TI Current Sensing Product Overview

Speaker: Andrew Wang
## Current Sensing Options

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Isolated Current Sensing
Current Sensing in Inverter Applications

- **Isolated ΔΣ modulators** for shunt resistors
- **Non-isolated ΔΣ modulators** for magnetic sensors
- **Isolated amplifier** for shunt resistors
- **Closed Loop** Hall / Flux Gate

**Inverter Stage**

**Gate Drivers**

**ADC**

**MCU**

- F2837x Series with integrated filter
- F28xx Series

**Digital Filter**

**Digital Filter**

**McLaren F1**

**Last generation designs**

**New generation designs**

**NEW**

**in design**

**Q-100**

**ADC**

**Q-100**

**ADC**

**NEW**

**DRV421**

**DRV411**

**DRV401**

**AMC1304**

**AMC1204**

**AMC1203**

**ADS1204 4ch**

**ADS1205 2ch**

**ADS1209 2ch**

**AMC1301**

**AMC1200**

**AMC1100 e-meter**

**Texas Instruments**
Isolated Current Sensing Methods

TI’s Integrated FluxGate technology enables new generation of magnetic current measurement solutions

- Closed-loop Fluxgate sensors
- Isolated shunt solutions
- Closed-loop Hall-effect
- Bus-Bar
- Open-loop Hall-effect

**MEASUREMENT ACCURACY**
- 0.1%
- 1%
- 10%

**PRIMARY CURRENT**
- 10 A
- 100 A
- 1000 A
Isolated Current Sensing – 2 types

Magnetic Sensing
- Magnetic core picks up field around conductor
- Sensor IC inside the core
- Compensation coil drives magnetic field to zero
- Products: DRV40x, DRV41x, DRV42x

Shunt-Based Sensing
- External shunt resistor
- Delta-Sigma modulator on high-side
- Isolated analog or digital (bit stream) output
- Products: AMC1200, 130x, ISO12x
Magnetic Current Sensing Methods

**ACCURACY**

**Closed loop**
- + highest accuracy
- + wide bandwidth
- + wide dynamic range
- - need concentrator
- - power dissipation

- DRV401/411/421

**Open loop**

**Concentrator**
- + shielding
- + lower power
- - saturation of core
- - core properties

- DRV425

**Bus bar**
- + CM field rejection
- + no concentrator
- + low power
- - disturbances

- DRV425

**Over the trace**
- + lowest cost
- + lower power
- - disturbances

- DRV425
Closed-Loop Measurement Principle

- Magnetic core concentrates the magnetic field generated by the measured current.
- Sensor measures the magnetic field.
- Compensation coil provides opposite magnetic field.
- Read-out circuit amplifies/filters magnetic field.
- Differential amplifier generates output voltage proportional to the compensation current.
- Primary (measured) current.
Closed-Loop Sensing
(Hall Effect / Flux Gate)

Components:
1. Ferro-magnetic core picks up magnetic field of measured current
2. Sensor inside the core measures magnetic field
3. Read-out circuit amplifies/filters magnetic field
4. Feedback coil provides opposite magnetic field to drive current to zero

Note: for high-frequency currents, system works as a transformer

Force to be 0V
DRV411 (TIPD180)
Hall-Element Conditioner for Closed-Loop Current Sensors

**Features**

- Work as current transducer
- Accuracy $< +/− 0.2\%$ at room temp (+/−50A)
- Compensation Coil Driver Output: 250mA
- Precision Difference Amplifier:
  - Offset Error and Drift: $±0.1\text{mV}$ max, $±1\text{µV/°C}$ max
  - Gain Error and Drift: $±0.3\%$ max, $±5\text{ppm/°C}$ max
- Precision On-Chip Reference:
  - Accuracy and Drift: $±0.2\%$ max $±50\text{ppm/°C}$ max
  - Selectable Voltage: 1.65V or 2.5V
- Wide System Bandwidth: 200kHz
- Small Package: 4x4mm QFN or TSSOP-20

**Closed Loop**
**Features**

- **High Precision Integrated Magnetic Fluxgate Sensor**
  - Offset: $\pm 3 \mu T$ max, Drift: $\pm 10 \text{nT/}^\circ\text{C}$ typ
- **H-Bridge Output Driver** (250 mA typ)
- **Precision differential amplifier**
  - Offset error & Drift: $\pm 100 \text{uV}$ max, $\pm 2 \text{uV/}^\circ\text{C}$ max
- **Precision Reference**
  - Accuracy and Drift: $\pm 2\%$ max, $\pm 100 \text{ppm/}^\circ\text{C}$ max
  - Selectable Voltage: 1.65 V or 2.5 V or VDD/2
- **Over-Range and ERROR flag**
- **Power Supply** 3 V to 5.5 V

**Applications**

- Closed-Loop Current Sensor Modules for
  - Leakage current measurement
  - Motor Control
  - Frequency and Voltage-Inverters
  - Photovoltaic Inverters
  - Current Monitoring

**Benefits**

- Targeting system overall accuracy ~0.1% across temp
- Integrated closed-loop core de-gauss
- Sensor integration for lower system cost
- The high sensor sensitivity, low offset and drift relax core requirements
- Integrated sensor reduces coil coupling, emissions and increase dynamic range

**Practical current measurement range** 0.2A ~ 0.6A
Isolated Current Sensing – 2 types

**Magnetic Sensing**
- Magnetic core picks up field around conductor
- Sensor IC inside the core
- Compensation coil drives magnetic field to zero
- Products: DRV40x, DRV41x, DRV42x

**Shunt-Based Sensing**
- External shunt resistor
- Delta-Sigma modulator on high-side
- Isolated analog or digital (bit stream) output
- Products: AMC1200, 130x, ISO12x
Shunt-Based Sensing – Analog versus Digital Output Isolators

• Either can be used for either high or low-side current sensing
• Accuracy & Resolution (system-wise): Digital > Analog
Isolated Amplifiers

1st Generation: isolated amplifier with basic isolation

- ±250mV
- 2V
- Status: in production
- Product: AMC1200

2nd Generation: improved signal chain & reinforced isolation

- ±250mV
- 2V
- Status: in development
- Product: AMC1301
Isolated ΔΣ-Modulators

1st Generation: Basic Isolation

\[ V_{in} = \pm 250\text{mV} \]

Data
Clock

Status: in production
Product: AMC1203
AMC1204

2nd Generation: improved signal chain and reinforced isolation

\[ V_{in} = \pm 50\text{mV}, \pm 250\text{mV} \]

Data
Clock

Status: in production
Product: AMC1304

3rd Generation: integrated power

\[ V_{in} = \pm 50\text{mV}, \pm 250\text{mV} \]

Data
Clock

Status: Prototype
Product: AMC1404
AMC1200B
4.25 kV_{PEAK} Isolated Amplifier

Features
• SNR <= 60dB
• ±250mV input voltage range
• Fixed gain: 8
• Gain error: 0.5% max; drift: ±56 ppm/°C
• Input bandwidth: 100kHz typ, 60kHz min
• Noise: 3.1 mV_{RMS}
• Input offset voltage: ±1.5mV max;
  • drift: ±10μV/°C max
• Non-linearity: ±0.075/0.1% max

AMC1305
7 kV_{PEAK} Isolated Delta-Sigma Modulator

Features
• 82db SNR (Max)
• ±50-mV or ±250-mV Input Voltage Ranges
• Isolation Voltages: 7000 V_{PEAK}, 10000 V_{SURGE}
• Working Voltages: 1500 V_{DC}, 1000 V_{AC, rms}
• Transient Immunity: 15 kV/μs (min)
• Offset Error: ±150 μV (max), Offset Drift: 1.3 μV/°C (max)
• Gain Error: ±0.3% (max), Gain Drift: ±40 ppm/°C (max)
AMC1304
20MHz isolated ΔΣ modulator

Features

- UL1577 & IEC60747-5-5 approved
  - Working voltage: 1.5kV\textsubscript{RMS}, 1.5kV\textsubscript{DC}
  - Isolation voltage: 7kV\textsubscript{PEAK} / 10kV\textsubscript{SURGE} (reinforced isolation)
- CMTI: 15 kV/μs (min.)
- 5-20 MHz external clock
- Family with different input voltage ranges:
  - ±50mV\textsubscript{IN} (BW = 1MHz, R\textsubscript{IN} = 5kΩ)
  - ±250mV\textsubscript{IN} (BW = 1MHz, R\textsubscript{IN} = 20kΩ)
- LDO allows 4V ... 18V supply voltage range
- standard CMOS Interface and LVDS Interface
- Temp range: -40 to 125°C
- SO-16 (DW) package

Benefits

- Galvanic barrier provides EMI immunity and robust isolation barrier lifetime
- Wide clock range gives sample rate flexibility for customer
- reduced input voltage range enables higher shunt currents
- extended industrial temperature range fully specified

Applications

- Shunt-based Current measurement in:
  - Solar Inverter
  - Frequency Inverter Applications
  - Uninterruptible Power Supplies

![Diagram of AMC1304](image-url)
AMC1305
20MHz isolated ΔΣ modulator

Features

- UL1577 & IEC60747-5-5 approved
  - Working voltage: \( 1.5\text{kV}_{\text{RMS}}, 1.5\text{kV}_{\text{DC}} \)
  - Isolation voltage: \( 7\text{kV}_{\text{PEAK}} / 10\text{kV}_{\text{SURGE}} \) (reinforced isolation)
- CMTI: \( 15\text{kV/\mu s} \) (min.)
- 5-20 MHz external clock
- Family with different input voltage ranges:
  \( \pm 50\text{mV}_{\text{IN}} \) \( (\text{BW} = 1\text{MHz}, R_{\text{IN}} = 5\text{k}\Omega) \)
  \( \pm 250\text{mV}_{\text{IN}} \) \( (\text{BW} = 1\text{MHz}, R_{\text{IN}} = 25\text{k}\Omega) \)
- standard **CMOS** Interface and **LVDS** Interface
- Temperature range: -40 to 125°C
- SO-16 (DW) package

Benefits

- Galvanic barrier provides EMI immunity and robust isolation barrier lifetime
- Wide clock range for sample rate flexibility
- reduced input voltage range enables higher shunt currents
- extended industrial temperature range fully specified
- Compatible to ACPL-796J and AD7401A

Applications

- Shunt-based Current measurement in:
  - Motor Control
  - Frequency Inverter Applications
  - Shunt Current Measurement
Non-Isolated Current Sensing
Non-Isolated Sensing Choices

Operational Amplifier

Difference Amplifier

Instrumentation Amp

Current Shunt Monitor

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Operational Amplifiers

- Cost effective
- Bandwidth
- Flexible

- Single ended
- Only low side sensing (Vcm≈GND)
- Sensitive to PCB layout parasitics

Example – OPA188
Difference Amplifier

• Either **high** or **low-side** current sensing
• Can tolerate very large common-mode voltages (e.g. INA149 $V_{CM} = \pm 275V$). This is due to large resistive divider on input pins
• Resistor pair has similar temp-co, so shifts in same direction

- Not very high impedance input, the resistive network loads the system
- Any resistor connect to input will introduce significant gain error

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**Example – INA149**

- $V_{OUT} = \frac{V_{IN} - V_{REF}}{R_{REF}}$
- $V_{IN}$ is input voltage
- $V_{REF}$ is reference voltage
- $R_{REF}$ is reference resistor

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Texas Instruments

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Instrumentation Amplifier

- Large input impedance
- Change gain with one resistor
- High CMRR

- Common-mode voltage must remain within supply voltage
- Usually higher cost due to 2~3 op-amp

Example – INA826
Current Shunt Monitors

- Either **high** or **low-side** current sensing
- Unique input stage topologies (e.g. common-base)
- This allows for $V_{CM}$ values **outside** of supply voltages AND very large input impedances
- Spec guarantees the max error which is easy for customer to design

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- Limited to maximum $V_{CM}$ value at currently 80V
- BW is usually **not as flexible as other solution**

Example – INA193

[Image of INA193 circuit diagram]
Current Sensing Output Signal Types

Current Output

Voltage Output

Digital Output
Voltage Output:
INA282 to INA286
High Accuracy -14V to 80V CMR Bi-directional Current Shunt Monitor

Features

- Wide Common Mode & Noise Rejection
  - $V_{cm} = -14V$ to 80V
  - CMRR: 120dB (min)
- High Accuracy
  - Voltage offset: 20µV (typ), 70µV (max)
  - Offset Drift: 1.5µV/°C (max)
  - Gain Error: 1.4% (max)
- Integrated reference voltage divider

Benefits

- Maintains accuracy in high voltage applications with high degrees of common mode noise
- Saves system power by allowing for smaller shunt resistors to be used without affecting accuracy.
- Simplifies setup of output bias for interfacing to ADC.

Applications

- Industrial Power Supplies
- Solar Inverters
- Servers
- Motor Control
- Telecom Power Supply Modules

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<tr>
<th>Part #</th>
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<tr>
<td>INA286</td>
<td>100 V/V</td>
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<tr>
<td>INA283</td>
<td>200 V/V</td>
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<tr>
<td>INA284</td>
<td>500 V/V</td>
</tr>
<tr>
<td>INA285</td>
<td>1000 V/V</td>
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Package: SOIC-8
Voltage Output:
INA250:
Internal Shunt Zerø-Drift Current Shunt Monitors

Features

- Up to +/-15A @ -40 ~ 85°C
- 0.1% Integrated 2mΩ Shunt Resistor
- -0.3 to +36V Common-Mode Range
- ±0.75% Gain + Shunt Tolerance MAX over -40°C to +125°C temperature range
- Available gains:
  - 200mV/A
  - 500mV/A
  - 800mV/A
  - 2V/A
- TSSOP16 Package: 6.5mm x 5mm

Benefits

- Complete current sense solution
- Smaller and more accurate than amplifier plus external shunt
- Eliminates error due to tolerance and layout of external shunt

Applications

- Automotive
- Power Supply
- Telecom
- Test equipment
- Solar Inverters
- Servers
- Motor Control
Precision Integrated Current Sense Resistor

Exhausting Solution

Existing Solution

Amplifier + Discrete Sense Resistor

2mΩ Internal Sense Resistor
Specified to 10A @ -40°C to +125°C

Analog Output

0.75% Total Error (Shunt + Gain)
Over Full Temperature Range
0V to 36V Common-Mode Range
4 Available Gains Options
200mV/A, 500mV/A, 800mV/A, 2V/A

Digital Output

0.5% Total Error (Shunt + Gain)
Over Full Temperature Range
0V to 36V Common-Mode Range
Current/Power Monitor w/ Programmable Alert

Amplifier

Power Supply

RSHUNT

INA250

INA260

LOAD
Relative Packaging Size Comparison

- 0805
- 1206
- 1210
- 2010
- 2512

- RSW QFN-10
- SC70
- SOT23
- MSOP
- SOIC

0.1% 2mΩ 3637 (50ppm/°C)
0.5% 2mΩ 2512 (50ppm/°C)
0.1% 2mΩ (50ppm/°C)
# Current Output: INA139
High Speed Current Shunt Monitor

## Features
- Complete current sense solution
- Offset 1mV MAX
- 4.4MHz Bandwidth
- Supply independent common-mode range of 2.7V to 40V
  - See INA169 for 2.7 to 60V
- Low quiescent current: 60 µA (typ)
- Single resistor gain set

## Benefits
- Easy design and minimizes board space
- Ideal for high speed applications
- Allows high common-mode inputs using a low single supply
- Enables maximum power efficiency
- Flexible for gains from 1 to 100

## Applications
- Automotive
- Computers
- Portable and battery backup systems
- Battery chargers
- Power management
- Precision current source

![INA139 Circuit Diagram](image)
Digital Output: INA226
Current, Voltage, Power Sensor with I²C Interface

**Features**

- **HIGH ACCURACY**
  - 10uV Offset Voltage (Max)
  - 0.05µV/°C Offset Drift (Max)
  - 0.1% Gain Error (Max)

- **WIDE DYNAMIC RANGE**
  - Common-Mode Range: -0.3V to 36V
  - Supply Range: 2.7V to 5.5V
  - 80mV Maximum Shunt Drop

- **APPLICATION CONFIGURABLE**
  - Reports Current, Voltage and Power
  - Programmable Sample Averaging
  - Independent Bus and Shunt Voltage Conversion Times
  - Programmable Alert

**Applications**

- Industrial Power Supplies
- Solar Inverters
- Servers
- Telecom Power Supply Modules
- Test & Measurement
- Battery Management

**Benefits**

- Accurate power monitoring at low current with wide dynamic range for high peak currents

- Large input range to integrate into increasing common-mode voltage applications

- Adaptable configuration to optimize performance under multiple operating conditions

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**Diagram:**

- Power Supply (0V to 36V)
- High-Side Shunt
- Low-Side Shunt
- Load
- Voltage Register
- Current Register
- Power Register
- Alert Register

**Package:** MSOP-10 (3 x 5)
Comparator Output (OCP):
INA300
High-Speed Current Sense Comparator

Features
- Wide Common-Mode Range: 0V to +36V
- Programmable Threshold
  - Adjust Through External Resistor
  - Programmable from 0mV to 250mV
- Selectable Delay to eliminate false trips
  - 10 / 50 / 100µS Response Time
- Selectable Hysteresis: 2 / 5 / 10mV
- Open-Drain Output With Latching Capability
- Package: 2 x 2 mm QFN-10

Benefits
- Simple Current Trip Point Solution (Electronic Fuse)
- Integrates Sensing and Comparator for complete over-current protection block
- Programmable delay allows over-current detection without false alerts from noise.

Applications
- Over-Current Detection
- Power Supply Protection
- Circuit Breaker
- Compute Servers
- Battery Management
- Hand Held Radios

Diagram:
- INA300
- VS
- IN+
- IN-
- CMP
- LIMIT
- LATCH
- ALERT
- DELAY
- HYS
- GND
- CBYPASS 0.1µF
- +2.7V to 5.5V
- 10kΩ
- RPull-up
- GPIO
- DAC
- RLIMIT
- Load
- Processor
- Power Supply (0V to 36V)
Current & Power Monitoring: Common Mode Voltage < 60V
**Current & Power Monitoring**

**Common Mode Voltage ≥ 60V**

- **INA282–286**
  - -14V to +80V CMR
  - 70uV Offset
  - Gain: 50, 100, 200, 500, 1000V/V
  - SOIC

- **INA193 - 198**
  - -16V to +80V CMR
  - 2mV Offset
  - Gain: 20V/V, 50V/V, 100V/V
  - SOIC-8

- **LMP8601 - 8603**
  - Bidirectional
  - -22V to +60V CMR
  - 1mV Offset
  - Gain: 20V/V, 50V/V, 100V/V
  - SOIC-8/23

- **LMP8640HV / 8645HV**
  - -2V to +76V CMR
  - 900uV to 1000uV Offset
  - Gain: Adj, 20, 50, 100V/V
  - TSOT-6

- **LMP8480 / 8481**
  - 4.5V to +76V CMR
  - 265uV Offset
  - Gain: 20, 50, 60, 100V/V
  - MSOP-8 and LLP8

- **INA200-208**
  - -16V to +80V CMR
  - 2.5mV Offset
  - Gain: 20V/V, 50V/V, 100V/V
  - Dual Pinouts
  - SOIC, TSSOP

- **INA170**
  - Bidirectional
  - 2.7V to +60V CMR
  - 1mV Offset
  - MSOP

- **INA169**
  - 2.7V to +60V CMR
  - 1mV Offset
  - BW: 440kHz
  - SOT-23

- **INA168**
  - 2.7V to +60V CMR
  - 1mV Offset
  - BW: 80kHz
  - SOT-23

**Texas Instruments**
Non-Isolated Current Shunt Solutions

- Smallest: INA231
- Lowest Offset: INA226
- Lowest Power: INA226, INA3221
- Triple Channel: INA3221
- Programmable Alerts: INA226, INA230, INA231, INA3221

**Integrated Shunt**
- Precision, Low-Drift 2mΩ Internal Shunt
- Analog Voltage Output
  - VCM > 60V
- Analog Voltage Output
  - VCM < 60V
- Digital Output

**Overcurrent Protection (OCP)**
- Analog Current Output
- Overcurrent Protection (OCP)
- VCM Up To 36V
- VCM Up To 60V

**Electronic Fuse**
- INA300

**I2C/SMBus interface**

*Pre-Release - Product Samples & Evaluation Boards Available*
Questions?

- Thank you for your time!