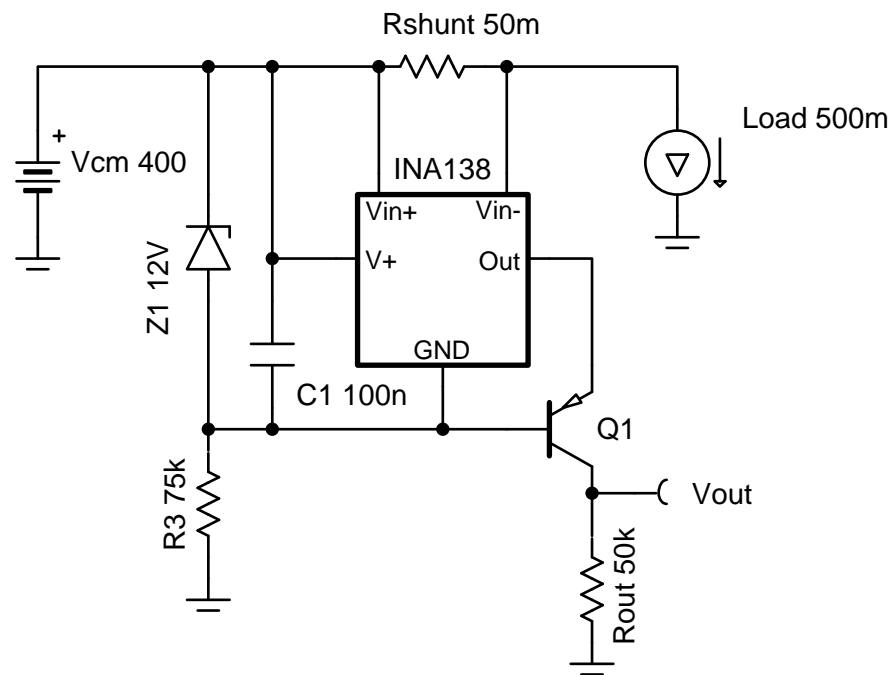


## High-voltage, high-side floating current sensing circuit using current output, current sense amplifier

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 $\mu A$  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  $V_{sense} = 100mV$ :

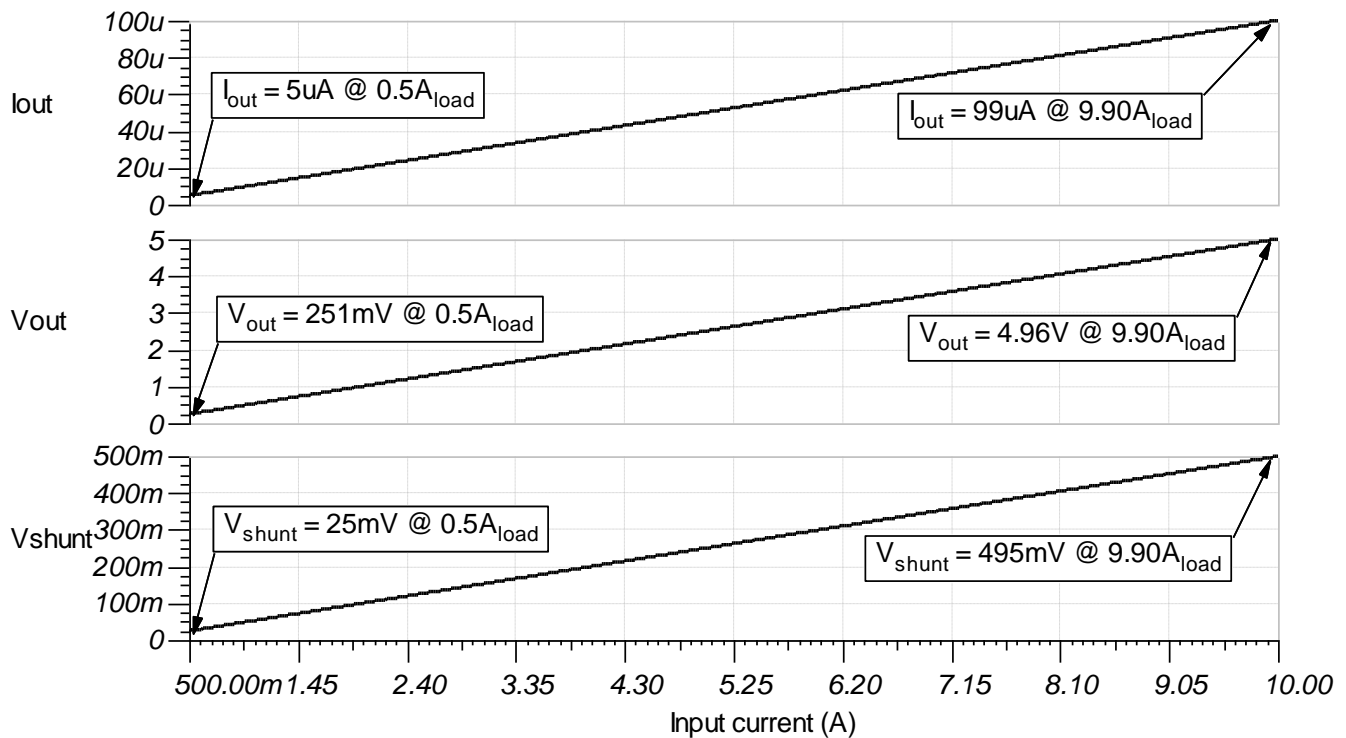
$$I_{out \text{ INA138}} = 200 \frac{\mu A}{V} \times (V_{sense \text{ max}}) \rightarrow 200 \frac{\mu A}{V} \times (0.5V) = 100\mu A$$

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

## Design Simulations

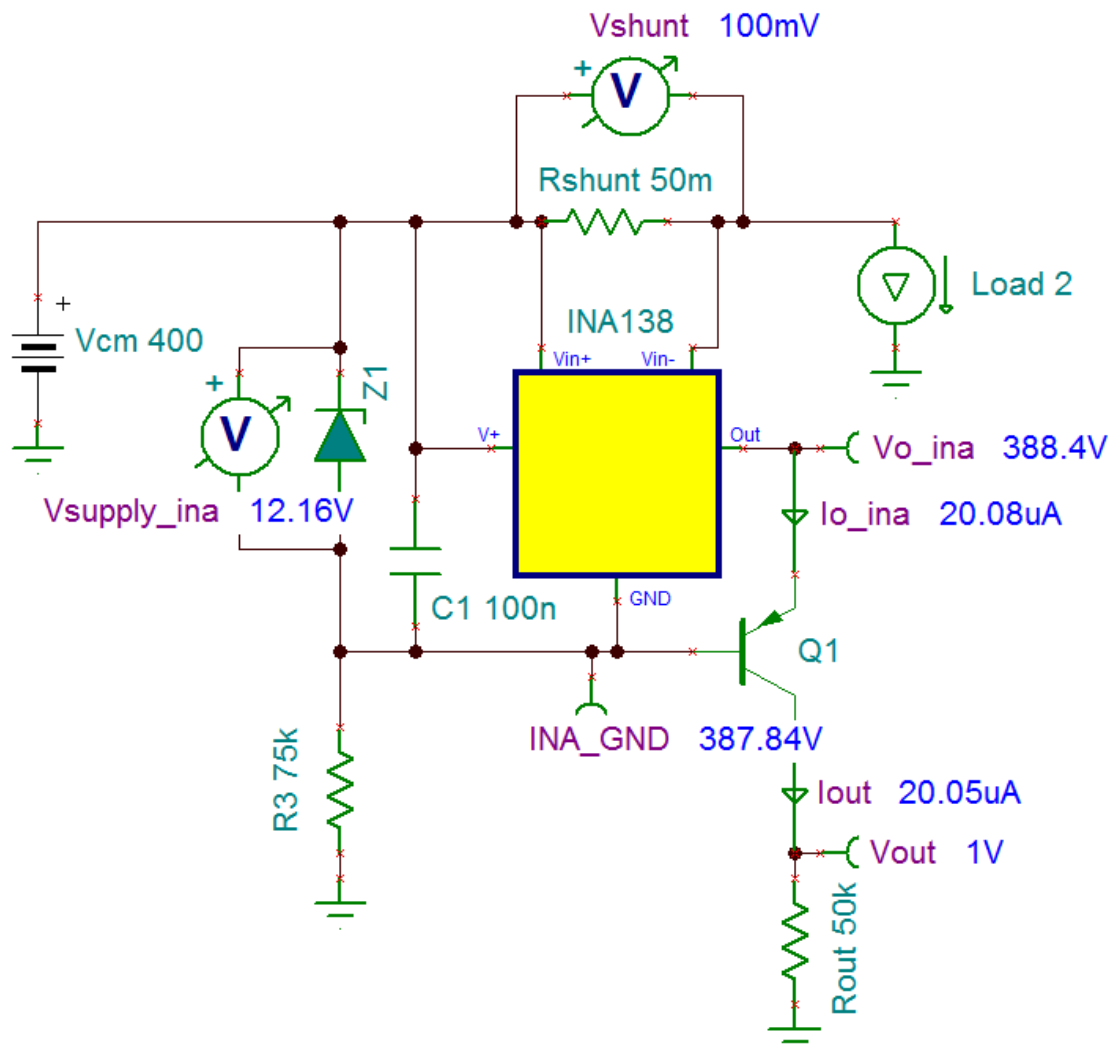
### DC Simulation Results

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 $\mu\text{A}$ to 45 $\mu\text{A}$
$I_b$	2 $\mu\text{A}$
UGBW	800kHz
# of Channels	1
<a href="http://www.ti.com/product/ina138">http://www.ti.com/product/ina138</a>	

### 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 $\mu\text{A}$ to 45 $\mu\text{A}$
$I_b$	2 $\mu\text{A}$
UGBW	800kHz
# of Channels	1
<a href="http://www.ti.com/product/ina168">http://www.ti.com/product/ina168</a>	

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