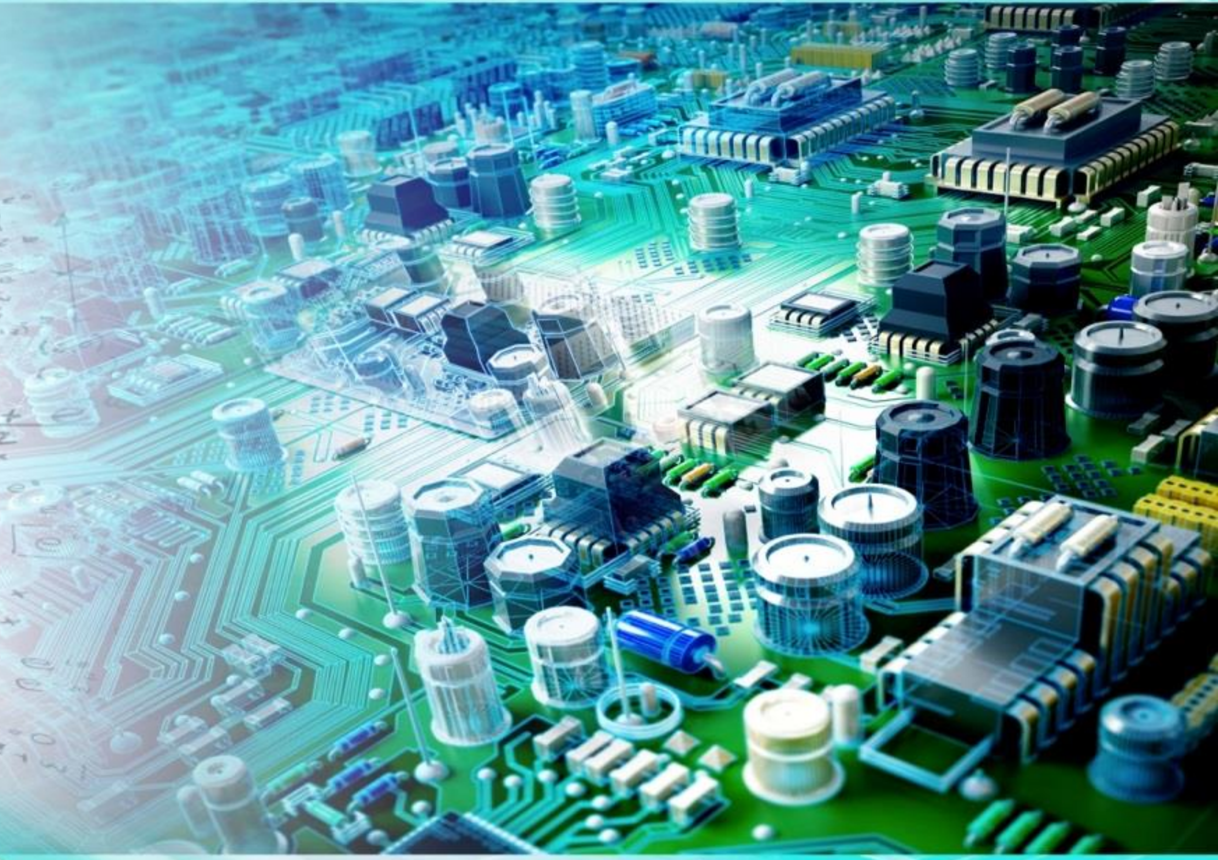
Reading Current Sense Amplifier Datasheets

TI Precision Labs – Current Sense Amplifiers



Presented and prepared by Peter Iliya

Hello, and welcome to the TI Precision Labs series on current sense amplifiers. My name is Peter Iliya, and I’m an applications engineer in the Current & Position Sensing product line. In this video, we will discuss how to read and interpret current sense amplifier datasheets.

The general TI datasheet

1. Features
2. Applications
3. Product Description
4. Functional Block Diagram (FBD)
5. Revision History
6. Pin Configuration and Functions
7. Specifications
8. Detailed Description
9. Applications
10. Layout Recommendations
11. Device & Documentation Support
12. Mechanical, Package, and Orderable Information

Front Page (items 1–4)

Specifications:

- *Absolute Maximum Ratings*
- *ESD Ratings*
- *Recommended Operating Conditions*
- *Thermal Information*
- *Electrical Characteristics (EC)Table*
- *Typical Characteristics Curves*

Let us begin by addressing the overall structure of the standard integrated-circuit datasheet. The first four sections comprise the “Front Page”, which allows the engineer to quickly determine if the part is relevant to their application. The next major section is the Specifications section, which we will spend the majority of time breaking down.

The Detailed Description and Applications sections are the textual components to the datasheet to allow for in-depth understanding.

The front page

- Brief overview of
  - Key specifications
  - Potential applications
  - Operation
  - Package options
  - Functional block diagram

Descriptor	Meaning
Low-side	Sense at 0-V V_{CM}.
High-side	Sense at $V_{CM} > V_S$.
In-line	Sense during V_{CM} switching (e.g., 0-V to 36-V).
Unidirectional	Sense current in one direction.
Bidirectional	Sense current in both directions.

TEXAS INSTRUMENTS

INA293

SBOS470 – DECEMBER 2019

INA293 –4-V to 110-V, 1-MHz, High-Precision Current Sense Amplifier

1 Features

- Wide common-mode voltage:
  - Operational voltage: −4 V to +110 V
  - Survival voltage: −20 V to +120 V
- Excellent CMRR:
  - 160-dB DC-CMRR
  - 85-dB AC-CMRR at 50 kHz
- Accuracy:
  - Gain:
    - Gain error: ±0.15% (maximum)
    - Gain drift: ±10 ppm/°C (maximum)
  - Offset:
    - Offset voltage: ±15 μV (typical)
    - Offset drift: ±0.05 μV/°C (typical)
- Available gains:
  - INA293A1, INA293B1 : 20 V/V
  - INA293A2, INA293B2 : 50 V/V
  - INA293A3, INA293B3 : 100 V/V
  - INA293A4, INA293B4 : 200 V/V
  - INA293A5, INA293B5 : 500 V/V
- High bandwidth: 1.3 MHz
- Slew rate: 2.5 V/μs
- Quiescent current: 1.5 mA

2 Applications

- Active antenna system mMIMO (AAS)
- Macro remote radio unit (RRU)
- 48-V rack server
- 48-V merchant network & server power supply (PSU)
- 48-V battery management systems (BMS)

3 Description

The INA293 is a high-precision current sense amplifier that can measure voltage drops across shunt resistors over a wide common-mode range from –4 V to 110 V. The negative common-mode voltage allows the device to operate below ground, thus accommodating precise measurement of recirculating currents in half-bridge applications. The combination of a low offset voltage, small gain error and high DC CMRR enables highly accurate current measurement. The INA293 is not only designed for DC current measurement, but also for high-speed applications (ex. Fast over-current protection) with a high bandwidth of 1.3 MHz and an 85-dB AC CMRR (at 50 kHz).

The INA293 operates from a single 2.7-V to 20-V supply, drawing 1.5 mA of supply current. The INA293 is available with five gain options: 20 V/V, 50 V/V, 100 V/V, 200 V/V, and 500 V/V. These gain options address wide dynamic range current-sensing applications.

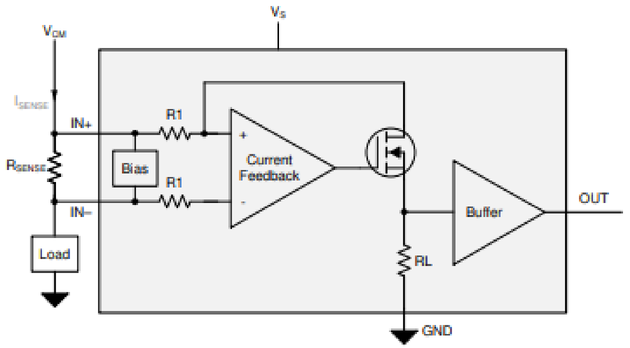
The INA293 is specified over an operating temperature range of −40°C to +125°C and is offered in a space-saving SOT-23 package with two pin-out variants.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA293	SOT-23 (5)	2.90 mm × 1.60 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.

Functional Block Diagram

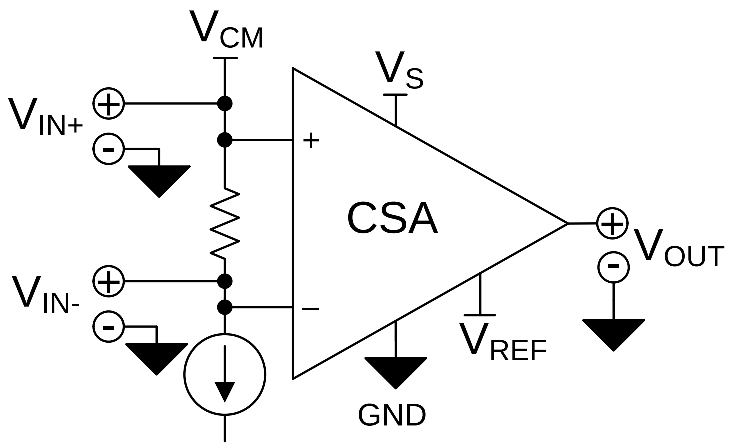


The front page of the datasheet allows the reader to quickly determine whether a part could or could not work in their system. Aside from key electrical specifications like offset and IQ, the front page for current-sense amplifiers, or CSAs for short, can contain key functional descriptors. Some devices are best designed to sense at relatively stable common-mode voltages, in which case they are low-side and/or high-side capable. Other devices can have the ability to accurately sense current while the input common-mode voltage, or VCM, is switching rapidly. This is referred to as in-line sensing.

A unidirectional device is one that can only sense current flowing in one direction, while a bidirectional current sense amplifier can sense current flowing in both directions across the shunt resistor. Analog, bidirectional amplifiers will most always have a reference pin that allows the output voltage to be offset, usually to mid-supply.

Absolute maximum ratings (“abs max”)

- Define the maximum (minimum) voltages for all pins & temperatures of device.



6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
Supply Voltage (V_s)		-0.3	22	V
Analog Inputs, V_{IN+}, $V_{IN–}$ (2)	Differential (V_{IN+}) – ($V_{IN–}$), INA293A5, INA293B5	–6	6	V
	Differential (V_{IN+}) – ($V_{IN–}$), All others	–12	12	
	Common - mode	–20	120	
Output		GND – 0.3	Vs + 0.3	V
T_A	Operating temperature	–55	150	°C
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Rating* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Condition*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) VIN+ and VIN– are the voltages at the IN+ and IN– pins, respectively.

Footnote (2) specifies that the “Common-mode” rating is really an absolute voltage rating for each pin separately.

The Absolute Maximum Ratings section, or “Abs Max”, are the limits beyond which permanent damage may occur. For current-sense amplifiers, the most critical rating is usually the input “Common-mode” voltage rating for the input pins. The voltage at the input pins cannot go beyond the ratings specified, even for very short events or else the device can be permanently damaged.

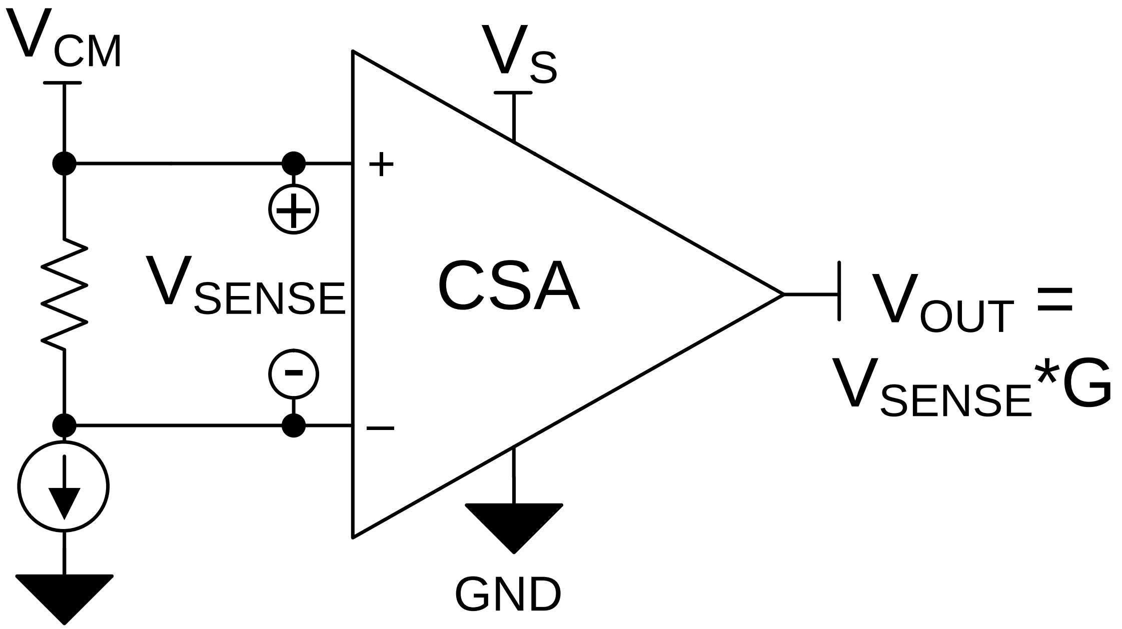
Note that the “Common-mode” rating is not representing the standard definition (the average voltage of input pins). This rating pertains to the individual absolute voltage at each pin.

Recommended operating conditions (ROC)

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V_{CM}	Common-mode input range	-4	48	110	V
V_S	Operating supply range	2.7	5	20	V
V_{SENSE}	Differential sense input range	0		V_S / G	V
T_A	Ambient temperature	–40		125	°C



The recommended operating conditions detail the range of conditions the device is designed to operate within . These conditions will always be more limited compared to the Absolute Maximum ratings.

Datasheet specifications (“specs”)

7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, V_{SENSE} = V_{IN+} – $V_{IN–}$, V_{CM} = 12 V, and V_{REF1} = V_{REF2} = V_S / 2 (unless otherwise noted)

Global test conditions

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV T_A = – 40°C to 125°C	–4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV T_A = –40°C to 125°C	120	132		dB
		f = 50 kHz		93		
V_{OS}	Offset voltage, input-referred	V_{SENSE} = 0 mV		±5	±25	μV

7.6 Typical Characteristics

at T_A = 25°C, V_S = 5 V, V_{CM} = 12 V, and V_{REF} = V_S / 2 (unless otherwise noted)

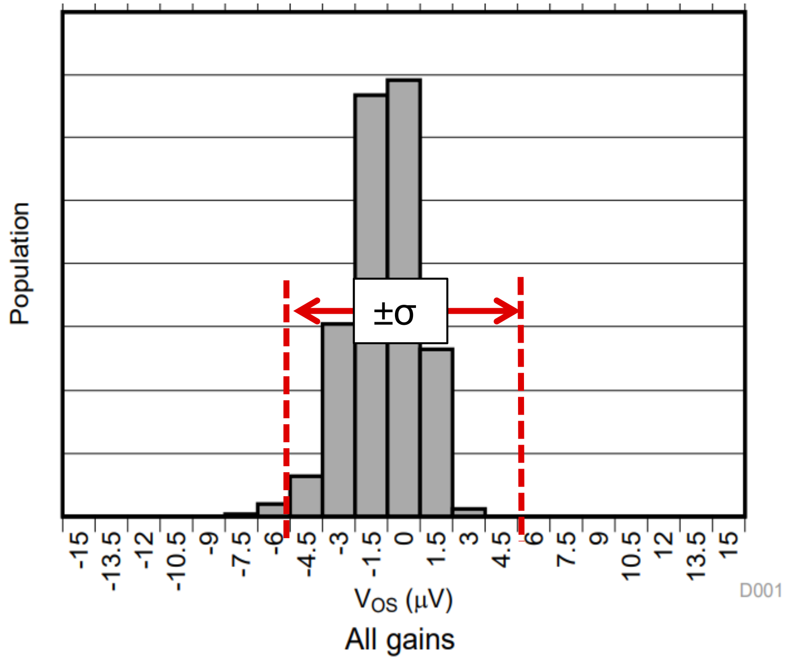
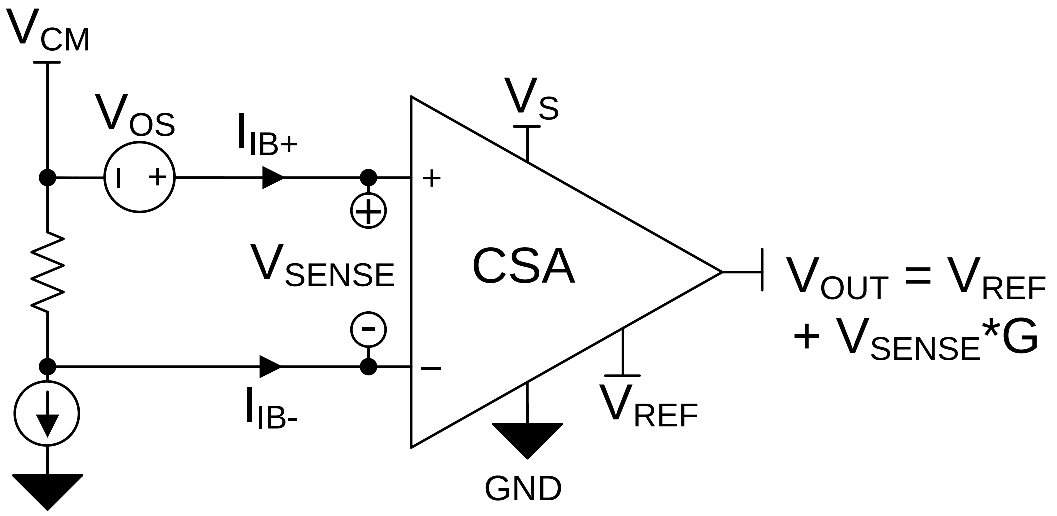


Figure 1. Input Offset Voltage Production Distribution



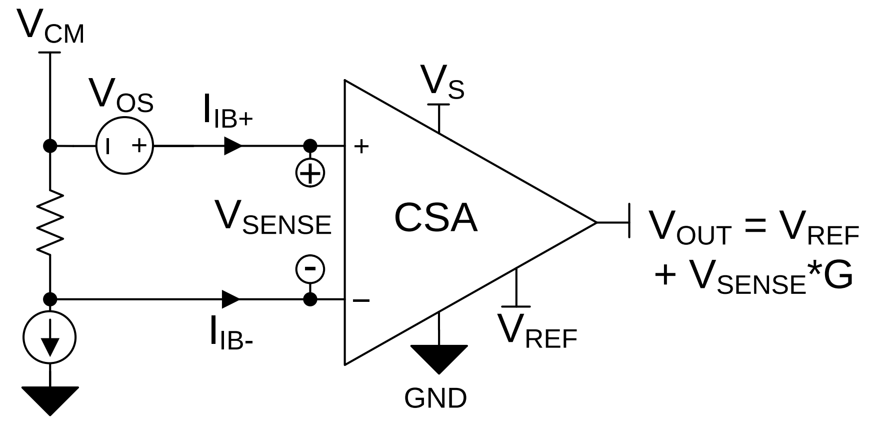
Before detailing the specifications individually, let us address the structure. Specifications are broken up into two sections: the parametric table and the typical datasheet plots. Each will have their own global testing conditions listed at the top, which detail how the device was tested unless otherwise noted.

The difference between the table and the plots, is that the specification table will list typical and maximum specification values. The typical specification value normally covers plus or minus one standard deviation, OR plus or minus sigma on a Gaussian distribution of a single test population. This means that roughly 68% of the device population will be less than the typical value. For some parameters, typical specifications may represent the mean value of a distribution.

The maximum and minimum specifications can be referred to as “Limit specs” or “max specs” and are more important than the typical. Max specs are guaranteed at their testing conditions shown. They can be guaranteed through test, a statistical characterization, and or design. So for this part and it specification shown you will never find a device with an offset greater than the maximum of plus or minus 25 microvolts given the device is operating with the exact same testing conditions.

It is important to note that the typical characteristic plots represent a one-time characterization of a single device or population manufactured around the time of the device’s release. Because of this, the true center of the distribution can vary slightly over time due to process variation; however, the maximum and minimum values do not fluctuate as these can be screened for during final testing. This is why it is important to always use the max specs when performing an error analysis.

Electrical characteristics table – Input



7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$, V_{CM} = 12 V, and $V_{REF1} = V_{REF2} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input range	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV T_A = – 40°C to 125°C	–4		80	V
CMRR	Common-mode rejection ratio	V_{IN+} = –4 V to 80 V, V_{SENSE} = 0 mV T_A = –40°C to 125°C	120	132		dB
		f = 50 kHz		93		
V_{OS}	Offset voltage, input-referred	V_{SENSE} = 0 mV		±5	±25	µV
dV_{OS}/dT	Offset voltage drift	V_{SENSE} = 0 mV, T_A = –40°C to 125°C		±50	±250	nV/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{SENSE} = 0 mV T_A = –40°C to 125°C		±1	±10	µV/V
I_B	Input bias current	I_{B+}, I_{B-}, V_{SENSE} = 0 mV		90		µA

V_{CM} operation and CMR performance ensured over temperature range.

Offsets are usually referred to the input (RTI), unless otherwise specified.

- I_{IB} is defined with no input voltage (V_{SENSE} = 0 mV).
- I_{IB} applies for both IN+ and IN- pins.

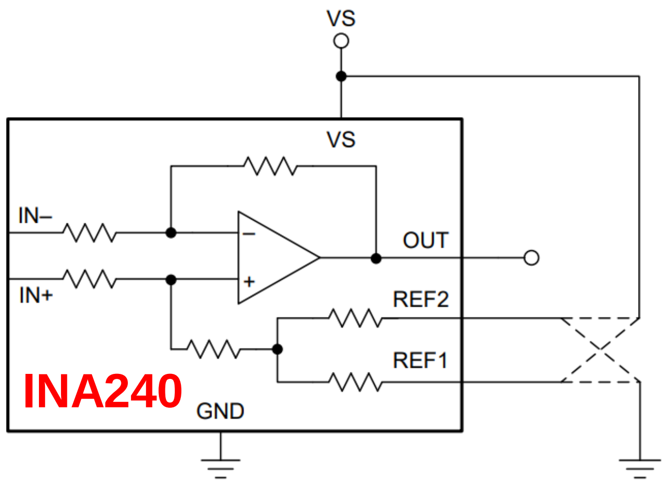
Key Takeaway → *Lowest, guaranteed device offset (±25 µV) will occur under the global test conditions: T_A = 25°C, V_S = 5 V, V_{CM} = 12 V, $V_{REF1} = V_{REF2}$ = 2.5 V.*

Continuing along with specification table, specifically the input section, we see the many common specifications reported in most amplifier datasheets. Note that common-mode voltage is independent of supply and it is tested over temperature, so regardless of a system's operating temperature, the worst-case CMRR of 120 dB should be used when calculating a total offset.

While some specs may not dictate it, all of the error sources such as CMRR, drift, and PSRR, should be considered input-referred, unless otherwise stated. This allows for the easy calculation of a worst-case input offset when performing an error analysis. Note that when the conditions list Vsense equaling 0, this means the inputs are shorted together. This is seen with the input bias current spec.

One key takeaway from these specs is that the lowest, guaranteed offset error will occur when the device is operating at the global testing conditions. Since CMRR, PSRR, and offset drift could be positive or negative, the addition of their respective offsets errors can always yield a larger offset voltage. Simply put, if the device is operating at the global testing conditions, then additional offsets from CMR, PSR, and drift will not be generated.

Electrical characteristics table – Output / Gain



Offset error specific to the INA240 architecture.

INA240 should not drive a capacitive load > 1nF, especially over temperature.

7.5 Electrical Characteristics

at T_A = 25 °C, VS = 5 V, $V_{SENSE} = V_{IN+} – V_{IN–}$, V_{CM} = 12 V, and $V_{REF1} = V_{REF2} = V_S / 2$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
G	Gain	INA240A1		20		V/V
		INA240A2		50		
		INA240A3		100		
		INA240A4		200		
	Gain error	GND + 50 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.05%	±0.20%	
		T_A = –40°C to 125°C		±0.5	±2.5	ppm/°C
	Non-linearity error	GND + 10 mV ≤ V_{OUT} ≤ V_S – 200 mV		±0.01%		
	Reference divider accuracy	V_{OUT} = | (V_{REF1} – V_{REF2}) | / 2 at V_{SENSE} = 0 mV, T_A = –40°C to 125°C		0.02%	0.1%	
RVRR	Reference voltage rejection ratio (input-referred)	INA240A1		20		μV/V
		INA240A3		5		
		INA240A2, INA240A4		2		
	Maximum capacitive load	No sustained oscillation		1		nF

RVRR creates an input offset similar to CMRR and PSRR.

Key Takeaway → *Lowest, guaranteed device gain error (±0.2% ±0.01%) will occur under the global test conditions and when 50 mV + V_{OUT} ≤ V_{OUT} ≤ V_S – 200 mV.*

Next is the output specifications section. Since gain error dominates as sense voltage increases, this section provides the device's baseline error. A current sense amplifier family can have multiple gain variants. The real gain will deviate from its typical value. Using two data points and calculating the slope, or device's true gain, a gain error can be established. For this example, once the output voltage drops below 50mV or exceeds Vs-200mV, then the gain error of the device can begin to deviate from the specification. For more information consider watching our gain error video.

Specific to the INA240, there is another error listed in the datasheet called "Reference divider accuracy". This specifies the absolute error in the reference voltage created by supplying a reference when driving both REF1 and REF2 pin to separate voltage levels. Note that this is an offset error and not a gain error since the testing conditions show Vsense equal to 0mV.

Another offset error here is the reference voltage rejection ratio, or RVRR. This specification works the same way as CMRR and PSRR, in that as the reference voltage deviates from testing condition of Vs/2, there will be some change in the offset.

Lastly a common spec for many CSA is the maximum capacitive load with no sustained oscillation, which says the INA240 should not drive a purely capacitive load greater than 1nF, especially over temperature.

Once again, a key takeaway when studying these specs is that lowest, guaranteed gain error will occur when device is operating under its testing conditions, which include the global and that the VOUT is within the specified range.

Electrical characteristics table – Voltage Output

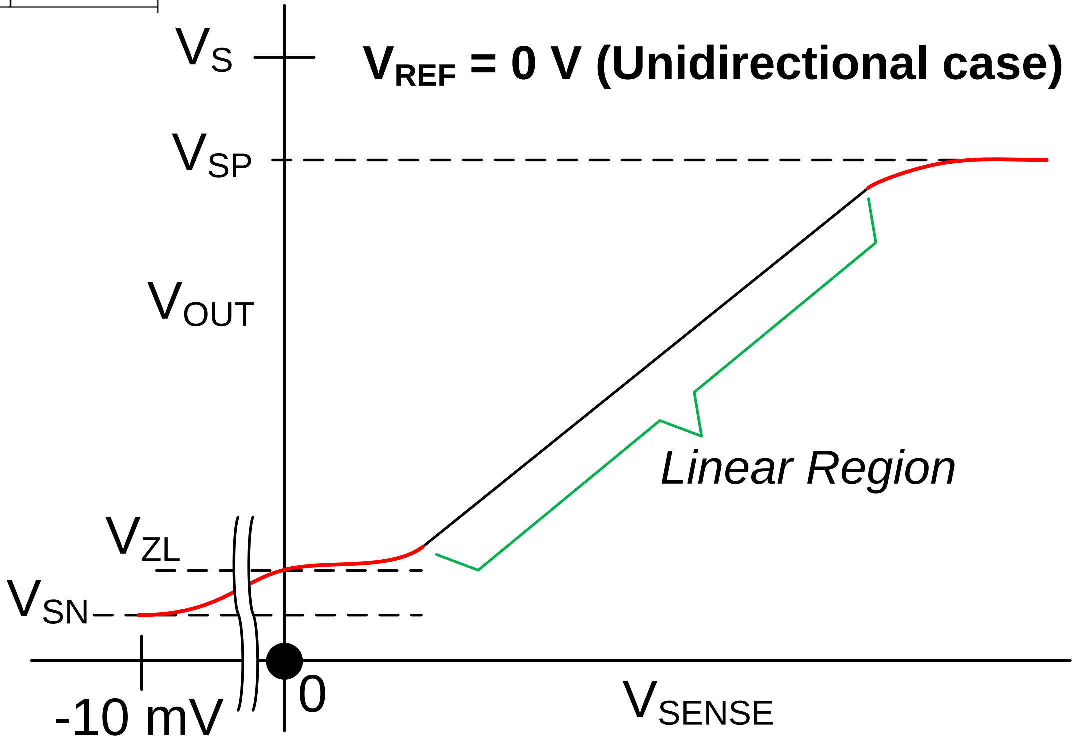
6.5 Electrical Characteristics

at T_A = 25°C, V_{SENSE} = V_{IN+} – $V_{IN–}$, V_S = 1.8 V to 5.0 V, V_{IN+} = 12 V, V_{REF} = V_S / 2, and V_{ENABLE} = V_S (unless otherwise noted)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
VOLTAGE OUTPUT							
V_{SP}	Swing to V_S power-supply rail	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C			(V_S) – 20	(V_S) – 40	mV
V_{SN}	Swing to GND	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = –10 mV, V_{REF} = 0 V			(V_{GND}) + 0.05	(V_{GND}) + 1	mV
V_{ZL}	Zero current output voltage	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = 0 mV, V_{REF} = 0 V	A1, A2, A3 devices		(V_{GND}) + 1	(V_{GND}) + 3	mV
			A4 devices		(V_{GND}) + 2	(V_{GND}) + 4	mV
			A5 devices		(V_{GND}) + 3	(V_{GND}) + 9	mV

V_{SP}, V_{SN}, & V_{ZL} are specified at a single output current (I_{OUT} = V_{OUT}/R_L.

Spec	Meaning	V_{SENSE} (V_{REF} = 0 V)
V_{SP}	How close OUT can swing to V_S rail.	
V_{SN}	How close OUT can swing to GND rail.	
V_{ZL}*	OUT voltage when inputs are shorted.	



*V_{ZL} is not always specified explicitly. Sometimes V_{SN} is specified with V_{SENSE} = 0mV. Overall, V_{ZL} can always be approximated with V_{ZL} = $V_{OS,MAX}$*$Gain_{MAX}$.

The next specification section is for voltage output. These are the swing to rail specifications and they do not necessarily determine the linear region of the device, rather they detail the physical operating capabilities of the device's output stage. The specified linear region is ultimately determined using the testing conditions for gain error as seen in previous slide.

So let us explain the meaning of each spec. Swing-to-Vs power rail (or VSP) shows how close the output voltage can swing to the VS rail. This is accomplished by overdriving the input with a voltage beyond the full-scale range of the device.
The swing-to-GND (or VSN) conversely shows how close OUT can swing the GND rail by overdriving the input with a voltage below the full-scale range. In this example, since the VREF=0V for the testing condition, a Vsense of -10mV will slam the output to ground.

The third specification is the zero-current output voltage (or VZL) and it can be helpful in understanding where the output can start when sense current is zero Amps, or essentially when the inputs are shorted. Note that the VZL is not always specified and that sometime VSN is specified with Vsense = 0mV, so be sure to always check the testing conditions. If needed, VZL can be approximated by calculating the worst-case offset and multiplying it with the worst-case gain.

Lastly, note that each specification shows a 10kΩ load resistor to ground, which means each specification is tested at a single output current.

Voltage output and the "claw curve"

6.5 Electrical Characteristics

at T_A = 25°C, $V_{SENSE} = V_{IN+} - V_{IN-}$, V_S = 1.8 V to 5.0 V, V_{IN+} = 12 V, $V_{REF} = V_S / 2$, and $V_{ENABLE} = V_S$ (unless otherwise noted)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
VOLTAGE OUTPUT						
V_{SP}	Swing to V_S power-supply rail	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C		$(V_S) - 20$	$(V_S) - 40$	mV
V_{SN}	Swing to GND	V_S = 1.8 V, R_L = 10 kΩ to GND, T_A = –40°C to +125°C, V_{SENSE} = –10 mV, V_{REF} = 0 V		$(V_{GND}) + 0.05$	$(V_{GND}) + 1$	mV

Typical Characteristics (continued)

at T_A = 25°C, V_S = 1.8 V, V_{IN+} = 12 V, $V_{REF} = V_S / 2$, $V_{ENABLE} = V_S$, and for all gain options (unless otherwise noted)

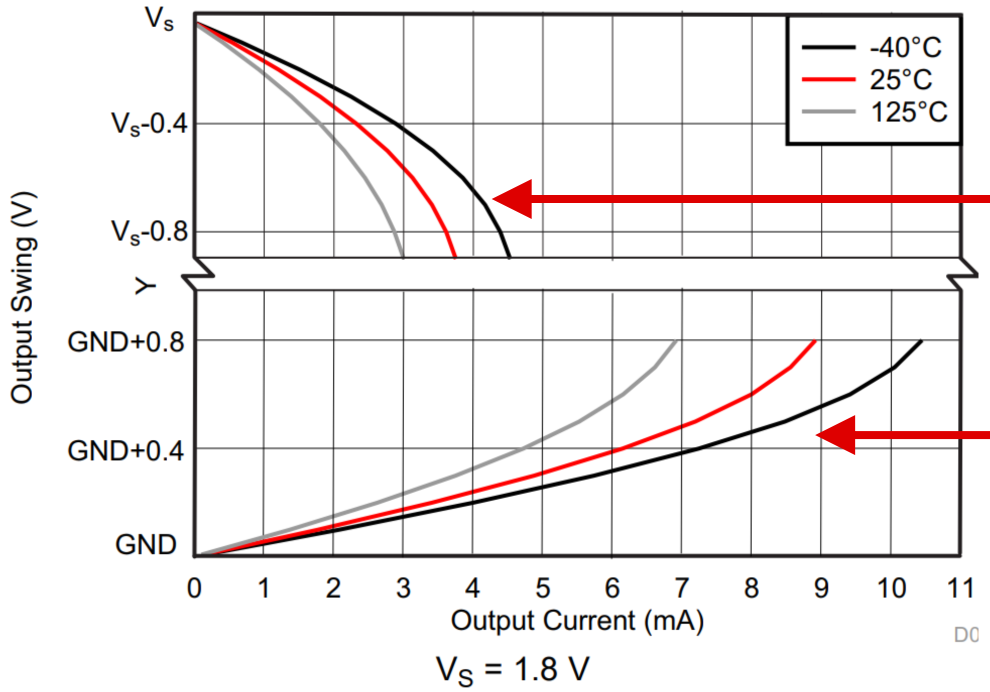


Figure 12. Output Voltage Swing vs Output Current

I_{OUT} sourcing (flows out of OUT)

- As more I_{OUT} is required, V_{SP} increases.

I_{OUT} sinking (flows into OUT)

- As more I_{OUT} is required, V_{SN} increases.

While discussing the output swing specifications, it is important to understand their relationship to the typical characteristic plot of output voltage vs output current, or what can be referred to as the “claw curve” due to its resemblance.

Let’s start with the VSP spec. The VSP spec is determined by overdriving the input and measuring VOUT. The output current (or IOUT) can be calculated by VOUT divided by the load resistor (or RL), which is 1.8V/10kΩ, equaling 180μA.

But what happens to VSP when the output load is higher creating a larger IOUT. This is in fact what the “claw curve” shows. By connecting a variable load to OUT pin and simultaneously measuring VOUT, we can characterize how the swing specs change as IOUT increases. The top curves represent sourcing IOUT currents, which flow out of OUT pin. The relationship is: as sourcing IOUT increases, so does the VSP.

The bottom curves represent sinking currents, which flow into the OUT pin. The relationship is: as sinking current IOUT increases, so does the VSN.

Overall, the more current the amplifier is required to drive, the less output dynamic range it will have because it’s swing-to-the-rail capability will decrease.

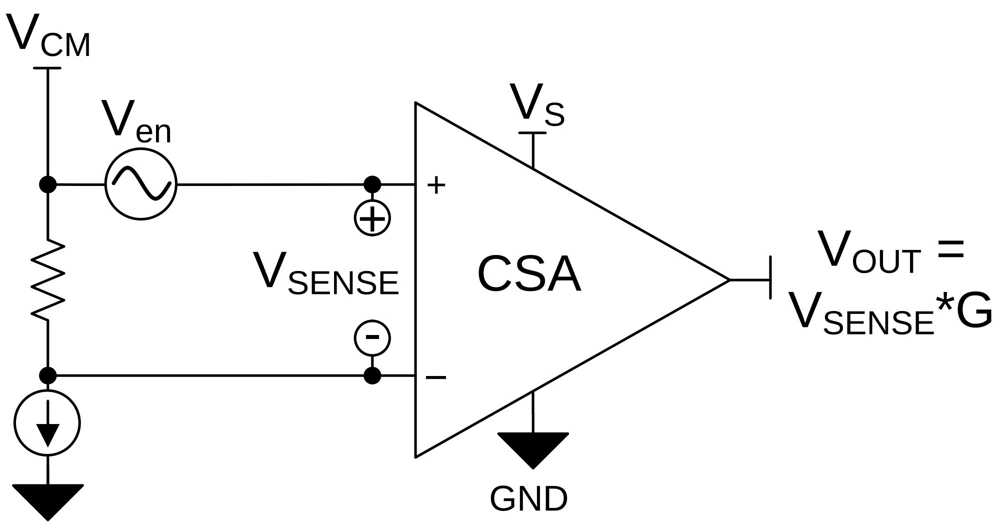
Electrical characteristics table – AC, Noise, Power

6.5 Electrical Characteristics

at T_A = 25 °C, V_S = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$ = 0.5 V / Gain, $V_{CM} = V_{IN-}$ = 48 V (unless otherwise noted)

FREQUENCY RESPONSE						
BW	Bandwidth	INA293x1, C_{LOAD} = 5 pF, V_{SENSE} = 200 mV		1300		kHz
		INA293x2, C_{LOAD} = 5 pF, V_{SENSE} = 80 mV		1300		
		INA293x3, C_{LOAD} = 5 pF, V_{SENSE} = 40 mV		1000		
		INA293x4, C_{LOAD} = 5 pF, V_{SENSE} = 20 mV		900		
		INA293x5, C_{LOAD} = 5 pF, V_{SENSE} = 8 mV		900		
SR	Slew rate	Rising edge		2.5		V/µs
	Settling time	V_{OUT} = 4 V ± 0.1 V step, Output settles to 0.5%		10		µs
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 1%		5		
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 5%		1		
NOISE						
Ven	Voltage noise density			50		nV/√Hz
POWER SUPPLY						
Vs	Supply voltage	T_A = –40°C to +125°C	2.7		20	V
I_Q	Quiescent current			1.5	2	mA
		T_A = -40°C to +125°C			2.25	mA

V_{SENSE} > 0 V to provide DC bias for unidirectional CSAs.



The last section of parametric specifications are frequency response, noise, and power supply. The specifications shown are for the INA293, which is a unidirectional amplifier so it has no reference pin. This means its input will require some DC bias voltage to offset the amplifier into the linear region when determining small-signal AC analyses. This is also shown in the testing conditions with DC input voltages that are scaled according to device variants' gain. The AC input Vsense is not specified, but it should be assumed to be a small-signal, so somewhere in the range of 1 mV to 100 mV depending upon the device's gain.

Slew rate for CSAs is always referred to the output and by definition slew rate is a large-signal analysis parameter.
Settling times are a function of BW and based upon a small-signal analysis while device output is in the linear region. This can be confirmed with the testing conditions listed as ± 0.1V step on top of a 4V output bias. Note that if the device was bidirectional and had a reference pin, then the input bias voltages would not be needed for these specifications.

Voltage noise density is always referred to the input and considered broadband. Similar to operational amplifiers, noise density can be modeled as a voltage source at the IN+ pin of the CSA as shown in the schematic.

The power supply requirements are straight-forward, but note that IQ (quiescent current) could vary depending on the common-mode and supply voltages.

In order to determine more specific behavior, the engineer must study the typical characteristic plots.

To find more current sense amplifier technical resources and search products, visit ti.com/currentsense

That concludes this video - thank you for watching! Please try the quiz to check your understanding of the content.

For more information and videos on current sense amplifiers please visit ti.com/currentsense.

Reading Current Sense Amplifier Datasheets

TI Precision Labs – Current Sense Amplifiers

Quiz

Reading CSA Datasheets – quiz

1. Is the following device capable of measuring voltages at 0-V common-mode?

TEXAS INSTRUMENTS

INA138-Q1, INA168-Q1

SGLS174J – SEPTEMBER 2003 – REVISED AUGUST 2018

INA1x8-Q1 Automotive-Grade, High-Side, Current-Output, Current-Shunt Monitor

1 Features

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
  - Device Temperature Grade 1: –40°C to 125°C Ambient Operating Temperature Range
  - Device HBM ESD Classification Level 2
  - Device CDM ESD Classification Level C6
- Complete Unipolar High-Side Current-Measurement Circuit
- Wide Supply and Common-Mode Ranges:
  - INA138-Q1: 2.7 V to 36 V
  - INA168-Q1: 2.7 V to 60 V
- Independent Supply and Input Common-Mode Voltages
- Single Resistor Gain Set
- Low Quiescent Current (25 µA Typical)
- Wide Temperature Range: –40°C to +125°C
- Packages: TSSOP-8, SOT-23-5 (INA168-Q1)

2 Applications

- Electric Power Steering (EPS) Systems
- Body Control Modules
- Brake Systems
- Electronic Stability Control (ESC) Systems

3 Description

The INA138-Q1 and INA168-Q1 (INA1x8-Q1) devices are high-side, unidirectional, current sense amplifiers. Wide input common-mode voltage range, low quiescent current, and TSSOP and SOT-23 packaging enable use in a variety of applications.

Input common-mode and power-supply voltages are independent, and range from 2.7 V to 36 V for the INA138-Q1, and 2.7 V to 60 V for the INA168-Q1. Quiescent current is only 25 µA, which permits connecting the power supply to either side of the current-measurement shunt with minimal error.

The device converts a differential input voltage to a current output. This current is converted back to a voltage with an external load resistor that sets any gain from 1 to over 100. Although designed for current shunt measurement, the circuit invites creative applications in measurement and level shifting.

Both devices are available in a TSSOP-8 package. The INA168-Q1 is also available in a SOT-23-5 package. Both devices are specified for the –40°C to +125°C temperature range.

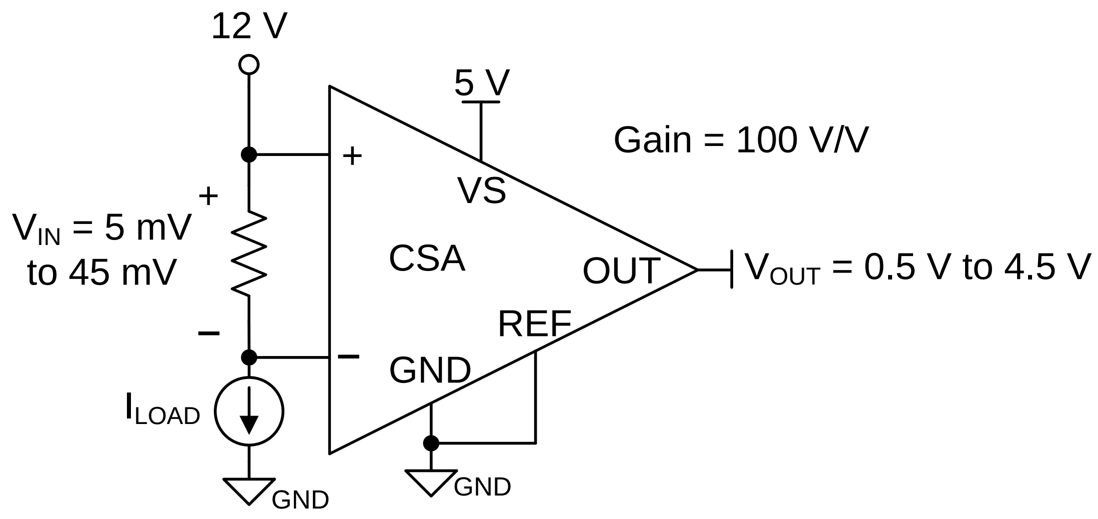
Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA138-Q1	TSSOP (8)	4.40 mm × 3.00 mm
INA168-Q1		
INA168-Q1	SOT-23 (5)	2.90 mm × 1.60 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.

Reading CSA Datasheets – quiz

2. Assuming the following circuit, which spec table would generate the lowest guaranteed error at 25°C?



at T_A = 25°C, $V_{SENSE} = V_{IN+} – V_{IN–}$, V_S = 5 V, $V_{REF} = V_S$ / 2, and V_{IN+} = 12 V (unless otherwise noted)

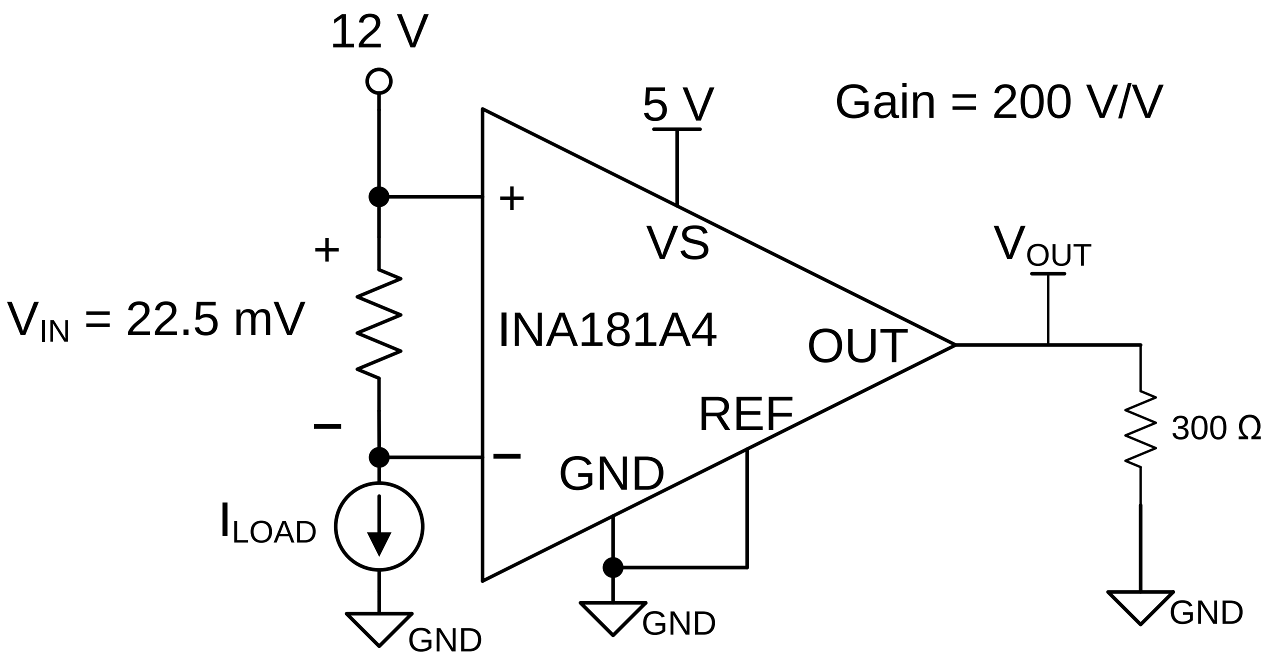
PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
INPUT							
CMRR	Common-mode rejection ratio, RTI [1]	V_{IN+} = 0 V to 26 V, V_{SENSE} = 0 mV, T_A = –40°C to +125°C	A1 device	86	100		dB
			A2, A3 devices	96	100		
			A4 devices	106	120		
V_{OS}	Offset voltage, RTI	V_{SENSE} = 0 mV, V_{IN+} = 0 V	A1 devices		±25	±135	µV
			A2, A3, A4 devices		±5	±55	
		V_{SENSE} = 0 mV, V_{IN+} = 12 V	A1 devices		±100	±450	
			A2, A3 devices		±25	±130	
			A4 device		±25	±100	
dV_{OS}/dT	Offset drift, RTI	V_{SENSE} = 0 mV, T_A = –40°C to +125°C			0.2	0.5	µV/°C
PSRR	Power supply rejection ratio, RTI	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, V_{SENSE} = 0 mV			±8	±30	µV/V
I_B	Input bias current	V_{SENSE} = 0 mV, V_{CM} = 0 V			-6		µA
		V_{SENSE} = 0 mV			75		
I_{IO}	Input offset current	V_{SENSE} = 0 mV			±0.05		µA
OUTPUT							
G	Gain		A1 devices		20		V/V
			A2 devices		50		
			A3 devices		100		
			A4 devices		200		
E_G	Gain error	V_{OUT} = 0.5 V to V_S – 0.5 V, T_A = –40°C to +125°C	A1, A2, A3 devices		±0.05%	±0.2%	
			A4 device		±0.07%	±0.25%	
	Gain error drift	T_A = –40°C to +125°C			1.5	8	ppm/°C

at T_A = 25°C, $V_{SENSE} = V_{IN+} – V_{IN–}$ = 10 mV, V_S = 5 V, V_{IN+} = 12 V, and V_{LIMIT} = 2 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input voltage range		0		36	V
V_{IN}	Differential input voltage range	$V_{IN} = V_{IN+} – V_{IN–}$, INA301A1	0		250	mV
		$V_{IN} = V_{IN+} – V_{IN–}$, INA301A2	0		100	
		$V_{IN} = V_{IN+} – V_{IN–}$, INA301A3	0		50	
CMR	Common-mode rejection	INA301A1, V_{IN+} = 0 V to 36 V, T_A = –40ºC to +125ºC	100	110		dB
		INA301A2, V_{IN+} = 0 V to 36 V, T_A = –40ºC to +125ºC	106	118		
		INA301A3, V_{IN+} = 0 V to 36 V, T_A = –40ºC to +125ºC	110	120		
V_{OS}	Offset voltage, RTI [1]	INA301A1		±25	±125	µV
		INA301A2		±15	±50	
		INA301A3		±10	±35	
dV_{OS}/dT	Offset voltage drift, RTI [1]	T_A= –40ºC to +125ºC		0.1	0.5	µV/ºC
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, T_A = –40ºC to +125ºC		±0.1	±10	µV/V
I_B	Input bias current	I_{B+}, $I_{B–}$		120		µA
I_{OS}	Input offset current	V_{SENSE} = 0 mV		±0.1		µA
OUTPUT						
G	Gain	INA301A1		20		V/V
		INA301A2		50		
		INA301A3		100		
	Gain error	INA301A1, V_{OUT} = 0.5 V to V_S – 0.5 V		±0.03%	±0.1%	
		INA301A2, V_{OUT} = 0.5 V to V_S – 0.5 V		±0.05%	±0.15%	
		INA301A3, V_{OUT} = 0.5 V to V_S – 0.5 V		±0.11%	±0.2%	
		T_A= –40ºC to 125ºC		3	10	ppm/ºC

Reading CSA Datasheets – quiz

3. Can the following circuit amplify the input to 4.5 V?



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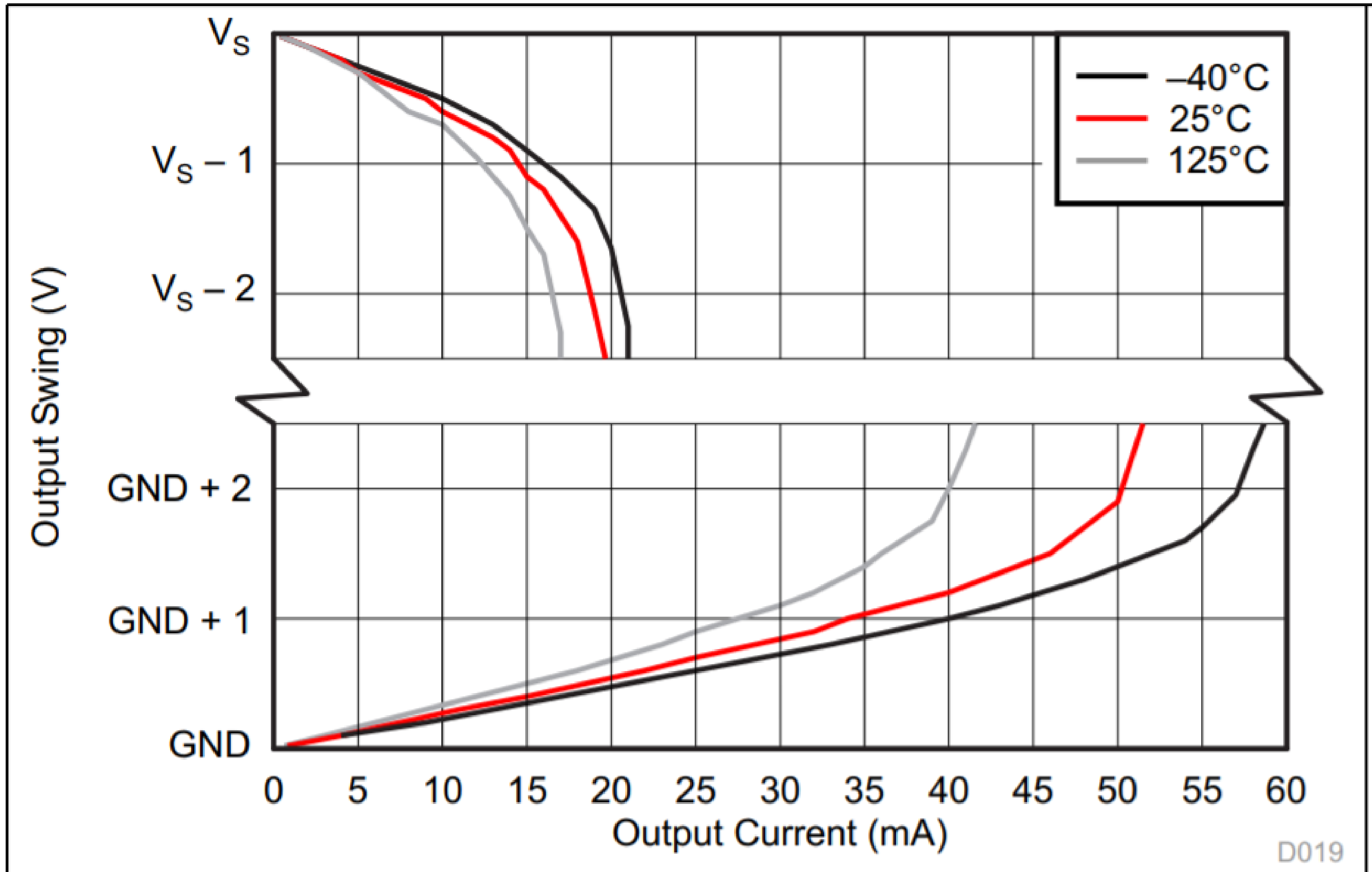
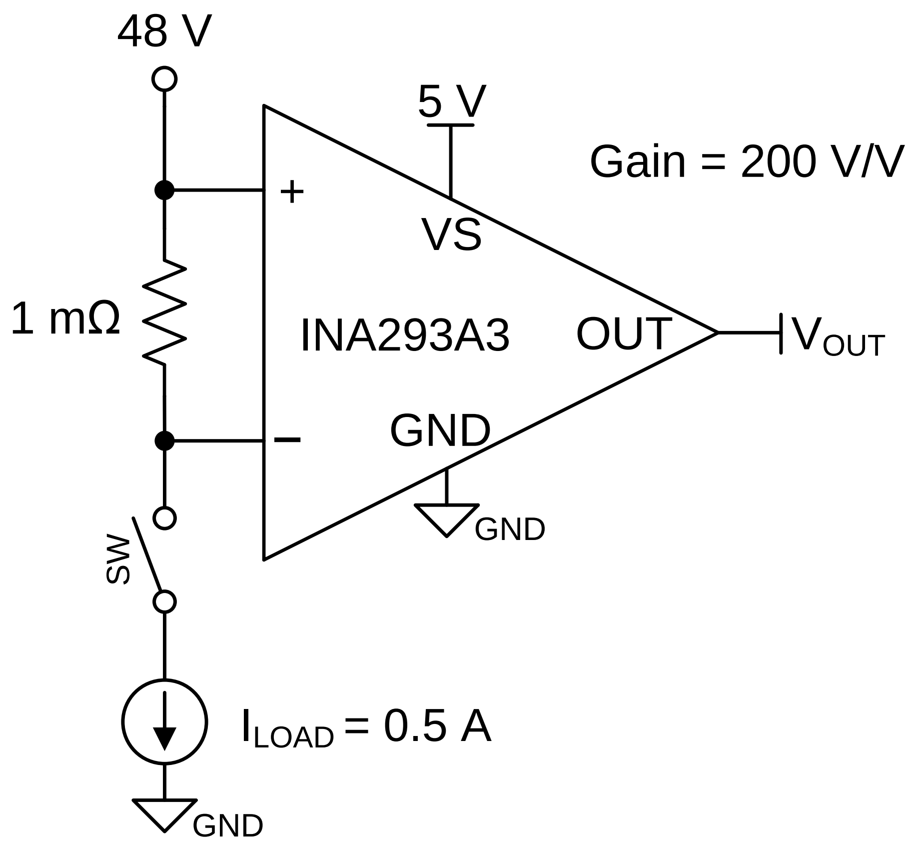


Figure 19. Output Voltage Swing vs Output Current

Reading CSA Datasheets – quiz

4. Will the following amplifier's output voltage response typically settle to 1% error within 5 µs once SW is closed?



6.5 Electrical Characteristics

at T_A = 25 °C, V_S = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$ = 0.5 V / Gain, $V_{CM} = V_{IN-}$ = 48 V (unless otherwise noted)

FREQUENCY RESPONSE					
BW	Bandwidth	INA293x1, C_{LOAD} = 5 pF, V_{SENSE} = 200 mV		1300	kHz
		INA293x2, C_{LOAD} = 5 pF, V_{SENSE} = 80 mV		1300	
		INA293x3, C_{LOAD} = 5 pF, V_{SENSE} = 40 mV		1000	
		INA293x4, C_{LOAD} = 5 pF, V_{SENSE} = 20 mV		900	
		INA293x5, C_{LOAD} = 5 pF, V_{SENSE} = 8 mV		900	
SR	Slew rate	Rising edge		2.5	V/µs
	Settling time	V_{OUT} = 4 V ± 0.1 V step, Output settles to 0.5%		10	µs
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 1%		5	
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 5%		1	
NOISE					
Ven	Voltage noise density			50	nV/√Hz
POWER SUPPLY					
Vs	Supply voltage	T_A = –40°C to +125°C	2.7	20	V
I_Q	Quiescent current		1.5	2	mA
		T_A = -40°C to +125°C		2.25	mA

Answers

Reading CSA Datasheets – quiz

1. Is the following device capable of measuring voltages at 0-V common-mode?

TEXAS INSTRUMENTS

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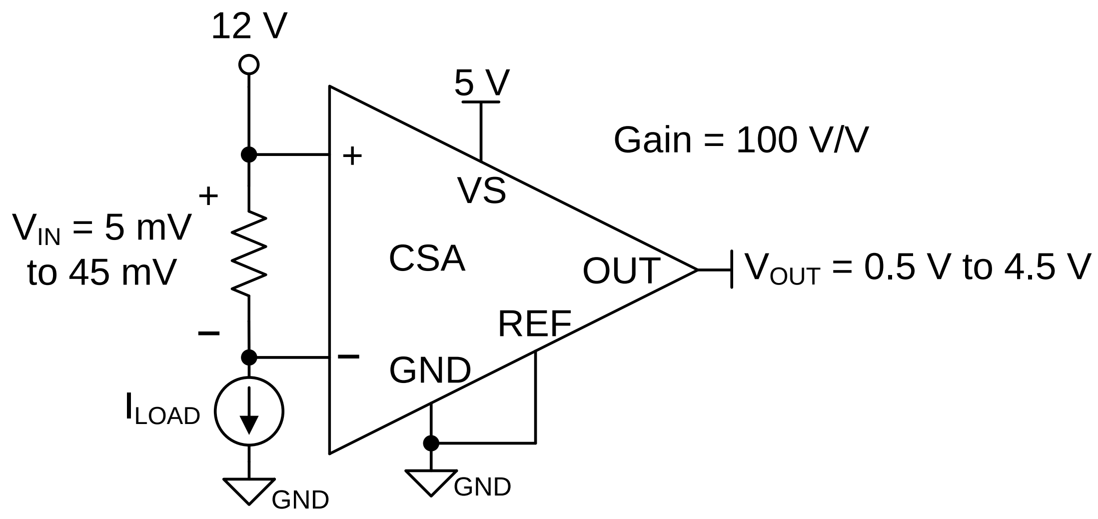
INA168-Q1		
INA168-Q1	SOT-23 (5)	2.90 mm × 1.60 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.

Answer: No. Note all of the highlighted text that indicate exclusive high-side operation.

Reading CSA Datasheets – quiz

2. Assuming the following circuit, which spec table would generate the lowest guaranteed error at 25°C?



at T_A = 25°C, V_{SENSE} = V_{IN+} – $V_{IN–}$, V_S = 5 V, V_{REF} = V_S / 2, and V_{IN+} = 12 V (unless otherwise noted)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNIT
INPUT							
CMRR	Common-mode rejection ratio, RTI (1)	V_{IN+} = 0 V to 26 V, V_{SENSE} = 0 mV, T_A = –40°C to +125°C	A1 device	86	100		dB
			A2, A3 devices	96	100		
			A4 devices	106	120		
V_{OS}	Offset voltage, RTI	V_{SENSE} = 0 mV, V_{IN+} = 0 V	A1 devices		±25	±135	μV
			A2, A3, A4 devices		±5	±55	
		V_{SENSE} = 0 mV, V_{IN+} = 12 V	A1 devices		±100	±450	
			A2, A3 devices		±25	±130	
			A4 device		±25	±100	
dV_{OS}/dT	Offset drift, RTI	V_{SENSE} = 0 mV, T_A = –40°C to +125°C			0.2	0.5	μV/°C
PSRR	Power supply rejection ratio, RTI	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, V_{SENSE} = 0 mV			±8	±30	μV/V
I_{IB}	Input bias current	V_{SENSE} = 0 mV, V_{CM} = 0 V			-6		μA
		V_{SENSE} = 0 mV			75		
I_{IO}	Input offset current	V_{SENSE} = 0 mV			±0.05		μA
OUTPUT							
G	Gain		A1 devices		20		V/V
			A2 devices		50		
			A3 devices		100		
			A4 devices		200		
E_G	Gain error	V_{OUT} = 0.5 V to V_S – 0.5 V,	A1, A2, A3 devices		±0.05%	±0.2%	

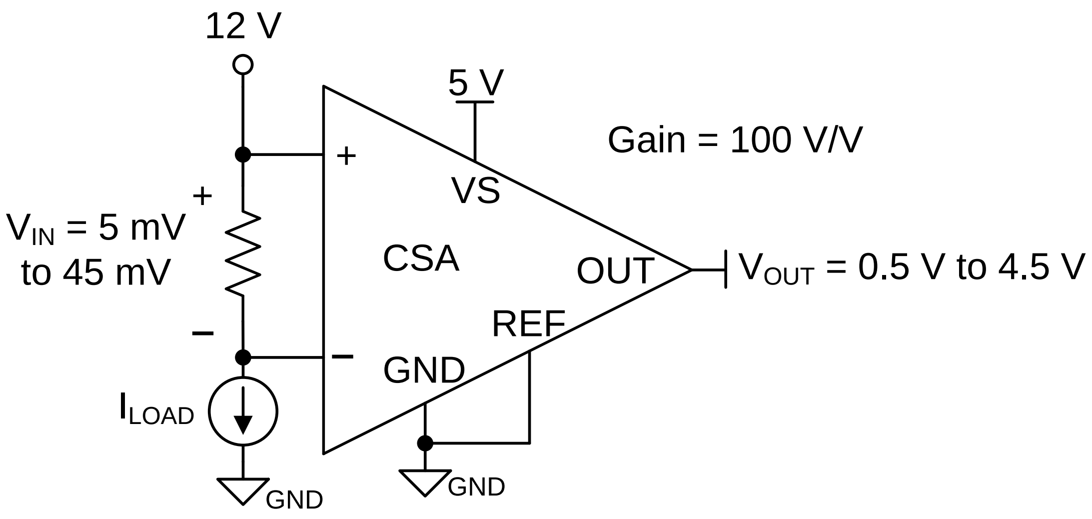
at T_A = 25°C, V_{SENSE} = V_{IN+} – $V_{IN–}$ = 10 mV, V_S = 5 V, V_{IN+} = 12 V, and V_{LIMIT} = 2 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input voltage range		0		36	V
V_{IN}	Differential input voltage range	V_{IN} = V_{IN+} – $V_{IN–}$, INA301A1	0		250	mV
		V_{IN} = V_{IN+} – $V_{IN–}$, INA301A2	0		100	
		V_{IN} = V_{IN+} – $V_{IN–}$, INA301A3	0		50	
CMR	Common-mode rejection	INA301A1, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	100	110		dB
		INA301A2, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	106	118		
		INA301A3, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	110	120		
V_{OS}	Offset voltage, RTI (1)	INA301A1		±25	±125	μV
		INA301A2		±15	±50	
		INA301A3		±10	±35	
dV_{OS}/dT	Offset voltage drift, RTI (1)	T_A= –40°C to +125°C		0.1	0.5	μV/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, T_A = –40°C to +125°C		±0.1	±10	μV/V
I_B	Input bias current	I_{B+}, $I_{B–}$		120		μA
I_{OS}	Input offset current	V_{SENSE} = 0 mV		±0.1		μA
OUTPUT						
G	Gain	INA301A1		20		V/V
		INA301A2		50		
		INA301A3		100		
		INA301A1, V_{OUT} = 0.5 V to V_S – 0.5 V		±0.03%	±0.1%	
		INA301A2, V_{OUT} = 0.5 V to V_S – 0.5 V		±0.05%	±0.15%	

Answer: The right spec table will yield the lowest error. The only difference will be the offset and the right table's 100 V/V variant has a lower offset.

Reading CSA Datasheets – quiz

2. Assuming the following circuit, which spec table would generate the lowest guaranteed error at 25°C?



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			A2, A3 devices	96	100		
			A4 devices	106	120		
V_{OS}	Offset voltage, RTI	V_{SENSE} = 0 mV, V_{IN+} = 0 V	A1 devices		±25	±135	μV
			A2, A3, A4 devices		±5	±55	
		V_{SENSE} = 0 mV, V_{IN+} = 12 V	A1 devices		±100	±450	
			A2, A3 devices		±25	±130	
			A4 device		±25	±100	
dV_{OS}/dT	Offset drift, RTI	V_{SENSE} = 0 mV, T_A = –40°C to +125°C			0.2	0.5	μV/°C
PSRR	Power supply rejection ratio, RTI	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, V_{SENSE} = 0 mV			±8	±30	μV/V
I_B	Input bias current	V_{SENSE} = 0 mV, V_{CM} = 0 V			-6		μA
		V_{SENSE} = 0 mV			75		
I_{IO}	Input offset current	V_{SENSE} = 0 mV			±0.05		μA
OUTPUT							
G							
E_G							

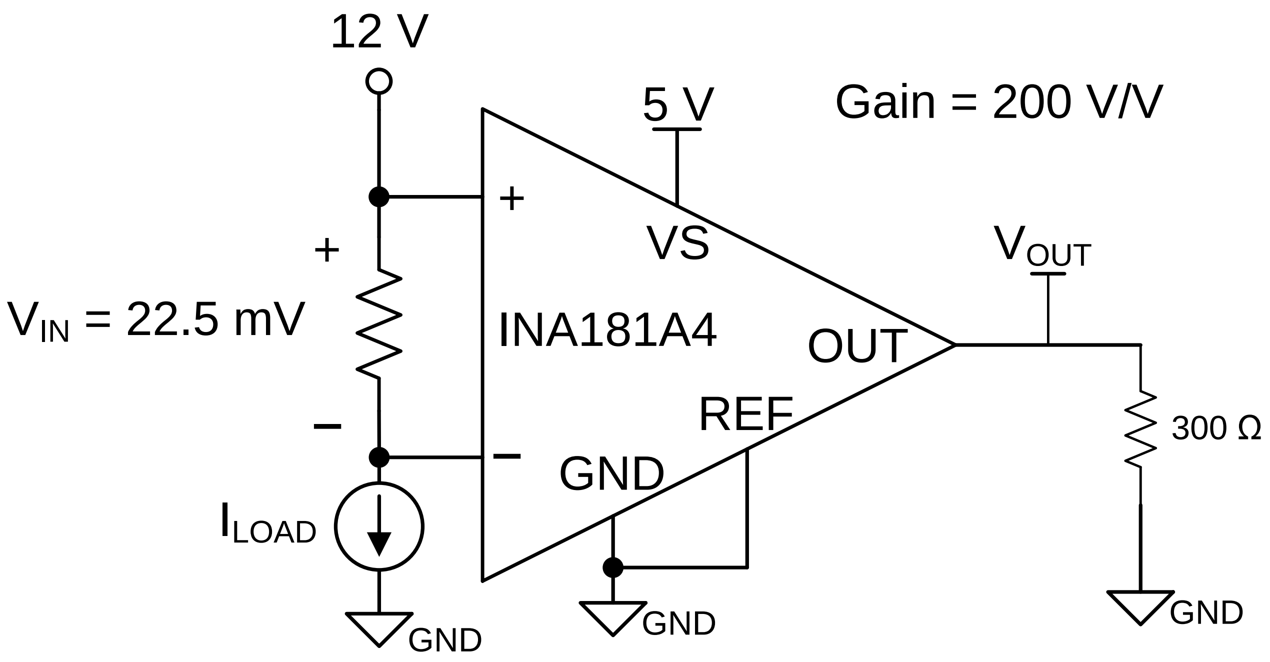
at T_A = 25°C, $V_{SENSE} = V_{IN+} – V_{IN–}$ = 10 mV, V_S = 5 V, V_{IN+} = 12 V, and V_{LIMIT} = 2 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT						
V_{CM}	Common-mode input voltage range		0		36	V
V_{IN}	Differential input voltage range	$V_{IN} = V_{IN+} – V_{IN–}$, INA301A1	0		250	mV
		$V_{IN} = V_{IN+} – V_{IN–}$, INA301A2	0		100	
		$V_{IN} = V_{IN+} – V_{IN–}$, INA301A3	0		50	
CMR	Common-mode rejection	INA301A1, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	100	110		dB
		INA301A2, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	106	118		
		INA301A3, V_{IN+} = 0 V to 36 V, T_A = –40°C to +125°C	110	120		
V_{OS}	Offset voltage, RTI (1)	INA301A1		±25	±125	μV
		INA301A2		±15	±50	
		INA301A3		±10	±35	
dV_{OS}/dT	Offset voltage drift, RTI (1)	T_A= –40°C to +125°C		0.1	0.5	μV/°C
PSRR	Power-supply rejection ratio	V_S = 2.7 V to 5.5 V, V_{IN+} = 12 V, T_A = –40°C to +125°C		±0.1	±10	μV/V
I_B	Input bias current	I_{B+}, $I_{B–}$		120		μA
I_{OS}	Input offset current	V_{SENSE} = 0 mV		±0.1		μA
OUTPUT						
						V/V
						ppm/°C

Answer continued: Given the conditions, both devices will incur no additional CMR, PSR, and drift errors. Additionally, the 200 V/V variants of both devices have the same max gain error at 25°C and gain error testing condition. The only error left is the initial offset (V_{OS}). On the left V_{OS} = ±130 μV and on the right V_{OS} = ±35 μV.

Reading CSA Datasheets – quiz

3. Can the following circuit amplify the input to 4.5 V?



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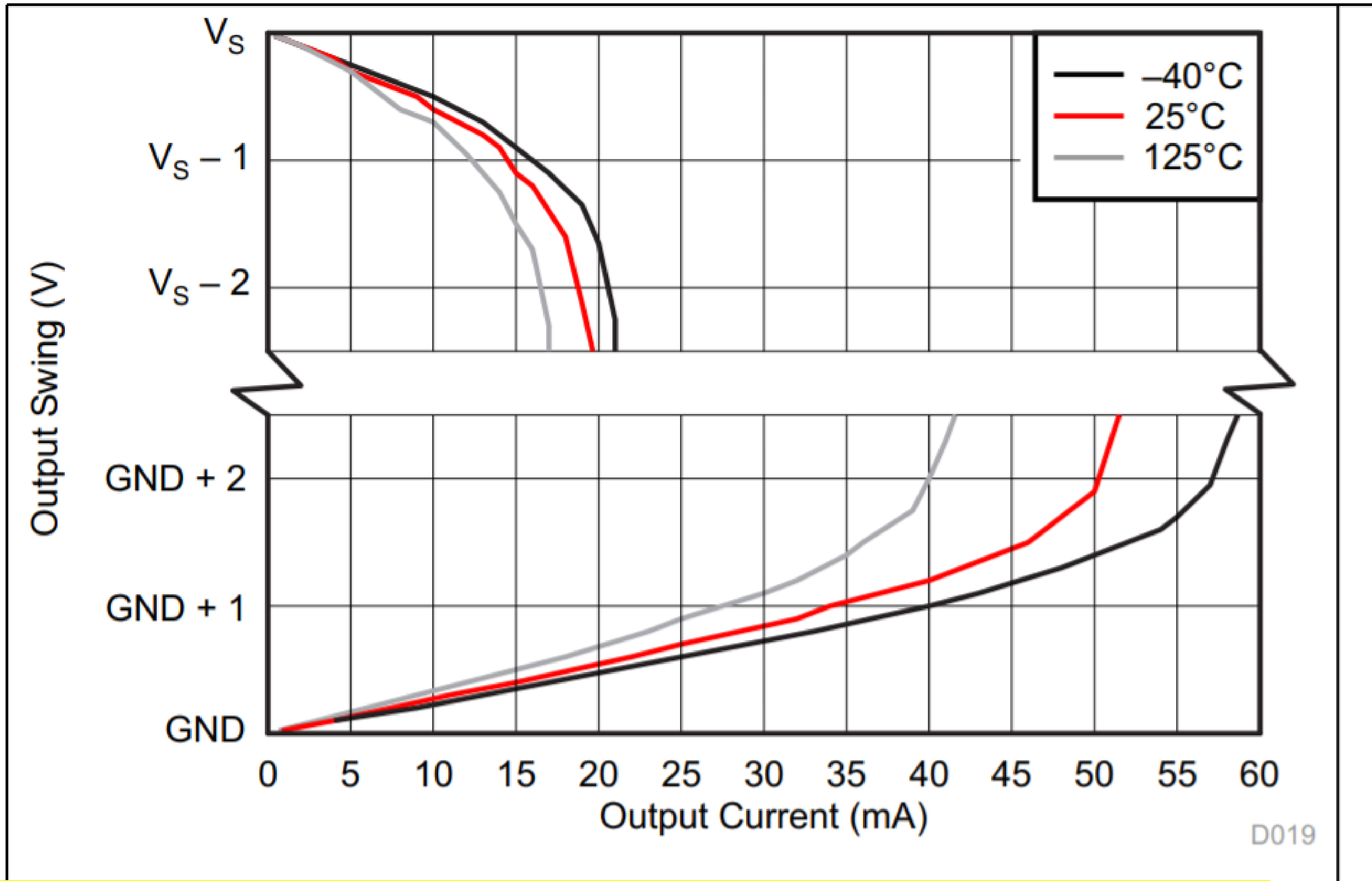

Answer: No. If device is to drive 4.5 V, then output current is 4.5 V/300 Ω = 15 mA; however, at 15 mA, the output will droop just below 4 V.

Reading CSA Datasheets – quiz

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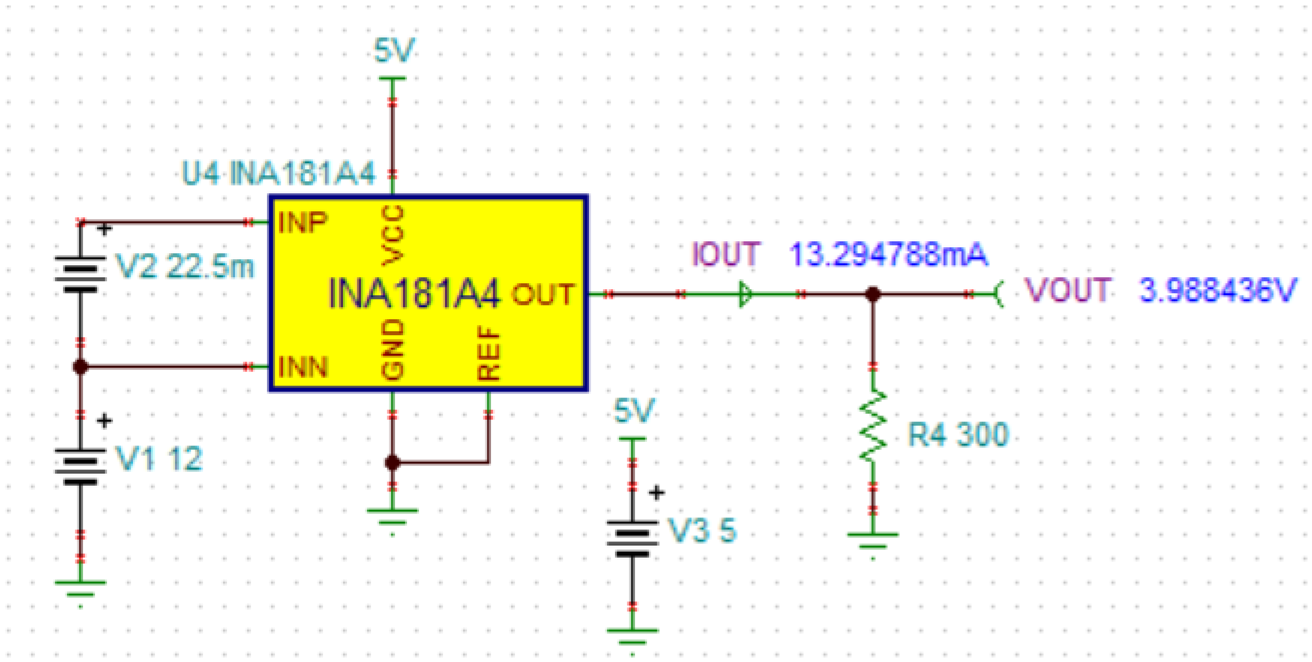

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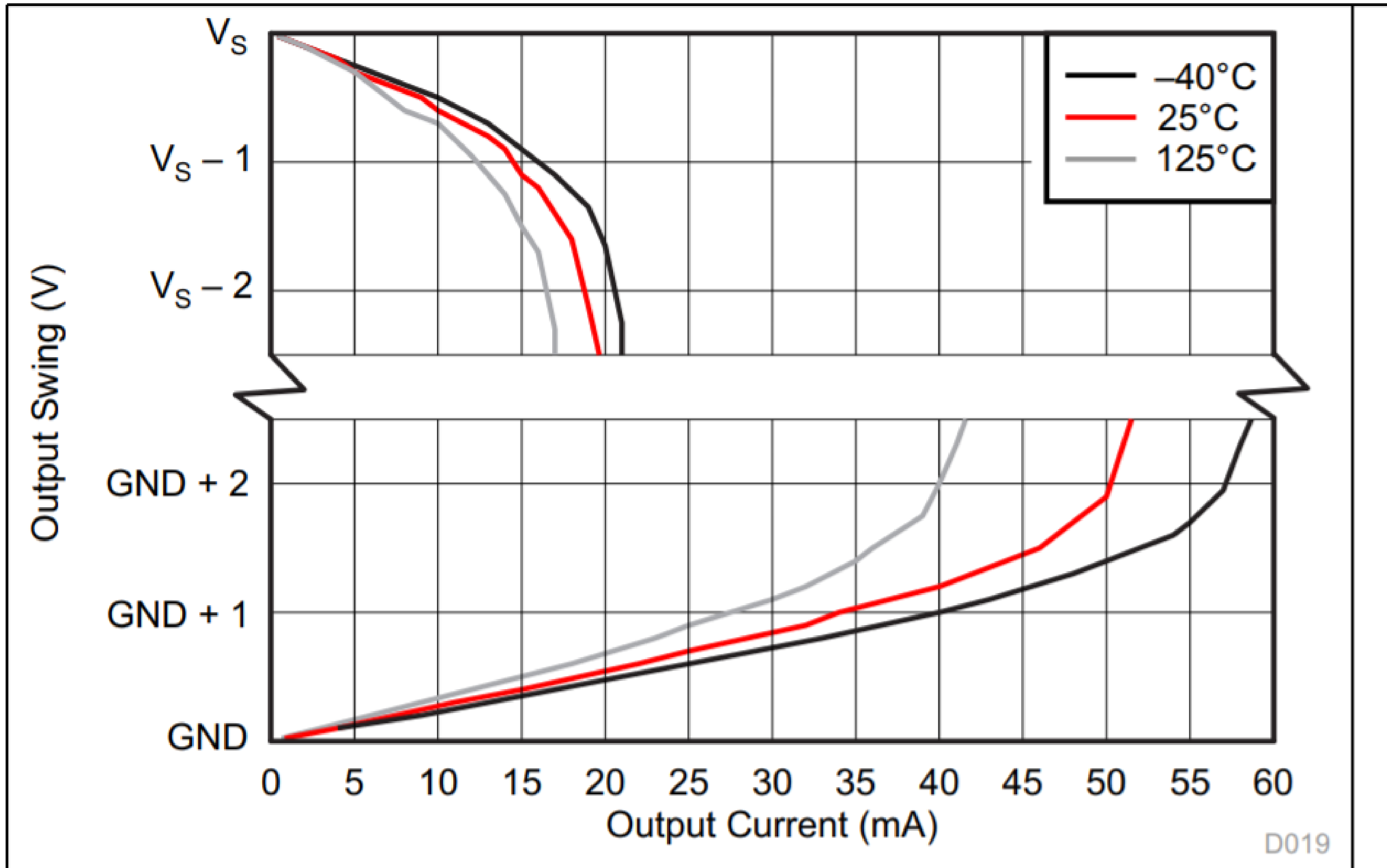
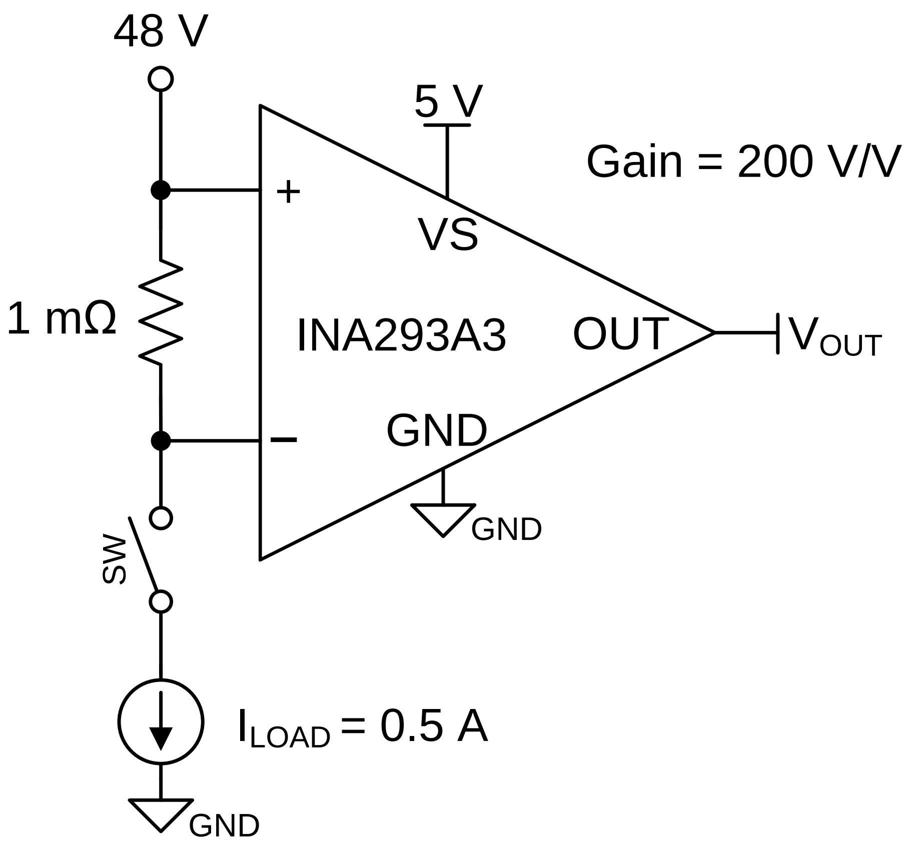


Answer continued: This lack of output current drive can be simulated in TINA-TI.

Reading CSA Datasheets – quiz

4. Will the following amplifier's output voltage response typically settle to 1% error within 5 µs once SW is closed?



6.5 Electrical Characteristics

at T_A = 25 °C, V_S = 5 V, $V_{SENSE} = V_{IN+} - V_{IN-}$ = 0.5 V / Gain, $V_{CM} = V_{IN-}$ = 48 V (unless otherwise noted)

FREQUENCY RESPONSE				
BW	Bandwidth	INA293x1, C_{LOAD} = 5 pF, V_{SENSE} = 200 mV	1300	kHz
		INA293x2, C_{LOAD} = 5 pF, V_{SENSE} = 80 mV	1300	
		INA293x3, C_{LOAD} = 5 pF, V_{SENSE} = 40 mV	1000	
		INA293x4, C_{LOAD} = 5 pF, V_{SENSE} = 20 mV	900	
		INA293x5, C_{LOAD} = 5 pF, V_{SENSE} = 8 mV	900	
SR	Slew rate	Rising edge	2.5	V/µs
	Settling time	V_{OUT} = 4 V ± 0.1 V step, Output settles to 0.5%	10	µs
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 1%	5	
		V_{OUT} = 4 V ± 0.1 V step, Output settles to 5%	1	
NOISE				
Ven	Voltage noise density		50	nV/√Hz
POWER SUPPLY				
				V
				mA
				mA

Answer: No. In order for the device to perform according to the settling time specification, input voltage needs a DC bias of 4V/gain = 20 mV.

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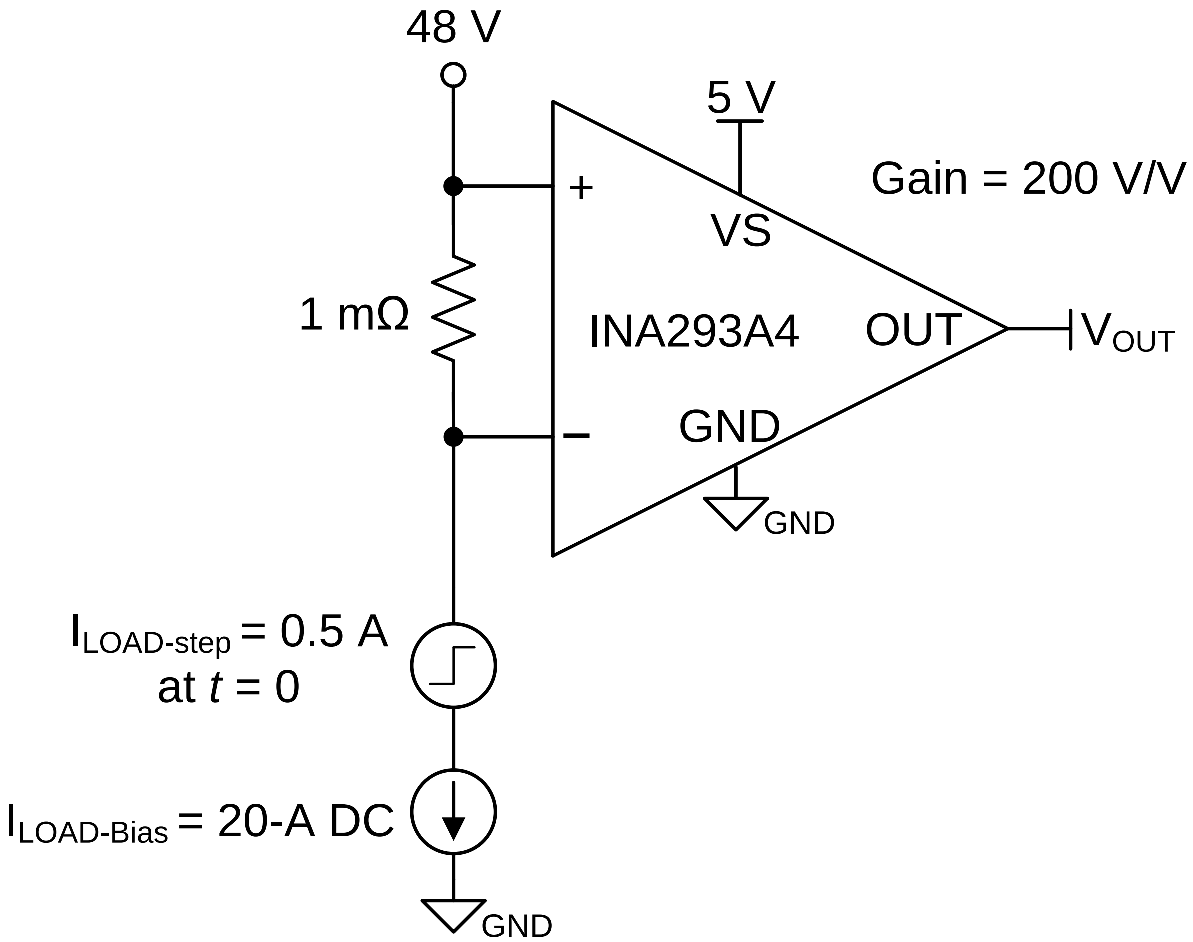

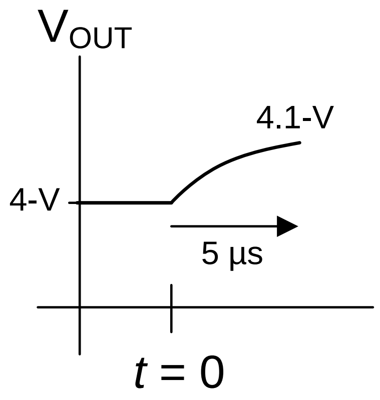

Answer continued: Realistically, the output bias does not need to be 4 V in order to satisfy the 1% error at 5-µs settling time.

As long as the output is biased to somewhere in the linear region, then we can expect a linear response.