NCS199A1R, NCS199A2R, NCS199A3R

Current-Shunt Monitors, Voltage Output, Bidirectional, Zero-Drift, Low- or High-Side Current Sensing

ON Semiconductor®

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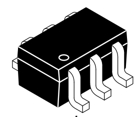
The NCS199A1R, NCS199A2R, and NCS199A3R are voltage output, current shunt monitors (also called current sense amplifiers) which can measure voltage across shunts at common−mode voltages from −0.3 V to 26 V, independent of supply voltage. The low offset of the zero−drift architecture enables current sensing across the shunt with maximum voltage drop as low as 10 mV full−scale. These devices can operate from a single +2.2 V to +26 V power supply, drawing a maximum of 80 μA of supply current, and are specified over the extended operating temperature range (–40°C to +125°C). Available in the SC70−6 package.

Features

- Wide Common Mode Input Range: −0.3 V to 26 V
- Supply Voltage Range: 2.2 V to 26 V
- Low Offset Voltage: ±150 μV max
- Low Offset Drift: 0.5 μV/°C max
- Low Gain Error: 1.5% max
- Low Gain Error Drift: 10 ppm/°C
- Rail−to−Rail Output Capability
- Low Current Consumption: 40 μA typ, 80 μA max

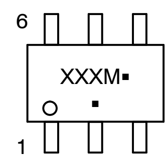
Typical Applications

- Current Sensing (High−Side/Low−Side)
- Telecom
- Power Management
- Battery Charging and Discharging



SC70−6
SQ SUFFIX
CASE 419B

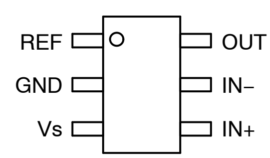
MARKING DIAGRAM



XXX	= Specific Device Code
M	= Date Code
▪	= Pb−Free Package

(Note: Microdot may be in either location)

PIN CONNECTIONS



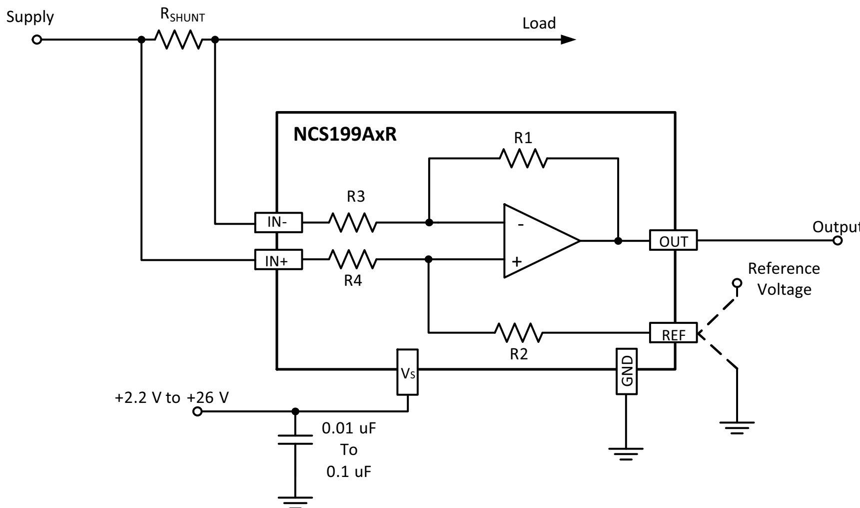
(Top View)

ORDERING INFORMATION

See detailed ordering, marking and shipping information on page 2 of this data sheet.

March, 2018 − Rev. 1

Publication Order Number:
NCS199A1R/D



$$V_{OUT} = \left(I_{LOAD} \times R_{SHUNT}\right)GAIN + V_{REF}$$

ORDERING INFORMATION

Device	Gain	R3 and R4	R1 and R2	Marking	Package	Shipping†
NCS199A1RSQT2G	50	20 kΩ	1 MΩ	AZ3	SC70−6	3000 / Tape and Reel
NCS199A2RSQT2G	100	10 kΩ	1 MΩ	AZ4	SC70−6	3000 / Tape and Reel
NCS199A3RSQT2G	200	5 kΩ	1 MΩ	AZY	SC70−6	3000 / Tape and Reel

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

Table 1. MAXIMUM RATINGS

Parameter		Symbol	Value	Unit
Supply Voltage (Note 1)		V_S	+30	V
Analog Inputs	Differential (V_{IN+})−($V_{IN−}$)	V_{IN+}, $V_{IN−}$	−30 to +30	V
	Common−Mode (Note 2)		(GND−0.3) to +30	
REF Input		V_{REF}	(GND−0.3) to (V_s+0.3)	V
Output (Note 2)		V_{OUT}	(GND−0.3) to (V_s+0.3)	V
Input Current into Any Pin (Note 2)			5	mA
Maximum Junction Temperature		$T_{J(max)}$	+150	°C
Storage Temperature Range		T_{STG}	−65 to +150	°C
ESD Capability, Human Body Model (Note 3)		HBM	±2000	V
Charged Device Model (Note 3)		CDM	±2000	V
Latch−Up Current (Note 4)		I_{LU}	100	mA

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

1. Refer to ELECTRICAL CHARACTERISTICS, RECOMMENDED OPERATING RANGES and/or APPLICATION INFORMATION for safe operating parameters.
2. Input voltage at any pin may exceed the voltage shown if current at that pin is limited to 5 mA.
3. This device series incorporates ESD protection and is tested by the following methods:
   ESD Human Body Model tested per JEDEC standard JS−001−2017.
   ESD Charged Device Model tested per JEDEC standard JS−002−2014.
4. Latch−up Current tested per JEDEC standard JESD78E.

Table 2. RECOMMENDED OPERATING RANGES

Parameter	Symbol	Min	Typ	Max	Unit
Common−Mode Input Voltage	V_{CM}	−0.3	12	26	V
Supply Voltage	V_S	2.2	5	26	V
Ambient Temperature	T_A	−40		125	°C

Functional operation above the stresses listed in the Recommended Operating Ranges is not implied. Extended exposure to stresses beyond the Recommended Operating Ranges limits may affect device reliability.

Table 3. THERMAL CHARACTERISTICS (Note 5)

Parameter		Symbol	Value	Unit
Thermal Resistance, Junction−to−Air (Note 6)	SC70−6	$R_{\theta JA}$	250	°C/W

5. Refer to ELECTRICAL CHARACTERISTICS, RECOMMENDED OPERATING RANGES and/or APPLICATION INFORMATION for safe operating parameters.
6. Values based on copper area of 645 mm^2 (or 1 in^2) of 1 oz copper thickness and FR4 PCB substrate.

Table 4. ELECTRICAL CHARACTERISTICS
At T_A = +25°C, $V_{SENSE} = V_{IN+} - V_{IN-}$; V_S = +5 V, V_{IN+} = 12 V, and $V_{REF} = V_S/2$, unless otherwise noted.
Boldface limits apply over the specified temperature range of T_A = −40°C to 125°C, guaranteed by characterization and/or design.

Symbol	Parameter		Test Conditions	Min	Typ	Max	Unit
INPUT							
V_{CM}	Common−Mode Input Voltage Range			**−0.3**		**26**	V
CMRR	Common−Mode Rejection Ratio		V_{IN+} = 0 V to +26 V, V_{SENSE} = 0 mV T_A = −40°C to 125°C	**100**	120		dB
V_{OS}	Offset Voltage RTI (Note 7)		V_{SENSE} = 0 mV		±5	±150	μV
dV_{OS}/dT	RTI vs Temperature (Note 7)		V_{SENSE} = 0 mV T_A = −40°C to +125°C		**0.1**	**0.5**	μV/°C
PSRR	RTI vs Power Supply Ratio (Note 7)		V_S = +2.7 V to +26 V, V_{IN+} = 18 V, V_{SENSE} = 0 mV		±0.1	±10	μV/V
I_{IB}	Input Bias Current		V_{SENSE} = 0 mV		39	60	μA
I_{IO}	Input Offset Current		V_{SENSE} = 0 mV		±0.1		μA
OUTPUT							
G	Gain	NCS199A1R			50		V/V
		NCS199A2R			100		
		NCS199A3R			200		
E_G	Gain Error		V_{SENSE} = −5 mV to 5 mV, T_A = −40°C to 125°C		±0.2	**±1.5**	%
	Gain Error vs Temperature		T_A = −40°C to 125°C		3	**10**	ppm/°C
	Nonlinearity Error		V_{SENSE} = −5 mV to 5 mV		±0.01		%
C_L	Maximum Capacitive Load		No sustained oscillation		1		nF
VOLTAGE OUTPUT							
V_{OH}	Swing to V_S Power Supply Rail		R_L = 10 kΩ to GND T_A = −40°C to +125°C		V_S − 0.075	**V_S − 0.2**	V
V_{OL}	Swing to GND		R_L = 10 kΩ to GND T_A = −40°C to +125°C		V_{GND} +0.005	**V_{GND} +0.05**	V
FREQUENCY RESPONSE							
BW	Bandwidth (f_{-3dB})	NCS199A1R	C_{LOAD} = 10 pF		90		kHz
		NCS199A2R			60		
		NCS199A3R			40		
SR	Slew Rate				1		V/μs
NOISE							
e_n	Voltage Noise Density		f = 1 kHz		45		nV/√Hz
POWER SUPPLY							
V_S	Operating Voltage Range		T_A = −40°C to +125°C	**2.2**		**26**	V
I_Q	Quiescent Current		V_{SENSE} = 0 mV		40	80	μA
	Quiescent Current Over Temperature		T_A = −40°C to +125°C			**100**	μA

7. RTI = referenced−to−input

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

TYPICAL CHARACTERISTICS (T_A = 25°C, V_S = 5 V, V_{IN}+ = 12 V and V_{REF} = V_S/2 unless otherwise noted.)
(The NCS199A3R is used for Typical Characteristics)

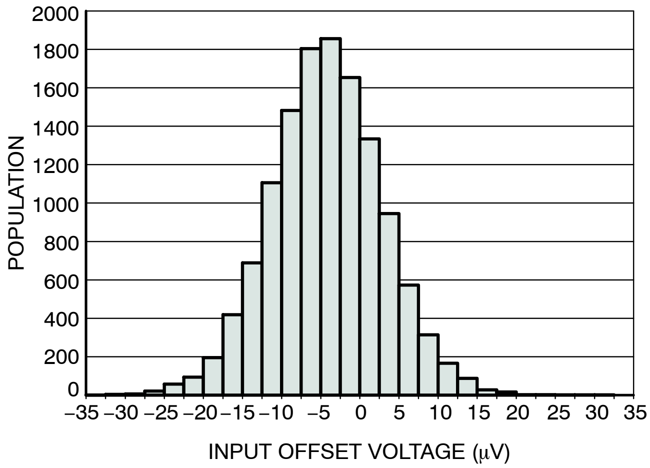


Figure 1. Input Offset Voltage Production Distribution

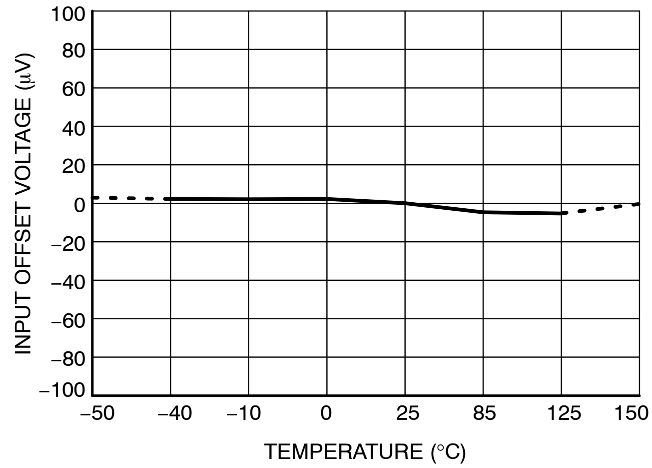


Figure 2. Input Offset Voltage vs. Temperature

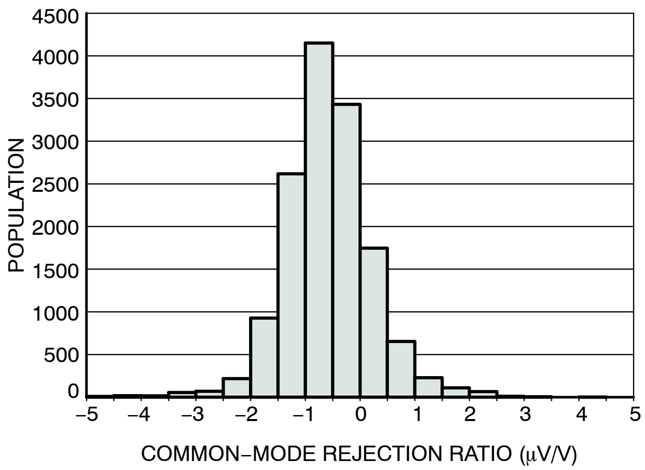


Figure 3. Common−Mode Rejection Production Distribution

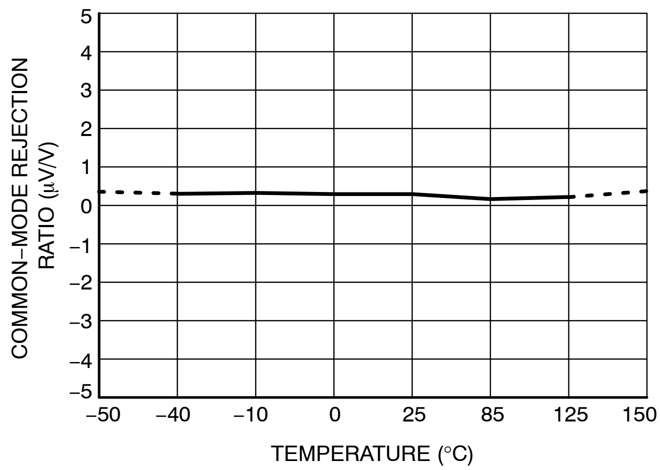


Figure 4. Common−Mode Rejection Ratio vs. Temperature

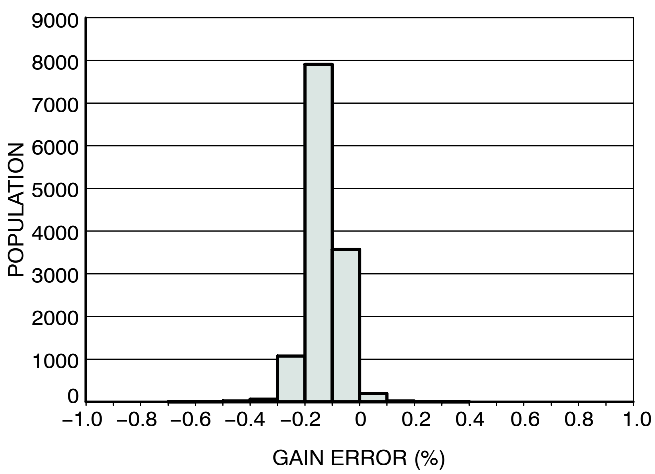


Figure 5. Gain Error Production Distribution

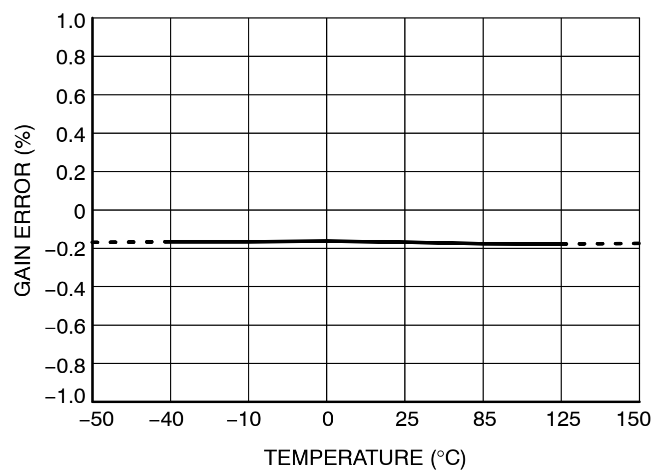


Figure 6. Gain Error vs. Temperature

TYPICAL CHARACTERISTICS (T_A = 25°C, V_S = 5 V, V_{IN}+ = 12 V and V_{REF} = V_S/2 unless otherwise noted.)

(The NCS199A3R is used for Typical Characteristics)

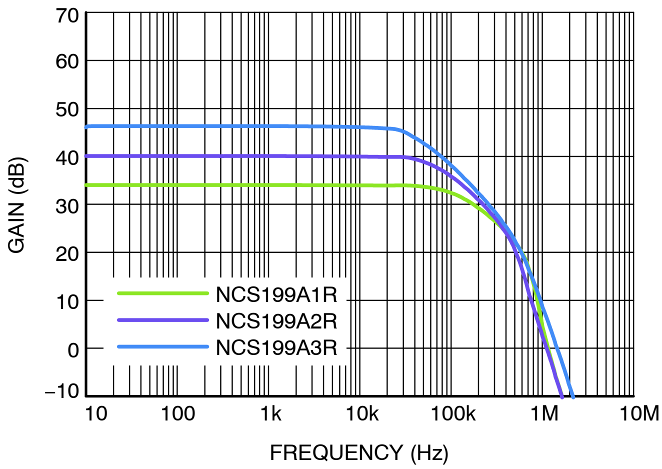


Figure 7. Gain vs. Frequency

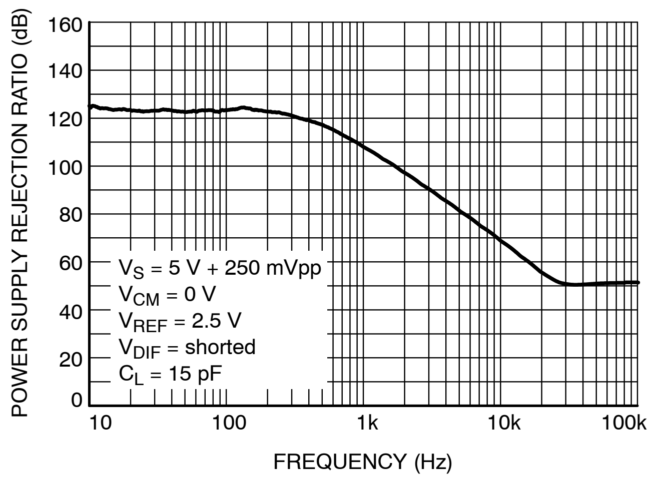


Figure 8. Power Supply Rejection Ratio vs. Frequency

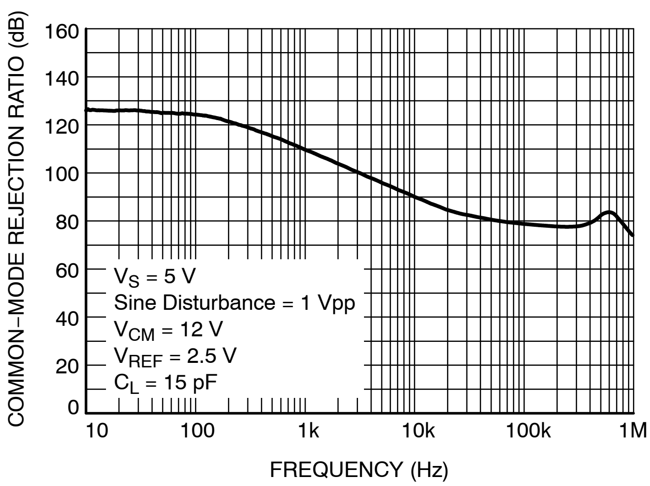


Figure 9. Common−Mode Rejection Ratio vs. Frequency

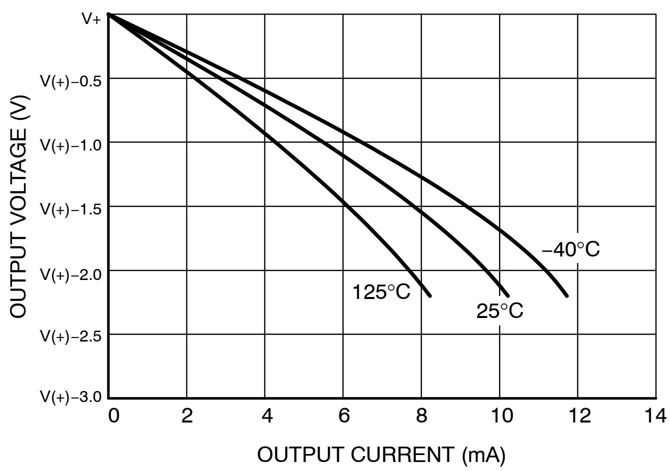


Figure 10. Positive Output Voltage Swing vs. Output Current, V_S = 2.2 V

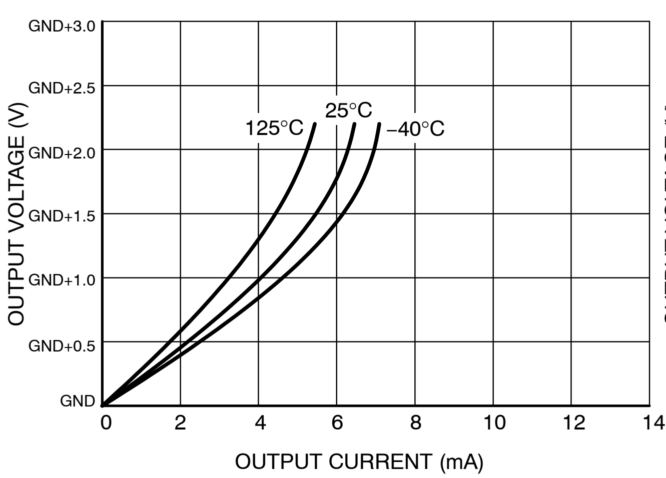


Figure 11. Negative Output Voltage Swing vs. Output Current, V_S = 2.2 V

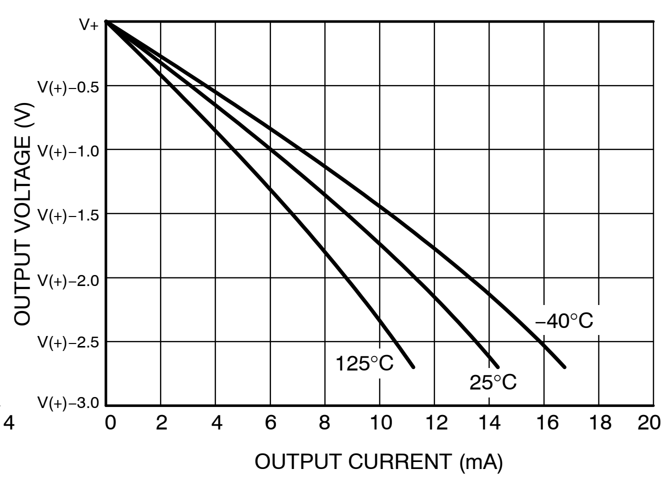


Figure 12. Positive Output Voltage Swing vs. Output Current, V_S = 2.7 V

TYPICAL CHARACTERISTICS (T_A = 25°C, V_S = 5 V, V_{IN}+ = 12 V and V_{REF} = V_S/2 unless otherwise noted.)

(The NCS199A3R is used for Typical Characteristics)

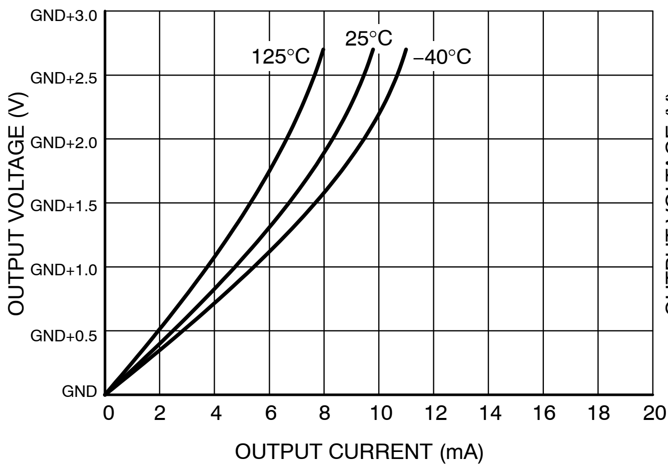


Figure 13. Negative Output Voltage Swing vs. Output Current, V_S = 2.7 V

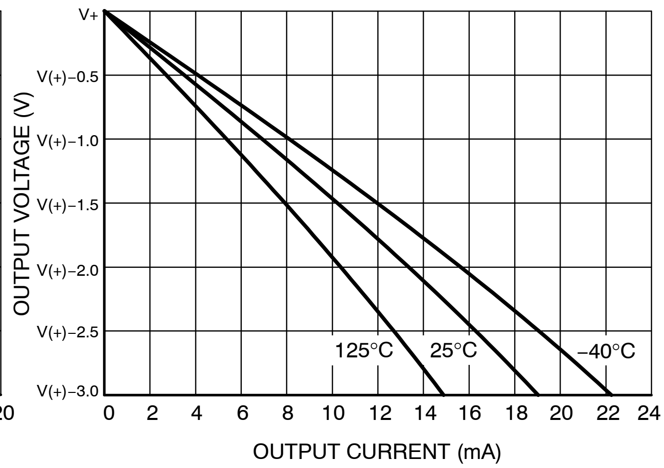


Figure 14. Positive Output Voltage Swing vs. Output Current, V_S = 5 V

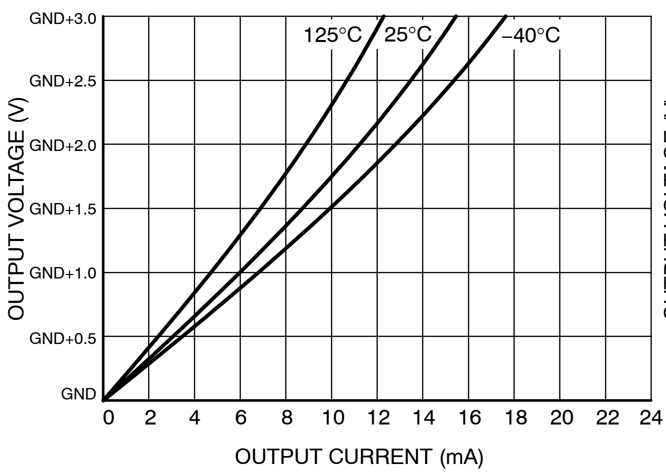


Figure 15. Negative Output Voltage Swing vs. Output Current, V_S = 5 V

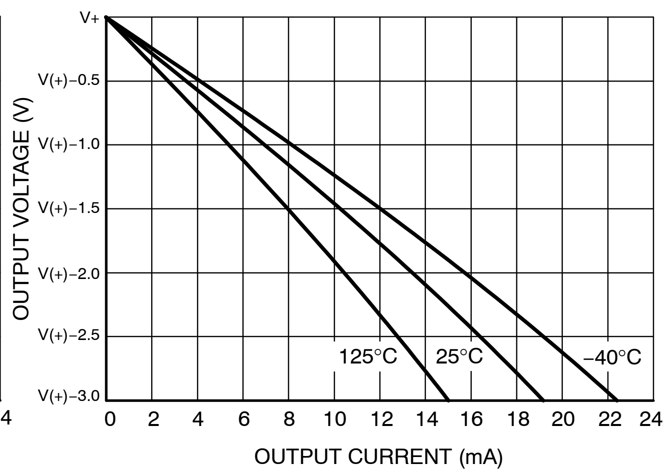


Figure 16. Positive Output Voltage Swing vs. Output Current, V_S = 26 V

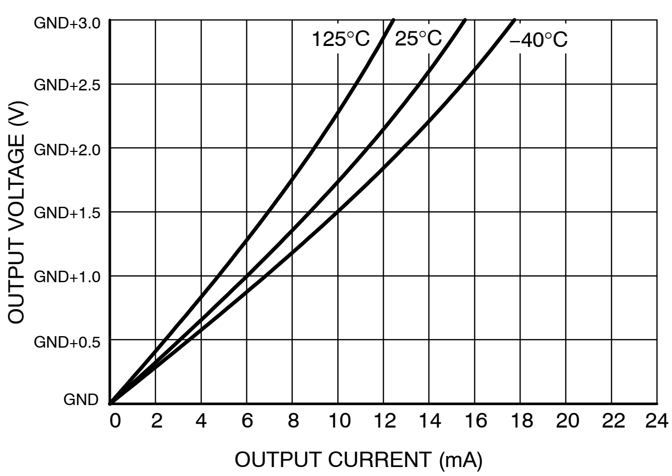


Figure 17. Negative Output Voltage Swing vs. Output Current, V_S = 26 V

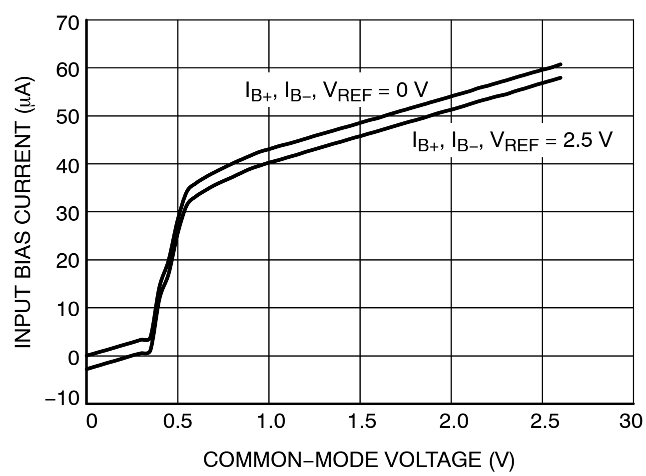


Figure 18. Input Bias Current vs. Common−Mode Voltage with V_S = 5 V

TYPICAL CHARACTERISTICS (T_A = 25°C, V_S = 5 V, V_{IN+} = 12 V and V_{REF} = V_S/2 unless otherwise noted.)
(The NCS199A3R is used for Typical Characteristics)

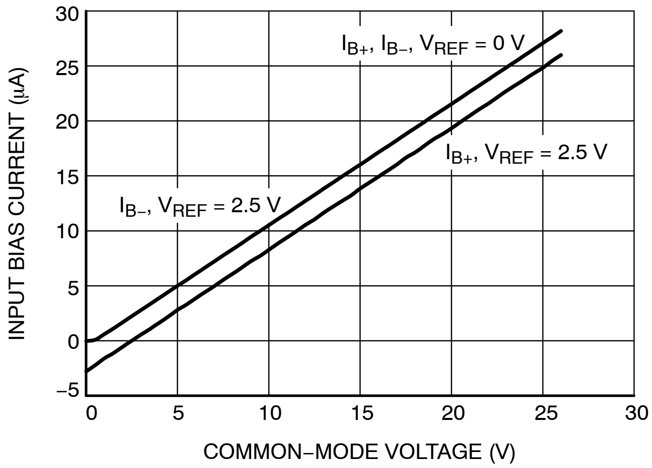


Figure 19. Input Bias Current vs. Common−Mode Voltage with V_S = 0 V (Shutdown)

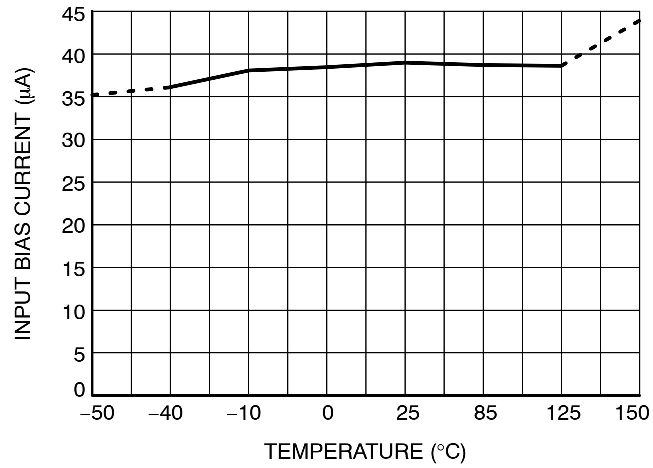


Figure 20. Input Bias Current vs. Temperature

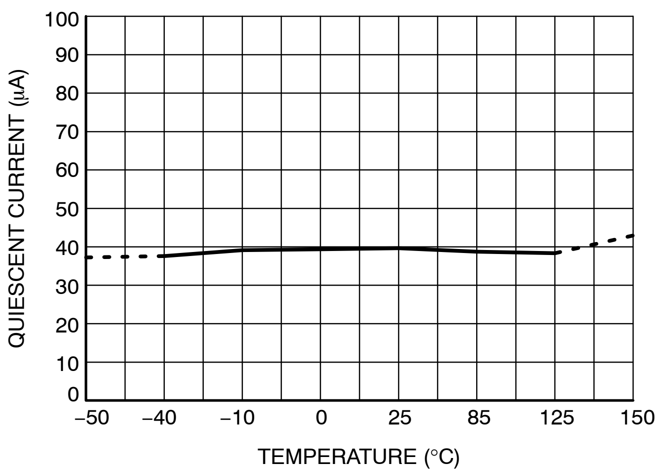


Figure 21. Quiescent Current vs. Temperature

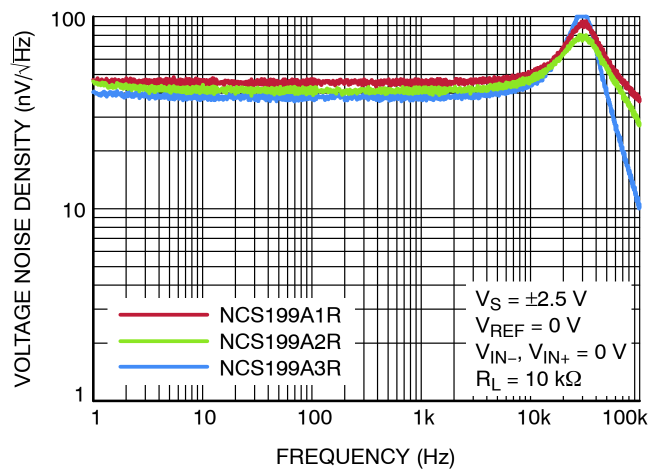


Figure 22. Voltage Noise Density vs. Frequency

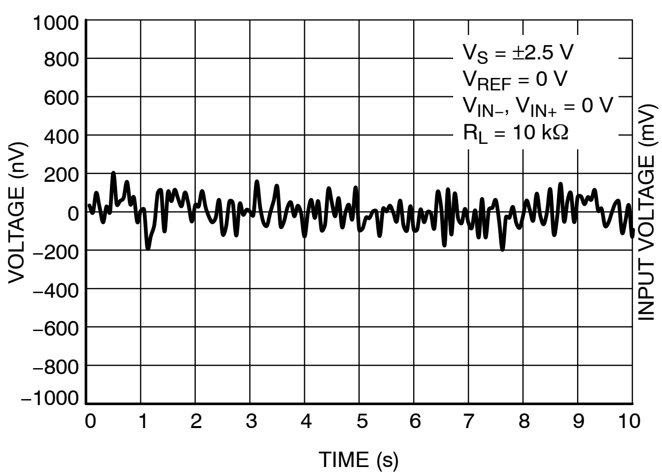


Figure 23. 0.1 Hz to 10 Hz Voltage Noise (Referred to Input)

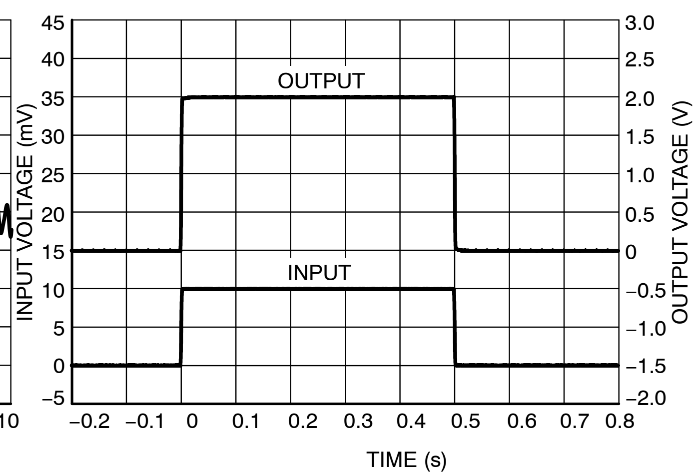


Figure 24. Step Response (10 mVpp Input Step)

TYPICAL CHARACTERISTICS (T_A = 25°C, V_S = 5 V, V_{IN}+ = 12 V and V_{REF} = V_S/2 unless otherwise noted.)
(The NCS199A3R is used for Typical Characteristics)

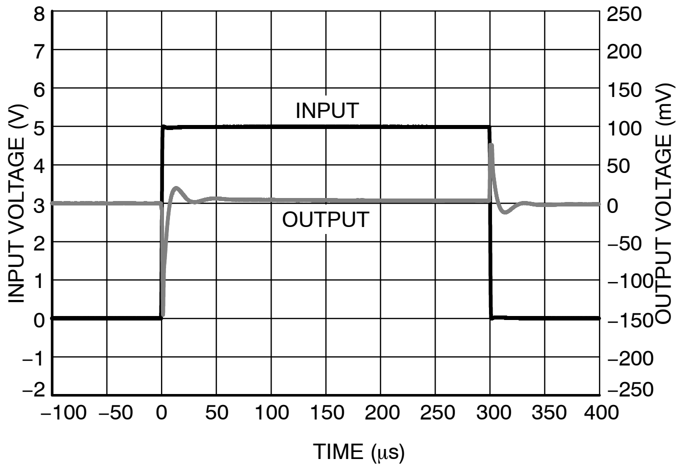


Figure 25. Common−Mode Voltage Transient Response

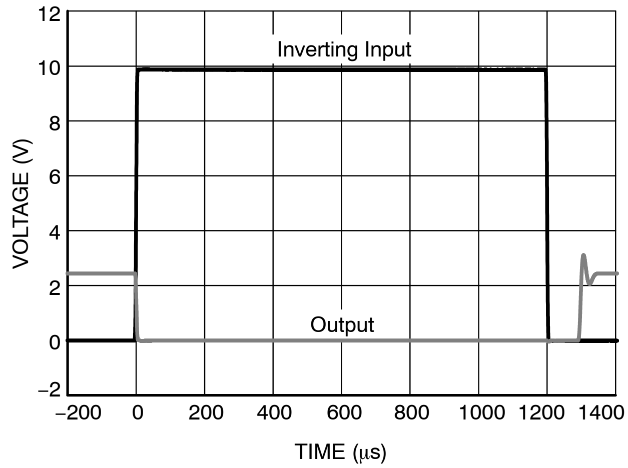


Figure 26. Inverting Differential Input Overload

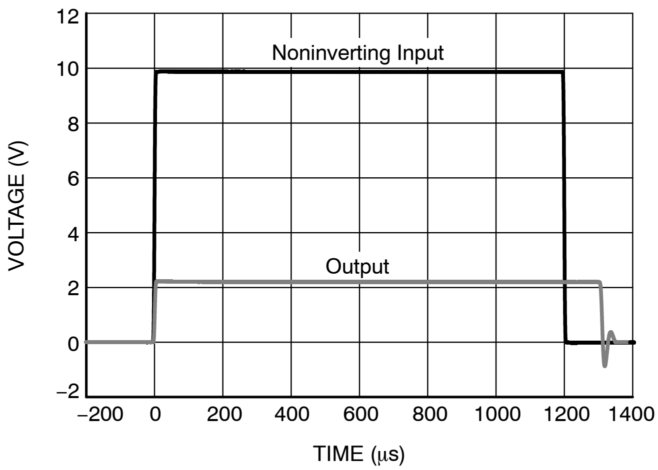


Figure 27. Noninverting Differential Input Overload

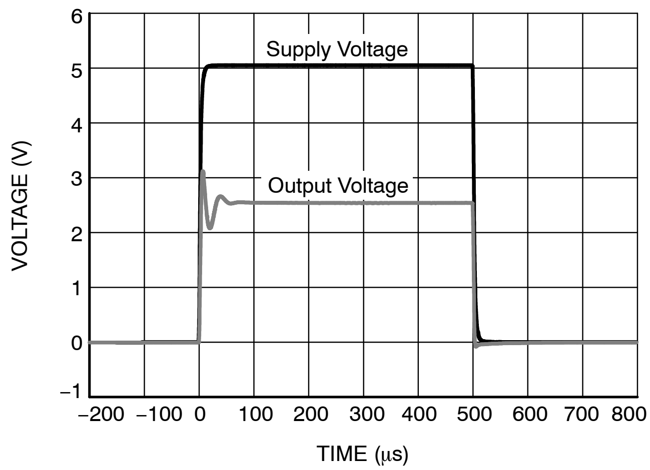


Figure 28. Start−Up Response

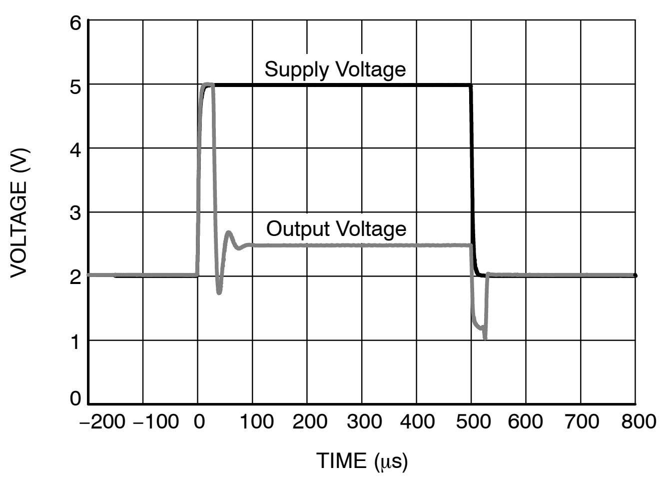


Figure 29. Brownout Recovery

Basic Connections

Current Sensing Techniques

The NCS199AxR current−sense amplifiers can be configured for both low−side and high−side current sensing. Low−side sensing appears to have the advantage of being straightforward, inexpensive, and can be implemented with a simple op amp circuit. However, the NCS199AxR series of devices provides the full differential input necessary to get accurate shunt connections, while also providing a built−in gain network with precision difficult to obtain with external resistors. While at times the application requires low−side sensing, only high−side sensing can detect a short from the positive supply line to ground. Furthermore, high−side sensing avoids adding resistance to the ground path of the load being measured. The sections below focus primarily on high−side current sensing.

Unidirectional Operation

In unidirectional current sensing, the current always flows in the same direction. Common applications for unidirectional operation include power supplies and load current monitoring. Figure 30 shows the NCS199AxR circuit implementation for unidirectional operation using high−side current sensing.

Basic connections for unidirectional operation include connecting the load power supply, connecting a current shunt to the differential inputs of the NCS199AxR, grounding the REF pin, and providing a power supply for the NCS199AxR. The NCS199AxR can be connected to the same power supply that it is monitoring current from, or it can be connected to a separate power supply. If it is necessary to detect short circuit current on the load power supply, which may cause the load power supply to sag to near zero volts, a separate power supply must be used on the NCS199AxR. When using multiple supplies, there are no restrictions on power supply sequencing.

When no current is flowing though the R_{SHUNT}, and the REF pin is connected to ground, the NCS199AxR output is expected to be within 50 mV of ground. When current is flowing through R_{SHUNT}, the output will swing positive, up to within 200 mV of the applied supply voltage, V_S.

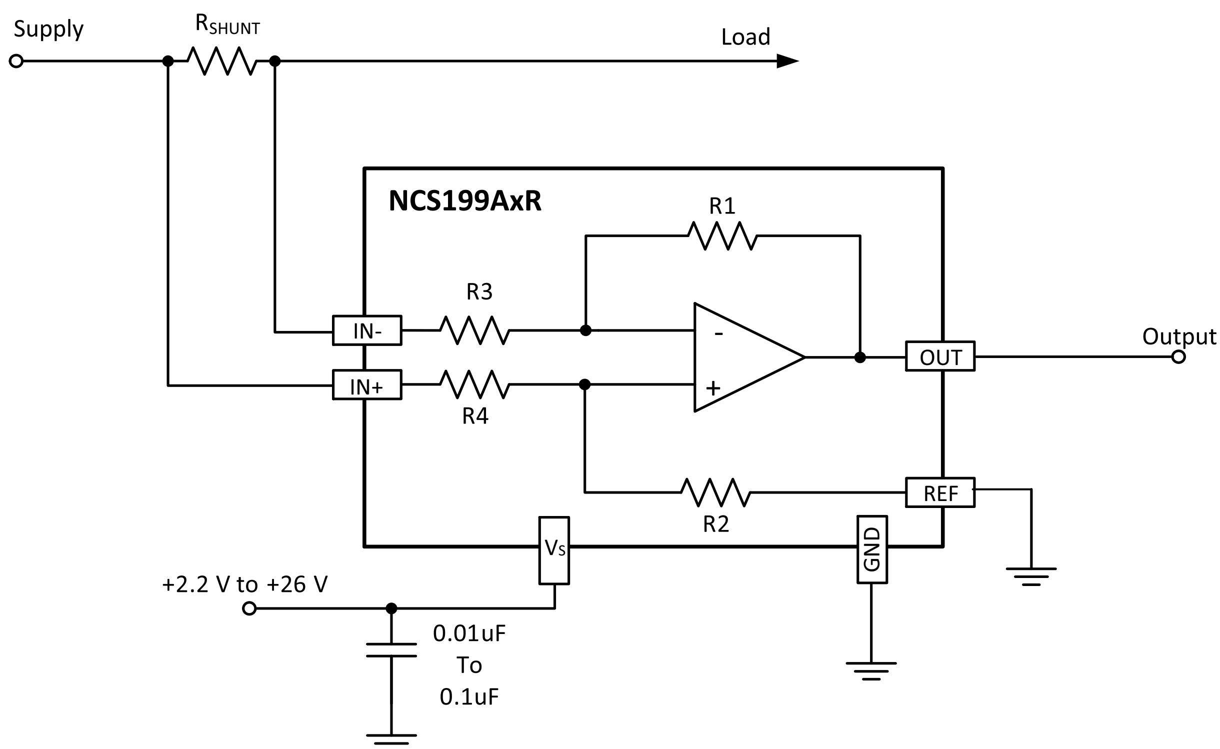


Figure 30. Basic Unidirectional Connection

Bidirectional Operation

In bidirectional current sensing, the current measurements are taken when current is flowing in both directions. For example, in fuel gauging, the current is measured when the battery is being charged or discharged. Bidirectional operation requires the output to swing both positive and negative around a bias voltage applied to the REF pin. The voltage applied to the REF pin depends on the application. However, most often it is biased to either half of the supply voltage or to half the value of the measurement system reference. Figure 31 shows bidirectional operation with three different circuit choices that can be connected to the REF pin to provide a voltage reference to the NCS199AxR.

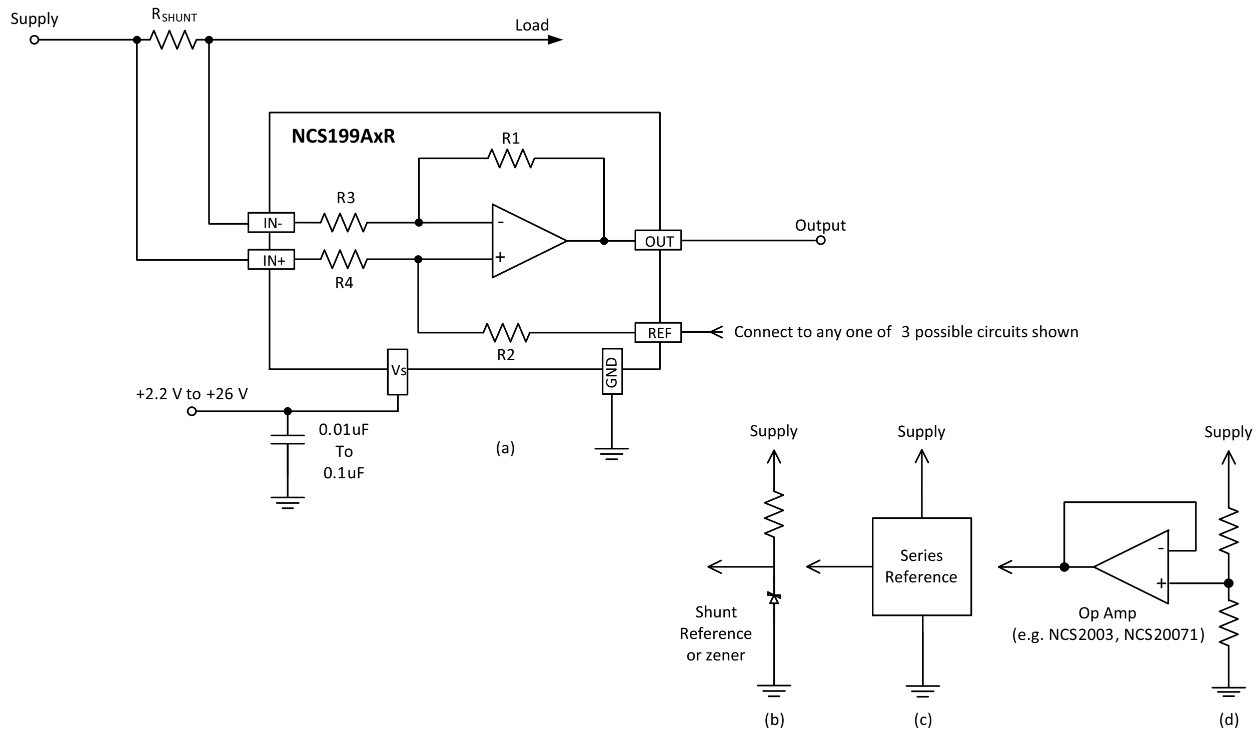


Figure 31. Bidirectional Current Sensing with Three Example Voltage Reference Circuits

The REF pin must always be connected to a low impedance circuit, such as in the Figure 31(b), (c), and (d). The REF pin can be connected directly to any voltage supply or voltage reference (shunt or series). However, if a resistor divider network is used to provide the reference voltage, a unity gain buffer circuit must be used, as shown in Figure 31(d).

In bidirectional applications, any voltage that exceeds V_S+0.3 V applied to the REF pin will forward bias an ESD diode between the REF pin and the V_S pin. Note that this exceeds the Absolute Maximum Ratings for the device.

Input and Output Filtering

Filtering at the input or output may be required for several different reasons. In this section we will discuss the main considerations with regards to these filter circuits.

In some applications, the current being measured may be inherently noisy. In the case of a noisy signal, filtering after the output of the current sense amplifier is often simpler, especially where the amplifier output is fed into high impedance circuitry. The amplifier output node provides the greatest freedom when selecting components for the filter and is very straightforward to implement, although it may require subsequent buffering.

Other applications may require filtering at the input of the current sense amplifier. Figure 32 shows the recommended schematic for input filtering.

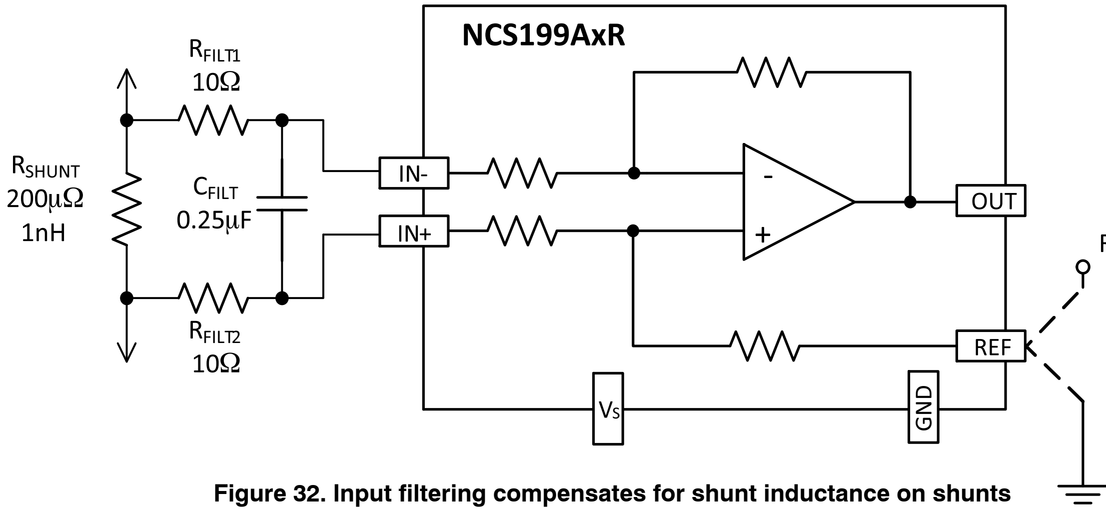


Figure 32. Input filtering compensates for shunt inductance on shunts less than 1 mΩ, as well as high frequency noise in any application

Input filtering is complicated by the fact that the added resistance of the filter resistors and the associated resistance mismatch between them can adversely affect gain, CMRR, and V_{OS}. The effect on V_{OS} is partly due to input bias currents as well. As a result, the value of the input resistors should be limited to 10 Ω or less. Ideally, select the capacitor to exactly match the time constant of the shunt resistor and its inductance; alternatively, select the capacitor to provide a pole below that point. As an example, a filtering frequency of 100 kHz would require an 82 nF capacitor. The capacitor can have a low voltage rating, but should have good high frequency characteristics.

Make the input filter time constant equal to or larger than the shunt and its inductance time constant:

$$\frac{L_{SHUNT}}{R_{SHUNT}} \geq 2 \cdot R_{FILT} \cdot C_{FILT}$$

This simplifies to determine the value of C_{FILT} based on using 10 Ω resistors for each R_{FILT}:

$$C_{FILT} \geq \frac{L_{SHUNT}}{20R_{SHUNT}}$$

If the main purpose is to filter high frequency noise, the capacitor should be increased to a value that provides the desired filtering.

As the shunt resistors decrease in value, shunt inductance can significantly affect frequency response. At values below 1 mΩ, the shunt inductance causes a zero in the transfer function that often results in corner frequencies in the low 100's of kHz. This inductance increases the amplitude of high frequency spike transient events on the current sensing line that can overload the front end of any shunt current sensing IC. This problem must be solved by filtering at the input of the amplifier. Note that all current sensing IC's are vulnerable to this problem, regardless of manufacturer claims. Filtering is required at the input of the device to resolve this problem, even if the spike frequencies are above the rated bandwidth of the device.

Advantages When Used for Low−Side Current Sensing

The NCS199AxR series offer many advantages for low−side current sensing. The true differential input is ideal for connection to either Kelvin Sensing shunts or conventional shunts. Additionally, the true differential input rejects the common−mode noise often present even in low−side current sensing. The NCS199AxR also provides a reference pin to set the output offset from an external reference. Providing all of these features in a tiny package makes the NCS199AxR very competitive when compared to discrete op amp solutions.

Designing for Input Transients Exceeding 30 Volts

For applications that have transient common−mode voltages greater than 30 volts, external input resistors of 10 Ω provide a convenient location to add either Zener diodes or transient voltage suppression diodes (also known as TVS diodes). There are two possible configurations: one using a single TVS diode with diodes across the amplifier inputs as shown in Figure 33, and the second configuration using two TVS diodes as shown in Figure 34.

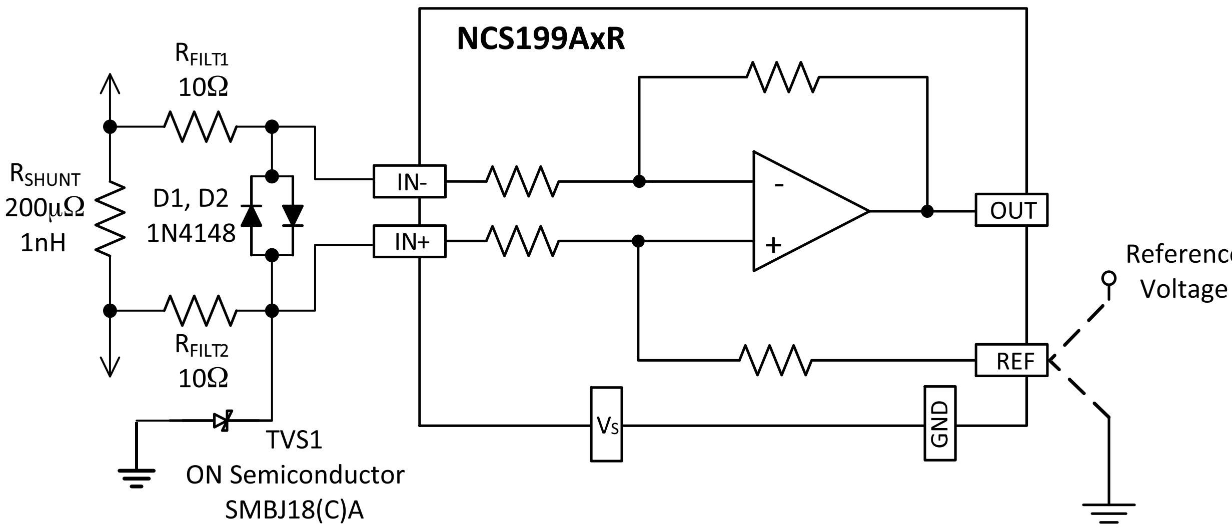


Figure 33. Single TVS transient common−mode protection

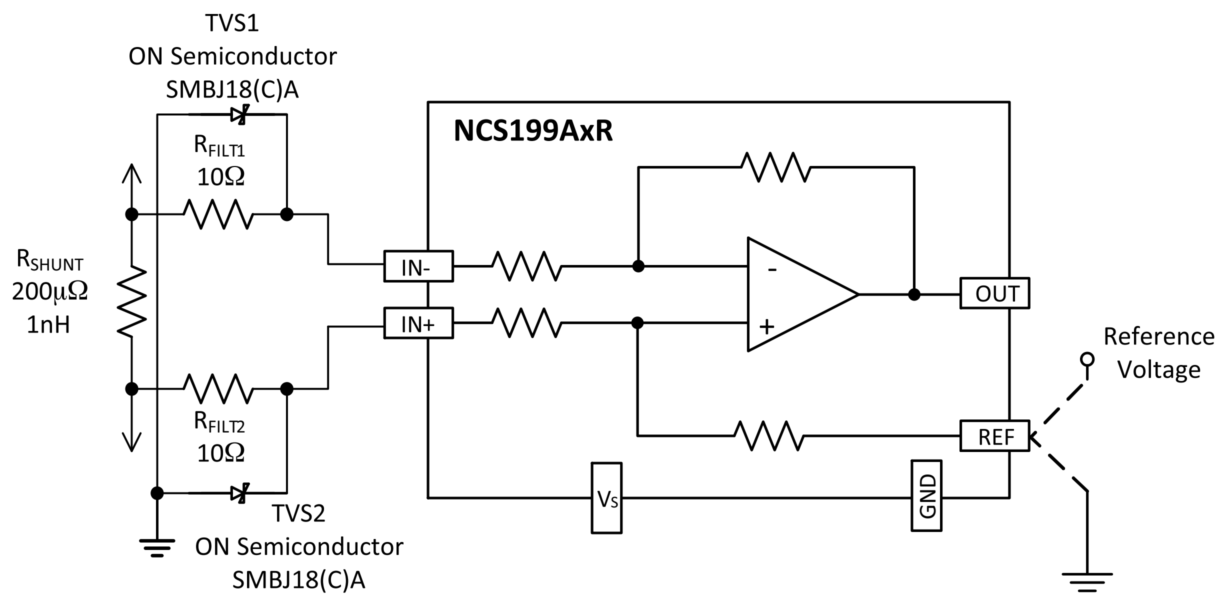


Figure 34. Dual TVS Transient Common−mode Protection

Use Zener diodes or unidirectional TVS diodes with clamping voltage ratings up to a maximum of 30 volts. Select TVS diodes with the lowest voltage rating possible for use in the system. There is a wide range between standoff voltage and maximum clamping voltage in TVS diodes. Most diodes rated at a standoff voltage of 18 V have a maximum clamping voltage of 29.2 V. Refer to the TVS data sheet and the parameters of your power supply to make the selection. In general, higher power TVS diodes demonstrate a sharper clamping knee; providing a tighter relationship between rated breakdown and maximum clamping voltage.

Selecting the Shunt Resistor

The desired accuracy of the current measurement determines the precision, shunt size, and the resistor value. The larger the resistor value, the more accurate the measurement possible, but a large resistor value also results in greater current loss.

For the most accurate measurements, use four terminal current sense resistors, as shown in Figure 35. It provides two terminals for the current path in the application circuit, and a second pair for the voltage detection path of the sense amplifier. This technique is also known as *Kelvin Sensing*. This insures that the voltage measured by the sense amplifier is the actual voltage across the resistor and does not include the small resistance of a combined connection. When using non−Kelvin shunts, follow manufacturer recommendations on how to lay out the sensing traces closely.

Figure 35. Surface Mount Kelvin Shunt

Current Output Configuration

In applications where the readout boards are remotely located, the voltage output of the NCS199AxR can be converted to a precision current output. The precision output current measurements are read more accurately as it overcomes the errors due to ground drops between the boards.

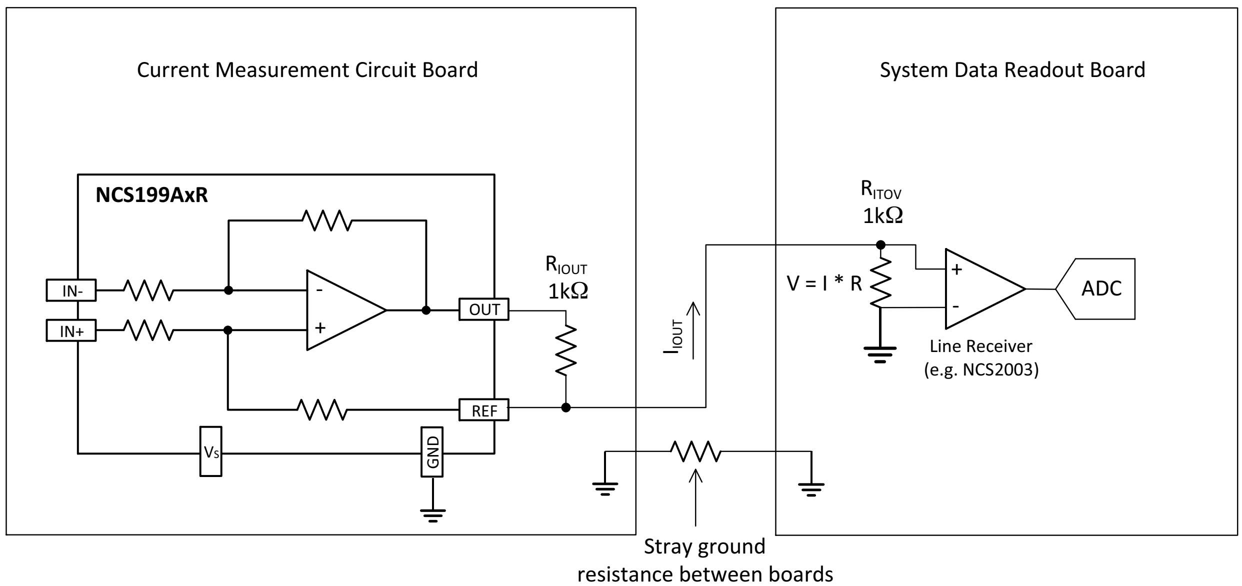


Figure 36. Remote Current Sensing

As shown in Figure 36, the R_{IOUT} resistor is added between the OUT pin and the REF pin to convert the voltage output to a current output which is taken from the REF pin to the readout board. This circuit is intended to function with low potentials between the boards due to ground drops or noise. The current output is simply the relationship of the normal output voltage of the NCS199AxR:

$$I_{OUT} = \frac{V_{OUT}}{R_{IOUT}}$$

A resistor value of 1 kΩ for R_{IOUT} is always a convenient value as it provides 1 mA/V scaling.

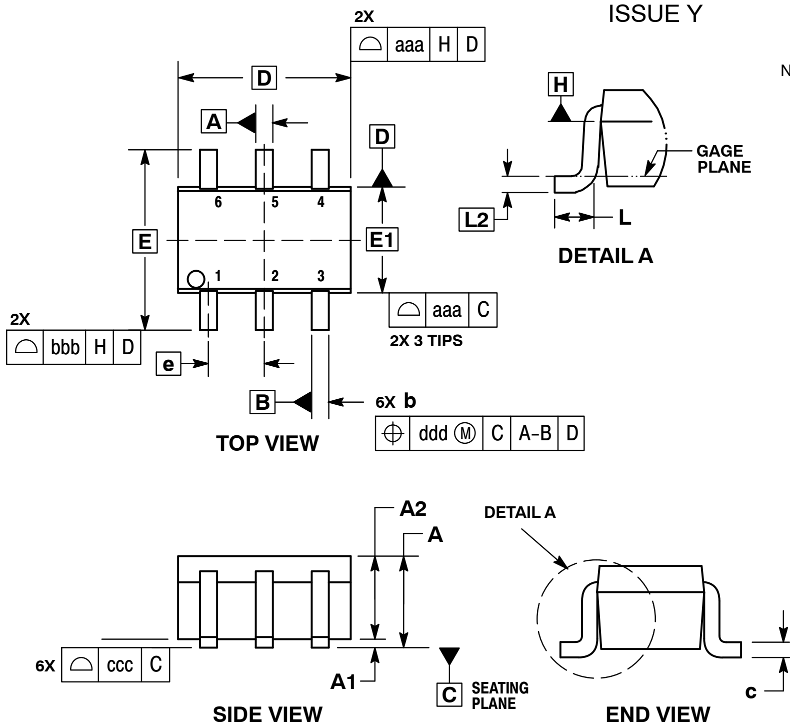
On the readout board, for simplicity, R_{ITOV} can be equal to R_{IOUT} to provide identical voltage drops across both. It is important to take into consideration that R_{ITOV} and R_{IOUT} add additional voltage drops in the current measurement path. The current source can provide enough compliance to overcome most ground voltage drop, stray voltages, and noise. However, accuracy will degrade if noise or ground drops exceed 1 V.

Shutting Down the NCS199AxR

While the NCS199AxR does not provide a shutdown pin, a simple MOSFET, power switch, or logic gate can be used to switch off the power to the NCS199AxR and eliminate the quiescent current. Note that the shunt input pins will always have a current flow via the input and feedback resistors (total resistance of each leg always equals slightly higher than 1 MΩ). Also note that when powered, the shunt input pins will exhibit the specified and well−matched typical bias current of 39 μA. The shunt input pins support the rated common mode voltage even when the NCS199AxR does not have power applied.

PACKAGE DIMENSIONS

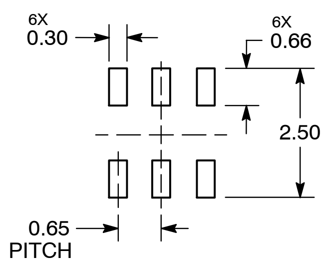
SC−88/SC70−6/SOT−363
CASE 419B−02
ISSUE Y



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSIONS D AND E1 DO NOT INCLUDE MOLD FLASH, PROTRUSIONS, OR GATE BURRS. MOLD FLASH, PROTRUSIONS, OR GATE BURRS SHALL NOT EXCEED 0.20 PER END.
4. DIMENSIONS D AND E1 AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY AND DATUM H.
5. DATUMS A AND B ARE DETERMINED AT DATUM H.
6. DIMENSIONS b AND c APPLY TO THE FLAT SECTION OF THE LEAD BETWEEN 0.08 AND 0.15 FROM THE TIP.
7. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 TOTAL IN EXCESS OF DIMENSION b AT MAXIMUM MATERIAL CONDITION. THE DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OF THE FOOT.

	MILLIMETERS			INCHES		
DIM	MIN	NOM	MAX	MIN	NOM	MAX
A	---	---	1.10	---	---	0.043
A1	0.00	---	0.10	0.000	---	0.004
A2	0.70	0.90	1.00	0.027	0.035	0.039
b	0.15	0.20	0.25	0.006	0.008	0.010
C	0.08	0.15	0.22	0.003	0.006	0.009
D	1.80	2.00	2.20	0.070	0.078	0.086
E	2.00	2.10	2.20	0.078	0.082	0.086
E1	1.15	1.25	1.35	0.045	0.049	0.053
e	0.65 BSC			0.026 BSC		
L	0.26	0.36	0.46	0.010	0.014	0.018
L2	0.15 BSC			0.006 BSC		
aaa	0.15			0.006		
bbb	0.30			0.012		
ccc	0.10			0.004		
ddd	0.10			0.004		

RECOMMENDED SOLDERING FOOTPRINT*



DIMENSIONS: MILLIMETERS

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

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