Exploring current-sense amplifiers

STMicroelectronics Tech Days

Key parameters to choose a current-sensing device

Chapter 3

User guide

This presentation provides a written explanation of the topic covered in the second chapter of the video: “

Key parameters for choosing a current sensing device #3”, which is available on our YouTube channel at the following link:

[Video on YouTube]

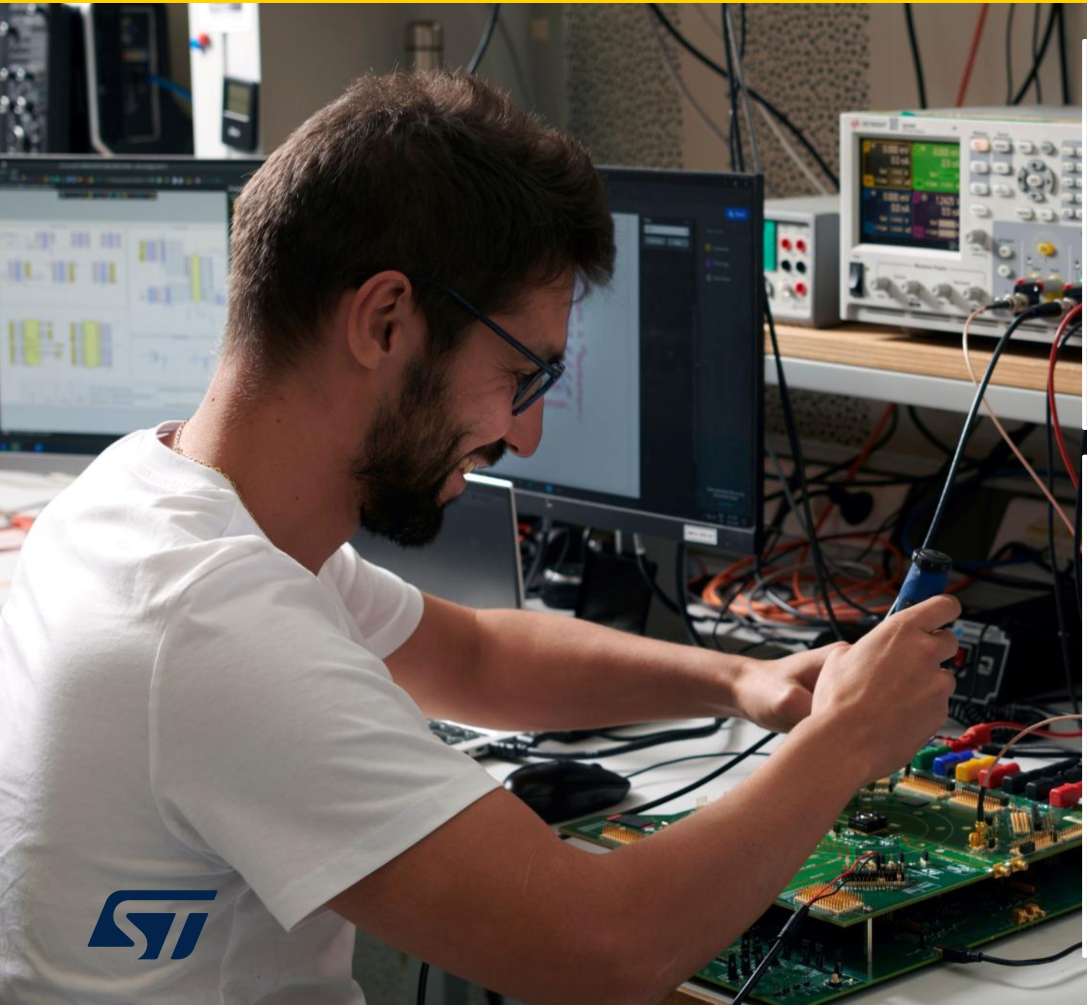
Recommendations

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

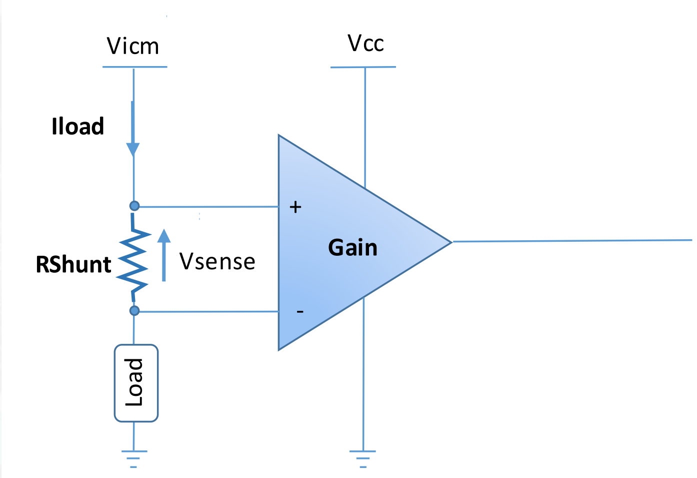
- When you see this icon: Explanation the topic is explained in detail on the following page(s)
- Each explanation page shows the page or page range where the topic is explained: (page # to #)
- If you see this icon: Continue the explanation continues on the next page(s)

How to choose a current sensing device?

Three key parameters to consider



1. **Current range**
   - Associated with R_{shunt} → V_{sense} range
2. **R_{shunt} value**
   - Associated with current range → Power dissipation
3. **Gain of the current-sense amplifier**
   - Associated with current range → widest output range



Explanation

How to choose a current-sensing device?

Explanation of page 4

Selecting the right current-sense amplifier from a broad portfolio can be challenging. The starting point is to define three key, tightly related parameters:

1. **Current range (dynamic range)**
   The device must measure, with a single shunt resistor, both the minimum and maximum load current. Combined with the shunt value, this defines the sensed voltage range
   $$V_{\text{sense}} = I_{\text{load}} \times R_{\text{shunt}}$$
   and therefore, the required gain of the current-sense amplifier.

2. **Shunt resistance value**
   Together with the current range, R_{shunt} sets both V_{sense} and the power dissipated in the shunt:
   $$P_{\text{shunt}} = I_{\text{load}}^2 \times R_{\text{shunt}}$$
   These aspects are usually constrained by the application (efficiency, thermal limits, measurement resolution).

How to choose a current-sensing device?

Explanation of page 4

3. **Amplifier gain**
   For a given current range and R_{shunt}, the gain determines how the V_{sense} range is translated into the output voltage range. The objective is to use the widest possible output span without saturating.

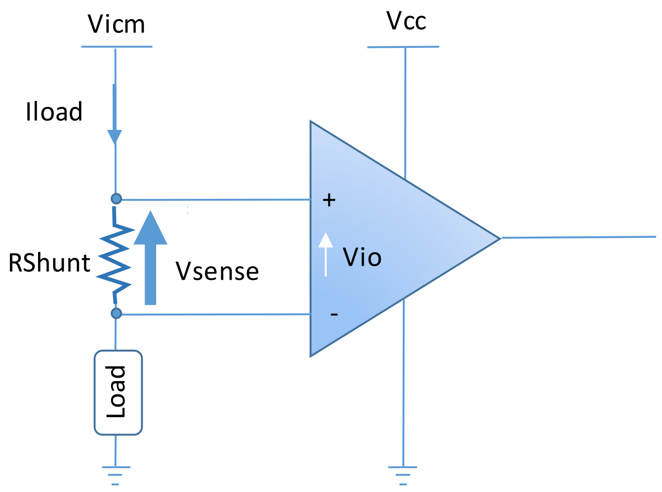
In practice, the application typically fixes the current range and R_{shunt}. Within these constraints, you must find the best trade-off between shunt value, amplifier gain, and required measurement accuracy.

Current range

The minimum current flowing into the load can generate a very small V_{sense} across R_{shunt}

This minimum V_{sense} must be related to the intrinsic error of the current-sense amplifier, the input offset voltage, for example:

V_{sense} >> V_{io} in order to limit the error at the output of the current-sense amplifier



Example: load min = 1A, R_{shunt} = 10 mΩ → V_{sense} = 10 mV
V_{icm} = 12 V

Current sensing	Max Vio (temp)	Error due to Vio only
TSC2010	1100µV	11%
TSC2020	200µV	2%
TSC240	35µV	0.35%

Explanation of page 7

The application usually defines the required current range.
Here, this entire range must be measured with one shunt resistor and one current-sense amplifier.

Because the amplifier output is limited by its supply voltage, the measurable current range is also limited. A typical combination of one shunt and one amplifier covers about 2.5 decades of current (for example, from 100 mA to 50 A).

Once the shunt value R_{shunt} is fixed, Ohm's law gives the sensed voltage:

$$V_{sense} = I_{load} \times R_{shunt}$$

The minimum current sets the minimum V_{sense}, which must be compared to the amplifier input-offset voltage V_{io}. The ratio between these two values gives a first estimate of the measurement error.

Example:

- $I_{min} = 1$ A
- $R_{shunt} = 10$ mΩ $\Rightarrow V_{sense,\ min} = 10$ mV

Current range

Explanation of page 7

With **TSC2010**, $V_{io,max}$ = 1.1 mV

→ Error due to offset ≈ 1.1 mV / 10 mV = 11 %

With **TSC240**, $V_{io,max}$ = 35 µV

→ Error due to offset ≈ 35 µV / 10 mV = 0.35 %

As the current increases, V_{sense} becomes larger and the impact of Vio decreases, so the measurement accuracy improves.

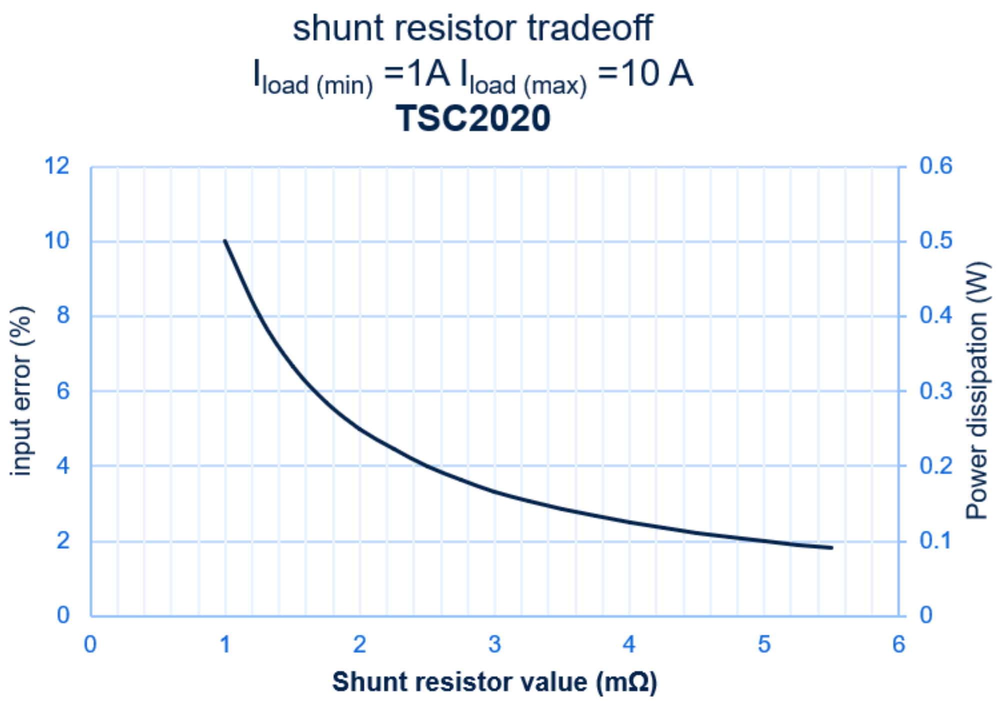
To maintain a good accuracy, especially at low current, you can either:

- **increase** R_{shunt} to generate a higher V_{sense}, or
- **select a more precise current-sense amplifier** with a lower input offset voltage V_{io}.

R_{shunt} selection

Trade-off between accuracy at minimum current and power dissipation

Shunt resistor vs input error at minimum current (1A)



Increasing the shunt resistor value improves current measurement accuracy but also increases power dissipation

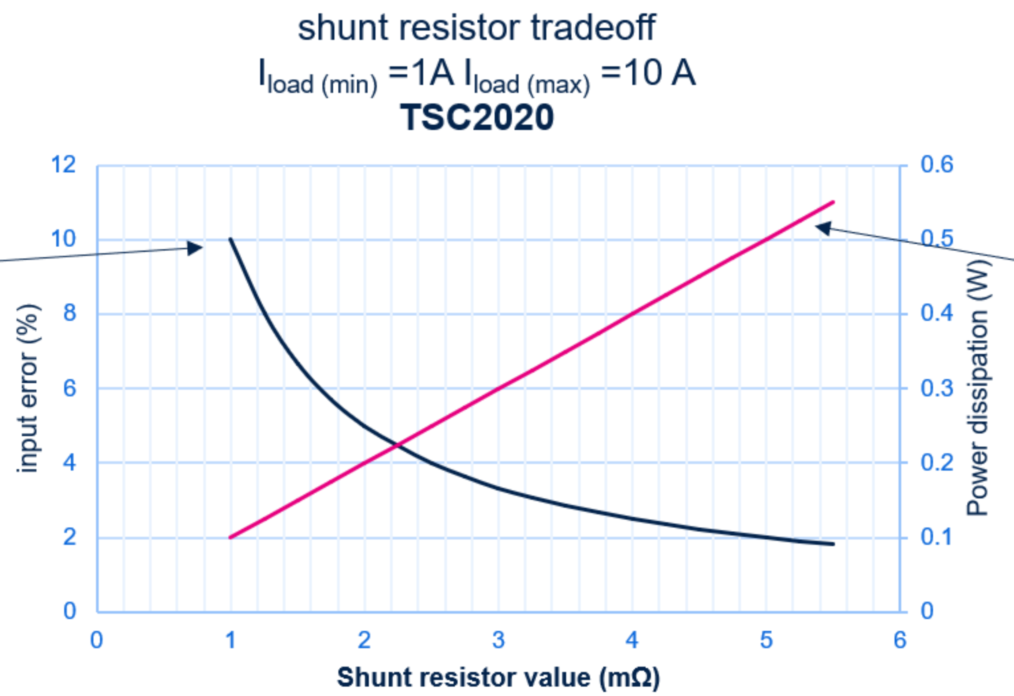
Current Sense Amplifiers

Explanation

R_{Shunt} selection

Trade-off between the accuracy at minimum current and power dissipation

Shunt resistor vs input error at minimum current (1A)



Shunt resistor vs power dissipation at maximum current (10A)
P=Rshunt*I²

Increasing the shunt resistor value improves current measurement accuracy but also increases power dissipation!

Current Sense Amplifiers

Explanation

Explanation of pages 10–11

Is increasing the shunt value always the best solution?

As seen previously, a very small V_{sense} limits measurement accuracy.
We now use TSC2020 to measure a current from 1 A to 10 A and study the impact of the shunt resistor value.

(page 10) – Accuracy at minimum current

For the **minimum current (1 A)**, we first look at the accuracy of the current measurement.
The **blue curve** on the graph shows the expected error versus Rshunt:

- when R_{shunt} increases, the input error at 1 A decreases;
- in other words, **the higher the shunt value, the better the accuracy**.

Explanation of pages 10–11

(Page 11) Power dissipation at maximum current

We must also consider **power dissipation** in the shunt:

$$P_{shunt} = I^2 \times R_{shunt}$$

To estimate the worst-case power, we use the **maximum current (10 A)**.
The **red curve** on the graph shows that:

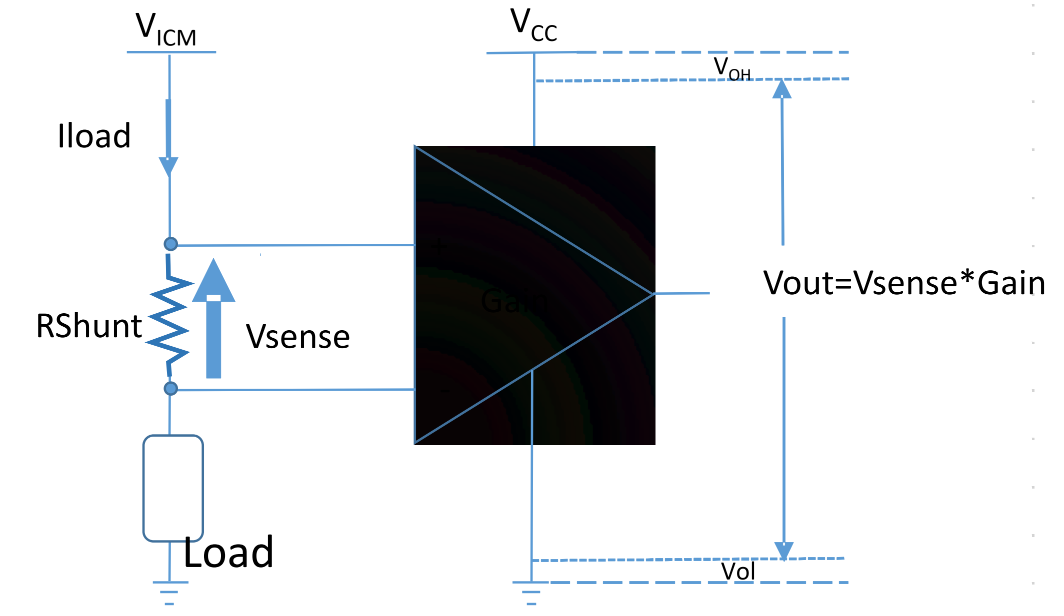
- when R_{shunt} increases, power dissipation also increases;
- this wastes energy and forces the use of a more robust and more expensive shunt resistor.

There is therefore a clear **trade-off between accuracy and power dissipation**, especially when the current dynamic range is large. In addition, a higher shunt value also causes a larger voltage drop across the shunt in the application.

Gain of current-sense amplifiers

The maximum current flowing into the load can generate a large V_{sens} across R_{shunt}

This large V_{sense} should not saturate the current-sense amplifier when it is multiplied by the gain of the amplifier



$$Gain = \frac{V_{cc} - (Voh + Vol)}{Imax.Rhunt}$$

Gain of current-sense amplifiers

Explanation of page 14

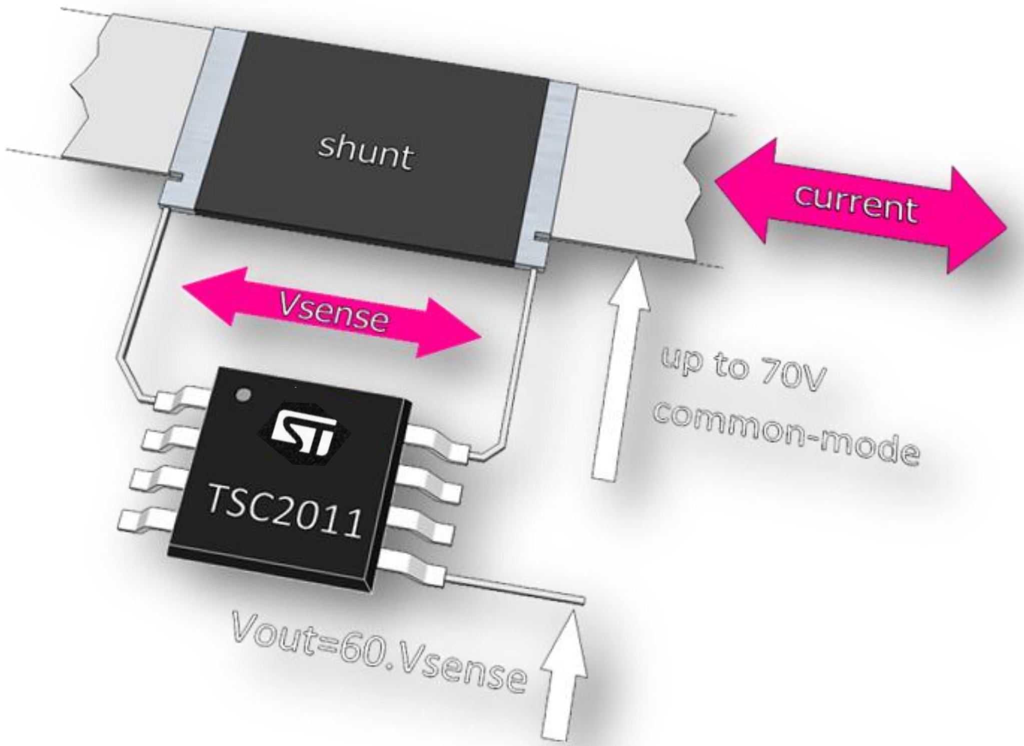
To size the shunt resistor, we must consider the maximum current flowing through it. This defines the maximum power dissipation in the shunt and also the maximum sense voltage, V_{sense} ,which is used by the current-sensing amplifier.

To select the correct gain and fully use the output range of the current-sense device, we need to account for:

- the maximum load current I_{load} through the shunt,
- the supply voltage range V_{CC},
- the output saturation limits V_{OH} and V_{OL}.

The maximum sense voltage multiplied by the amplifier gain must remain below $V_{\mathrm{CC}} - (V_{\mathrm{OH}} + V_{\mathrm{OL}})$ .It is recommended to keep some safety margin in this calculation to cover non-idealities such as input offset and gain error, while keeping the effective gain as accurate as possible.

Next step – choosing a current-sense amplifier



Current range?
- R_{shunt}
- Gain of the current sensor

High-side or low side?
- V_{ICM} range

Does the load sink or source current?
- Bidirectional
- Unidirectional

What is the expected accuracy?

Next step – choosing a current-sense amplifier

Explanation of page 16

Once the current range, shunt value and required gain are defined, a few additional questions will guide the selection of the most suitable device in the current-sensing portfolio:

- **Input common-mode range** (V_{ICM})
  Clearly define the required common-mode range.
  - ✓ For low-side current measurement, a standard op amp can be used (most current-sense devices are also suitable).
  - ✓ For high-side current measurement, a dedicated current-sense amplifier is usually required.

- **Current direction**
  Decide whether the application must measure current in one or both directions.
  - ✓ If in doubt, choose a bidirectional current-sense amplifier, which can also operate in a unidirectional configuration.

Next step – choosing a current-sense amplifier

Explanation of page 16

- **Required measurement accuracy**
  Define the target accuracy for the current measurement. This determines which device parameters are most critical, such as input offset voltage, gain error, and other non-idealities that affect the final result.

If you can answer these questions, you can confidently select the appropriate current-sensing solution for your application.

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