

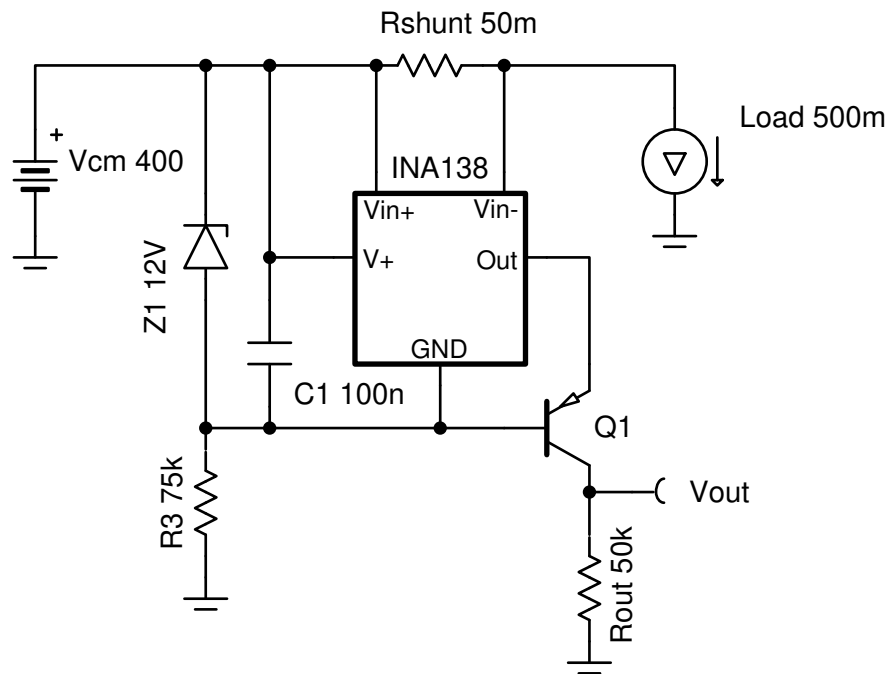
High-Voltage, High-Side Floating Current Sensing Circuit Using Current Output, Current Sense Amplifier



Input		Output		Supply		
$I_{load\ Min}$	$I_{load\ Max}$	$V_{out\ Min}$	$V_{out\ Max}$	$V_{cm\ Min}$	$V_{cm\ Max}$	V_{ee}
0.5 A	9.9 A	250 mV	4.95 V	12 V	400 V	GND (0 V)

Design Description

This cookbook is intended to demonstrate a method of designing an accurate current sensing solution for systems with high common mode voltages. The principle aspect of this design uses a unidirectional circuit to monitor a system with $V_{cm} = 400\text{ V}$ by floating the supplies of the device across a Zener diode from the supply bus (V_{cm}). This cookbook is based on the [High Voltage 12 V – 400 V DC Current Sense Reference Design](#).



Design Notes

1. The [Getting Started with Current Sense Amplifiers](#) video series introduces implementation, error sources, and advanced topics for using current sense amplifiers.
2. This example is for high V_{CM} , high-side, unidirectional, DC sensing.
3. To minimize error, make the shunt voltage as large as the design will allow. For the INA138 device, keep $V_{sense} \gg 15$ mV.
4. The relative error due to input offset increases as shunt voltage decreases, so use a current sense amplifier with low offset voltage. A precision resistor for R_{shunt} is necessary because R_{shunt} is a major source of error.
5. The INA138 is a current-output device, so voltages referenced to ground are achieved with a high voltage bipolar junction transistor (BJT).
 - Ensure the transistor chosen for Q1 can withstand the maximum voltage across the collector and emitter (for example, need 400 V, but select > 450 V for margin).
 - Multiple BJTs can be stacked and biased in series to achieve higher voltages
 - High beta of this transistor reduces gain error from current that leaks out of the base

Design Steps

1. Determine the operating load current and calculate R_{shunt} :
 - Recommended V_{sense} is 100mV and maximum recommended is 500 mV, so the following equation can be used to calculate R_{shunt} where $V_{sense} \leq 500$ mV:

$$R_{shunt} = \frac{V_{sense \max}}{I_{load \max}} \rightarrow \frac{0.5V}{10A} = 50m\Omega$$

- For more accurate and precise measurements over the operating temperature range, a current monitor with integrated shunt resistor can be used in some systems. The benefits of using these devices are explained in [Getting Started with Current Sense Amplifiers, Session 16: Benefits of Integrated Precision Shunt Resistor](#).
2. Choose a Zener diode to create an appropriate voltage drop for the INA138 supply:
 - The Zener voltage of the diode should fall in the INA138 supply voltage range of 2.7 V to 36 V and needs to be larger than the maximum output voltage required.
 - The Zener diode voltage regulates the INA138 supply and protects from transients.
 - Data sheet parameters are defined for 12 V V_{in+} to the GND pin so a 12 V Zener is chosen.
 3. Determine the series resistance with the Zener diode:
 - This resistor (R_3) is the main power consumer due to its voltage drop (up to 388 V in this case). If R_3 is too low, it will dissipate more power, but if it is too high R_3 will not allow the Zener diode to avalanche properly. Since the data sheet specifies I_Q for $V_S = 5$ V, estimate the maximum quiescent current of the INA138 device at $V_S = 12$ V to be 108 μ A and calculate R_3 using the bias current of the Zener diode, 5 mA, as shown:

$$R_3 = \frac{V_{CM} - V_{zener}}{I_{zener} + I_{INA138}} = \frac{400V - 12V}{5mA + 108\mu A} \approx 75.96k\Omega$$

standard value $\rightarrow 75k\Omega$

- The power consumption of this resistor is calculated using the following equation:

$$Power_{R3} = \frac{(V_{cm} - V_{Zener})^2}{R3} \rightarrow \frac{(400V - 12V)^2}{75k\Omega} \approx 2.007W$$

4. Calculate R_{out} using the equation for output current in the INA138 data sheet.
 - This system is designed for 10 V/V gain where $V_{out} = 1$ V if $V_{sense} = 100$ mV:

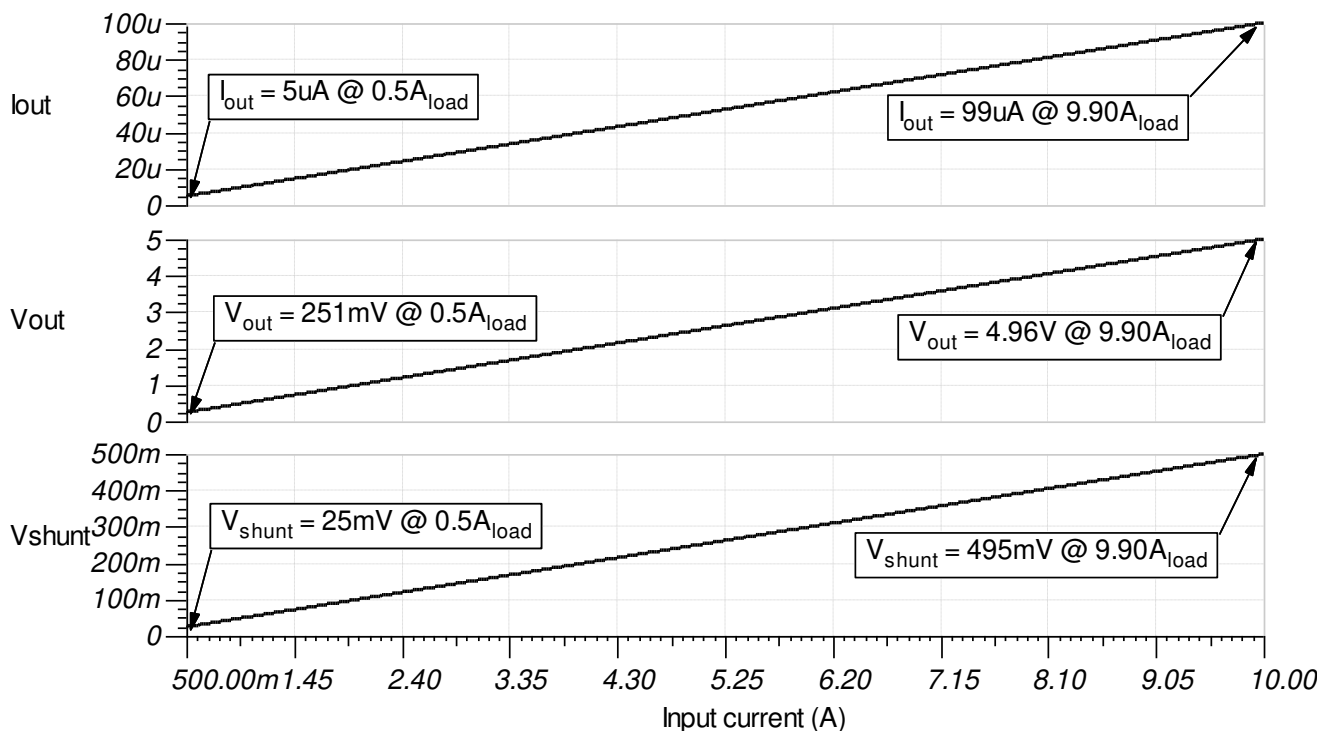
$$I_{\text{out INA138}} = 200 \frac{\mu\text{A}}{\text{V}} \times (V_{\text{sense max}}) \rightarrow 200 \frac{\mu\text{A}}{\text{V}} \times (0.5\text{V}) = 100\mu\text{A}$$

$$R_{\text{out}} = \frac{V_{\text{out max}}}{I_{\text{out INA138}}} \rightarrow \frac{5\text{V}}{100\mu\text{A}} = 50\text{k}\Omega$$

Design Simulations

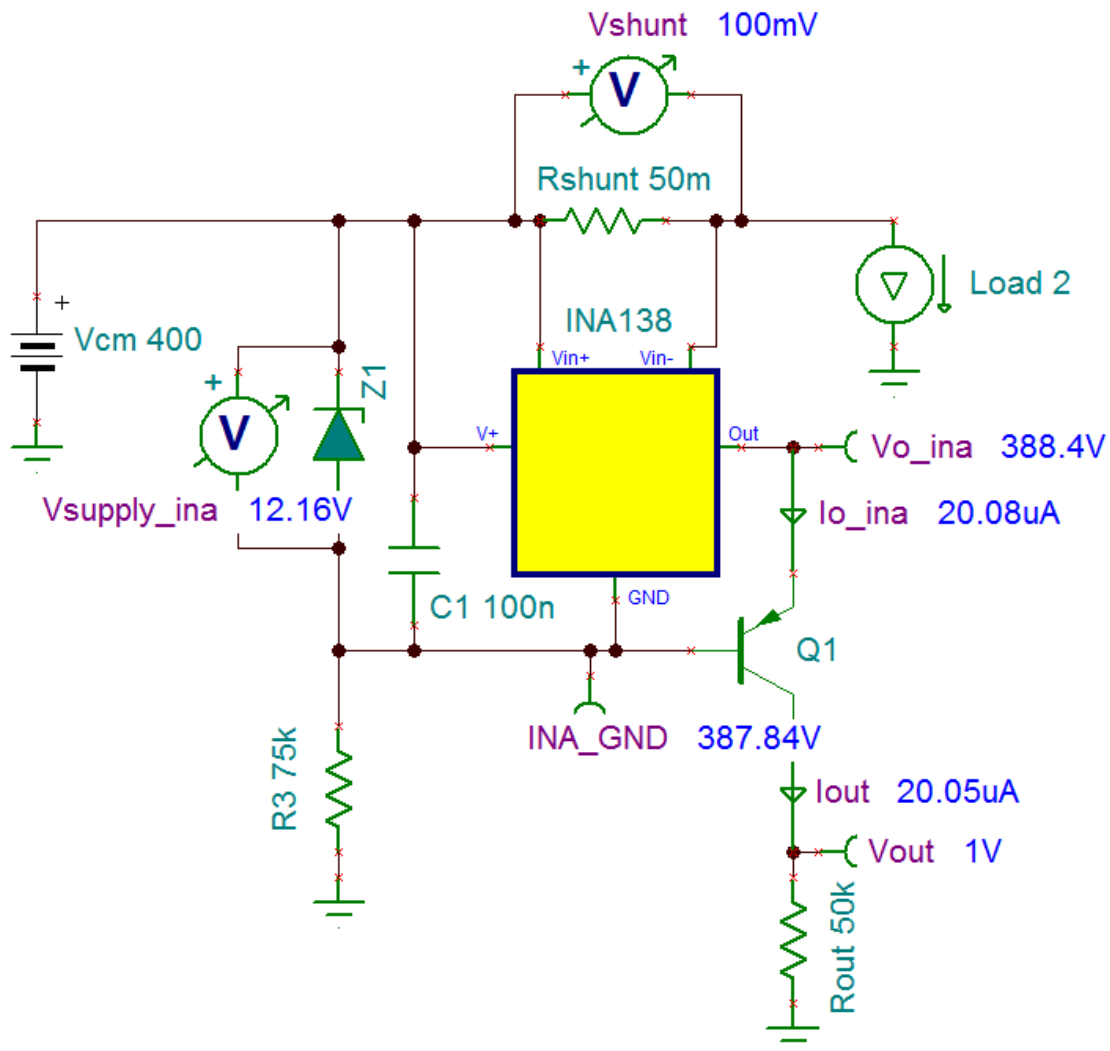
DC Simulation Results

The following graph shows a linear output response for load currents from 0.5 A to 10 A and $12\text{ V} \leq V_{\text{cm}} \leq 400\text{ V}$. I_{out} and V_{out} remain constant over a varying V_{cm} once the Zener diode is reverse biased.



Steady State Simulation Results

The following image shows this system in DC steady state with a 2 A load current. The output voltage is 10× greater than the measured voltage across R_{shunt} .



Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

See circuit SPICE simulation file [SGLC001](#).

Getting Started with Current Sense Amplifiers video series:

<https://training.ti.com/getting-started-current-sense-amplifiers>

Abstract on Extending Voltage Range of Current Shunt Monitor:

[Extending Voltage Range of Current Shunt Monitor](#)

High Voltage 12 V – 400 V DC Current Sense Reference Design:

[TIDA=00332](#)

Cookbook Design Files:

[SGLC001](#)

Current Sense Amplifiers on TI.com:

[Current sense amplifiers - Products](#)

For direct support from TI Engineers use the **E2E** community:

[TI E2E™ design support forums](#)

Design Featured Current Shunt Monitor

INA138	
V_{SS}	2.7 V to 36 V
$V_{in\ cm}$	2.7 V to 36 V
V_{out}	Up to (V+) -0.8 V
V_{OS}	± 0.2 mV to ± 1 mV
I_q	25 μ A to 45 μ A
I_b	2 μ A
UGBW	800 kHz
# of Channels	1
INA138	

Design Alternate Current Shunt Monitor

INA168	
V_{SS}	2.7 V to 60 V
$V_{in\ cm}$	2.7 V to 60 V
V_{out}	Up to (V+) -0.8 V
V_{OS}	± 0.2 mV to ± 1 mV
I_q	25 μ A to 45 μ A
I_b	2 μ A
UGBW	800 kHz
# of Channels	1
INA168	

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