Analog Engineer's Circuit

Fast-Response Overcurrent Event Detection Circuit

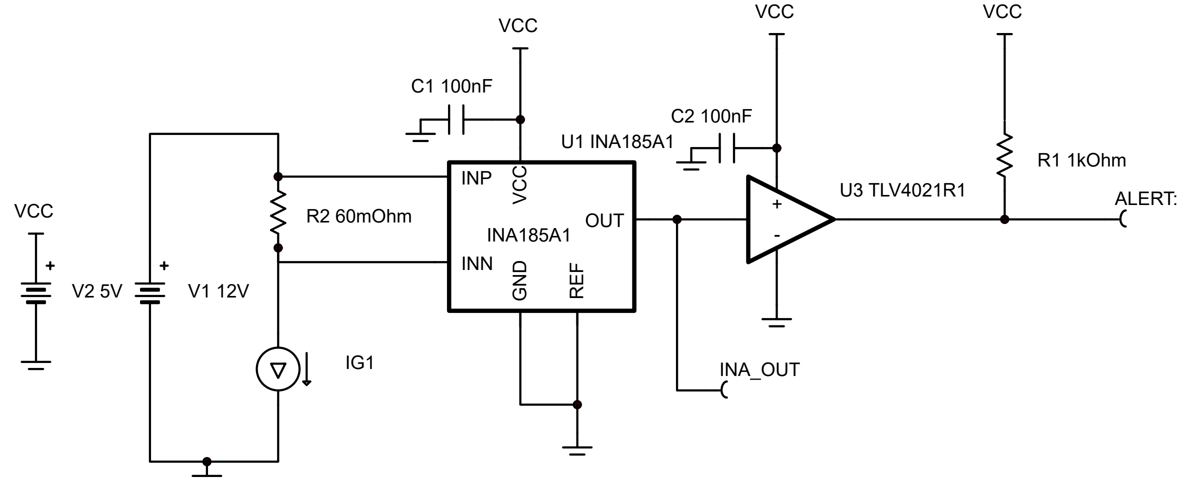
TEXAS INSTRUMENTS

Design Goals

Input		Overcurrent Conditions		Output		Supply	
$I_{load\ Min}$	$I_{load\ Max}$	I_{OC_TH}	t_{resp}	V_{out_OC}	$V_{out\_release}$	V_S	V_{REF}
80 mA	900 mA	1 A	< 2 µs	1.2 V	1.18 V	5 V	0 V

Design Description

This is a fast-response unidirectional current-sensing solution, generally referred to as overcurrent protection (OCP), that can provide a < 2 µs time response, t_{resp}, overcurrent alert signal to power off a system exceeding a threshold current. In this particular setup, the normal operating load is from 80 mA to 900 mA, with the overcurrent threshold defined at 1 A (I_{OC_TH}). The current shunt monitor is powered from a 5 V supply rail. OCP can be applied to both high-side and low-side topologies. The solution presented in this circuit is a high-side implementation. This circuit is useful in smart speakers and docking stations.



Design Notes

1. Use decoupling capacitors C1 and C2 to ensure the device supply is stable. Place the decoupling capacitor as close to the device supply pin as possible.
2. If a larger dynamic current measurement range is required with a higher trip point, a voltage divider from the INA185 OUT pin to ground can be incorporated with the divider output going to the TLV4021R1 input.

Design Steps

1. Determine the slew rate, SR, needed to facilitate a fast enough response when paired with the propagation delay of a comparator. In this example, the TLV4021 device is selected as the external comparator due to its quick propagation delay (t_P = 450 ns) and its quick fall time (t_f = 4 ns). The worst case occurs when the load ramps from 0 A to 1 A ($\Delta V_{out} = V_{trip}$ – 0 V). Device offset (V_{OS} × gain) can be subtracted from Vtrip in the numerator for less aggressive slew rates.

$$SR = \frac{\Delta V_{out}}{t_{resp} - t_P - t_F} = \frac{1.2V}{2\mu s - 450ns - 4ns} = 0.78V/\mu s$$

2. Choose a current shunt monitor with a slew rate greater than or equal 0.78 V/µs. The INA185 device satisfies the requirement with a typical slew of 2 V/µs.
3. For maximum headroom between the lowest measured current level and the overcurrent level, select the smallest gain variant of the chosen current shunt monitor. A 20 V/V current shunt monitor paired with 1.2 V comparator reference is adequate in this case.
4. Calculate the R_{shunt} value given 20 V/V gain. Use the nearest standard value shunt, preferably lower than the calculated shunt to avoid railing the output prematurely.

$$\mathrm{R_{shunt}} = \frac{\mathrm{V_{trip}}}{\mathrm{gain} \times \mathrm{I}_{trip}} = \frac{1.2\mathrm{V}}{20\mathrm{V/V} \times 1\mathrm{A}} = 0.06\Omega$$

$$\mathrm{R_{standard\ \ shunt}} = 60\mathrm{m}\Omega \text{ (standard 1\% value)}$$

5. Check that the minimum meaningful current measurement is significantly higher than the current shunt monitor input offset voltage. The recommended maximum error from offset, $error_{VOS}$ is 10%.

$$\mathrm{I_{Device\ \_min}} = \frac{\mathrm{V}_{OS}}{\frac{\mathrm{error}_{V_{OS}}}{100} \times \mathrm{R}_{shunt}} = \frac{450\mu V}{\frac{10}{100} \times 0.06\Omega} = 75mA$$

6. Check that $I_{Load\ Max}$ is below the hysteresis threshold, $I_{Release\_TH}$, to ensure that the ALERT signal is cleared after the system has taken corrective action to bring the load back under the upper limit of the normal operating range. In this case there is 83mA of margin between the 900 mA normal operating region maximum and the hysteresis level imposed by the comparator.

$$\mathrm{I_{Release\ \_TH}} = \frac{\mathrm{V}_{trip} - 20mV}{\mathrm{gain} \times \mathrm{R}_{shunt}} = \frac{1.2V - 20mV}{20V/V \times 0.06\Omega} = 0.983A$$

Design Simulations

DC Simulation Results

The DC transfer characteristic curve confirms that the OCP trigger occurs from a 1 A load.

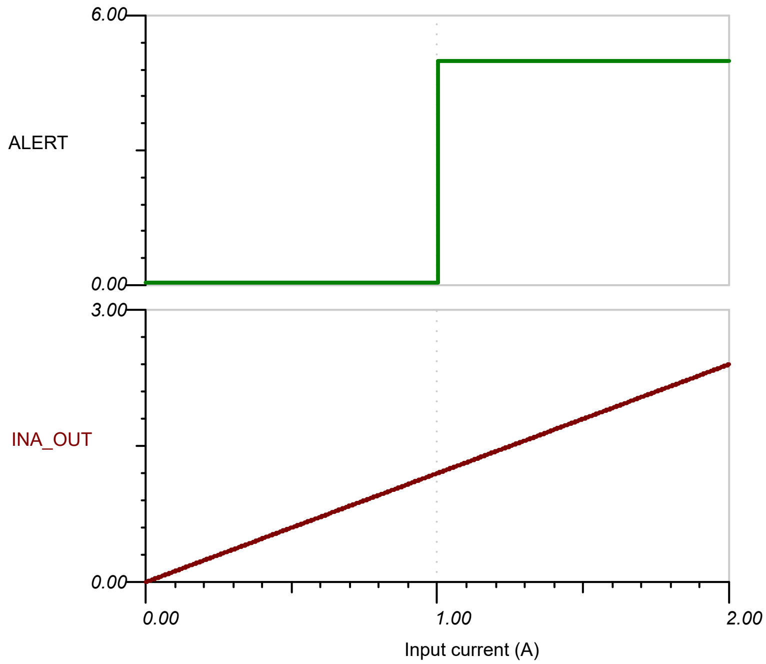
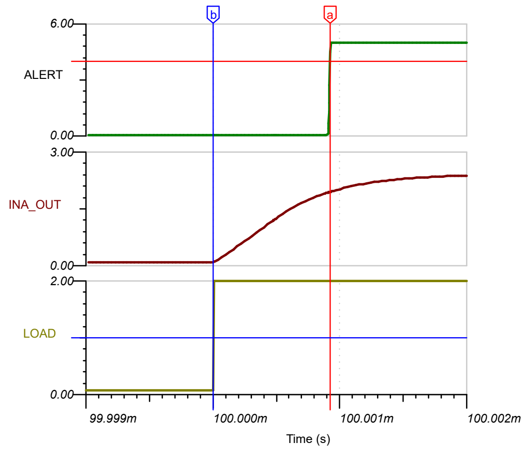


Figure 1-1.

Transient Simulation Results

The following result confirms that the INA185 device paired with the TLV4021 device can trigger an ALERT within 2 µs of the overcurrent threshold being exceeded. In this case, a typical value of almost 1µs is achieved. Please keep in mind that models used in these simulations are designed around typical device characteristics. Real-world performance many vary based on normal device variations.



A			
x:	100.0009289184ms	y:	4V
B			
x:	100.0001ms	y:	1A
A-B			
x:	918.9184ms	y:	

Design References

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

Key Files for Overcurrent Protection Circuit

Source files for this design:

High-Side OCP Tina Model

Low-Side OCP Tina Model

Getting Started With Current Sense Amplifiers Video Series

Getting started with current sense amplifiers

Design Featured Current Sense Amplifier

INA185	
V_S	2.7 V to 5.5 V
V_{CM}	GND-0.2 V to 26 V
V_{OUT}	GND + 500 µV to V_S – 0.02 V
Gain	20 V/V, 50 V/V, 100 V/V, 200 V/V
V_{OS}	±100 µV typical
SR	2 V/µs typical
I_q	200 µA typical
I_B	75 µA typical
INA185	

Design Alternate Current Sense Monitor

	INA181	INA180
V_S	2.7 V to 5.5 V	2.7 V to 5.5 V
V_{CM}	GND-0.2 V to 26 V	GND-0.2 V to 26 V
V_{OUT}	GND + 500 µV to V_S – 0.02 V	GND + 500 µV to V_S – 0.02 V
Gain	20 V/V, 50 V/V, 100 V/V, 200 V/V	20 V/V, 50 V/V, 100 V/V, 200 V/V
V_{OS}	±100 µV typical	±100 µV typical
SR	2 V/µs typical	2 V/µs typical
I_q	195 µA typical	197 µA typical
I_B	75 µA typical	80 µA typical
	INA181	INA180