



## Current Sense Amplifiers, Frequently Asked Questions (FAQ)

ON Semiconductor®

[www.onsemi.com](http://www.onsemi.com)

### APPLICATION NOTE

#### Summary

The following questions are typical questions that ON Semiconductor's application support team answers on the topic of current sense amplifiers. If you have a question not addressed here, please do not hesitate to contact your local ON Semiconductor representative, or visit our [Technical Support](#) site to call or email us, or visit our [Design Support](#) site.

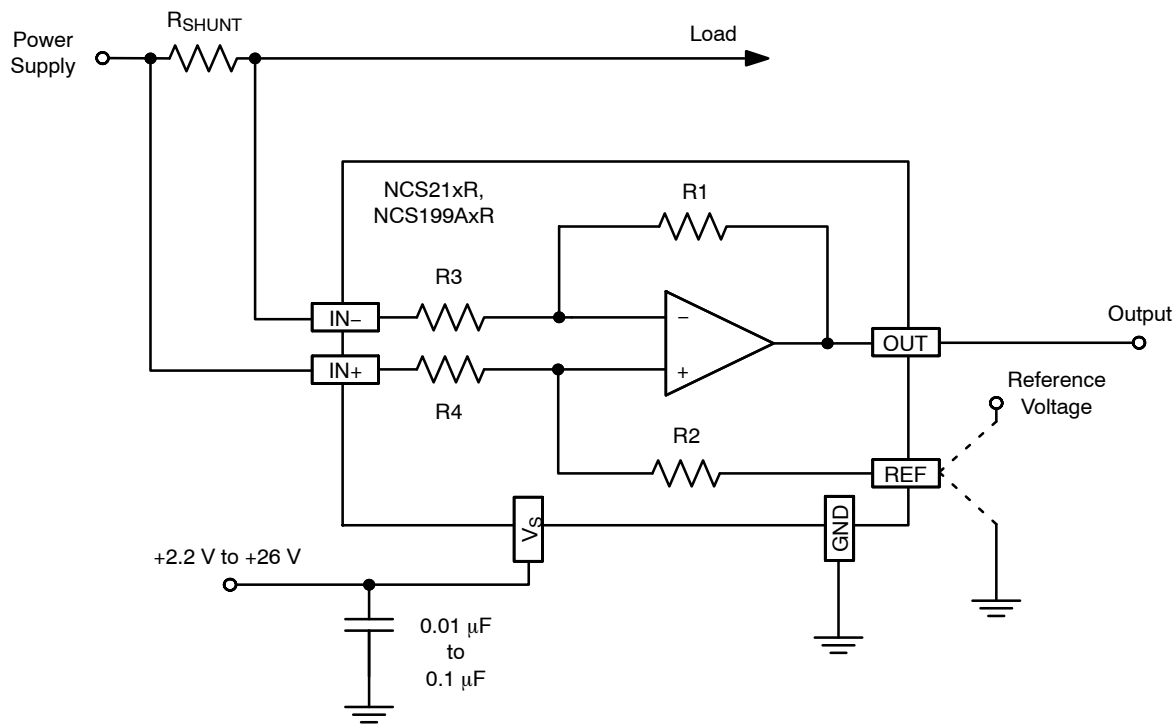


Figure 1. Example Application Schematic of a Current Sense Amplifier

## AND9750/D

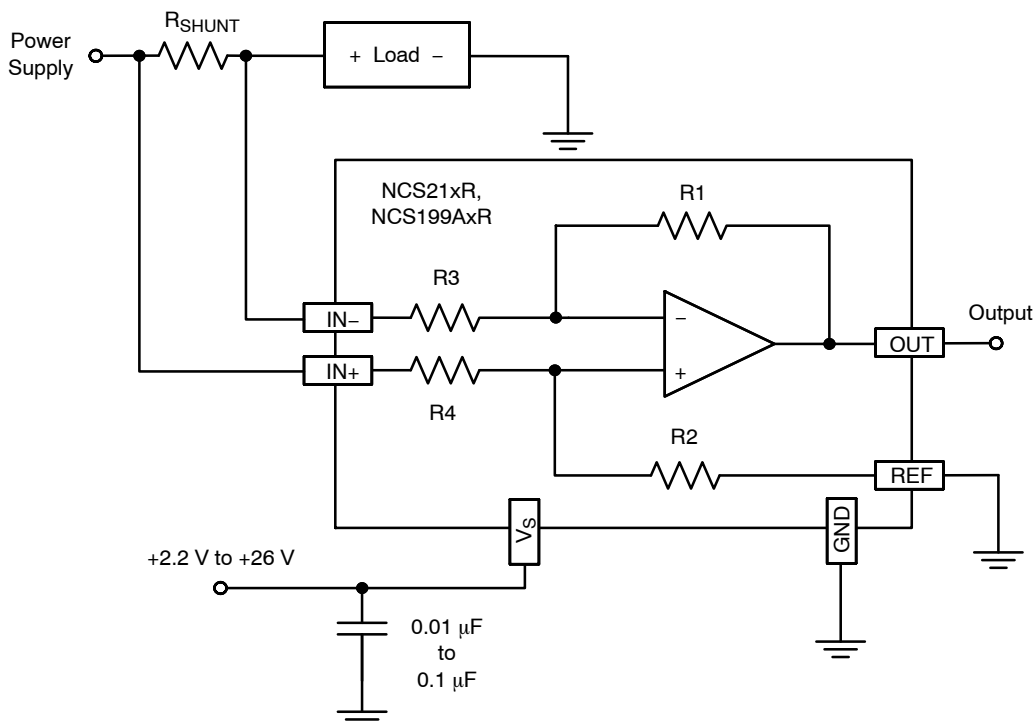


Figure 2. Example Application Schematic of a Current Sense Amplifier Configured for High-side Current Sensing

### FREQUENTLY ASKED QUESTIONS

#### What is a Current Sense Amplifier?

Current sense amplifiers such as the [NCS21xR](#) and [NCS199AxR](#) family of devices, (also called current shunt monitors or current shunt amplifiers) are amplifiers that feature internal precision resistors to create a full differential input. Current sense amplifiers also feature zero-drift architecture or low offset voltage and low offset drift over temperature. These devices measure small voltage drops across a shunt resistor that is connected to the inputs. These devices accurately amplify the 1 mV to 10 mV signal from the shunt, at various gains depending on the chosen device, up to a gain of 500. The output voltage is related to input current across the shunt resistor by:

$$I_{\text{SENSE}} = \frac{V_{\text{OUT}}}{R_{\text{SENSE}} \cdot \text{Gain}} \quad (\text{eq. 1})$$

where  $I_{\text{SENSE}}$  is the current flowing through the shunt resistor,  $V_{\text{OUT}}$  is the output voltage, Gain is the fixed internal gain of the amplifier, and  $R_{\text{SENSE}}$  is the sense (also called shunt) resistor.

#### What are the Common Current Sensing Circuit Configurations?

The common current sensing circuit configurations are:

- Low-side sensing,
- High-side sensing,
- Unidirectional sensing, and
- Bidirectional sensing.

The [NCS21xR](#) and [NCS199AxR](#) family of devices makes possible all of these configurations.

#### What is Low-side Current Sensing?

Low-side current sensing places the low side of the load at one end of the shunt or sense resistor, the other side of the sense resistor is connected to ground. The common mode voltage for low-side sensing will be close to 0 V. Low-side has the advantage of being simple to implement and inexpensive. However, it has the disadvantage of not being able to detect load high-side shorts, and the ground path is disturbed since the low side of the load is connected to ground through the sense resistor. See Figure 3 and take note of the position of the load.

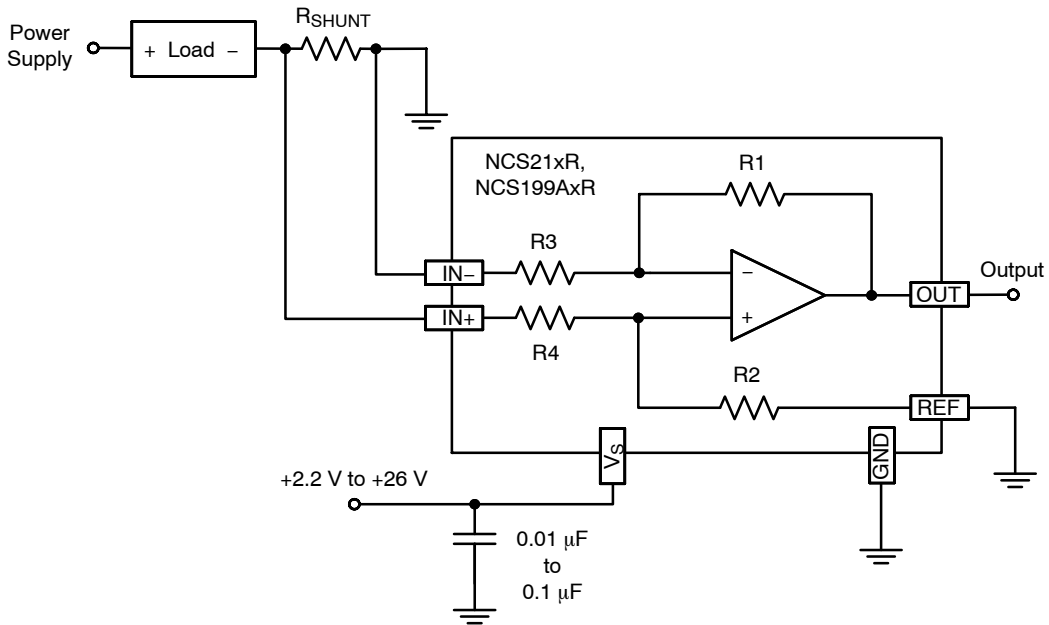


Figure 3. Low-side Current Sensing Example

**What is High-side Current Sensing?**

High-side current sensing places the high-side of the load at one end of the shunt or sense resistor and the low-side of the load will be connected directly to ground. Common mode voltages are typically quite high: 20 V, 40 V, or even 80 V. High-side has the advantage of being able to detect

load shorts and not having resistance in the ground path to the load. In the past, high-side sensing was more difficult and expensive to implement. However, current sense amplifiers have provided an economical and easy to use solution. See Figure 4 and take note of the position of the load.

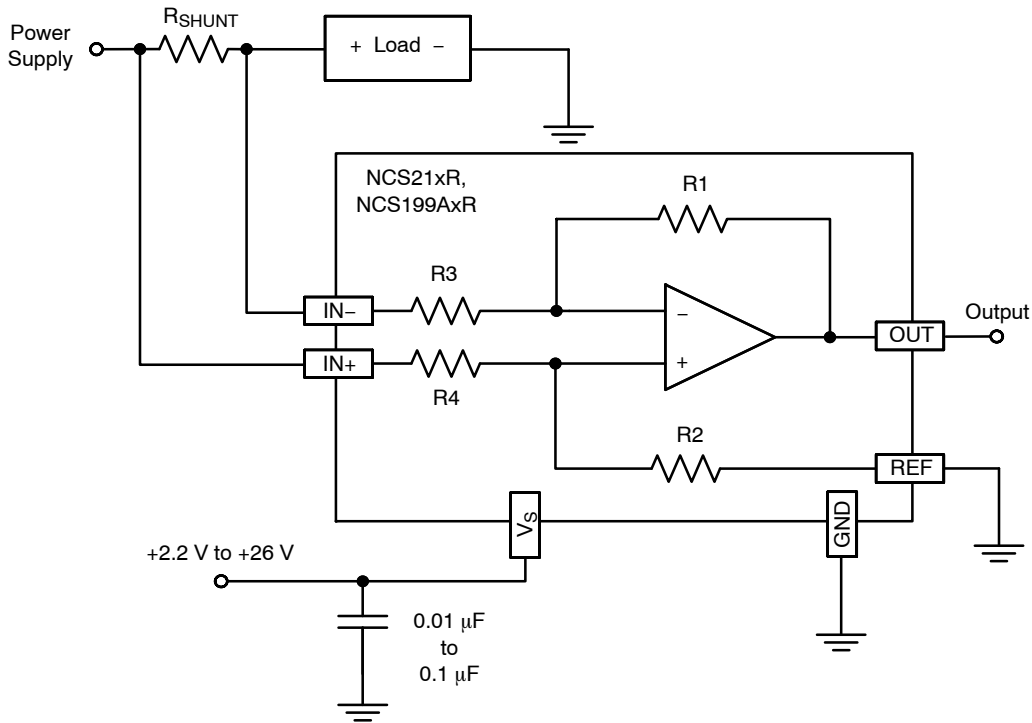


Figure 4. High-side Current Sensing Example

# AND9750/D

## What is Unidirectional Current Sensing?

Use unidirectional sensing only when current flowing in one direction (into a load) needs to be sensed. The output of the amplifier will only swing in one direction. Notice in

Figure 5 that the REF pin is connected to ground, this ground connection configures the device for unidirectional current sensing.

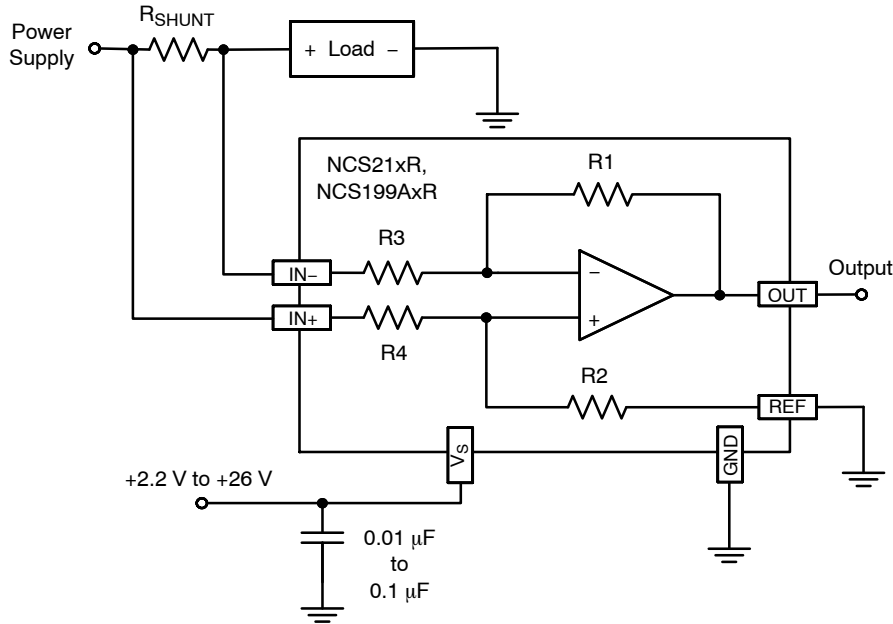


Figure 5. Unidirectional Current Sensing Example

## What is Bidirectional Current Sensing?

Use bidirectional sensing when sensing current flowing in both directions. For example, an application that monitors the current flowing in one direction as the system charges a battery and then monitors the current flowing the other direction as the battery discharges once the battery charger

power is disconnected would use bidirectional current sensing. Notice in Figure 6 that the REF pin is connected to some voltage potential above ground. This voltage potential allows the output of the amplifier to swing in both directions, positive and negative. Thus, current can be sensed in both directions.

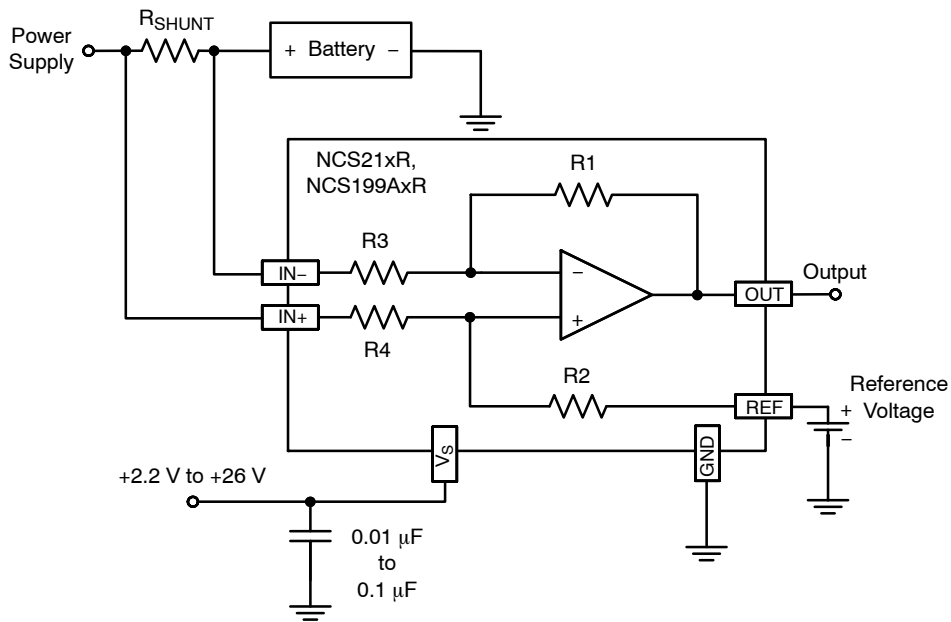


Figure 6. Bidirectional Current Sensing Example

### Why is Low Input Offset Voltage ( $V_{OS}$ ) Important?

It is desirable to keep the shunt voltage drop as low as possible, and input offset voltage is the key parameter that sets the low limit of what can be sensed. Low offset and the resulting low voltage drop makes possible smaller and more economical shunts and improves system efficiency. For example, measuring a 10 mV shunt drop on an amplifier with a 1 mV offset voltage would result in a 10% error due to the 1 mV offset voltage. By comparison, the [NCS213R](#) has a 100  $\mu$ V max offset voltage spec, which means only a 1% error with the same 10 mV shunt drop. The [NCS210R](#) has a max offset voltage of just 35  $\mu$ V. The error with a 10 mV shunt drop in this case would be only 0.35%.

### Why is Low Input Offset Voltage vs Temperature, or Offset Drift Important?

The Input Offset Voltage can be calibrated out of a system, but offset drift over temperature cannot be calibrated out, so it is important that the spec for this parameter be as low as possible. The [NCS21xR](#) and [NCS199AxR](#) series of current sense amplifiers offer low 0.5  $\mu$ V/ $^{\circ}$ C max offset drift over the full temperature range of  $-40^{\circ}$ C to  $+125^{\circ}$ C.

### Why is Low Gain Error Important?

Gain error defines how accurate the measurement will be over the entire dynamic range. Inaccuracy in current measurements can reduce system efficiency through lost power.

### Why is Low Gain Error vs Temperature, or Gain Error Drift Important?


The Gain Error can be calibrated out of a system, but gain error drift over temperature cannot be calibrated out and so it is important that the spec for this parameter be as low as possible. The [NCS21xR](#) and [NCS199AxR](#) offer low 10 ppm/ $^{\circ}$ C max gain error drift over the full temperature range of  $-40^{\circ}$ C to  $+125^{\circ}$ C.

### How Important is the Connection to the Current Shunt Resistor?

It is important to always follow the shunt resistor manufacturer's recommendations for connecting to the shunt resistor so that the current sense amplifier will accurately sense the current.

### Where Can I Find More Information on Current Sense Amplifiers (CSA)?

You can start here: [ON Semiconductor's Current Sense Amplifiers](#).

ON Semiconductor and  are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

## PUBLICATION ORDERING INFORMATION

### LITERATURE FULFILLMENT:

Literature Distribution Center for ON Semiconductor  
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA  
Phone: 303-675-2175 or 800-344-3860 Toll Free USA/Canada  
Fax: 303-675-2176 or 800-344-3867 Toll Free USA/Canada  
Email: [orderlit@onsemi.com](mailto:orderlit@onsemi.com)

**N. American Technical Support:** 800-282-9855 Toll Free  
USA/Canada  
**Europe, Middle East and Africa Technical Support:**  
Phone: 421 33 790 2910

**ON Semiconductor Website:** [www.onsemi.com](http://www.onsemi.com)  
**Order Literature:** <http://www.onsemi.com/orderlit>

For additional information, please contact your local Sales Representative