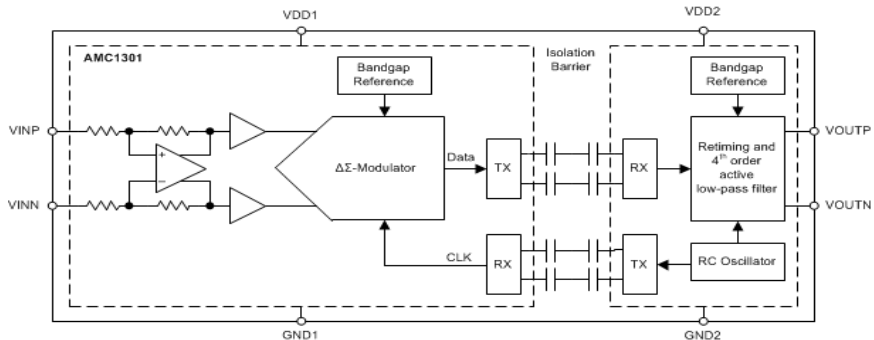


- **Isolated Output** provides a very high common mode capability to high side sensing

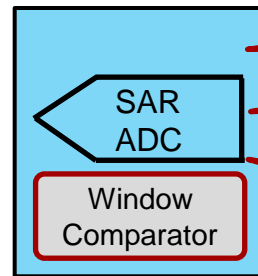


Isolated amplifier vs. $\Delta\Sigma$ -modulator

• Isolated amplifier



MCU

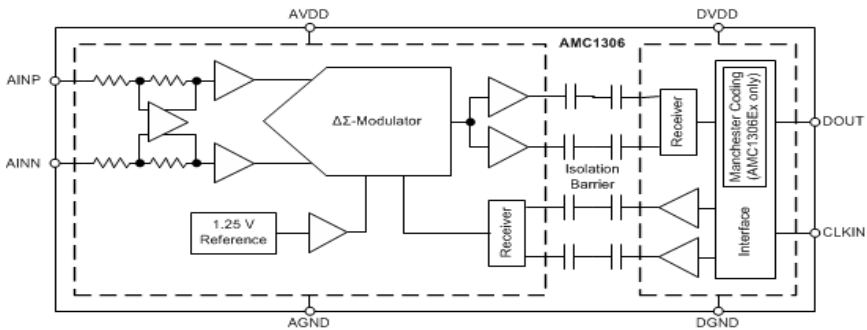


3 conversion stages...

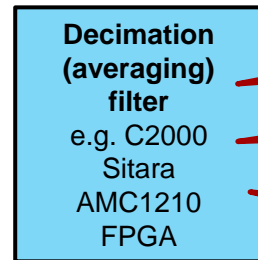
...each stage adds errors

<10 bit accuracy on system level

• Isolated $\Delta\Sigma$ modulator



MCU

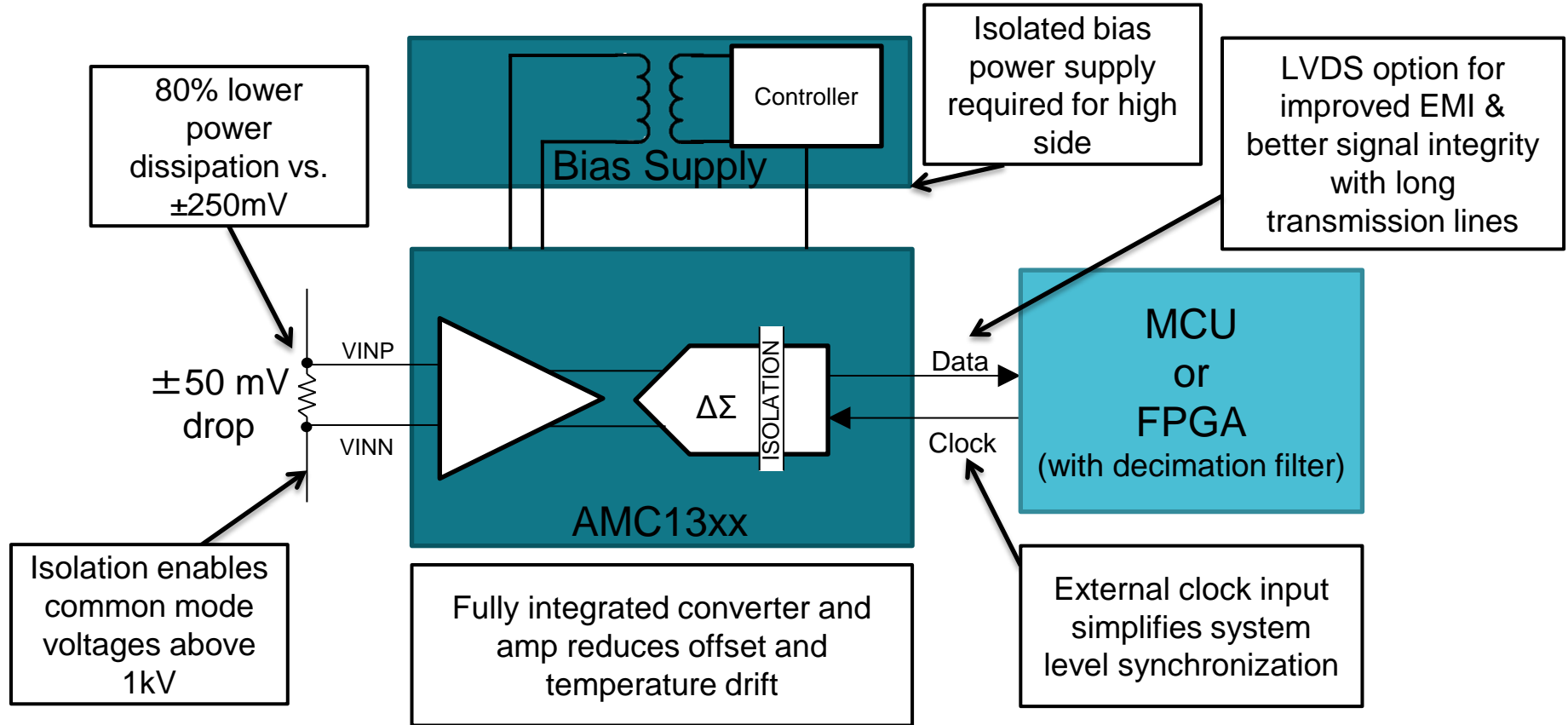


single conversion stage

All processing in digital domain

>14 bit accuracy on system level

Isolated modulator design considerations



Shunt-Based High Current Measurement (200-A) Reference Design with Reinforced Isolation Amplifier

Features

- Shunt-based 200 A peak current measurement solution with reinforced isolation
- Maximum shunt voltage limited to 25 mV to reduce power dissipation
- High-side current sense circuit with high common-mode voltage of 1500-V_{peak}, supporting up to 690-V AC mains powered drives
- Calibrated AC accuracy of <1% across temperatures -25°C to 85°C
- Can interface directly with differential or single-ended ADC
- On board 1.65-VREF to level shift output
- Small form factor push pull-based isolated power supply to power high-side circuit

Target applications

- Variable speed drives
- UPS
- Active front-end converters

Tools & resources

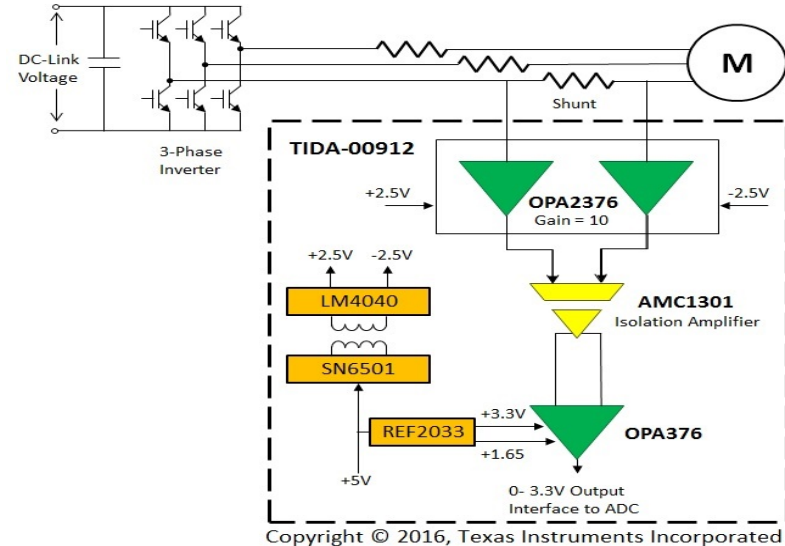
Board Image



- [TIDA-00912 and tools folder](#)
- [Design guide](#)
- **Design files:** Schematics, BOM, gerbers, and more
- **Device datasheets:**
 - [AMC1301](#)
 - [OPA2376](#)
 - [OPA376](#)
 - [REF2033](#)
 - [SN6501](#)
 - [LM4040](#)

Benefits

- High current measurement capability using shunts in a small form factor.
- Lower power dissipation reduces shunt sizing
- Common design for line current and motor current sensing



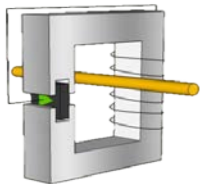
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Sensor implementations

Closed-loop current sensors

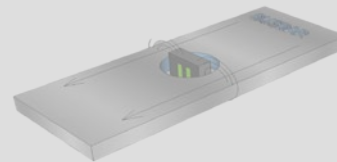


- Magnetic core picks up field around conductor
- **Sensor IC inside the core**
- Compensation coil drives magnetic field to zero

Fluxgate
DRV401
DRV421

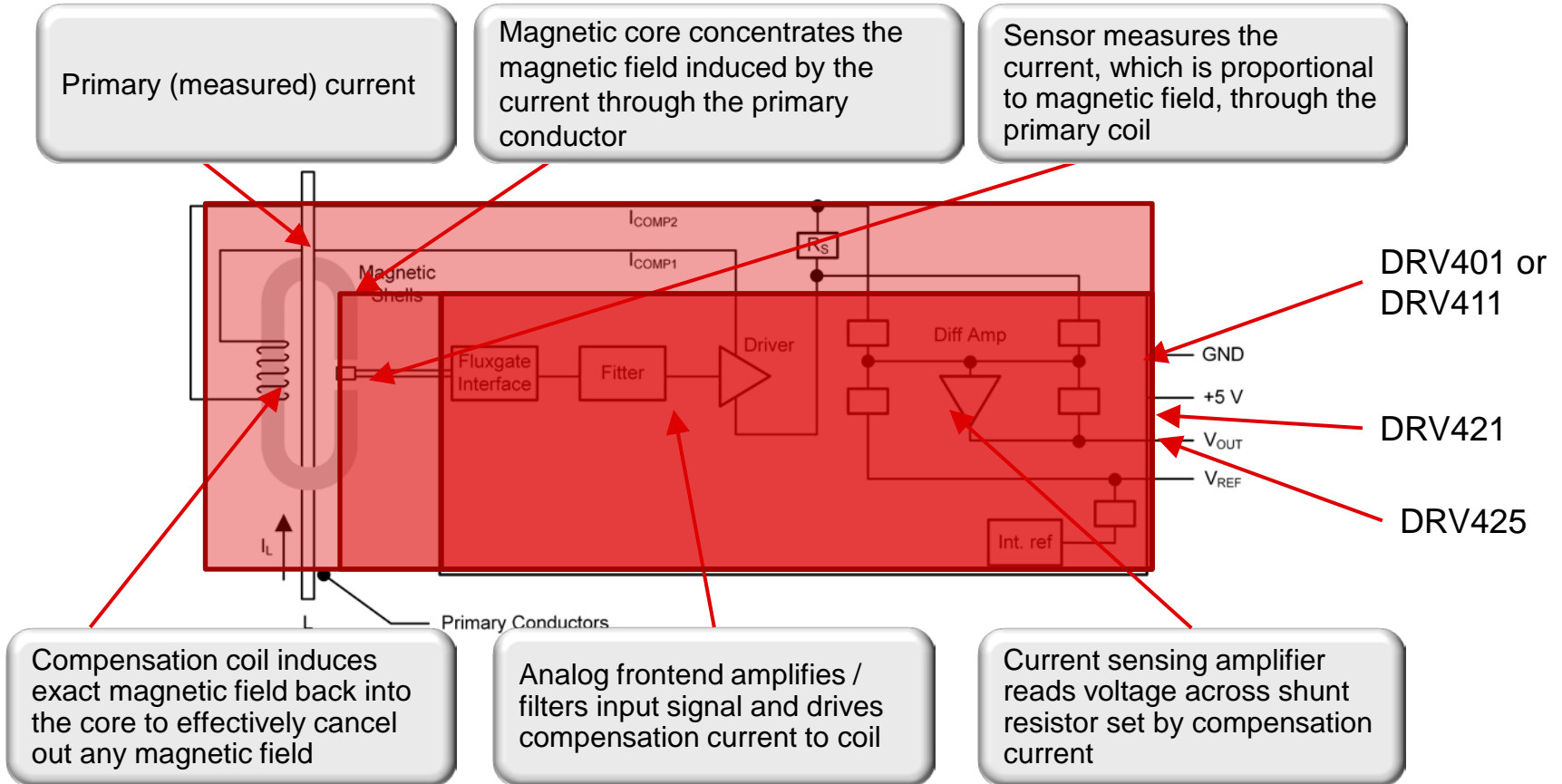
Hall
DRV411

Open-loop current sensor



- Magnetic field generated as current flows through conductor
- **Sensor IC (DRV425) inserted into the bus bar opening**
- Second DRV425 used to reject external disturbances

Closed-loop measurement principle



Fluxgate Magnetic Current Sensing Reference Design with High Linearity for 3-Phase Inverters



Features

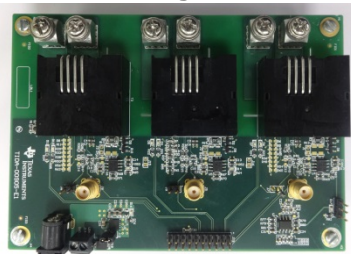
- Designed to accurately measure three phase inverter currents up to 50ARMS (nominal) and 150A (maximum)
- 200 kHz bandwidth, closed-loop current sensing using magnetic module and fluxgate sensor (DRV421)
- Calibrated current measurement accuracy of $\pm 1\%$ (typical) across temperature range from -25°C to 85°C
- Hardware based overload and ground fault detection enables fast response for protection of power switches

Target applications

- Variable speed drives
- UPS
- Solar inverters

Tools & resources

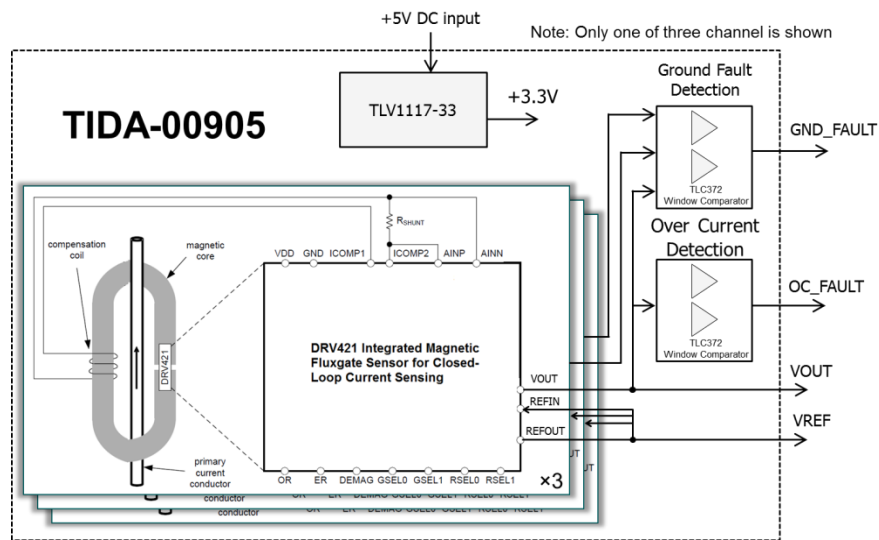
Board Image



- [TIDA-00905 and tools folder](#)
- [Design guide](#)
- **Design files:** Schematics, BOM, gerbers, and more
- **Device datasheets:**
 - [DRV421](#)
 - [TLV1117-33](#)
 - [TLC372](#)

Benefits

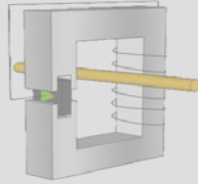
- Simplifies over-current protection for power switches
- Interface with 3.3V or 5V ADCs of microcontrollers
- Validated reference design for fluxgate current sensor
- Common reference design for line current and motor current measurement



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Sensor implementations

Closed-loop current sensors

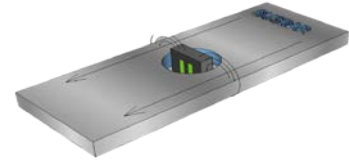
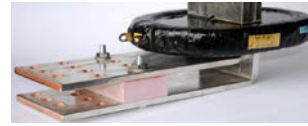


- Magnetic core picks up field around conductor
- **Sensor IC inside the core**
- Compensation coil drives magnetic field to zero

Fluxgate
DRV401
DRV421

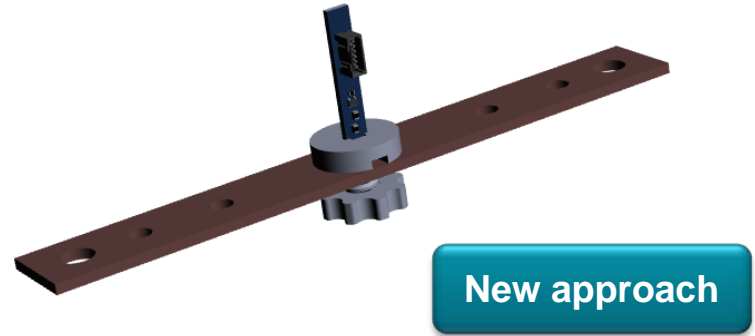
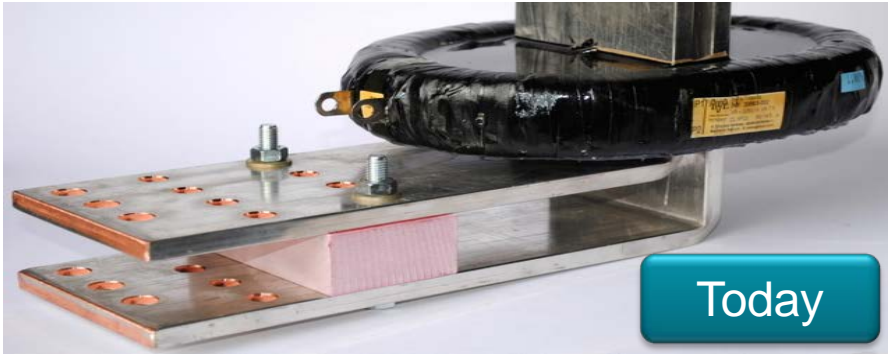
Hall
DRV411

Open-loop current sensor



- Magnetic field generated as current flows through conductor
- **Sensor IC (DRV425) integrated core and compensation coil**
- Compensation coil drives magnetic field to zero

DRV425 - value for high-current measurements



Benefits

- Sensor integrated into the bus bar for isolated measurement up to 1000s of amps
- Differential measurement inside the bus bar further increases immunity to stray fields and to frequency effects and to overcurrent conditions
- Lower power than shunt based solutions
- Compact module design and ease of installation
- High SNR by replacing discrete hall sensors
- Lower complexity and single temperature calibration
- <1% error over wide dynamic range

Bus bar application documentation



Application Report
SLOA237–November 2016

Bus Bar Theory of Operation

Scott Vestal, Javier Contreras

ABSTRACT

Traditional bus bar current measurement techniques use closed loop current modules to accurately measure and control current. These modules usually require a large magnetic core that encloses the entire bus bar. Because the compensation current generated inside the module is proportional to the bus bar current, the power dissipation can be as high as several watts. An alternative approach is to use two DRV425 devices connected in a differential configuration and mounted on opposite sides of a printed circuit board (PCB). This board is then placed into a cutout (hole or slot) located in the center of a bus bar.

Figure 1 shows the alternate approach using two DRV425 devices. When a cutout (hole or slot) is placed in the center of the bus bar, the current is split in two equal parts. Each side of the cutout will generate magnetic field gradients that oppose one another inside the cutout. The high sensitivity and linearity of the two DRV425 devices allow small opposing magnetic fields to be sensed and the current to be measured with high-accuracy levels. The DRV425 devices are placed equidistant from the center of the cutout and oriented in opposite directions to provide a differential measurement. This differential measurement also helps to reject outside stray magnetic fields.

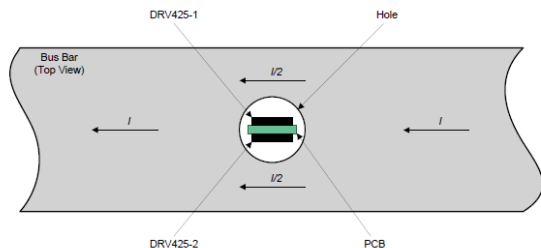


Figure 1. DRV425 Bus Bar Current Sensing Hole Configuration

Application report

Bus Bar Parameter Input

Design Configuration

PCB Device Configuration: Vertical
Bus Bar Cutout Configuration: Hole

Application Specific Parameters

Value	Unit
Current (I):	100.00 A
Bus Bar Width (x-dimension):	38.10 mm
Bus Bar Height (y-dimension):	2.29 mm
Hole Size (circle diameter, slot width):	12.70 mm
Sensor Spacing:	2.00 mm

Calculated Magnetic Field (Primary)

Calculated Parameter

Value	Unit
Magnetic Field at DRV425-1 (B_1):	0.2394 mT
Magnetic Field at DRV425-2 (B_2):	0.2394 mT
Differential Magnetic Field (B_{DIF}):	0.4788 mT

DRV425 Parameter Input

Application Specific Parameters

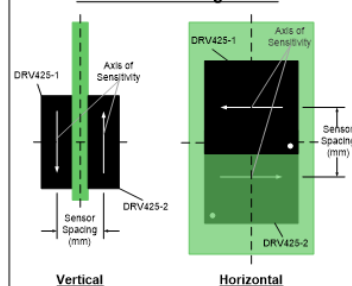
Value	Unit
Rshunt (R3):	75.00 Ohm
Reference Voltage (Vref):	2.50 V

Calculated DRV425 Output

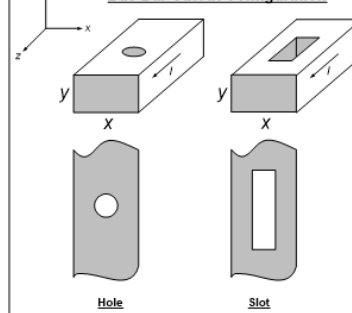
Calculated Parameter

Value	Unit
Vout (Vdiff):	4.2526 V

PCB Device Configuration



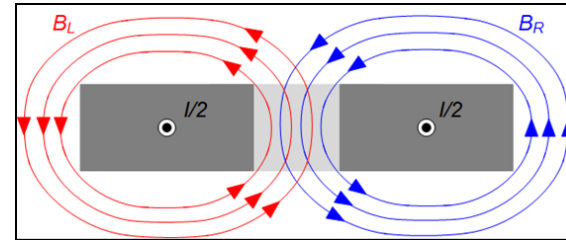
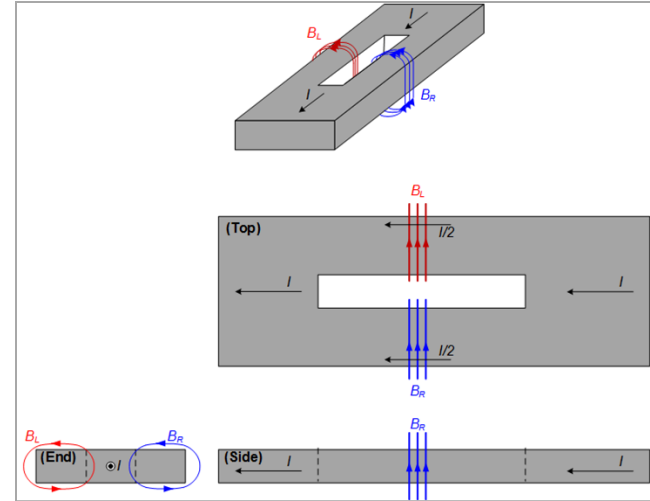
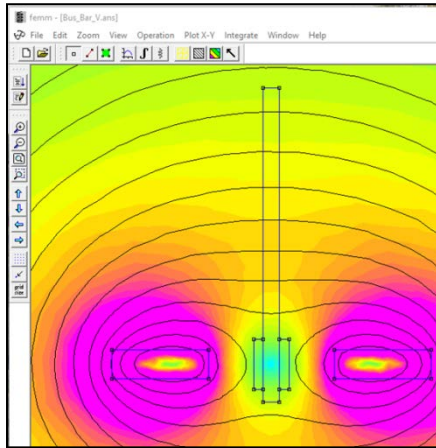
Bus Bar Cutout Configuration



Magnetic field calculator

Bus bar design simulation

- FEMM scripts to estimate magnetic field strength at each DRV425 device
 - 2D simulator
- Script definition and instruction presentation



Isolated High-Current Magnetic Bus Bar Sensing Circuit

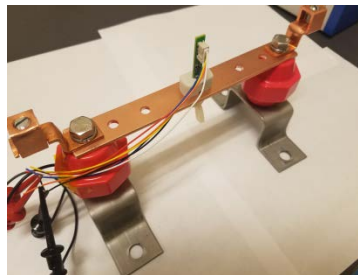
Features/Benefits

Isolated precision current measurement w/ fluxgate sensor	Greatly reduced system design complexity
Dual sensor design to eliminate external interferences	Measures up to 110A of AC, DC, or pulsed current
Small form factor	Greatly reduced cost vs current transformer approach

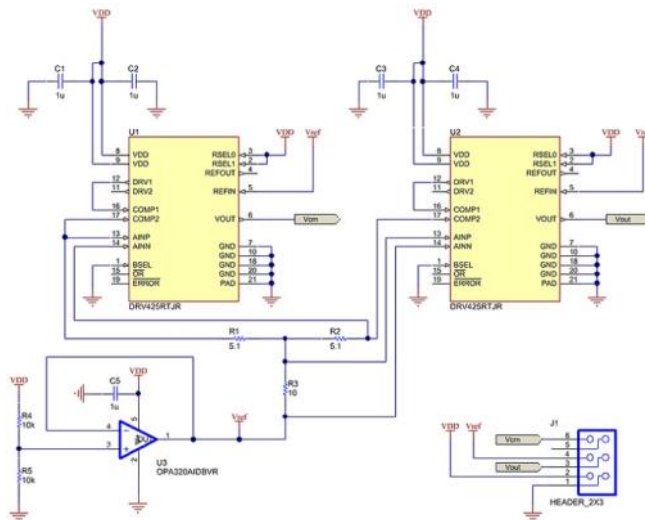
Target applications

- Distribution automation – terminal unit
- Bus-bar power monitoring

Tools & Resources



- **TIPD205**
- **Design guide**
- **Orderable #:** DRV425-BUSBAR-EVM
- **Design files:** Schematics, BOM, gerbers, software, and more
- **Device datasheets:**
 - TI DRV425



Design considerations for dual DRV425 bus bar applications

Problem statement

“What configuration is best for my design?”

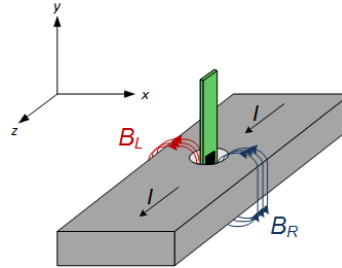
Understanding the system level influences for any magnetic field measurement is critical to achieving the best performing system. Stray magnetic fields cannot be eliminated but can be minimized.

Selecting the configuration that is best suited for a given design is critical for optimal performance.

- **Lead solution: DRV425**
- **TI tech note : SBOA185**

Applicable end equipments

- DC-DC converters
- 3-phase motor
- 3-phase AC current measurement
- General purpose drives



Isolated current measurement

Magnetic fields based current sensing is a common approach for measuring high currents (>100A) and/or high voltages (>100V).

Stray field rejection

Utilizing 2 DRV425 devices with the axis of sensitivity in opposite directions allows for cancelation of stray magnetic fields.

Overview

- System overview
- Overview current sensing
 - Shunt based measurement
 - Isolated current sensing
 - Magnetic measurement
- Overview voltage sensing
 - **Non-isolated measurement**
 - Isolated voltage sensing
- Additional information / Q&A

Voltage sensor key parameters

Configuration

Voltage range

Bandwidth

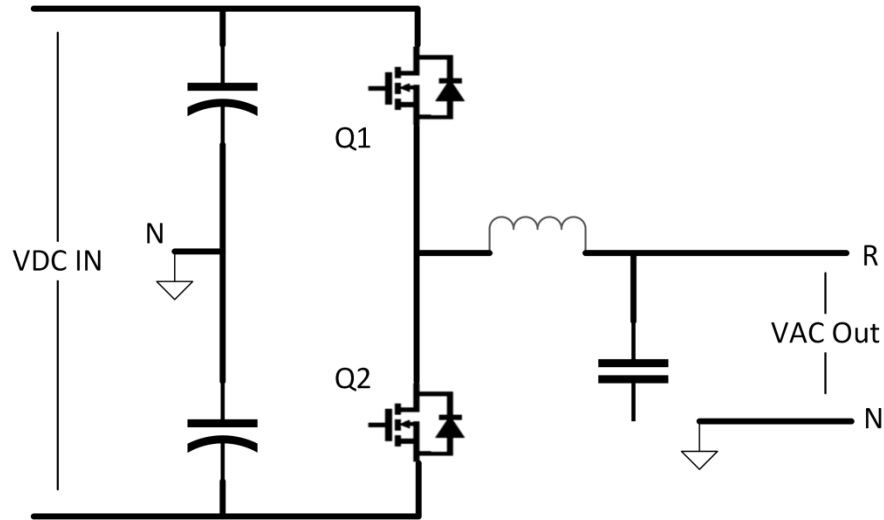
Polarity

Offset

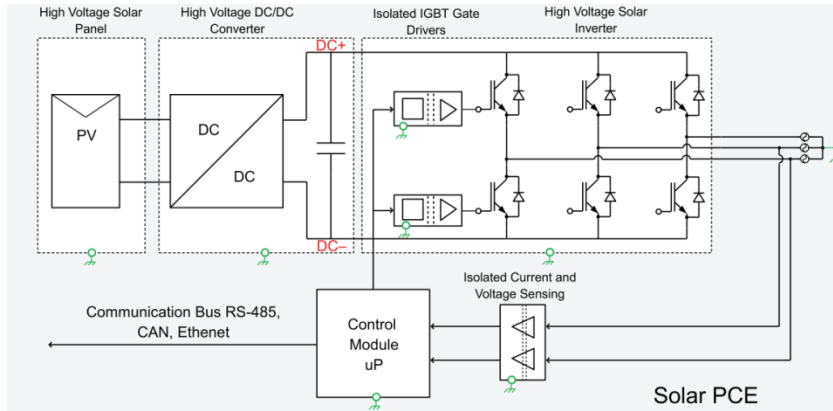
Gain

Output

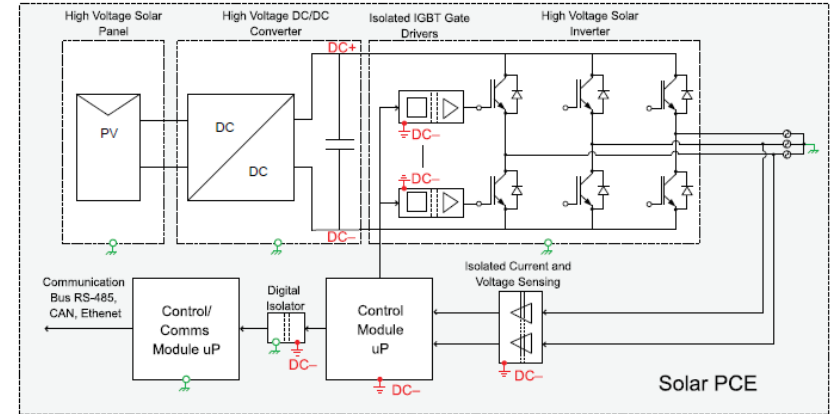
- What are the key parameters when selecting a **voltage sensor**?



System architecture



Option 1: System ground – Earth

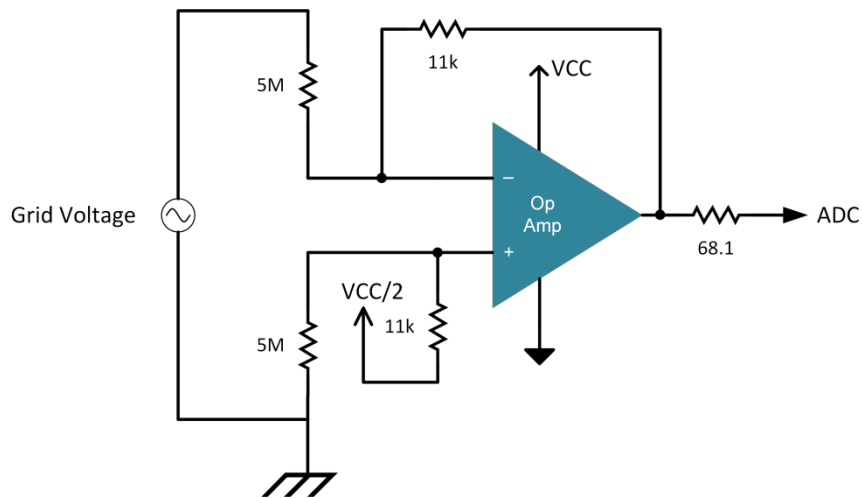


Option 2: System ground – DC-

Overview

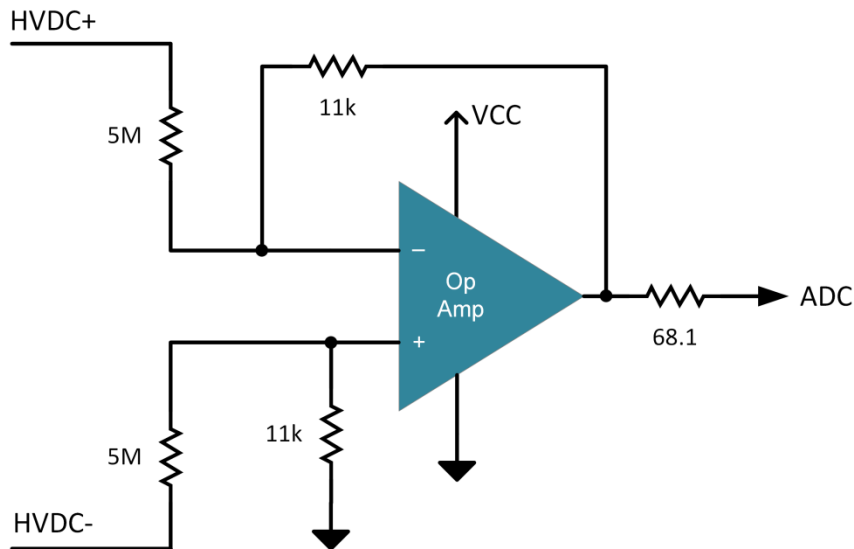
- System Overview
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- Overview Voltage Sensing
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 - Isolated Voltage Sensing
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AC voltage sensing



- Need to measure both positive and negative polarity of AC signal
- Resistor dropper chain of 10Mohm used to attenuate voltage signal
- Neutral reference works for multiple phases
- Center in ADC input range using $VCC/2$ reference voltage input

DC voltage sensing



- HV resistor dropper chain
- Floating reference to system ground
- Potentially unsafe depending on grounding and isolation topology

TIDA-01606 - 10kW 3-Phase 3-Level Grid Tie inverter reference design for solar string inverter

Features

- Rated nominal/Max input voltage at 800V/1000V DC
- Max 10kW/10KVA output power at 400VAC 50/60Hz Grid-tie connection
- Operating power factor range from 0.7lag to 0.7lead
- High Voltage (1200V) SiC MosFET based full bridge inverter for Peak efficiency of 98.5%
- Compact output filter by switching inverter at 50KHz
- <2% output current THD at full load.
- Isolated driver ISO5852S with reinforced isolation for driving High voltage SiC FET and UCC5320S for driving middle Si FET.
- Isolated current sensing using AMC1301 for load current monitoring
- TMS320F28379D Control card for digital control.

Benefits

- 3-Level T-type inverter topology for reduced ground current in transformer less grid tie inverter applications.
- Reduced size at higher efficiency using low Rdson SiC Mosfet for same output power.
- Platform for testing both 2-level and 3-level inverter by enabling or disabling middle devices through digital control.

Target Applications

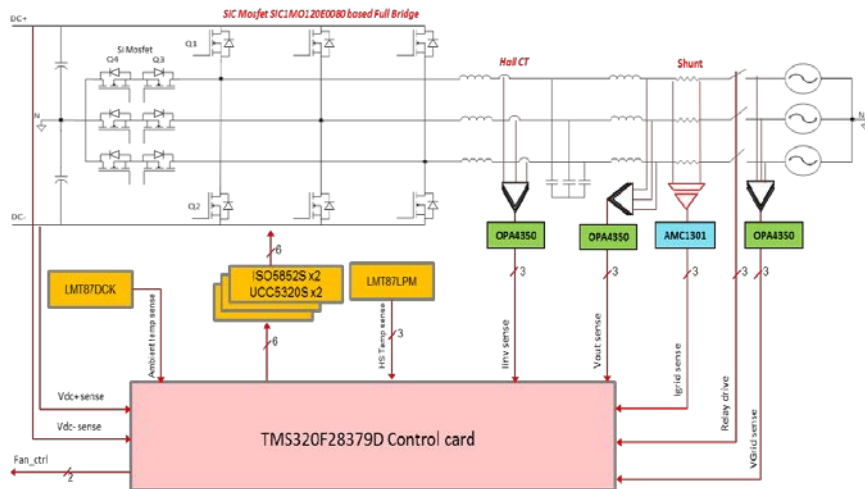
- String Inverter
- Central Inverter

Tools & Resources

Board Image



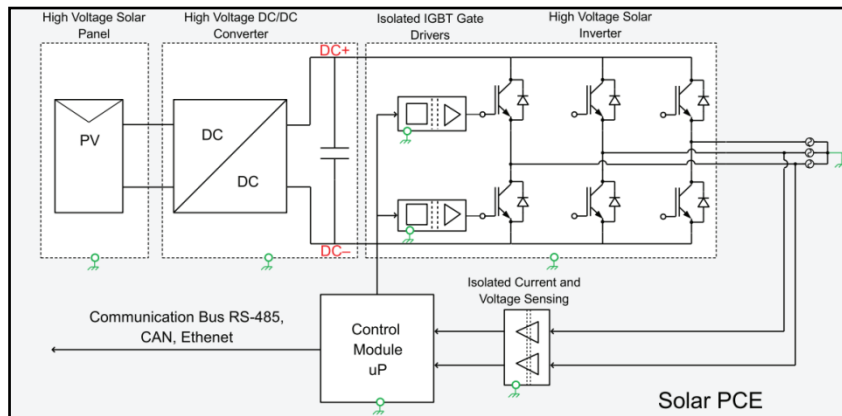
- [TIDA-01606 and Tools Folder](#)
- [Design Guide](#)
- Device Datasheets:
 - TMS320F28379D
 - ISO5852
 - UCC5320S
 - AMC1301
 - OPA4350
 - LMT87



Overview

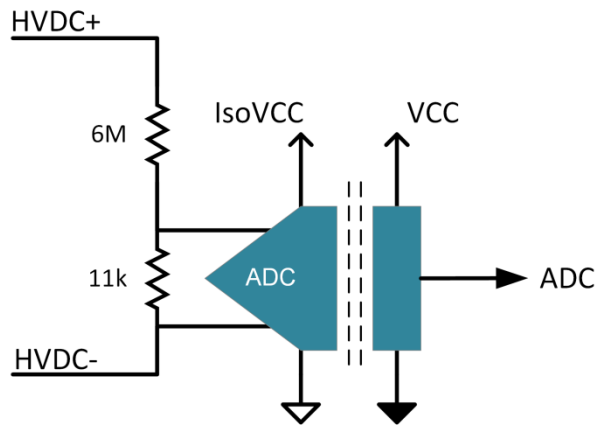
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 - **Isolated Voltage Sensing**
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When to use isolated voltage sensing

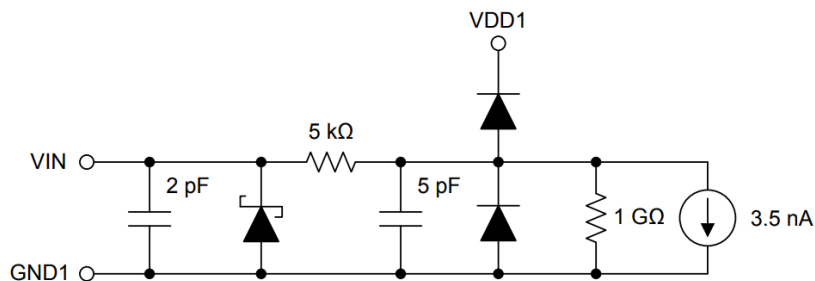


- The ADC (or MCU with on-chip ADC) is not referenced to the same point as the resistive divider (i.e. DC- or Neutral)
- Safety regulations require actual isolation barrier to be in place (while not relying on the resistors only)

Isolated DC voltage sensing



- Fully isolated voltage sensing solution
- Requires external bias supply
- Digital or analog output, like the current sensing amplifiers
- A high impedance input reduces impact on the voltage divider circuit



Isolated DC voltage sensing



- Implementable with AMC1311 reinforced isolation amplifier
- AMC1311 has a gain of 1V/V, so input should be scaled to match ADC
- DC-Link of 1000V is scaled down to 2V input using 6Mohm resistor chain
- 0-2V input range ensures linearity across signal chain
- Additional amp/filter can be used on the output if required

Overview

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TI Designs – current sensing

Shunts

Non-Isolated

TIDA-00528 (OPA333/INA226)

40 to 400 V Uni-Directional Current/Voltage/Power Monitoring Reference Design

Max Voltage: 400 V
Max Current: 8 A

TIDA-00639 (OPA333/INA226)

600 V Uni-Directional Current/Voltage/Power Monitoring for Smart Combiner Box

Max Voltage: 600 V
Max Current: 15 A

TIDA-01590 (INA260/ISO7842)

1200V Uni-Directional Current/Voltage/Power Monitoring for Smart Combiner Box

Max Voltage: 1200 V
Max Current: 15 A

Isolated

TIDA-00555 (AMC1100)

Isolated Current/Voltage Measurement Using Fully Differential Isolation Amplifier

Max Voltage: 300 V
Max Current: 40 A

TIDA-00080 (AMC1304)

Isolated Current/Voltage Measurement Using Fully Differential Isolation Amplifier

Max Voltage: 1 kVAC
Max Current: 200 A

TIDA-00601 (AMC1304)

Isolated Current/Voltage Measurement Using Fully Differential Isolation Amplifier

Max Voltage: 1 kVAC
Max Current: 90 A

TIDA-00738 (AMC1304)

Wide Input Current Using Shunts and Voltage Measurement for Protection Relays

Max Voltage: 300 VAC
Max Current: 60 A

Hall

TIDA-00218 (hall)

AC Current Measurement with Hall Effect Sensor

Max Current: 12 A

TIPD180

±50A Current Sensor using Closed-Loop Compensated Hall Element Reference Design

Max Current: 50 A

Fluxgate

TIPD196

±15 A Current Sensor Using Closed-Loop Compensated Fluxgate Sensor Reference Design

Max Current: 15 A

TI Designs – voltage sensing

Isolated

TIDA-00555 (AMC1100)

40 to 400 V Uni-Directional
Current/Voltage/Power
Monitoring Reference Design

Max Voltage: 400 V
Max Current: 8 A

TIDA-01541 (AMC1311)

High-Bandwidth Phase Current
and DC-Link Voltage Sensing
Reference Design for Three-
Phase Inverters

Max Voltage: 1000 V
Max Current: 15 A

Non-Isolated

TIDM-HV-1PH-DCAC (OPA4350)

Single-Phase Inverter
Reference

Max Voltage: 380V
Max Current: 6A

TIDA-01606 (OPA4350)

Three-Phase Grid Tie Inverter
Reference Design for Solar
String Inverters

Max Voltage: 1000V
Max Current: 18A

Additional information on EV charging

- [AC charging station](#)
- [DC charging station](#)
- [TI reference designs library](#)
- [TI.com training portal](#)

Reference designs & products

Quickly find featured reference designs and products for your system design. Narrow down TI's library of over 2,000 reference designs and 100,000+ devices to those most applicable to your design.

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Additional information on solar inverter

- [Solar inverter system resources](#)
- [TI reference designs library](#)
- [TI.com training portal](#)

Q&A