AN1185

ZXCT199/ZXCT21x Application Note

ChangWu Zheng/Kevin Lo, SAP SLL, Diodes Incorporated

Introduction

The ZXCT199/21x series features a voltage output and current-sensing circuit designed to detect a wide common-mode voltage range applied to the current-sensing resistor, with a range from -0.3V to 26V. The ZXCT199/21x series are equipped with internally fixed gains, offering multiple options from 50V/V to 1000V/V. The advantages include low input offset voltage and minimum 10mV differential voltage sensing across the current-sensing resistor.

With an operating range of 2.7V to 26V and drawing a maximum supply current of 100µA, regardless of their chosen gain these circuits exhibit operational temperature range from -40°C to +125°C.

Applications

- Notebook computers
- Server farms
- Telecoms
- Current sensing (high-side/low-side)
- Battery charging and discharging
- High-performance video cards
- Industrial power supplies
- Instrumentation
- Control systems
- Metering

Internal Circuit Block Diagram and Pin Descriptions

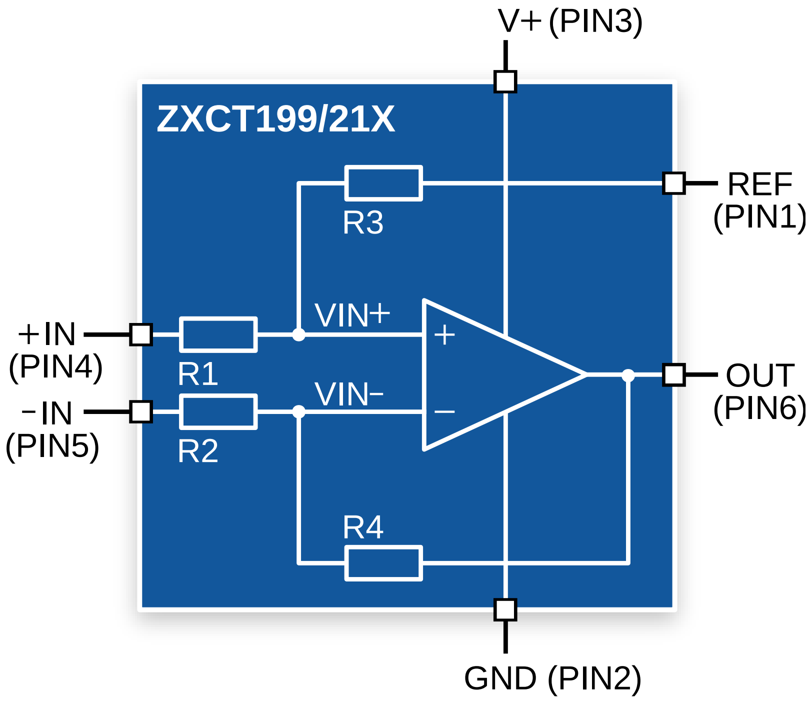

Figure 1. Internal gain diagram

Pin name	Pin number	Description
REF	1	Reference voltage: 0V~V+
GND	2	Ground
V+	3	Power supply: 2.7V~26V
+IN	4	Connect to supply side of current-sensing resistor
-IN	5	Connect to load side of current-sensing resistor
OUT	6	Output voltage

Table 1. Pin descriptions

Demo Board Overview

Figure 2. Demo board overview

The ZXCT199/21x DEMO board shown in Figure 2 includes one SOT363-packaged unit (ZXCT199/21x), one decoupling capacitor at the power supply end, one interference suppression capacitor at the input end, two voltage divider resistors for selecting V_{REF}, one selector for connecting different voltages to the V_{REF} terminal, and six test point connectors (R3 and R4 omitted).

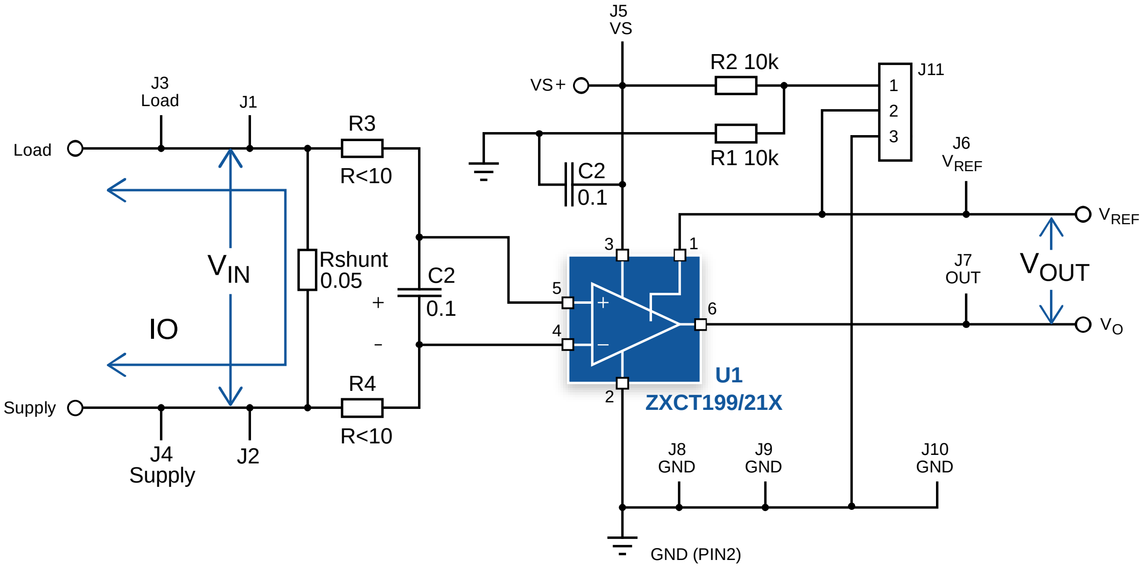

Figure 3. Demo board overview

Figure 3 shows the demo board circuit. In the diagram, R1 = R2 = 10kΩ, R3 = R4 = 0, C1 = C2 = 0.1µF/50V (C2 value can be adjusted as needed). J11 is used to select different settings at the V_{REF} terminal: when the shorting cap is not connected, users can set a voltage between 0 and V+ at J6. There are two other shorting options: one connects to GND, and the other connects to V+/2.

Output Voltage Calculation Based on Input Current

$V_{OUT} = V_{OUT}\text{-}V_{REF} = V_{IN} * \text{gain} = I_{OUT} * R_{shunt} * \text{gain}$

The voltage difference between the output terminal and the reference terminal is equal to the input current multiplied by the shunt resistor value multiplied by the gain. This calculation allows you to determine the output voltage based on the input current, the shunt resistor value and the chosen gain.

Recommended Application Circuit

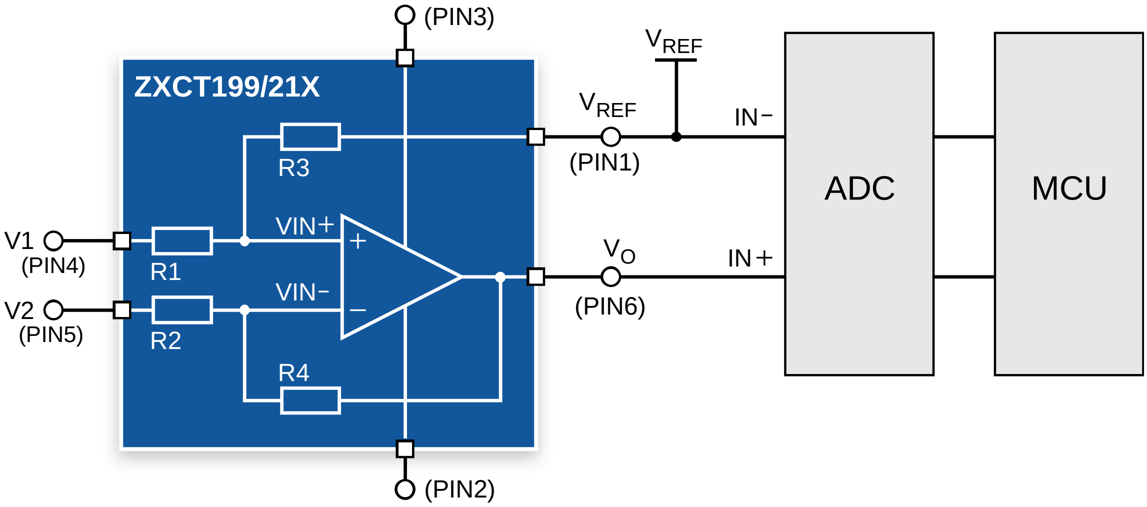

Figure 4a. Recommended application circuit

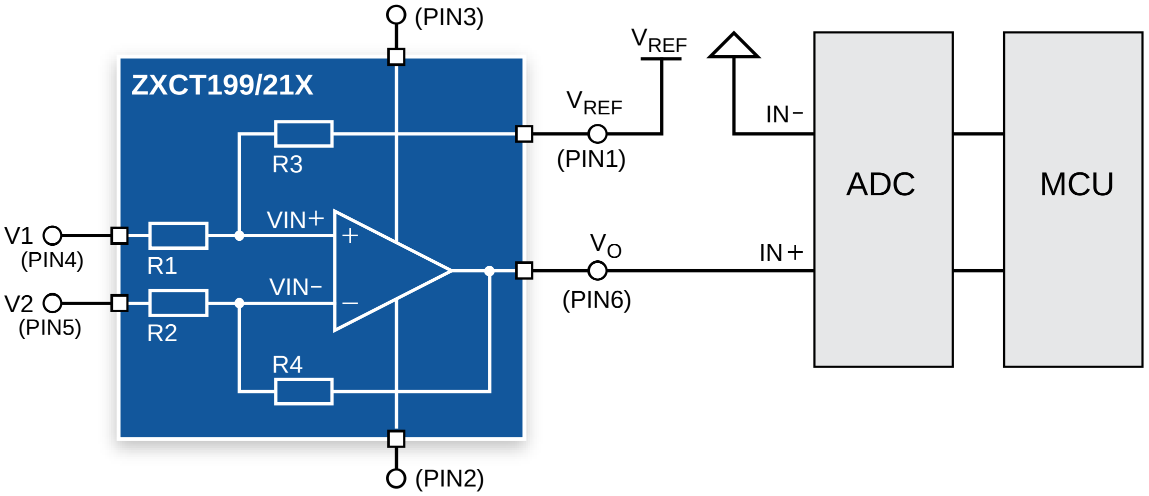

Figure 4b. Recommended application circuit

In common applications, the circuit shown in Figure 4a is often used, while the circuit shown in Figure 4b is less common. In Figure 4a, the ADC's in-pin is connected to the microcontroller's (MCU's) ground pin. This circuit has the advantage that the ADC input voltage is always equal to (V1.0-V2.0) × gain, regardless of how the V_{REF} pin is connected. This means that only one measurement is needed to obtain the desired data, which reduces the workload of the ADC and MCU and improves efficiency. In contrast, the circuit shown in Figure 4b requires the measured data to be subtracted from V_{REF}, and this V_{REF} value must either be set in advance or measured separately. This increases the workload of the MCU.

Typically, the power supply voltage for the ZXCT199/21X is set to 5V or 3.3V, and the input voltage range of the ADC is 0V~5V or 0V~3.3V, respectively. Since the ADC and MCU must have compatible voltage levels, it may be necessary to use a level-shifter circuit to convert the signals between the two devices if they operate at different voltages.

If there is interference, filters should be added to the input and output sections as necessary to filter out the interference signals and improve stability.

Reference Voltage Applications

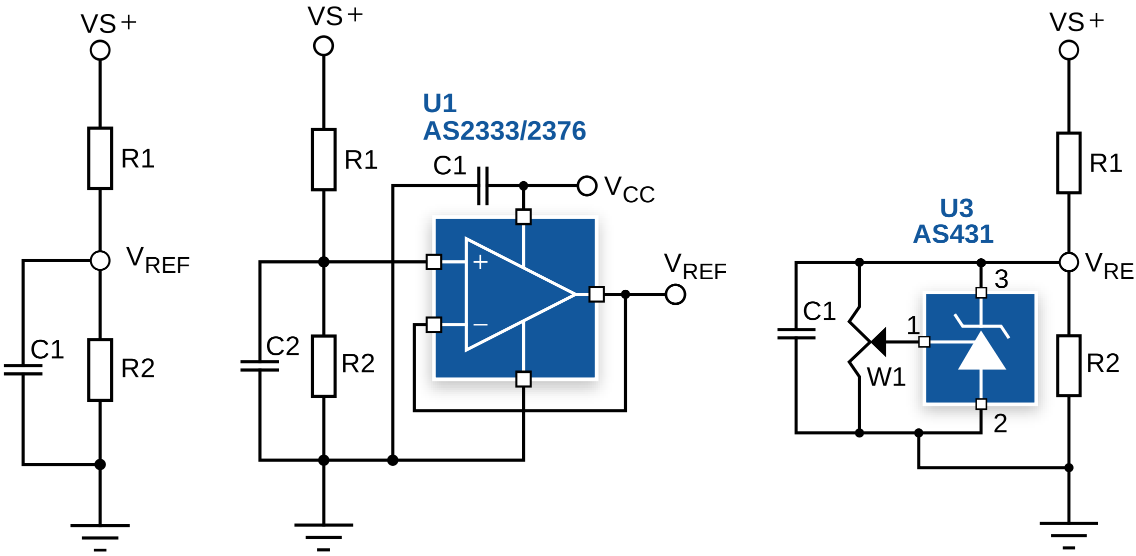

Figure 5a, 5b, 5c. Reference voltage applications

Three common V_{REF} circuits are shown in Figure 5. The simplest and most cost-effective circuit is shown in Figure 5a. However, the input resistance of the subsequent circuit can introduce a small offset in the V_{REF} signal. To reduce this offset, an isolation amplifier can be added as shown in Figure 5b. This results in a more accurate V_{REF} signal. The most accurate V_{REF} signal can be obtained using a dedicated reference voltage circuit, as shown in Figure 5c.

The most important feature of the V_{REF} pin of the device is to shift the output voltage, increasing the flexibility of the application. When the input voltage V_{IN} ($V_{IN} = V_{IN+} - V_{IN-}$) is 0, the output voltage V_{OUT} (voltage from the output to ground) is V_{REF}. When the input voltage $V_{IN} = V_{IN}$, the output voltage $V_{OUT} = V_{REF} + \text{gain} * V_{IN}$.

To measure bidirectional symmetrical current, set the V_{REF} voltage to half of the supply voltage (VS+/2). For unidirectional positive current, set the V_{REF} voltage to 0.5V (or 0.2V, etc.). This will give the output voltage a range of 0.5V to 4.5V (or 0.2V to 4.8V). At zero current, the output voltage will be equal to V_{REF}. At maximum current, the output voltage will be at its highest value. This increases the dynamic range of the output voltage.

Similarly, to measure unidirectional negative current, set the V_{REF} voltage to 4.5V (or 4.8V, etc.). This will give the output voltage a range of 0.5V to 4.5V (or 0.2V to 4.8V). At maximum current, the output voltage will be equal to V_{REF}. At minimum current, the output voltage will be at its lowest value. This also increases the dynamic range of the output voltage.

Output Noise Filtering

If the recommended application circuits do not meet your requirements, the following may be considered to improve the performance of the application circuitry.

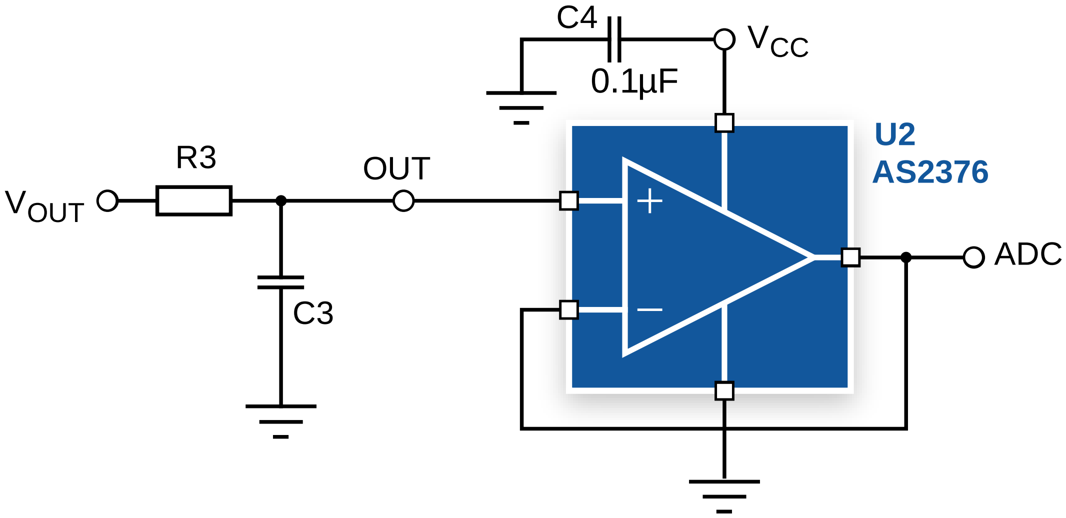

Figure 6a. Output noise filtering

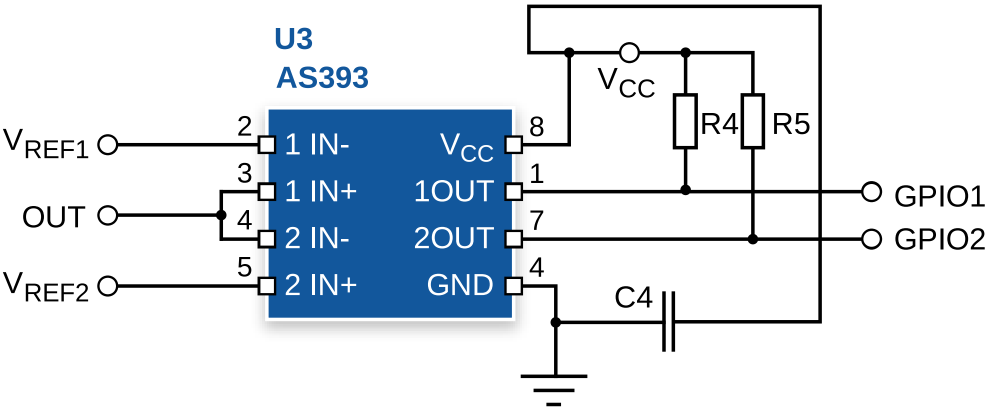

Figure 6b. Output noise filtering

In Figure 6a, R3 and C3 act as a low-pass filter to remove high-frequency noise from the output signal and stabilize the output voltage waveform, which is beneficial for the subsequent ADC block. If the ADC needs to drive a large current, it is recommended to insert a driving op-amp to better suppress noise, improve current driving capability and reduce the impact on the output voltage amplitude of ZXCT199/21x. Figure 6b is useful for applications that only need to detect large signal current instead of specific/precise current.

Front-End Filtering Error

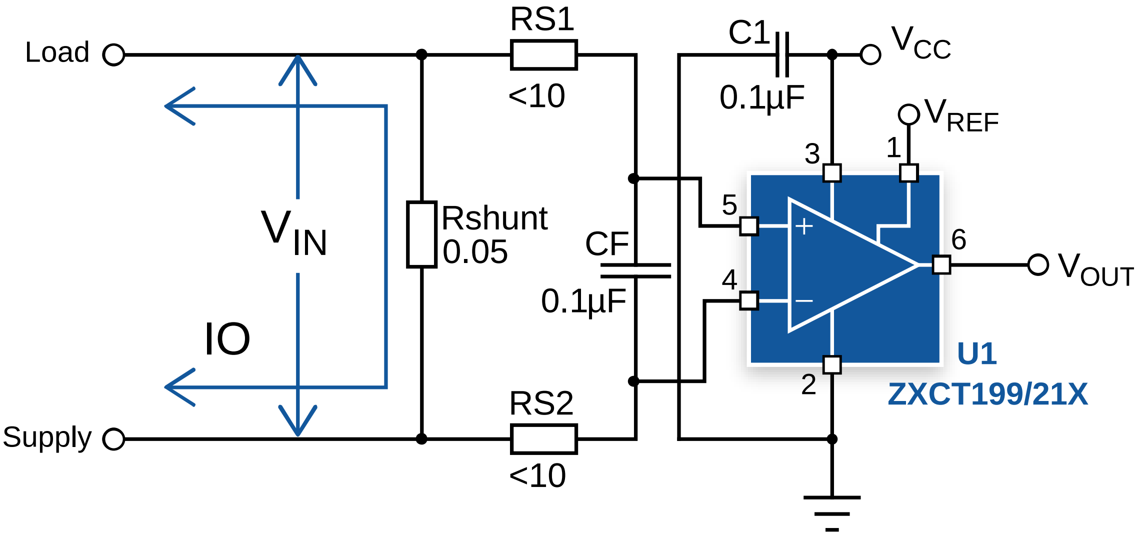

Figure 7. Front-end filtering error

Due to harsh application environments, long leads or strong electromagnetic interference, the output of the ZXCT199/21x may be unstable. In certain cases, it will be necessary to include an RC filter network (including RS1, RS2 and CF) to the front end to reduce interference, and stabilize the output to facilitate the backend work. As shown in Figure 7, this also introduces adverse factors such as gain error.

Furthermore, to reduce interference of backend work, the impact of RS has been calculated. To meet the requirements, the lowest resistance should be used. The calculation for the -3dB point frequency of this low-pass network is:

f_(-3dB) = 1 / (2π(RS1 + RS2)CF)

The gain error factor caused by the increase in resistance can be calculated from the following formula:

$$\textbf{Gain Error Factor} = \frac{(1250 \times R_{INT})}{(1250 \times R_S) + (1250 \times R_{INT}) + (R_S \times R_{INT})}$$

In this case, R_{INT} is the equivalent resistance of R1 and R2, which are the internal resistances of the circuit.

Product	Gain	R_{INT}	Gain Error Factor Equations	Gain Error % *		
				R_S=10 Ω	R_S=20 Ω	R_S=30.1 Ω
ZXCT199x1	50	20000	$\frac{20{,}000}{(17 \cdot R_S) + 20{,}000}$	0.8428%	1.6716%	2.4947%
ZXCT199x2	100	10000	$\frac{10{,}000}{(9 \cdot R_S) + 10{,}000}$	0.8920%	1.7682%	2.6375%
ZXCT199x3	200	5000	$\frac{1{,}000}{R_S + 1{,}000}$	0.9608%	1.9608%	2.9126%

*The percentages shown should be rounded to 2 significant figures. The excess can be used to check calculations. This is for a typical semiconductor process.

As the value of RS increases, the gain error of the circuit increases due to the increasing error factor. If the resistance values of RS1 and RS2 are not equal, this introduces an input offset voltage (V_{OS}), which further causes the output voltage to offset. Therefore, it is recommended to avoid using RS whenever possible. If RS must be used, the resistance value should be as small as possible and the two resistors should have the same resistance value. In applications that require high-frequency current detection (such as transient overcurrent protection), a low-pass filter should not be used at the input end in order to accurately reflect the reading.

Input/Output Voltage Range and Current Monitoring

Output voltage range

The ZXCT199/21x is a rail-to-rail output device, but considering the measurement accuracy and errors of the subsequent ADC, it is recommended to set the output voltage range between 0.2V and 4.8V (for 5V applications) to minimize the impact of the subsequent circuit on the output voltage amplitude of the ZXCT199/21x.

Input voltage range (current-sensing resistor selection)

The selection of the current-sensing resistor is determined by the input/output voltage range.

R_{shunt} = (V_{OUT} - V_{REF})/(I_{OUT} * gain) where:

- R_{shunt} is the resistance of the current-sensing resistor
- V_{OUT} is the output voltage
- V_{REF} is the voltage reference voltage
- I_{OUT} is the maximum current
- Gain is the gain of the op-amp

Bidirectional current sensing

In a bidirectional current-sensing application, set V+=5V, V_{REF}=2.5V and output voltage range at 0.5V~4.5V. When no current flows through the current-sampling resistor, theoretically, V_{OUT}=V_{REF}=2.5V.

When the forward current flows, the output voltage range is 2.5V~4.5V, and the dynamic range is 4.5V-2.5V=2V.

When the reverse current flows, the output voltage range is 0.5V~2.5V, and the dynamic range is also 2V (which can also be considered as -2V).

For example, if the ZXCT213 is used: gain=50.

According to the formula, V1-V2=2000/50=40mV.

In other words, V_{IN}=40mV=$R_{shunt} \times I_{load(MAX)}$.

Take the current value with the larger absolute value in the bidirectional current, and then the minimum resistance value of the current-sampling resistor can be determined: $R_{shunt(MIN)}$ =40mV/$I_{load(MAX)}$.

Unidirectional current sensing

In a unidirectional current-sensing application, only one direction of current needs to be detected, which expands the dynamic range of current.

Set V+=5V, V_{REF}=0.5V and output voltage range 0.5V~4.5V. When no current flows through the current-sampling resistor, theoretically, V_{OUT}=V_{REF}=0.5V.

Therefore, the dynamic range is 4.5V-0.5V=4V.

According to the formula, V1-V2=4000/50=80mV.

80mV=$R_{shunt} \times I_{load(MAX)}$, so $R_{shunt(MIN)}$=80mV/$I_{load(MAX)}$.

Under the allowed power consumption, a larger R_{shunt} value is preferred to reduce the error with small current.

Maximum current-sensing resistor value

The maximum current-sensing resistor value depends on the V_{OS}, the minimum measurable I_{load} and the resolution and accuracy of the ADC.

Assuming that the absolute value of the minimum measurable current is I_{MIN}, the measurement error is within 10%, and the input offset voltage of the device is, say, 50µV, then the voltage of I_{MIN} flowing through R_{shunt} must be greater than or equal to 450µV, then $R_{shunt(MAX)}$=450(µV)/I_{MIN}.

This is critical at small currents; when the current is large, the relative proportion of the input offset voltage is reduced, and the impact is irrelevant.

Device Output Voltage Errors

Device output voltage errors can affect the accuracy of measurement. These errors can be caused by the following factors:

- Input offset voltage and its temperature drift
- Gain error and its temperature drift
- If there is an additional RC filter network at the input end, the mismatch of the two resistor values will also introduce errors (equivalent to adding another V_{OS} source)
- V_{REF} deviation

Recommendations:

- For the first and second items, the error can be improved by using higher-grade devices (C-grade).
- For the third item, the error can only be improved by using better types of resistors, such as metal film resistors, or by using closed high-precision resistors.
- For the fourth item, the error can be improved by using Figure 4a (automatically tracks V_{REF}, ignoring the impact of V_{REF} deviation) or Figure 5b (reduces the impact of device input resistance).

Layout and Current-Sensing Resistors

A current-sensing resistor (or other filter RC) should be placed as close as possible to ZXCT199/21x, with leads as short as possible and of equal length. The Kelvin connection structure is preferred, as shown in Figure 8d.

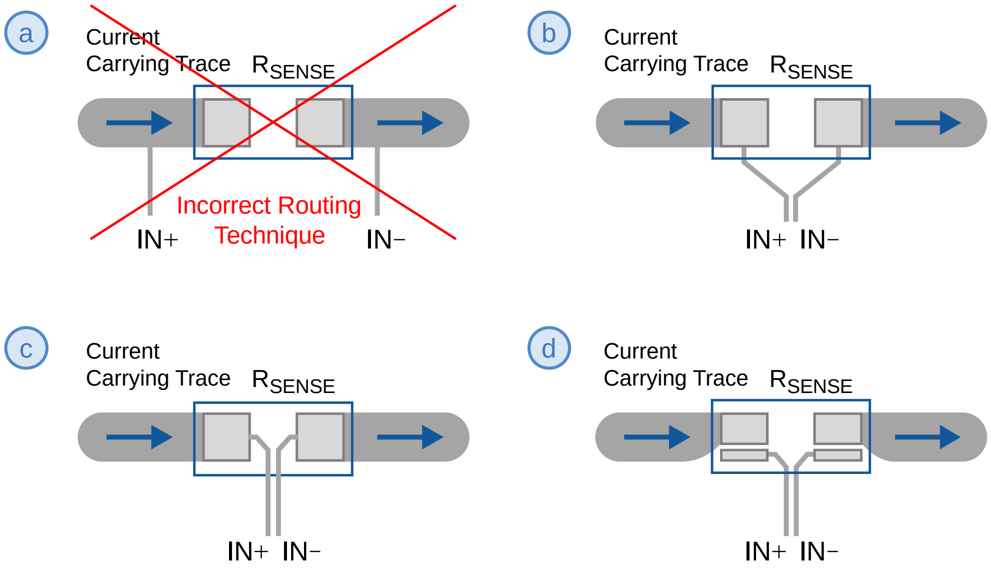

Figure 8. Current-sensing resistor layout

The structure shown in Figure 8a is not recommended, as it increases the value of the current-sampling resistor; the voltage should be taken directly from the two ends of the sampling resistor. If a more cost-effective solution is preferred, the structure shown in Figure 8c can be considered.

The maximum current and rated power values of a current-sensing resistor are critical factors to consider when designing a current measurement application circuit. The maximum current value determines the maximum current that can flow through the resistor without damaging it. The rated power value determines the maximum power that the resistor can dissipate without overheating.

A larger current-sensing resistor value will reduce the relative error caused by system offset, gain error and drift. This is because the voltage drop across the resistor is proportional to its resistance. Thus, a higher resistance results in a smaller voltage offset error impact.

However, a larger current-sensing resistor value will also increase power consumption. This is because the power dissipated by the resistor is proportional to the square of the current flowing through it. Therefore, it is important to choose a proper resistor value that balances the need for accuracy with tolerable overheating impact.

In practice, a current-sensing resistor value is often chosen between the minimum and maximum current and rated power. This allows for the best possible trade-off between accuracy, power consumption and cost.

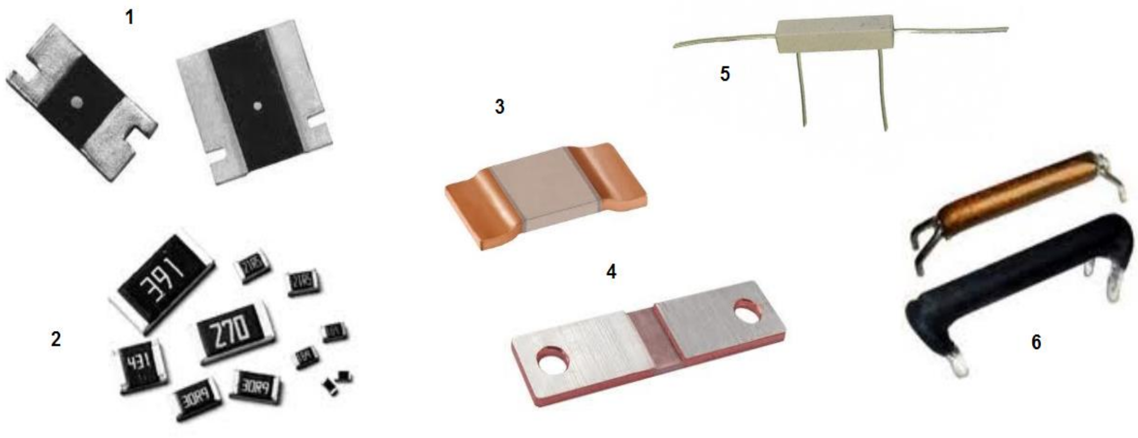

Figure 9. Most common current-sensing resistors

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