High-Speed Overcurrent Detection

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Design Goal

OVERCURRENT LEVELS		SUPPLY		TRANSIENT RESPONSE TIME
I_{IN} (min)	I_{IN} (max)	V+	V–	t
0 A	1.0 A	5 V	0 V	< 10 us

Design Description

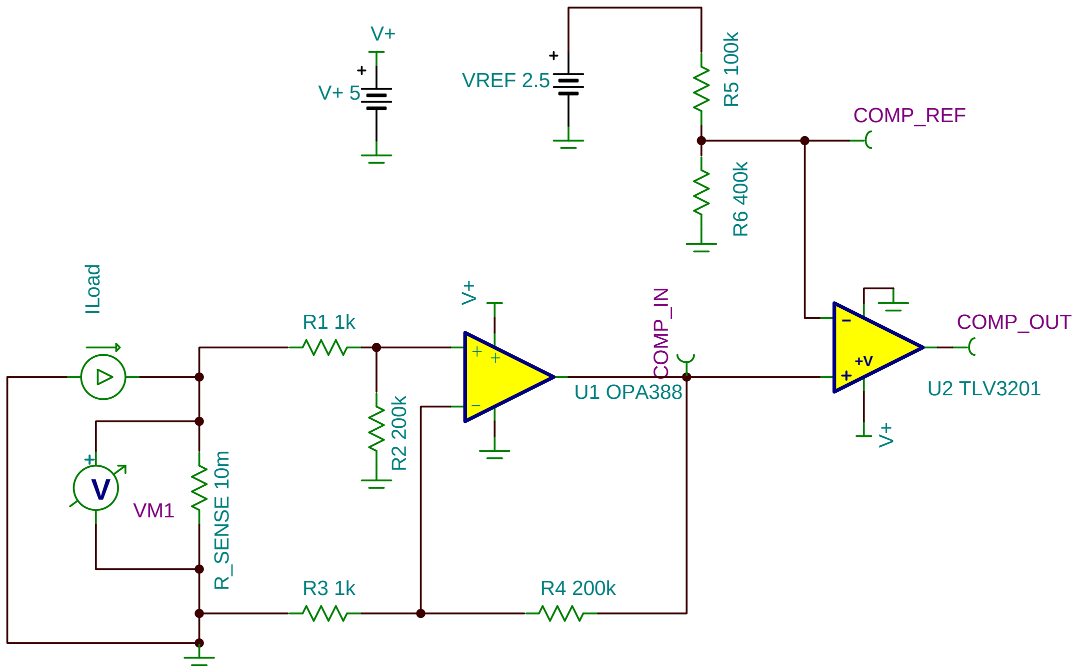
This high-speed, low-side overcurrent detection solution is implemented with a single zero-drift fast-settling amplifier (OPA388) and one high-speed comparator (TLV3201). This circuit is designed for applications that monitor fast current signals and overcurrent events, such as current detection in motors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

The OPA388 is selected for its widest bandwidth with ultra-low offset and fast slew rate. These parameters allow the circuit to be a well-balanced, high-speed solution in order to accurately detect high frequency current components. In applications that only require average current detection, devices with less bandwidth can be used like the LPV821. In applications that require faster response time, devices with larger bandwidth can be used like the THS4521.

The TLV3201 is selected for its fast response due to its small propagation delay of 40 ns and rise time of 4.8 ns. 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 40 µA.

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.

Dedicated current sense amplifiers can also be an option for high-speed current detection. The tradeoffs for each option should be taken into account when deciding on a current sense solution. Integrated solutions can provide larger bandwidth and savings on board space, but can be more costly and offer limited customization. Discrete solutions can be lower cost and easily customizable, but could require precision resistors to increase measurement precision.



V+
V+ 5
VREF 2.5
R5 100k
COMP_REF
R6 400k
ILoad
R1 1k
V+
COMP_IN
COMP_OUT
U1 OPA388
U2 TLV3201
R2 200k
V+
VM1
R_SENSE 10m
R3 1k
R4 200k

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 $R_2 = R_4$.

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

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.

$$R_{SENSE} = \frac{V_{SENSE}(\text{max})}{I_{LOAD}(\text{critical})} = \frac{10\ \text{mV}}{1\ \text{A}} = 10\ \text{m}\Omega \quad (2)$$

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

$$Gain = \frac{VREF}{R_{SENSE} \times I_{LOAD}(\text{critical})} = \frac{2\ \text{V}}{.01\ \text{V}} = \frac{R_2}{R_1 + R_2} \times 1 + \frac{R_4}{R_3} = 200 \quad (3)$$

$$Set\ R_1 = R_3 = 1\ \text{k}\Omega \quad (4)$$

$$R_2 = R_4 = 200\ \text{k}\Omega \quad (5)$$

4. Calculate the transimpedance gain of the amplifier in order to verify the AC simulation results shown below.

$$V_{OUT} = I_{LOAD} \times 10\ \text{m}\Omega \times 200 \quad (6)$$

$$\frac{V_{OUT}}{I_{LOAD}} = 10\ \text{m}\Omega \times 200 = 2 \quad (7)$$

Design Simulations

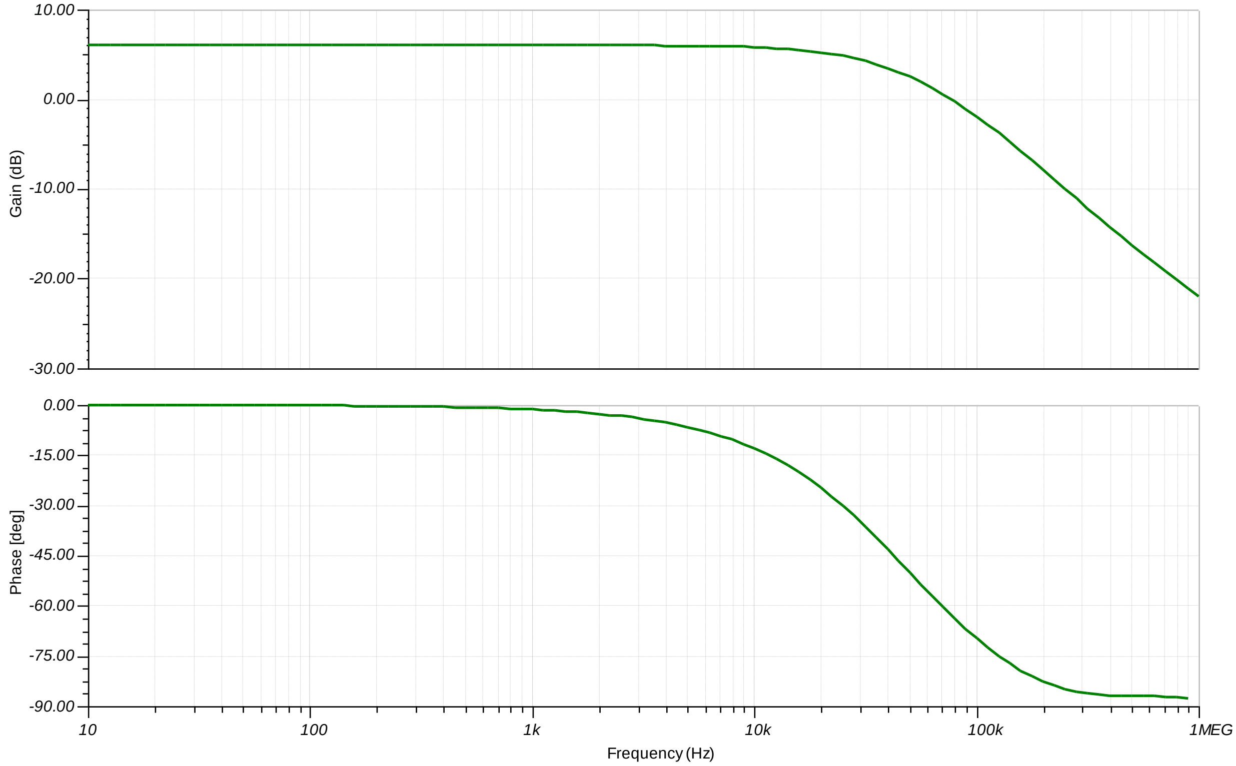


Figure 1. COMP_IN Transimpedance AC Simulation Results

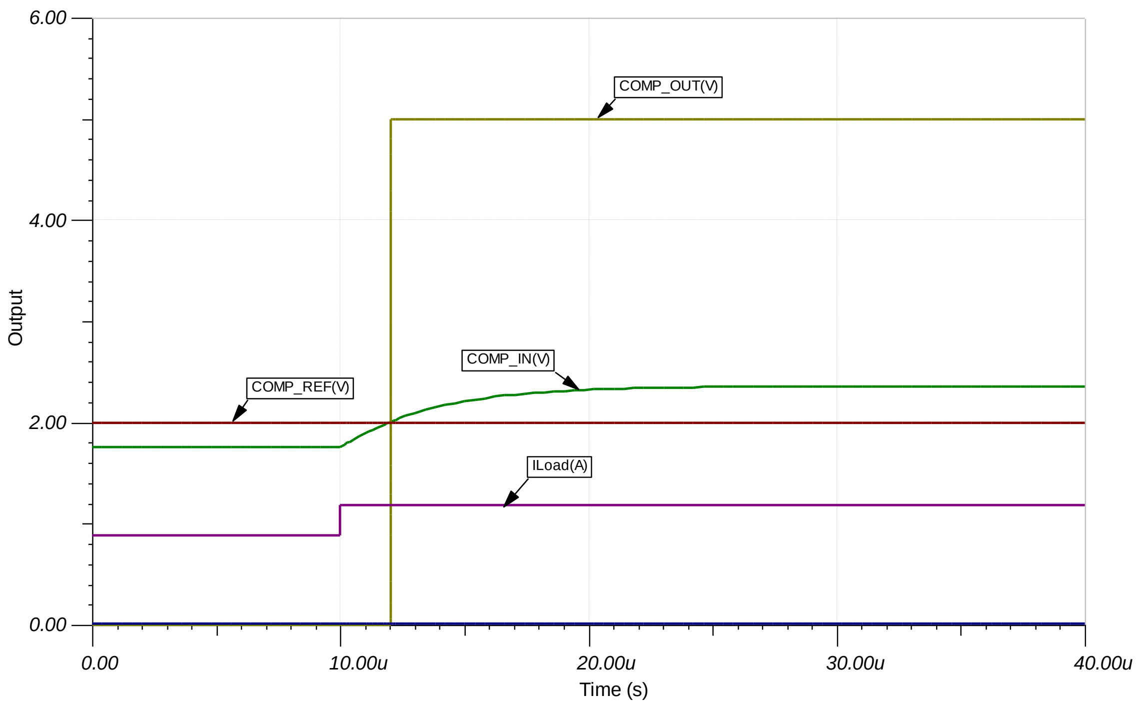


Figure 2. Transient Response Simulation Results

Tech Note and Blog References

See *Advantages of using Nanopower Zero Drift Amp for Mobile Phone Battery Monitoring* (SNOA977).

See *Current Sensing in No-Neutral Light Switches* (SNOA968).

See *GPIO Pins Power Signal Chain in Personal Electronics Running on Li-Ion Batteries* (SNOA983).

See the Current Sensing Using NanoPower Op Amps blog.

Table 1. Design Featured Comparator

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

Table 2. Design Alternate Comparator

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

Table 3. Design Featured Op Amp

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

Table 4. Design Alternate Op Amp

THS4521	
V_S	2.5 V to 5.5 V
Input V_{CM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	200 µV
V_{os} Drift	2 µV/°C
I_q	1 mA/Ch
I_b	0.65 µA
UGBW	145 MHz
THS4521	

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