Analog Engineer's Circuit: Amplifiers

SNOA987A–March 2018–Revised January 2019

High-speed overcurrent detection circuit

Design Goal

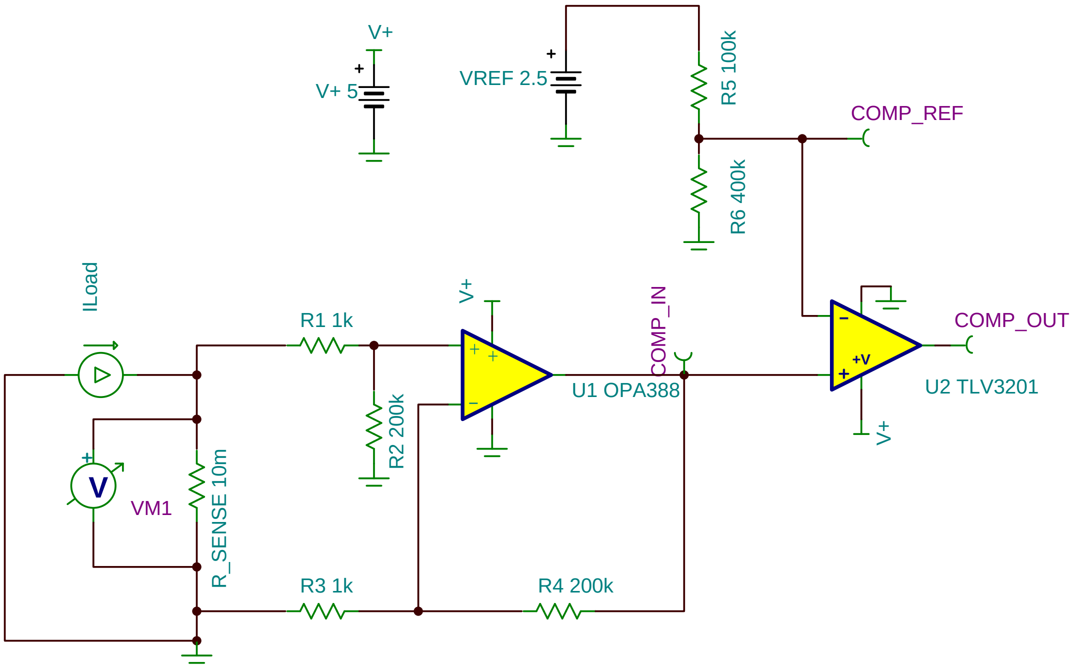
Overcurrent Levels		Supply		Transient Response Time
I_{IN} (min)	I_{IN} (max)	V+	V–	t
0A	1.0A	5V	0V	< 10µs

Design Description

This high-speed, low-side overcurrent detection solution is implemented with a single zero-drift fast-settling amplifier (OPA388) and one high-speed comparator (TLV3201). This circuit is designed for applications that monitor fast current signals and overcurrent events, such as current detection in motors and power supply units.

The OPA388 is selected for its widest bandwidth with ultra-low offset and fast slew rate. The TLV3201 is selected for its fast response due to its small propagation delay of 40ns and rise time of 4.8ns. This allows the comparator to quickly respond and alert the system of an overcurrent event all within the transient response time requirement. The push-pull output stage also allows the comparator to directly interface with the logic levels of the microcontroller. The TLV3201 also has low power consumption with a quiescent current of 40µA.

Typically for low-side current detection, the amplifier across the sense resistor can be used in a noninverting configuration. The application circuit shown, however, uses the OPA388 as a differential amplifier across the sense resistor. This provides a true differential measurement across the shunt resistor and can be beneficial in cases where the supply ground and load ground are not necessarily the same.



Design Notes

1. To minimize errors, choose precision resistors and set $R_1 = R_3$, and $R_2 = R_4$.
2. Select R_{SENSE} to minimize the voltage drop across the resistor at the max current of 1 A.
3. Due to the ultra-low offset of the OPA388 (0.25 µV), the effect of any offset error from the amplifier is minimal on the mV range measurement across R_{SENSE} .
4. Select the amplifier gain so COMP_IN reaches 2 V when the system crosses its critical overcurrent value of 1 A.
5. Traditional bypass capacitors are omitted to simplify the application circuit.

Design Steps

1. Determine the transfer equation where $R_1 = R_3$ and $R_2 = R_4$.

$$\text{COMP\_IN} = \left(R_{SENSE} \cdot I_{LOAD}\right) \cdot \left(\frac{R_2}{R_1 + R_2}\right) \cdot \left(1 + \frac{R_4}{R_3}\right)$$

2. Select the SENSE resistor value assuming a maximum voltage drop of 10 mV with a load current of 1 A in order to minimize the voltage drop across the resistor.

$$R_{SENSE} = \frac{V_{SENSE}(\text{max})}{I_{LOAD}(\text{critical})} = \frac{10\text{mV}}{1\text{A}} = 10\text{m}\Omega$$

3. Select the amplifier gain such that COMP_IN reaches 2V when the load current reaches the critical threshold of 1A.

$$\text{Gain} = \frac{\text{VREF}}{R_{SENSE} \cdot I_{LOAD}(\text{critical})} = \frac{2\text{ V}}{0.01\text{ V}} = \frac{R_2}{R_1 + R_2} \cdot 1 + \frac{R_4}{R_3} = 200$$

Set:

$$R_1 = R_3 = 1\text{k}\Omega$$

$$R_2 = R_4 = 200\text{k}\Omega$$

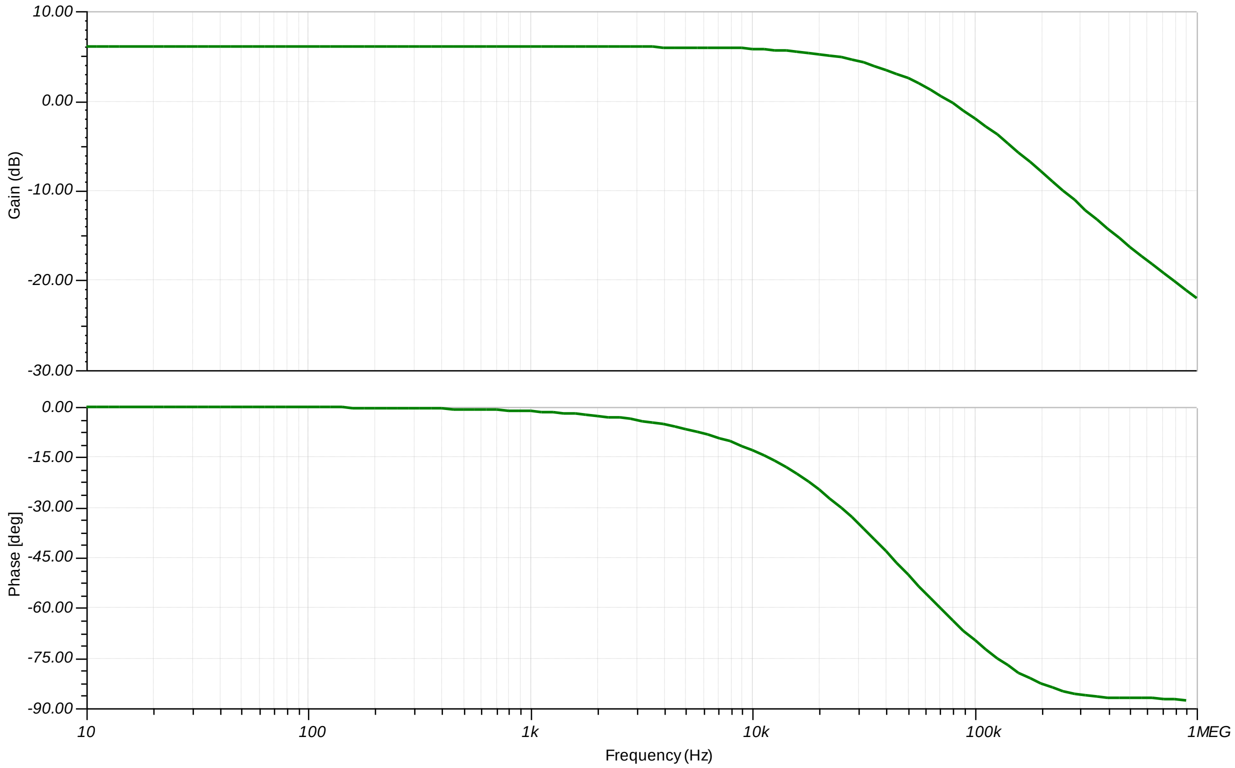
4. Calculate the transimpedance gain of the amplifier in order to verify the following AC simulation results:

$$V_{OUT} = I_{LOAD} \cdot 10\text{m}\Omega \cdot 200$$

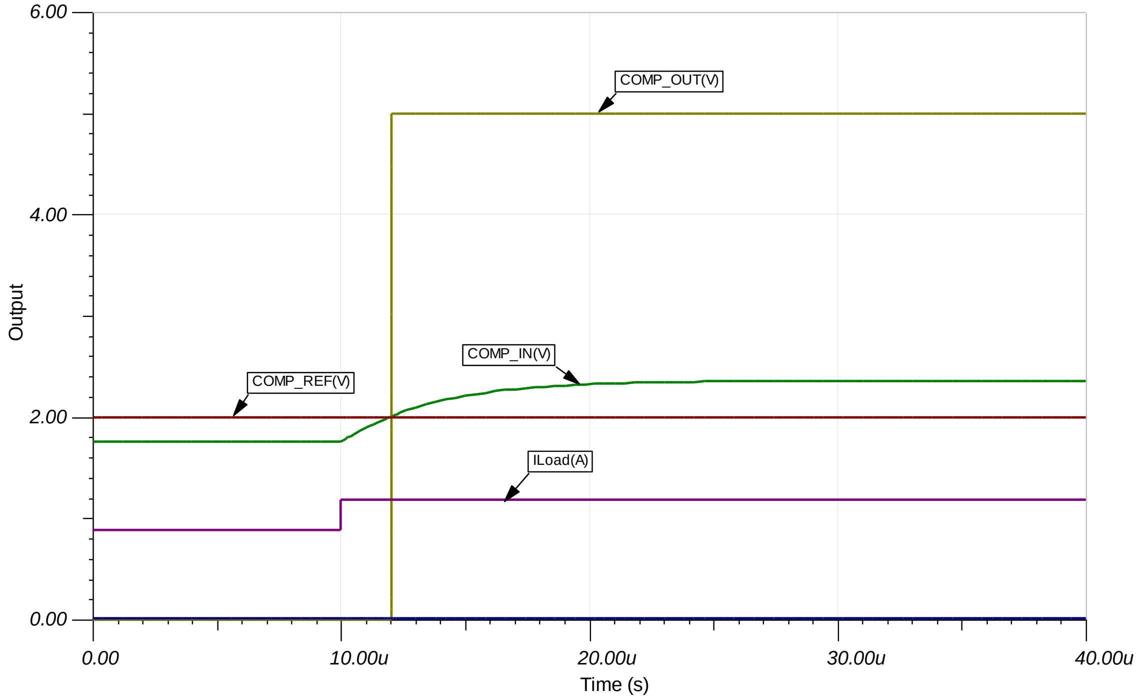
$$\frac{V_{OUT}}{I_{LOAD}} = 10\text{m}\Omega \cdot 200 = 2$$

Design Simulations

COMP_IN Transimpedance AC Simulation Results



Transient Response Simulation Results



Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

See the Current sensing using nanopower op amps blog.

References

1. Texas Instruments, *Advantages of using nanopower, zero drift amplifiers for battery voltage and current monitoring in portable applications TI tech note*
2. Texas Instruments, *Current sensing in no-neutral light switches TI tech note*
3. Texas Instruments, *GPIO Pins power signal chain in personal electronics running on Li-Ion batteries TI tech note*

Design Featured Comparator

TLV3201	
V_S	2.7V to 5.5V
t_{PD}	40ns
Input V_{CM}	Rail-to-rail
V_{os}	1mV
I_q	40µA
TLV3201	

Design Alternate Comparator

TLV7021	
V_S	1.6V to 5.5V
t_{PD}	260ns
Input V_{CM}	Rail-to-rail
V_{os}	0.5mV
I_q	5µA
TLV7021	

Design Featured Op Amp

OPA388	
V_S	2.5V to 5.5V
Input V_{CM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.25µV
V_{os} Drift	.005µV/°C
I_q	1.7mA/Ch
I_b	30pA
UGBW	10MHz
OPA388	

Design Alternate Op Amp

THS4521	
V_S	2.5V to 5.5V
Input V_{CM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	20 µV
V_{os} Drift	µV/°C
I_q	1mA/Ch
I_b	0.6 µA
UGBW	145MHz
THS4521	

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Copyright © 2019, Texas Instruments Incorporated