Exploring current sense amplifiers

STMicroelectronics Tech Days

Introduction

Chapter 1

User guide

This presentation provides a written explanation of the topic covered in the first chapter of the video: **“Getting Started with Current Sensing – Introduction #1”**, which is available on our YouTube channel at the following link:

Video on YouTube

Recommendations

In this document you will find key concepts explained through informative tables, graphs, sequences of graphs, followed by a detailed explanation.

- When you see this icon: Explanation the topic is explained in detail on the following page(s)
- Each explanation page shows the page or page range where the topic is explained: (page # to #)
- If you see this icon: Continue the explanation continues on the next page(s)

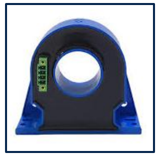
Different types of current sensing

Indirect current sensing

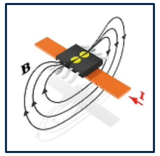
Based on Ampere's and Faraday's law


Rogowski coil


AMR contactless


Fluxgate


Current transformer


Hall effect contactless

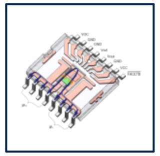
100A-1000A

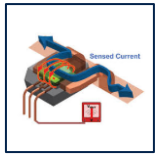
Direct current sensing

Based on Ohm's law


Shunt

Based on Ampere's and Faraday's laws


AMR contact


Hall effect contact

0A-100A

Current Sense Amplifiers

Explanation

Different types of current sensing

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Current sensing techniques can be grouped into two main categories:

1. **Indirect current sensing (≈100 A to 1000 A):** Based on Ampere's and Faraday's laws, by placing a coil around a current-carrying conductor, a voltage is induced across the coil proportional to the current.

Key benefits**:** Non-invasive measurement with high isolation. Very wide input common-mode voltage range, and capability to measure very large currents.

Main drawbacks: Generally higher cost, performance can degrade with temperature.

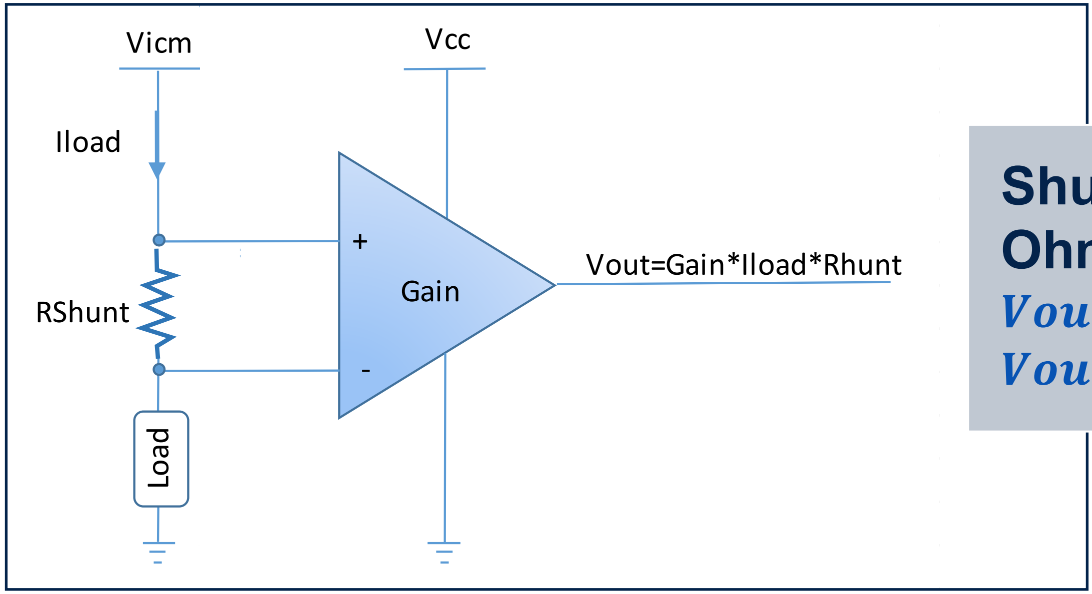
2. **Direct current sensing (≈mA to 100 A):** The current flows directly in the measurement path. Solutions include AMR and Hall effect sensors, still based on Ampere's and Faraday's laws, and shunt resistors based on Ohm's law.

Shunt-based sensing: Cost-effective, Very accurate at low currents (below about 2 A).

Limitations include: Typical common-mode voltage range of −20 V to 120 V. Maximum current mainly limited by the shunt itself.

This training will focus exclusively on shunt-based current sensing, detailing its parameters, limitations, and benefits.

How it works



Shunt current sensing is based on Ohm's law

$$Vout = Gain * Iload * Rshunt$$

$$Vout = Gain * Vsense$$

Key application parameter to choose a current sensing amplifier

- Input common voltage
- Load current range
- Current direction flowing into the load

Explanation

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Shunt current sensing is based on **Ohm's law**. The load current flows through a shunt resistor R_{shunt}, creating a small voltage drop V_{sense} which is therefore amplified by a dedicated operational amplifier.

The output voltage V_{out} is proportional to the load current:

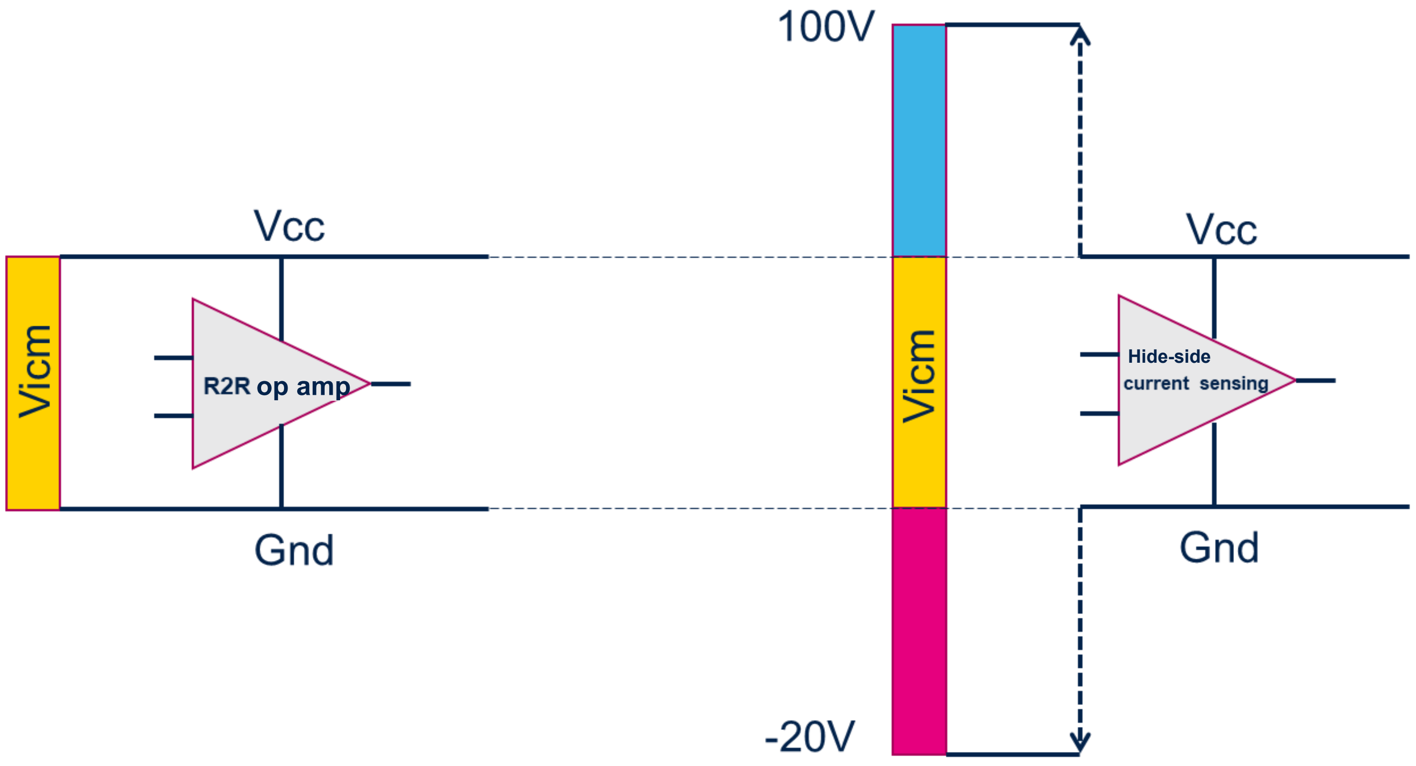
- V_{out}= Gain x I_{load} x R_{shunt}
- V_{out}= Gain x V_{sense}

This makes shunt-based current sensing straightforward to use.

To select the right current sense amplifier, a few key application parameters are required:

- **Load current range** to choose the appropriate gain
- **Current direction**, for example if both charge and discharge currents must be measured in a battery system
- **Input common-mode voltage range**, which determines whether a simple op amp is sufficient or if a dedicated current sense amplifier is needed

Main characteristics of high-current sensing extended V_{ICM}



Op amp **Current sensing**

- Motor control applications
- Car battery monitoring system

- Low-voltage battery management

- Free wheeling diode of solenoid valve
- Reverse car battery
- Fast current variation into an inductive shunt in low-side configuration

Current Sense Amplifiers

Explanation

Main characteristic of high-current sensing extended V_{ICM}

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What is the input common-mode voltage range?

The input common-mode voltage is the voltage seen simultaneously by both input pins.

For a rail-to-rail op amp, the input common-mode voltage V_{ICM} must stay within the supply range. If it exceeds V_{CC}, the ESD diodes conduct. In practice, the input voltage must remain between the supply rails.

Current-sense amplifiers are different: they operate with V_{ICM} well beyond the supply voltage. The common-mode voltage can be positive and much higher than V_{CC}, as in motor control or automotive battery monitoring at 12 V or 48 V.

It can also be negative in some cases, for example with reverse battery conditions or sudden current changes through a slightly inductive shunt.

In short, a current-sense amplifier is a differential amplifier with an extended input common-mode voltage range.

Current Sense Amplifiers

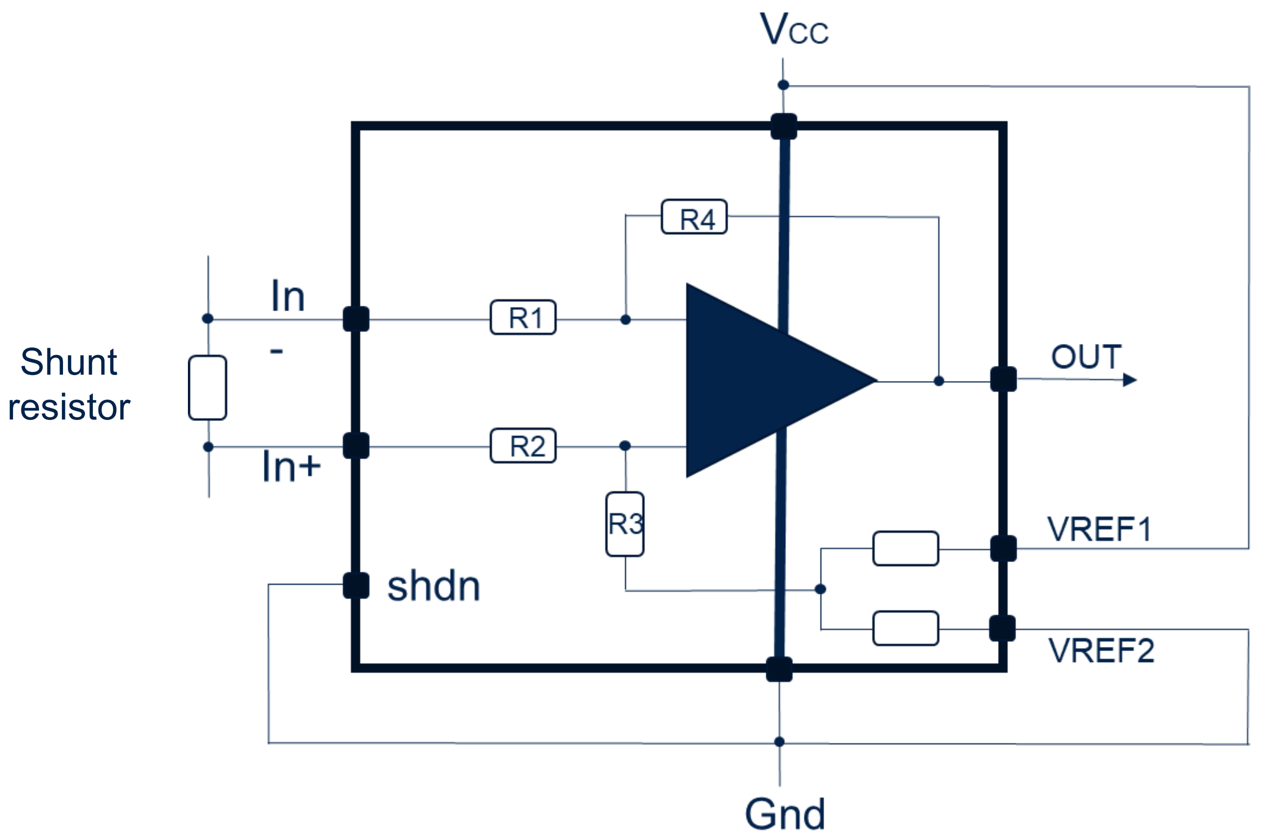
Current sensing output type

Voltage output

Alert output

Digital output

Voltage output



- Direct conversion I to V
- Integrated fixed gain
- Wide V_{ICM} supported

Current Sense Amplifiers

Explanation

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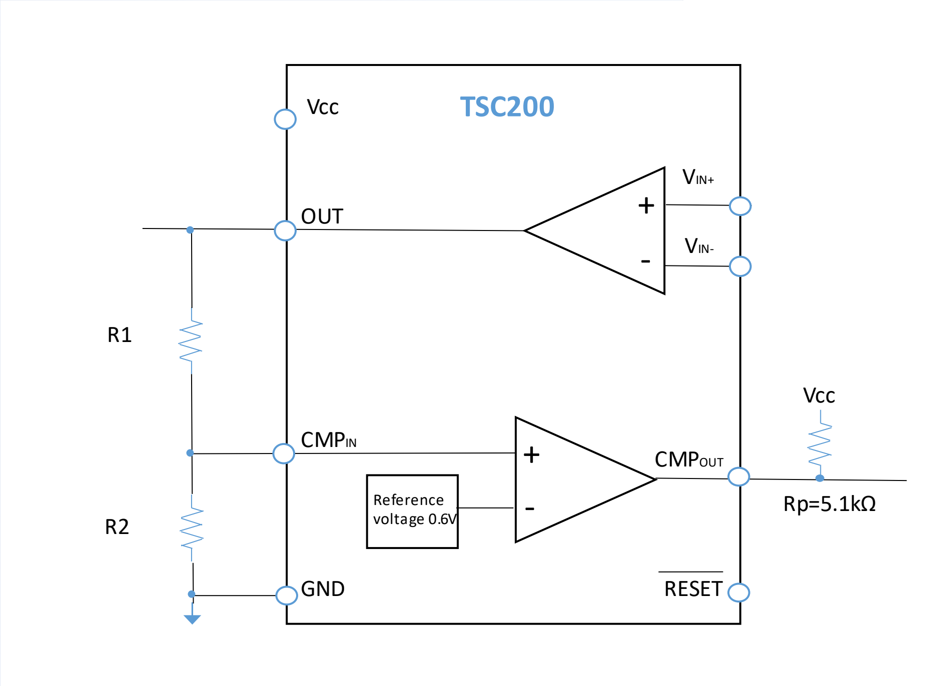
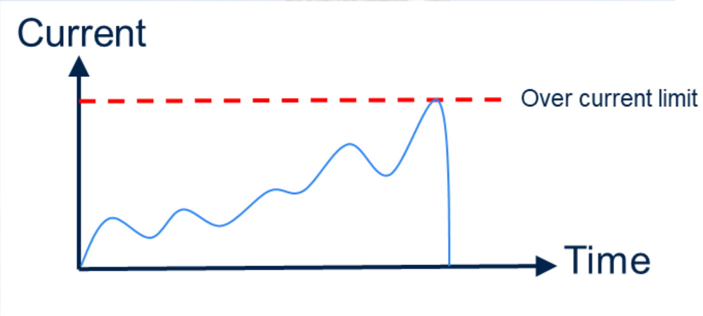
Voltage-output current-sense amplifiers

Most current-sense devices provide an analog voltage output, ideal when the current measurement is used in a control feedback loop. They can also interface directly with a microcontroller such as an STM32 via its embedded ADC.

Their key advantage is the integrated, fixed gain, which offers very good accuracy while supporting a wide input common-mode voltage range.

Overcurrent protection (OCP)





- Direct conversion I to V
- Integrated fixed gain
- Wide V_{ICM} supported
- Integrated comparator for overcurrent protection function

Explanation

Overcurrent protection (OCP)

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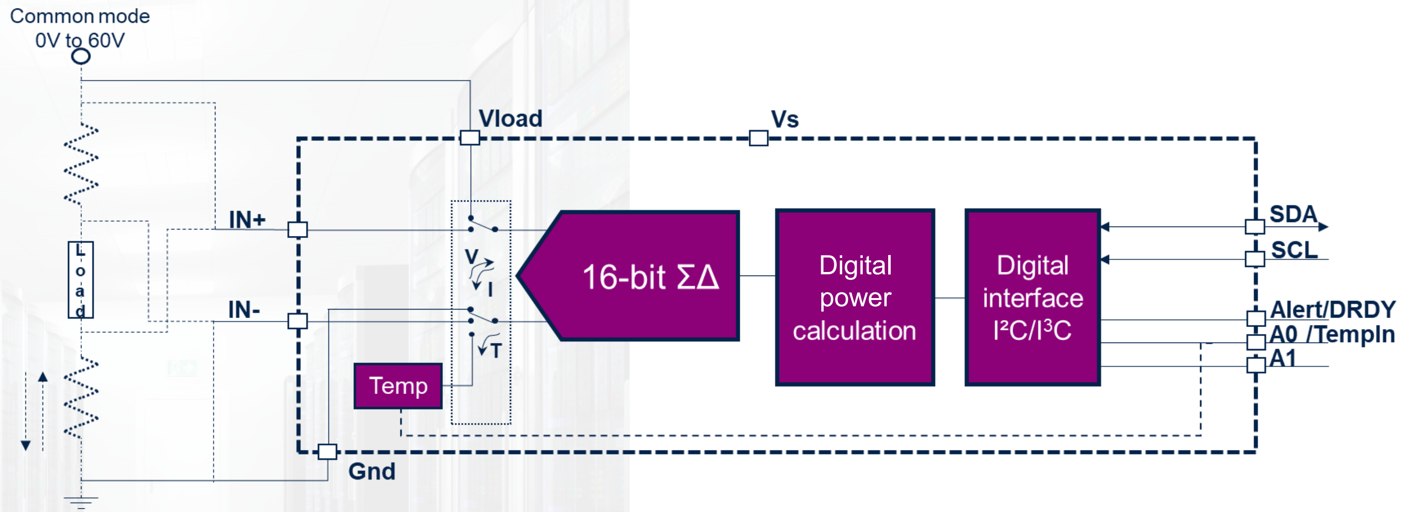
Overcurrent protection (OCP)

Some current-sense amplifiers integrate a comparator, as in the **TSC200**, making them ideal for overcurrent protection. You get both an accurate current measurement and an alert signal.

As all the paths are analog, the response time is very fast. Typical OCP goals are to:

- Provide a warning and/or critical alert to the user
- Protect the system before damage occurs
- Prevent overheating

Digital output



- Digital output
  - current, voltage, and temperature
- Large V_{ICM} supported
- Programmable alert function

Explanation

Digital output

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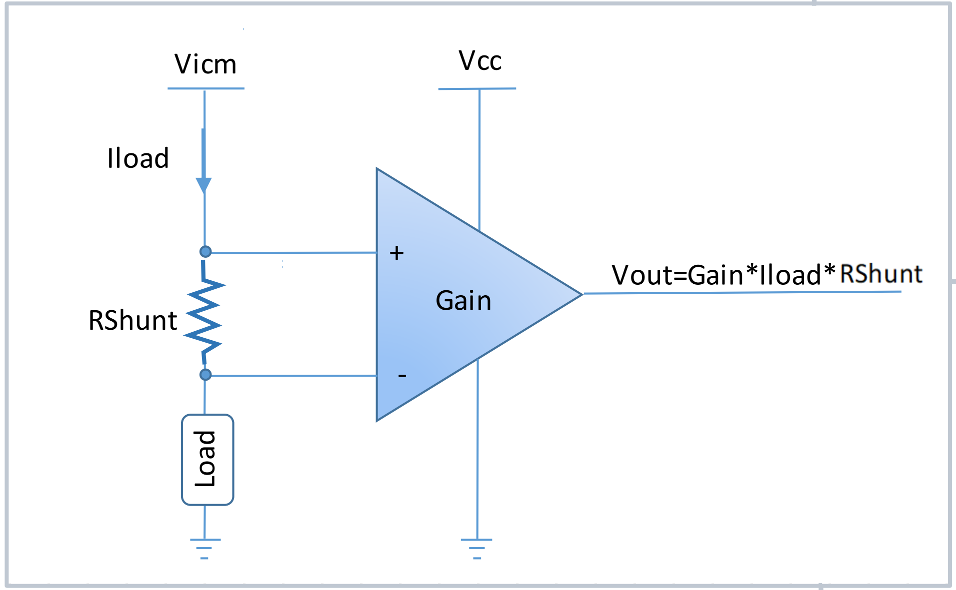
Digital-output current-sense devices

Some current sensing devices, such as the **TSC1641**, provide a digital output, making them ideal for direct connection to an ECU via I²C or I³C.

They can measure current, voltage, and temperature, and generate an alert when a programmable threshold is exceeded.

Current sensing devices



What are current sense amplifiers?

- Current measured through a shunt resistor in series with load
- Able to measure currents from a few mA to 100's A

What are the benefits?

- Real time current measurement in any topology
- Accurate measurement over the full temperature range

Key characteristics

- Precisely matched resistive gain network integrated
- Extended V_{ICM} significantly beyond the supply rails

Current Sense Amplifiers

Current sensing devices

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Current-sense devices: summary

Shunt-based current-sense devices are typically used to measure currents below $100\ \mathrm{A}$. They rely on Ohm’s law, amplifying the voltage generated by the current flowing through a shunt resistor.

They provide real-time current measurement and can operate with input common-mode voltages significantly beyond the supply rail. Their integrated fixed gain delivers very good accuracy.

Overall, they offer one of the best cost-versus-accuracy trade-offs for low-power applications.

Current Sense Amplifiers

Our technology starts with You

Find out more at www.st.com