Exploring current sense amplifiers

STMicroelectronics Tech Days

Current sensing configuration

Chapter 2

Introducing high-side and low-side current sensing, and unidirectional vs. bidirectional configurations.

User guide

This presentation provides a written explanation of the topic covered in the second chapter of the video: **“Current sensing configuration #2”**, 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)

Low-side configuration

The current is sensed between the ground and the load. The voltage seen on the current sensing input pins is close to ground.
The V_{ICM} in this case is the ground.

The V_{ICM} range of the current sensor must include 0V in the operating condition

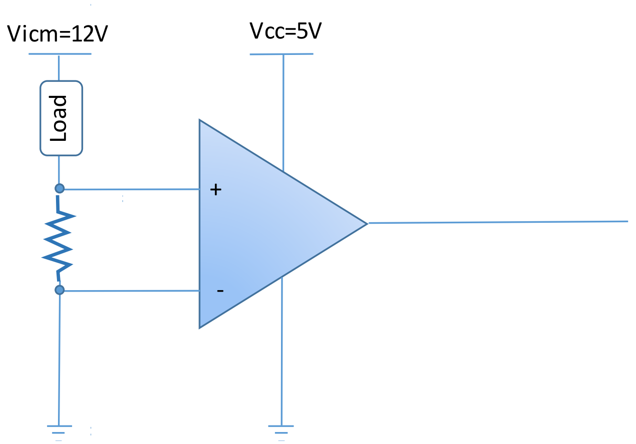


Table 4. Operating conditions

Symbol	Parameter	Value	Unit
V_{CC}	Supply voltage	2.7 to 26	V
V_{icm}	Common mode voltage on input pins	-0.3 to +26	V

TSC213 datasheet

V_{icm}	Common-mode voltage range referred to pin Vcc - (T_{min} to T_{max})	2.9 to 70	V

TSC103 datasheet

Current Sense Amplifiers

Explanation

Low-side configuration

Explanation of page 4

The simplest and most common topology is **low-side current sensing**.

What does “low-side” mean?
It defines where the current is measured relative to the load.
In a low-side configuration, the current is sensed **between the load and ground**. As a result, the voltage at the current-sense input pins (the input common-mode voltage V_{ICM}) is **close to 0 V**.

Because the common-mode level is near ground, this configuration can usually be implemented with a **standard low-rail op amp**. A dedicated current-sense amplifier can also be used, but its V_{ICM} **range must include 0 V** under operating conditions.

For example, in the [TSC213](TSC213) datasheet, the input common-mode range extends from $-0.3\ \mathrm{V}$ to $26\ \mathrm{V}$, so it is suitable for low-side current sensing. In contrast, the [TSC103](TSC103) input common-mode range does **not** include 0 V, so it cannot be used in a low-side configuration.

High-side configuration

The current is sensed between the supply and the load. The voltage seen on the current sensing input pins can be higher than the power supply. The V_{ICM} in this case is the bus voltage.

One of the advantages of a current sense amplifier, compared to an op amp, is that it can work with an extended V_{ICM} largely beyond the power supply rail

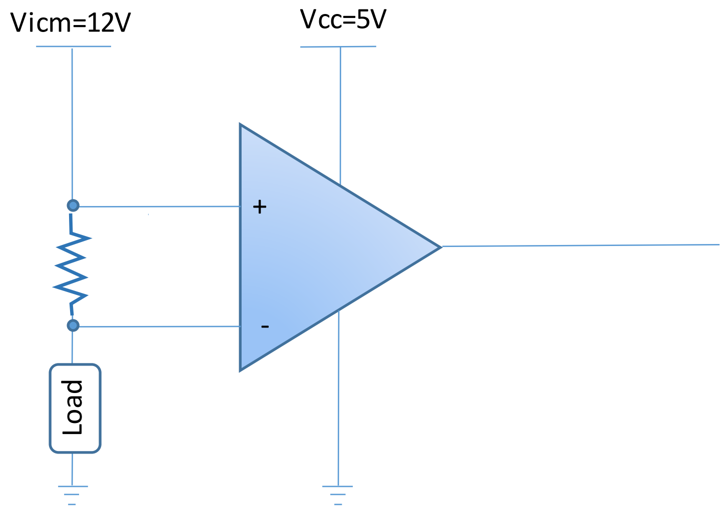


Table 3. Operating conditions

Symbol	Parameter	Value	Unit
V_{CC}	Supply voltage	2.7 to 5.5	V
V_{ICM}	Common-mode voltage on input pins	-4 to +100	V

TSC2020 datasheet

Current Sense Amplifiers

Explanation

High-side configuration

Explanation of page 6

In a **high-side configuration**, the current is sensed between the supply (bus) and the load. Depending on the application it’s sometimes not possible to implement a low-side configuration when the ground is a part of the load, as it can be with a chassis, for example.

In this configuration, the input common-mode voltage can be much higher than the amplifier supply voltage, so a dedicated current-sense amplifier must be used. Most of the time, this is identified as the **TSC family** in the STMicroelectronics portfolio

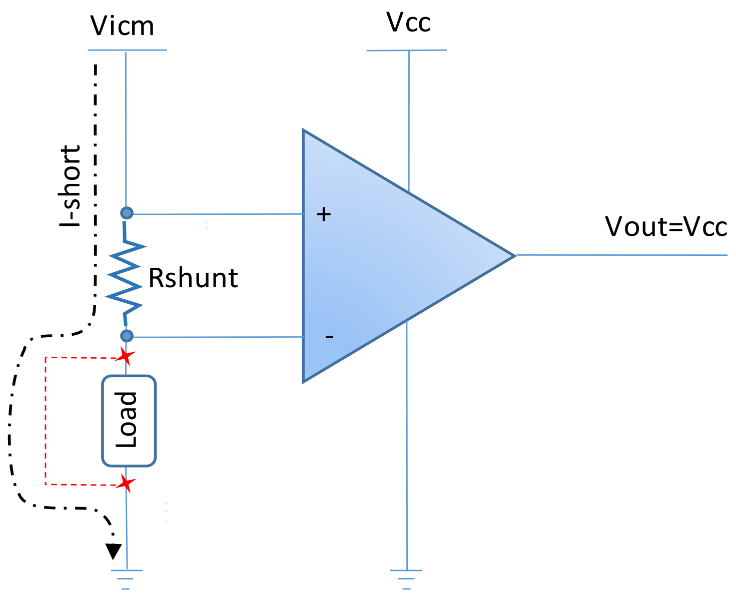
When selecting a current-sense amplifier, always check in the datasheet that the **input common-mode range** covers the actual operating conditions.

For instance, **TSC2020** is suitable for high-side configuration, supporting input common-mode voltages up to **100 V**, and it can also be used in low-side configurations.

Benefits of high-side configuration

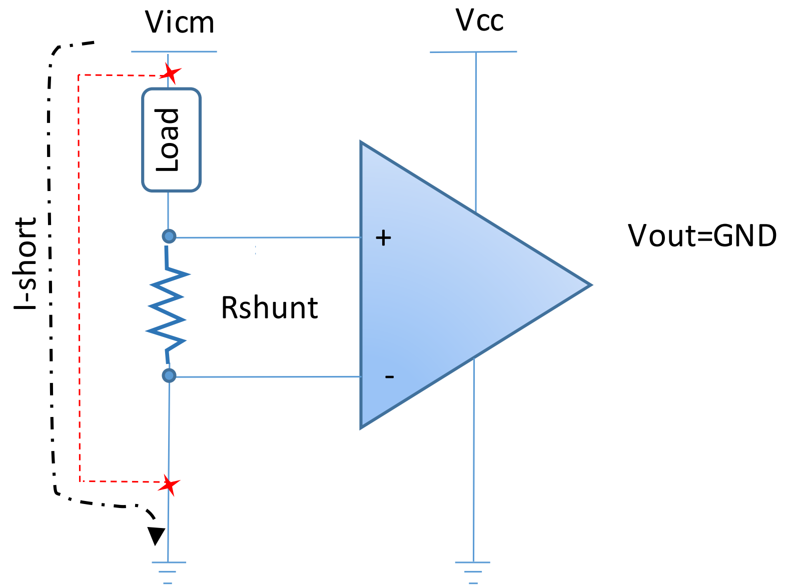
High-side current sensing can detect a load short to ground

High-side configuration



$V_{out}=V_{CC}$ indicated potential issue

Low-side configuration



V_{out}=GND indicated no current

Explanation

High-side configuration benefits

Explanation of page 8

Although **low-side current sensing** is simpler and often more cost-effective, **high-side sensing** provides important benefits, such as **detecting a load short to ground**.

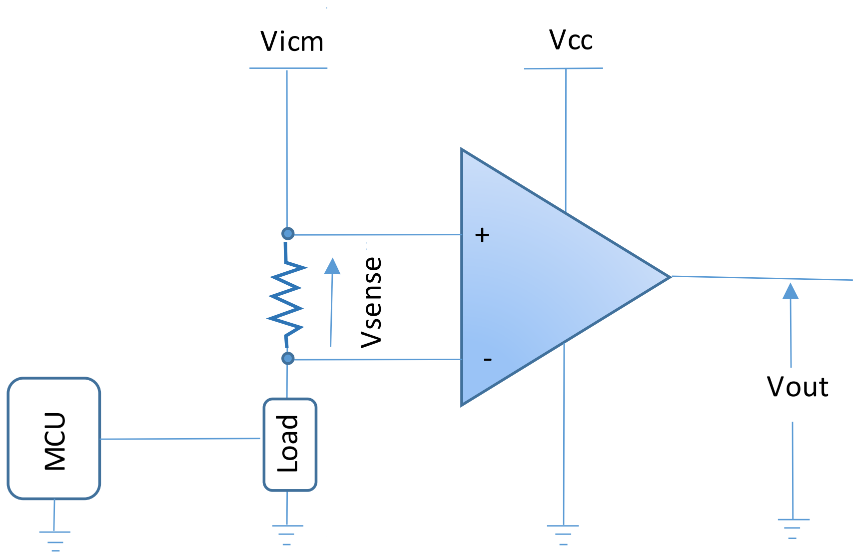
In the diagram, the red path shows the load being shorted to ground.
With a **high-side configuration**, the entire short-circuit current I_{short} flows through the shunt resistor. The sense amplifier output then jumps to the high rail, so an overcurrent condition can easily be detected, for example with a comparator.

In a **low-side configuration**, when the load is shorted to ground, I_{short} bypasses the shunt resistor. The output of the current-sense amplifier falls to the low rail and is interpreted as **no current**, which is exactly the opposite of what is really happening.

Benefits of high-side configuration

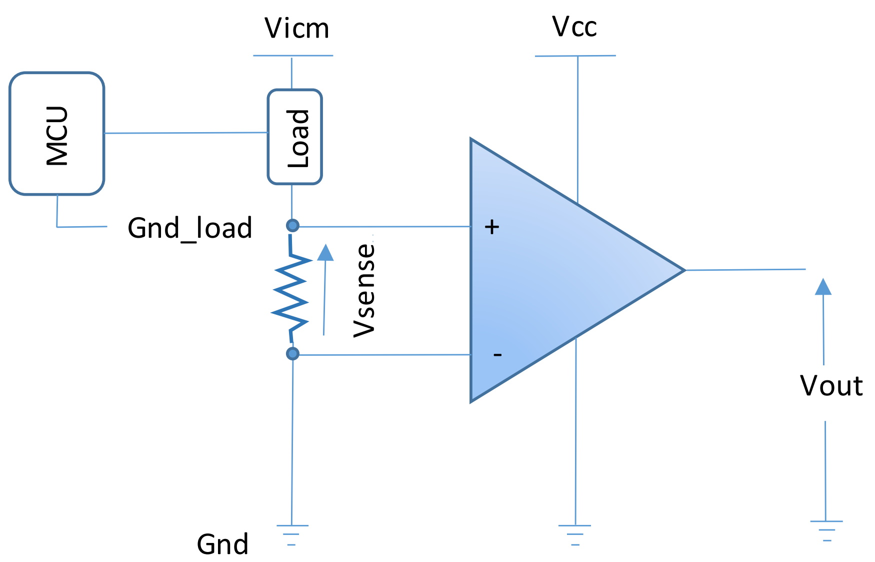
High-side current sensing amplifiers provide better immunity to ground disturbances

High-side configuration



Common GND

Low-side configuration



GND_load = V_{sense}

Explanation

Benefits high-side configuration

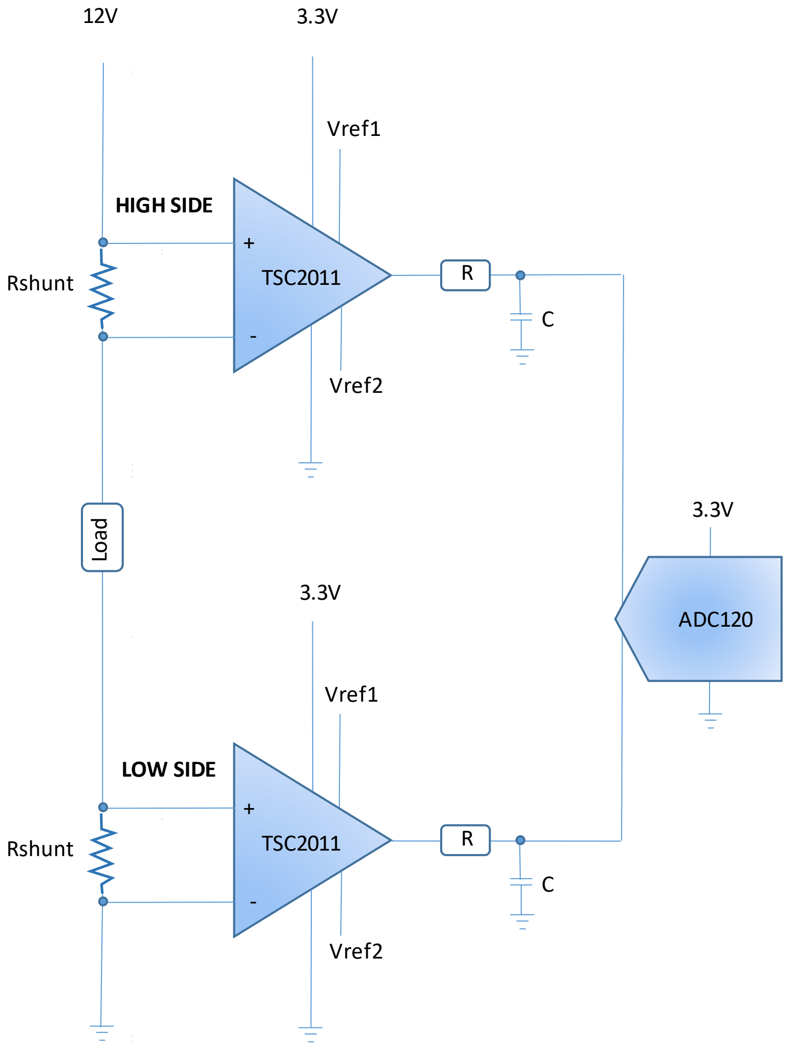
Explanation of page 10

Another advantage of **high-side current sensing** over low-side sensing is the avoidance of **ground disturbances**.

In applications where the current of several subsystems must be monitored, a **low-side shunt** lifts each load ground slightly above the system ground by the sense voltage. This can create differences between ground potentials and may lead to **ground-loop issues**.

With a **high-side configuration**, all loads can share the same ground reference, while the shunt is placed in the supply path. This keeps a **common ground** for the entire system and greatly reduces the risk of ground disturbances.

Low-side vs. high-side configurations



	High side	Low side
Pros	• Fault detection when load short to ground • High immunity against ground disturbance • Current monitored directly from the source • If ground line can't be cut (return to neutral by chassis)	• Simple to implement • Low-cost solution • V_{ICM} close to G_{ND}
Challenge	• High input common-mode voltages (hundreds of volts) • Supports fast variation of input common-mode voltage	• Difficult to detect short-cut to ground • Multiple output power supply (all currents are combined in (G_{ND} line) • May disturb the ground seen by the load

Current Sense Amplifiers

Explanation

Low-side vs. high-side configurations

Explanation of page 12

To summarize, **each current-sensing configuration has its own benefits and challenges**.

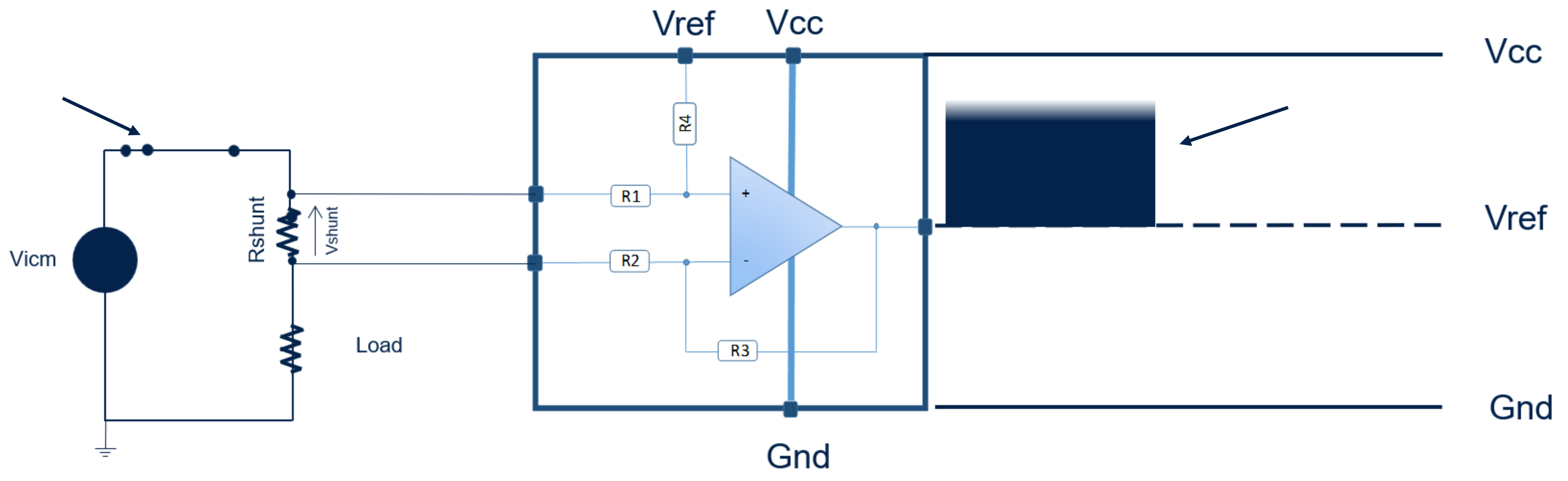
The **low-side configuration** is generally preferred for its simplicity and low cost, since a standard low-voltage op amp can be used. However, it cannot detect a short circuit to ground, and it can disturb the ground potential seen by the load.

For these reasons, **high-side sensing is often preferred**. It measures the current directly at the source and supports input common-mode voltages far above the supply voltage, which is ideal for **battery-monitoring systems**.

In addition, some dedicated current-sense amplifiers can tolerate very fast changes of common-mode voltage without output glitches, making them excellent choices for **motor-control** or **solenoid-drive** applications.

Bidirectional or unidirectional current sense amplifiers

A bidirectional current sense amplifier is able the measure a current flowing into a load in both directions thanks to an extra reference pin Vref.

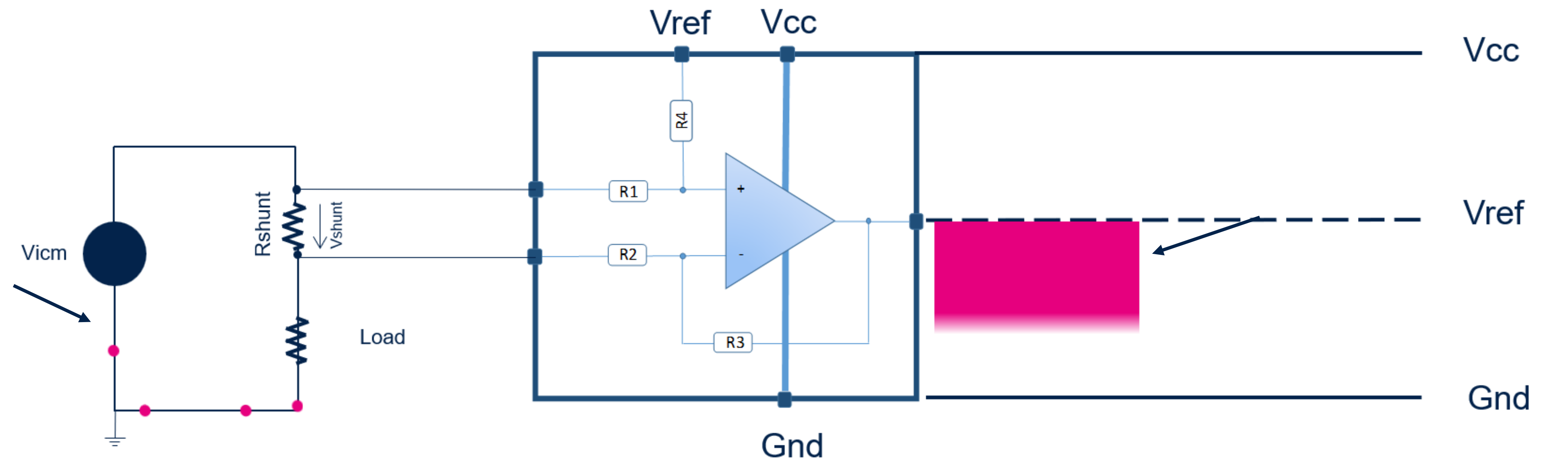


[Current Sense Amplifiers]

Explanation

Bidirectional or unidirectional current sense amplifiers

A bidirectional current sense amplifier is able the measure a current flowing into a load in both directions thanks to an extra reference pin Vref.



Current Sense Amplifiers

Explanation

Low-side vs. High-side configurations

Explanation of page 14 to 15

Some dedicated current-sense amplifiers are **bidirectional**: they can measure both current **sinking into** the load and current **sourcing from** the load, as in many battery-powered applications.

Bidirectional devices include a **reference pin (Vref)** that sets the output voltage at **zero current**. This reference defines the boundary between sink and source current.

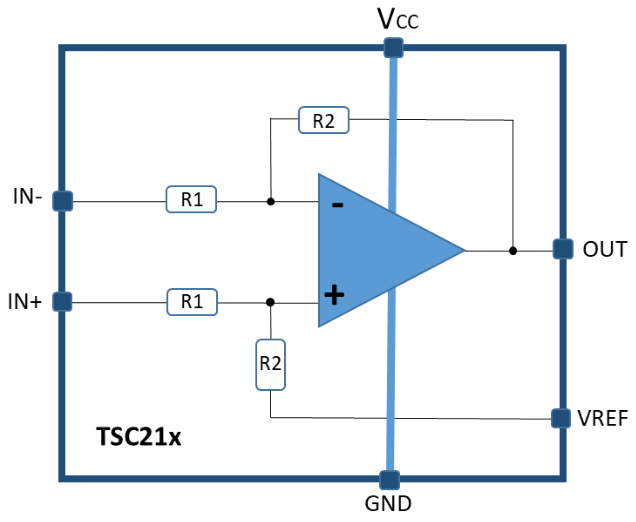
- **(Page 14)** – *Load sinking current*:
  When $V_{\text{out}} > V_{\text{ref}}$) dark blue output), the load is **sinking** current.

- **(Page 15)** – *Load sourcing current*:
  When $V_{\text{out}} < V_{\text{ref}}$) pink output), the load is **sourcing** current.

If a current-sense amplifier has **no reference pin**, it is only a **unidirectional** and can only measure current flowing in one direction, typically current sinking into the load.

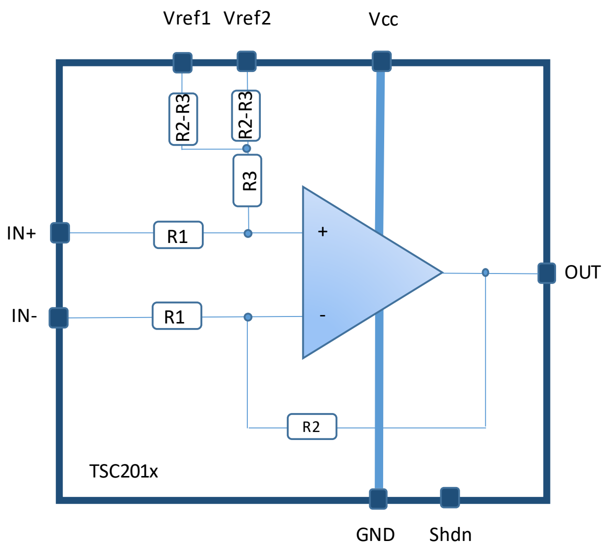
Voltage reference: 2 types of architectures

TSC210 series	
One voltage reference pin	



Pros	Smaller package
Cons	Need an external Vref for bidirectional mode

TSC2010 series	
Two voltage reference pins	



Pros	No external components need for bidirectional mode (Vref=Vcc/2)
Cons	Larger package

Current Sense Amplifiers

Explanation

Voltage reference: 2 types of architectures

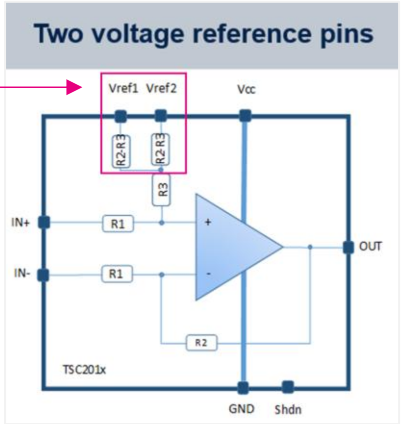
Explanation of page 17

Some bidirectional current-sense amplifiers, such as the TSC2010 and TSC2020, provide **two reference pins.**

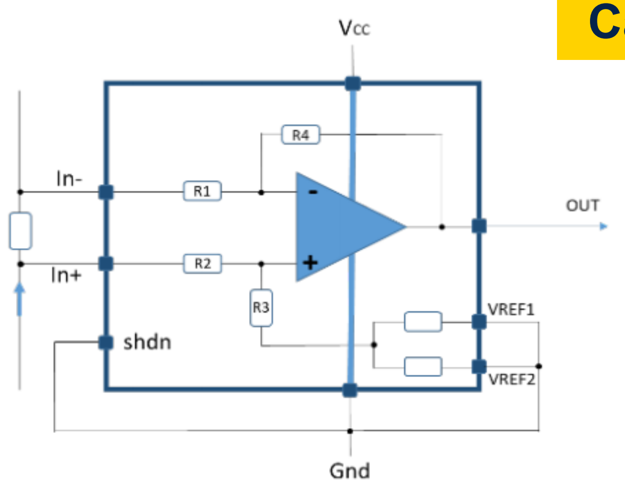
They include an integrated matched resistor divider, so the output common-mode (zero-current level) can be set at mid-supply without external components.

This is especially useful when measuring **sourcing and sinking currents of similar magnitude**, since the transfer function is centered around half of the supply voltage.

The trade-off is a **larger package**, as the device needs an additional reference pin.



Voltage reference –TSC2010 series use cases

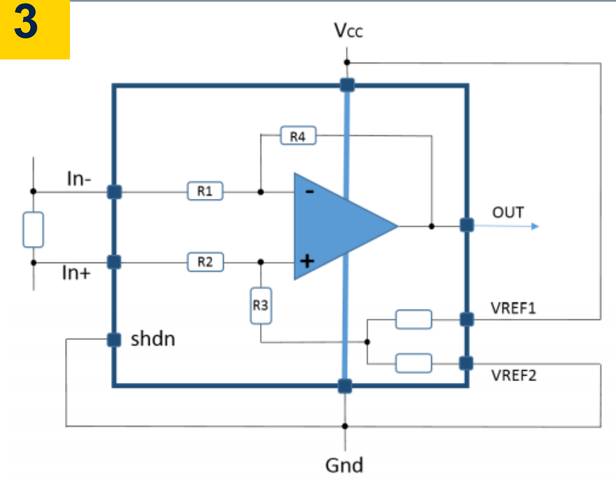


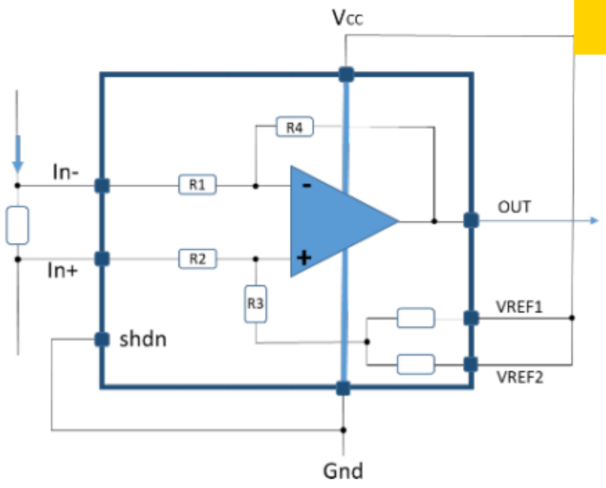
Case 1

Vref1 and Vref2 connected to GND
- Unidirectional
- Current input at IN+
- Output common-mode set to GND

Case 3

Vref1 to VCC and Vref2 to GND
- Bidirectional
- Output common-mode set to Vcc/2
- Symmetrical split of current range



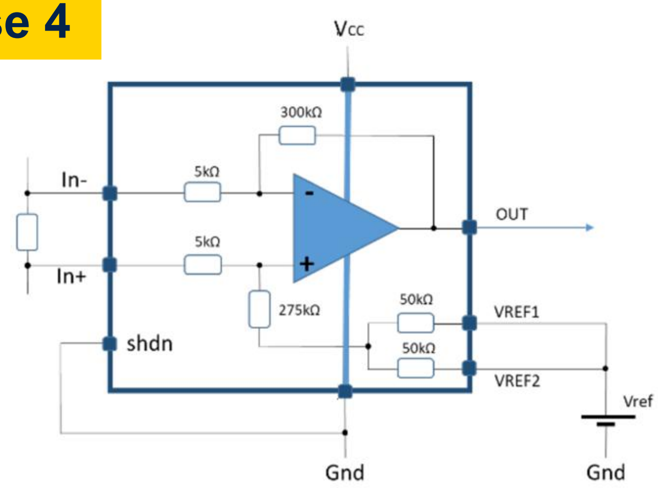


Case 2

Vref1 and Vref2connected to VCC
- Unidirectional
- Current input at IN-
- Output common-mode set to VCC
- Inverted output

Case 4

Vref1 and Vref2 connected to external Vref
- Bidirectional
- Output common-mode set to external Vref
- Asymmetrical split of current range



Voltage reference –TSC2010 series use cases

Explanation of page 19

Case 1 – Vref1 and Vref2 to GND (unidirectional, sinking only)
Connecting both reference pins to ground makes the device unidirectional.
It measures current sunk by the load, and the output common-mode is referenced to ground.

Case 2 – Vref1 and Vref2 to V_{CC} (unidirectional, sourcing only)
Connecting both pins to the supply makes it unidirectional for sourced current only.
The output common-mode is referenced to V_{CC}.

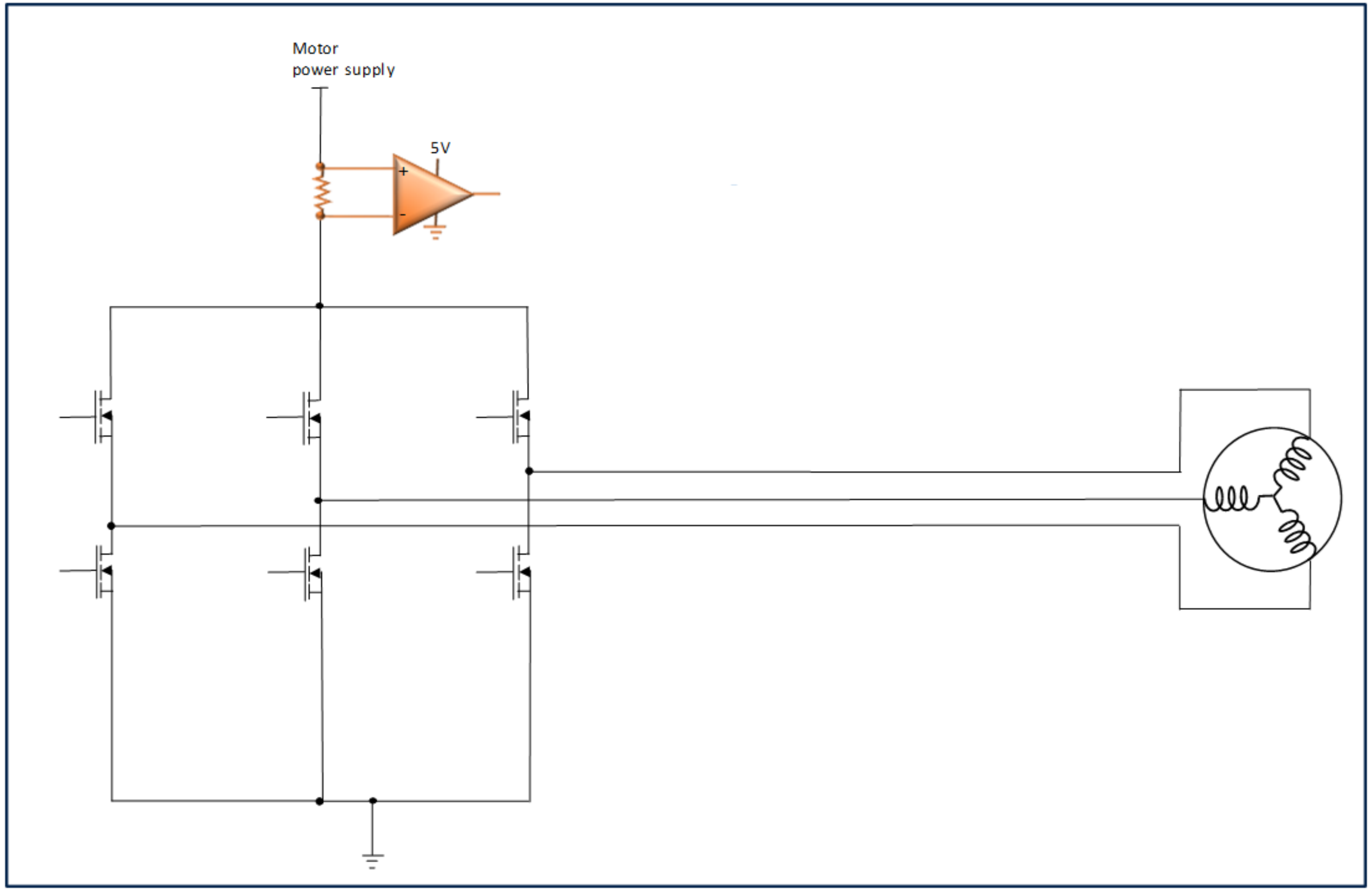
Case 3 – Vref1 to V_{CC}, Vref2 to G_{ND} (bidirectional, symmetric range)
With one pin at V_{CC} and the other at GND, the amplifier measures current in both directions with a **symmetric range**.
No external components are required, and the output common-mode is automatically set to **V_{CC}/2**.

Case 4 – Vref1 and Vref2 to an external Vref (bidirectional, asymmetric range)
Connecting both reference pins to an external reference still enables bidirectional sensing, but with an **asymmetric split** of the measurable current range around this external Vref.

Position of current sensing

High side

Amp	High-side current sensing
Pro	Short cut detection
Cons	Only global current information

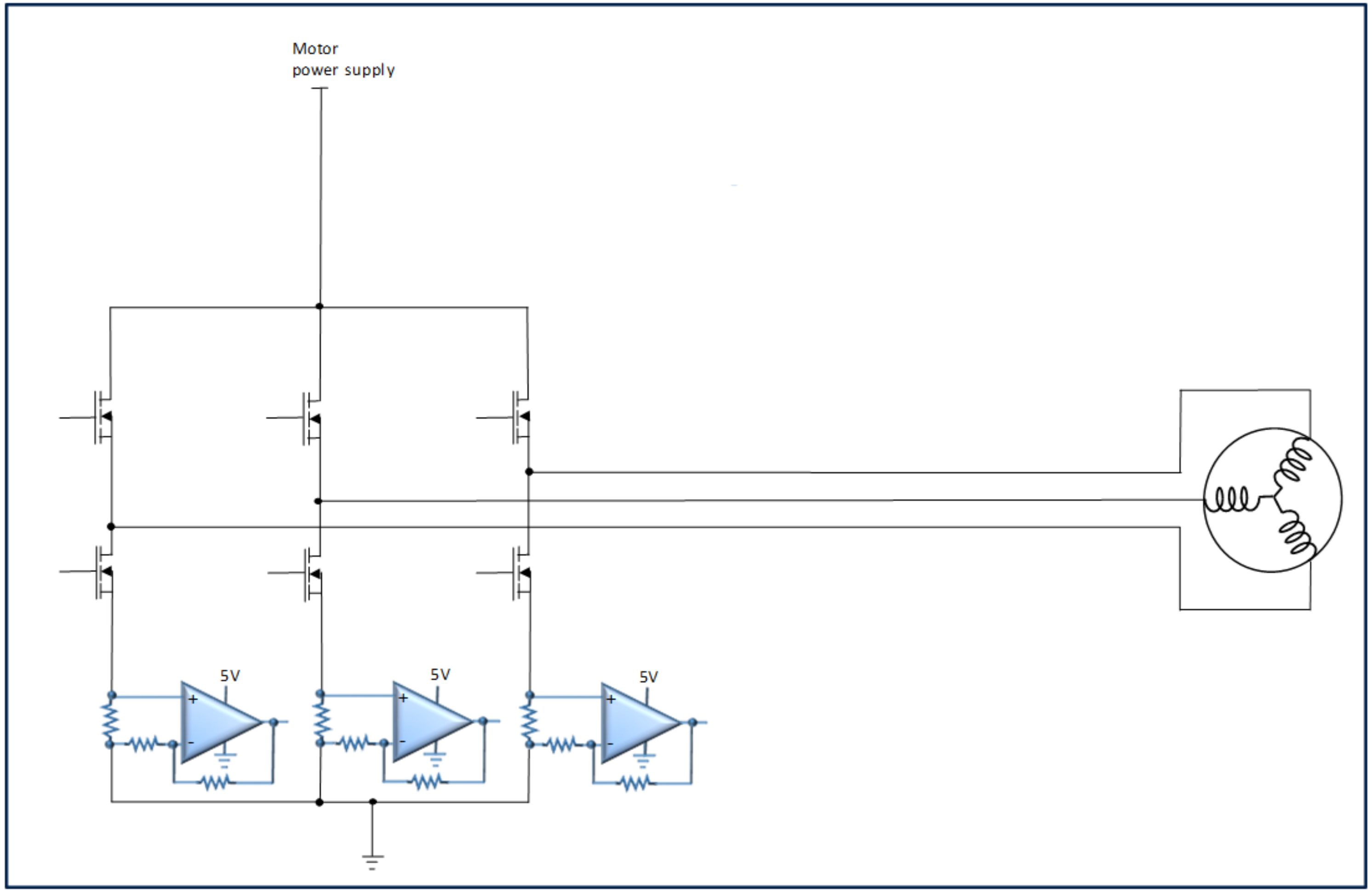


[Current Sense Amplifiers]

Explanation

Position of current sensing

High side	**Amp**	High-side current sensing
	Pro	Short cut detection
	Cons	Only global current information
Low side	**Amp**	High Slew rate op-amp
	Pro	Simple & cheaper
	Cons	Drive current ≠ Phase current

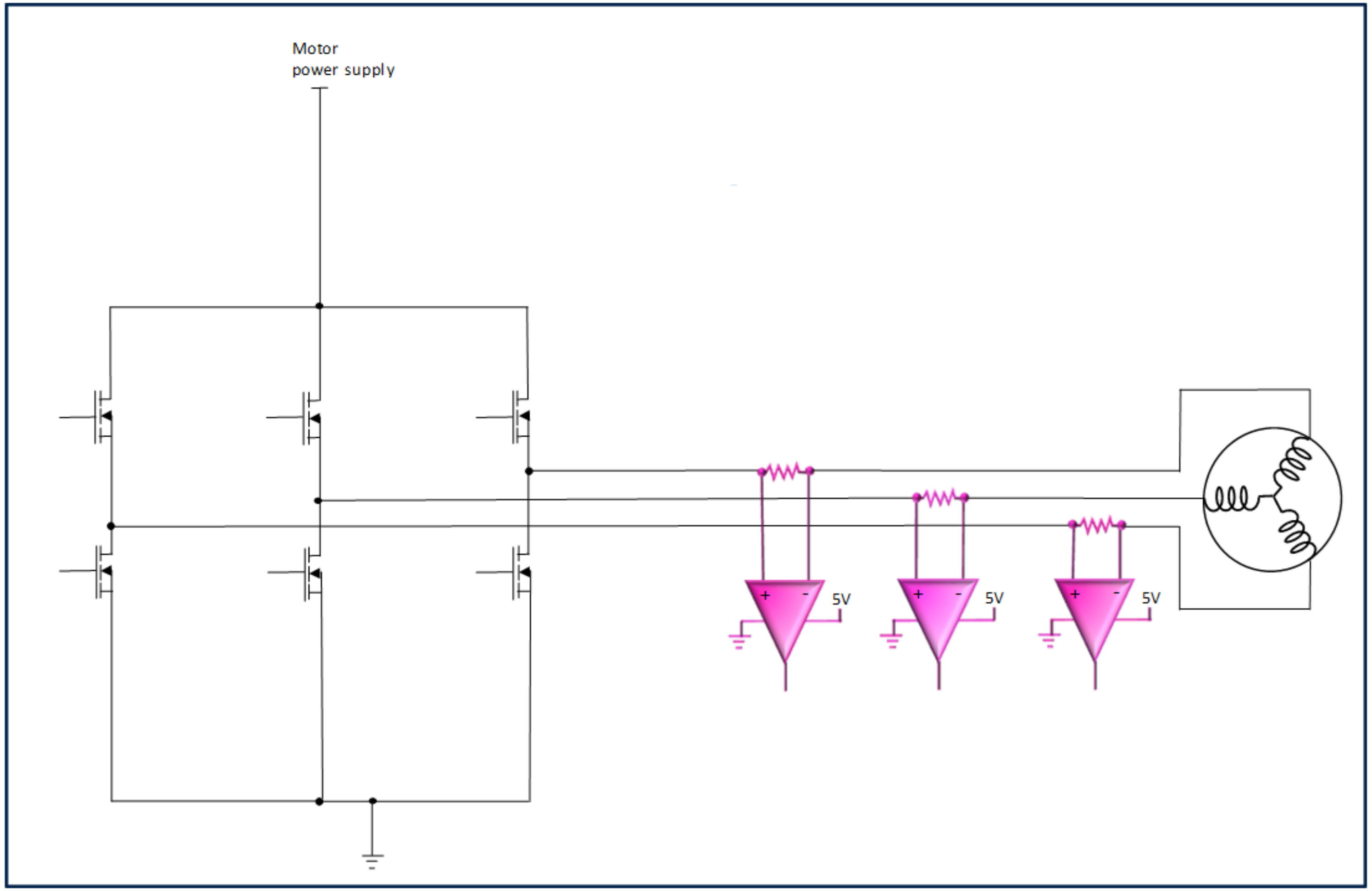


Current Sense Amplifiers

Explanation

Position of current sensing

High side	**Amp**	High-side current sensing
	Pro	Short cut detection
	Cons	Only global current information
Low side	**Amp**	High Slew rate op-amp
	Pro	Simple & cheaper
	Cons	Drive current ≠ Phase current
In-line	**Amp**	Dedicated high side current sensing
	Pro	True phase current continuous
	Cons	Support common-mode voltage transients



Current Sense Amplifiers

Explanation

Position of current sensing

Explanation of page 21 to 23

We have already seen that the shunt can be placed in a **high-side** or **low-side** position.
In motor-control applications, the current can actually be measured at different point.

(Page 21) High-side sensing
Placing the shunt on the high side gives a **global view of the motor current**.
It is mainly used for functions such as short-circuit detection.

(Page 22) Low-side phase sensing
More commonly, the shunt is placed on the low side of each phase and read with a **high-slew-rate op amp**, such as the **TSV722.**
However, current can only be measured when the low-side transistors are conducting.
Therefore, a **complex algorithm** is required to reconstruct the total current flowing into the motor.

Continue

Position of current sensing

Explanation of page 21 to 23

(Page 23) In-line sensing
A third topology is to place the shunt **in series with the motor phase**.
Here a **bidirectional current-sense amplifier** is mandatory, and the device must tolerate **fast common-mode voltage transients** generated by the transistor switching, without disturbing its output.

The main advantage of in-line sensing is that it measures the **true phase current continuously**, improving motor-drive efficiency and enabling fast fault detection.

The TSC2020 supports **low-side and high-side** operation, in both **bidirectional and unidirectional** modes.
It is specifically designed for good behavior under fast input common-mode transients, so it can be used in **all three topologies**, making it a real “Swiss-army-knife” current-sense amplifier.

Our technology starts with You