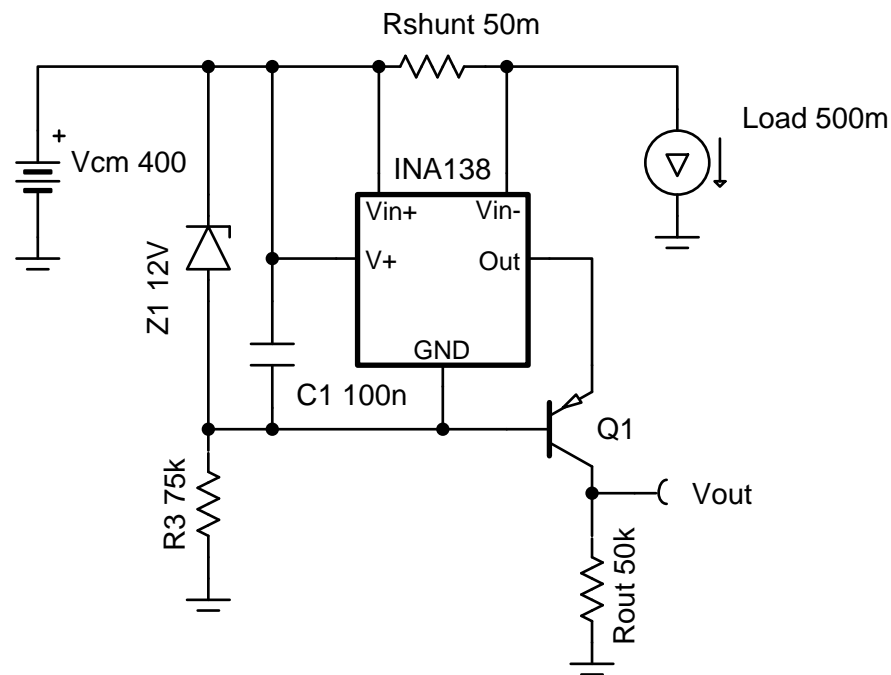


High-voltage, high-side floating current sensing circuit using current output, current sense amplifier

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

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 $V_{cm} = 400V$ 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 $V_{sense} \gg 15mV$.
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 400V, but select > 450V 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 500mV, so the following equation can be used to calculate R_{shunt} where $V_{sense} \leq 500mV$:

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

- 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 2.7V to 36V 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 388V 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 $V_S = 5V$, estimate the max quiescent current of the INA138 device at $V_S = 12V$ to be 108 μA and calculate R_3 using the bias current of the Zener diode, 5mA, 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 10V/V gain where $V_{out} = 1V$ if $V_{sense} = 100mV$:

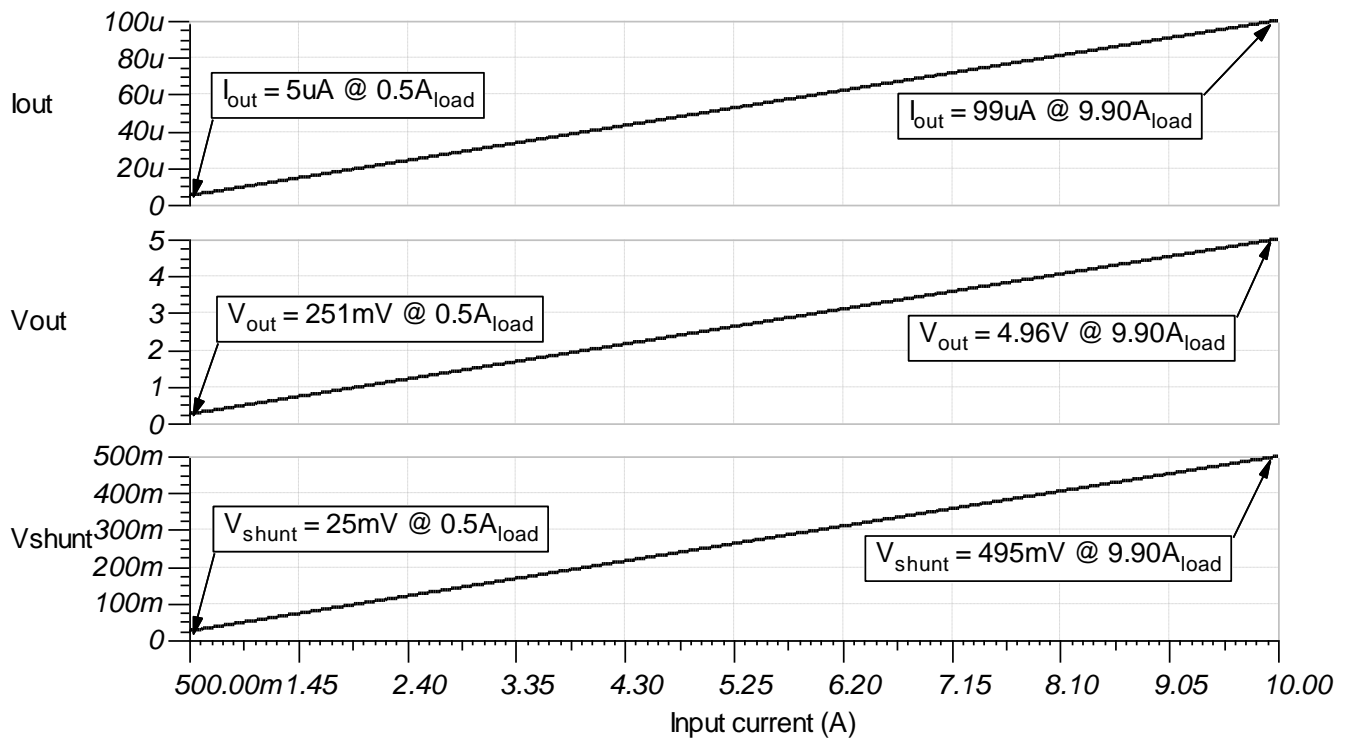
$$I_{out \text{ INA138}} = 200 \frac{\mu A}{V} \times (V_{sense \text{ max}}) \rightarrow 200 \frac{\mu A}{V} \times (0.5V) = 100\mu A$$

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

Design Simulations

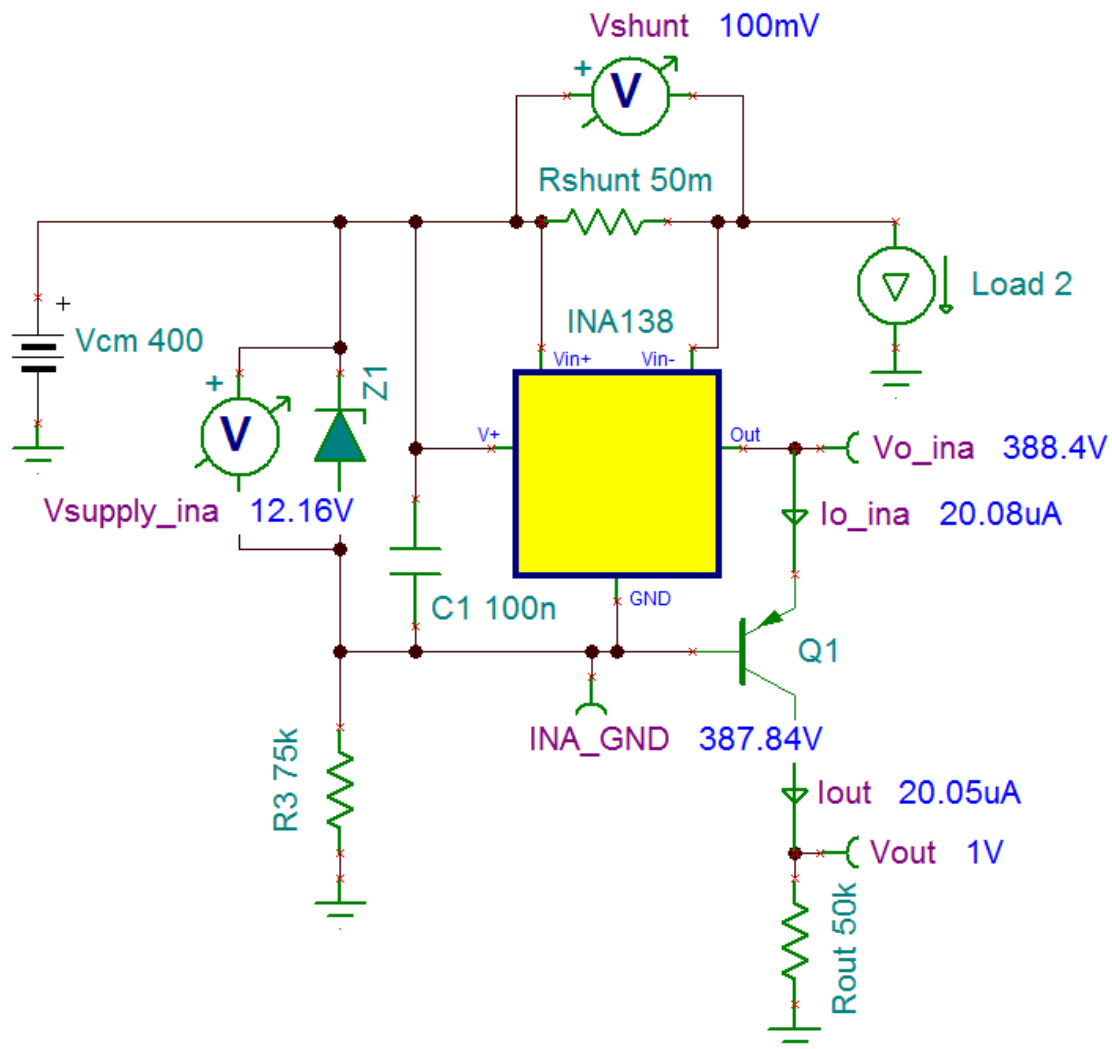
DC Simulation Results

The following graph shows a linear output response for load currents from 0.5A to 10A and $12V \leq V_{cm} \leq 400V$. 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 10x 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:

<http://www.ti.com/lit/an/slla190/slla190.pdf>

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

<http://www.ti.com/tool/TIDA-00332>

Cookbook Design Files:

<http://proddms.itg.ti.com/stage/lit/sw/sglc001a/sglc001a.zip>

Current Sense Amplifiers on TI.com:

<http://www.ti.com/amplifier-circuit/current-sense/products.html>

For direct support from TI Engineers use the E2E community:

<http://e2e.ti.com>

Design Featured Current Shunt Monitor

INA138	
V_{ss}	2.7V to 36V
$V_{in\ cm}$	2.7V to 36V
V_{out}	Up to (V+) - 0.8V
V_{os}	$\pm 0.2\text{mV}$ to $\pm 1\text{mV}$
I_q	25 μA to 45 μA
I_b	2 μA
UGBW	800kHz
# of Channels	1
http://www.ti.com/product/ina138	

Design Alternate Current Shunt Monitor

INA168	
V_{ss}	2.7V to 60V
$V_{in\ cm}$	2.7V to 60V
V_{out}	Up to (V+) - 0.8V
V_{os}	$\pm 0.2\text{mV}$ to $\pm 1\text{mV}$
I_q	25 μA to 45 μA
I_b	2 μA
UGBW	800kHz
# of Channels	1
http://www.ti.com/product/ina168	

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