

Overcurrent protection enables more efficient and reliable systems with longer lifecycles



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One key to preventing damage in modern electronic systems is the ability to rapidly detect and react to potentially damaging conditions. Accurate and precise overcurrent detection is one method for successful damage prevention.

Thermal management in modern electronics, whether the newest smart phone or the largest industrial machine, has become vitally important as two industry trends take hold. The first is the desire for more performance. Today's electronics have processing power in orders of magnitude more than their predecessors just since the early part of the millennium! The second is the desire for even smaller form factors. Historically, temperature has been used to manage the thermal protection of these systems. In many systems today, rather than measuring the lagging indicator (temperature), current (or the power which is the voltage times the current) is being measured, which is a leading indicator for thermal increase.

Overcurrent protection allows the design team to manage their system thermal performance more efficiently and anticipate problems versus react to potential issues. There are many reasons to monitor for overcurrent conditions, such as:

- Long-term system reliability
- System/user safety
- System efficiency
- Fault protection

System reliability

Long-term system reliability is affected by the amount of current flow. Current increases cause corresponding increases in the integrated circuits (IC) junction temperature. This temperature increase adversely affects the IC's performance (such as bandwidth, offset voltage, gain accuracy). **Figure 1** shows how the offset voltage of a typical high-speed amplifier is affected by temperature.

All ICs have a maximum junction temperature. If the junction temperature exceeds the maximum allowed, it likely will result in permanent damage to the IC. In turn this can damage other system components. Even if permanent damage is not the result, long-term exposure to elevated operating conditions can result in IC performance degradation, which can result in system reliability issues.

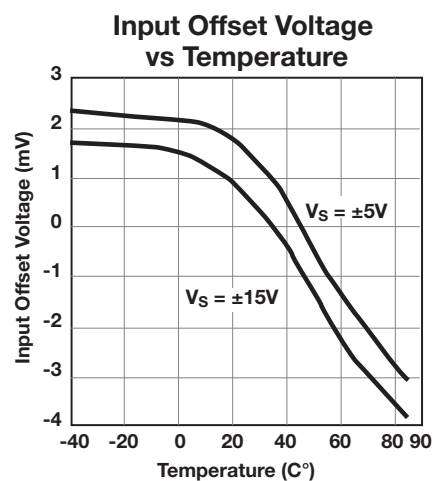


Figure 1. Large changes in temperature can cause serious performance degradation in integrated circuits. This figure shows an example of how offset voltage of a high-speed op amp is affected.

System/user safety

As mentioned, all components have maximum operating conditions. If left unmonitored, an increasing load current eventually will cause the IC to exceed the maximum ratings. In the worst case, the IC may actually ignite from the heat. While this level of failure is rare, the consequences will be costly in terms of system damage as well as the potential for bodily injury.

System efficiency

With the emphasis on creating more power-efficient (green) systems, and in many cases governmental regulations require it, minimizing power consumption has become a prime system design goal. Additionally, with the Internet of Things (IoT) driving the demand up for small battery-powered devices with extended run-times, saving power in these systems is vital. Monitoring the load current in systems and sub-systems can help maximize system resource usage efficiency, as well as power usage efficiency.

Fault protection

If a system has a fault such as a short to power or ground, serious system failures and damage are possible. Therefore, it is critical to detect faults as early as possible to prevent the damage. Clearly waiting for the corresponding increase in temperature related to the sudden increase in current that results from a short may be too late to prevent damage.

How to monitor for overcurrent?

Now that we understand why it is important to provide overcurrent protection, let us look at various options for implementation. Electronic monitoring systems typically provide a trigger in a

system management controller to take appropriate corrective action. System management controller responses range from simply turning on a cooling system (such as a fan) to a full system shutdown. Alternatively, the output could be routed to a relay that acts like a fuse and opens up the supply line, preventing system damage. Unlike a fuse, the relay resets once the system is reset, and the current drops below the threshold level.



Figure 2. Different styles and sizes of simple fuses.

Fuses

The fuse historically has been the most common method for providing overcurrent protection. Its sole purpose is to open in the event of an extended overcurrent condition. This approach is very low-cost, simple and effective in protecting the system from gross, overcurrent events. However, there are many draw-backs to such an implementation and trade-offs to consider.

By their very nature, the fuse only offers protection for a single event because the fuse is destroyed by the excess current. For the system to become functional again, the fuse must be replaced. This could be simply removing and replacing the fuse, or require rework at the board level. A single fuse for an entire system also does not help identify the actual faulty condition in the system. If the fault is not fixed, replacing the fuse will result in it blowing again, and more rework. Finally, the level of current

required to trip the fuse quickly must significantly exceed (four times or more) the fuse's rating. This makes it extremely difficult to predict the precise overcurrent level at which the fuse will open.

Electronic alternatives

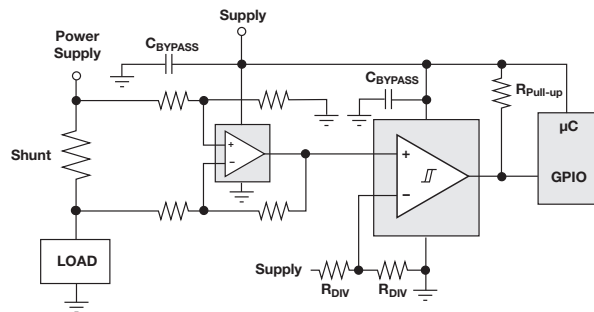


Figure 3. Overcurrent detection scheme with an op amp and a comparator.

Op amp plus comparator

An overcurrent detection solution can be easily created using a simple, low-cost operational amplifier (op amp), external gain-setting resistors, and a low-cost comparator (**Figure 3**). In addition to overcurrent detection, the output of the op amp can be used to measure the actual current level, which is of benefit in many systems. The threshold level of the comparator reference is determined by calculating the appropriate voltage that is applied to the input to the comparator, after the gain of the amplifier stage is applied to the voltage drop across the shunt that corresponds to the trigger current (**equation 1**):

$$V_{\text{threshold}} = I_{\text{TRG}} \times R_{\text{shunt}} \times \text{Gain} \quad (1)$$

This reference signal can vary from a simple resistor divider network (lowest cost and least accurate) (**Figure 1**) to a precision low-drift voltage reference (most expensive and highest accuracy). Normally the comparator's output is routed to a general purpose input/output (GPIO) pin on a microcontroller. The microcontroller will have code running that will use the signal as an interrupt to implement the system protection algorithms.

This scheme can offer very fast response times by using high-speed amplifiers and fast comparators. Since the op amp's common-mode voltage cannot exceed the amplifier's supply voltage, this scheme is normally used only on the low-side. (For more on these topics, check out TI's "[Getting Started with Current Sense Amplifiers](#)" video training series). This implementation's accuracy will be traded off versus the cost to implement. The more accuracy desired, the more expensive will be the system cost, whether the amplifier's performance or external discrete components. Finally, this implementation requires many components and the requisite board space required for those components.

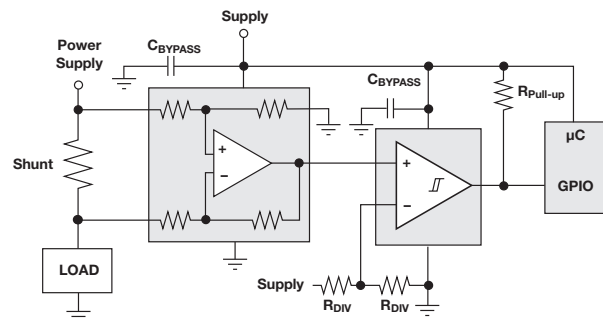


Figure 4. An overcurrent detection scheme with a current-sense amplifier and a comparator.

Current-sense amplifier and comparator

By replacing the op amp with a dedicated current-sense amplifier (also called a current shunt monitor), **Figure 4** can allow for further optimization of the system protection scheme. A current-sense amplifier is a specialized device that integrates the op amp and the gain-setting resistors. This integration of all the discrete components in the measurement portion enables a more accurate measurement while offering a smaller footprint. The shunt resistor value most likely can be reduced due to the increased accuracy enabled by improved V_{OFFSET} . This reduction in shunt resistor value enables lower power consumption in the measurement system, resulting in improved system power efficiency. Other than the change in accuracy

achievable in this implementation, it operates almost identically to that described in the op amp and comparator discussion.

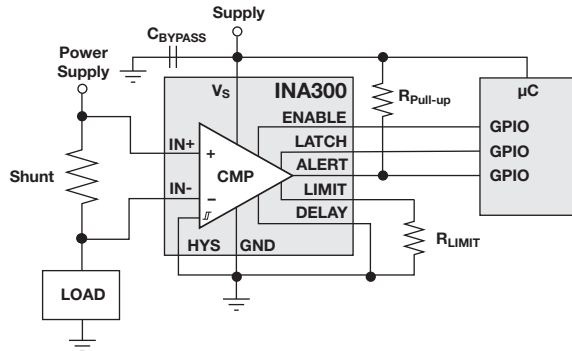


Figure 5. Overcurrent detection scheme via a current sense comparator.

Dedicated overcurrent comparator

A third option is to integrate all of the detection circuitry into a single device, such as the Texas Instruments [INA300](#). This device is a dedicated current-sense comparator optimized for overcurrent protection. It integrates both the precision measurement circuitry as well as the comparison portion, to create an all-in-one overcurrent detection solution (**Figure 5**) that is extremely simple to design into a system. The principle of operation is simplified versus that of either of the two-stage implementations described earlier. The threshold voltage is directly equal to the voltage drop across the shunt resistor corresponding to the trigger current allowed (**equation 2**):

$$V_{\text{threshold}} = R_{\text{SHUNT}} \times I_{\text{TRG}} \quad (2)$$

This adjustable threshold is set using a single external limit-setting resistor or via a voltage input from a digital-to-analog converter (DAC). The output can be configured to operate in either a transparent mode, where the output status follows the input state, or in a latched mode where the alert output is cleared when the latch is cleared, indicating that the

overcurrent alert has been received. The drawback of the implementation is the lack of information of the actual current being measured, just like with a fuse. As a matter of fact, the INA300 implementation can be thought of as an eFuse. (See this [TI design](#) for more information.) The output is treated just like the output of the comparator.

In addition to the simplicity when implementing this type of solution, board space savings are substantial. Miniaturization of overcurrent detection enables the rethinking of system-level management via subsystem monitoring, enabling:

- Use and efficiency: only the system portions needed are enabled
- Localized fault identification: shortens debug time by pinpointing the specific sub-system in which the overcurrent condition occurred
- Offload event detection: operates independently and only wakes system controller when needed

Let us compare the estimated footprint required for the three implementations discussed so far. Obviously implementation size will vary depending on the actual components chosen, but let us put some average numbers on the comparison. Table 1 summarizes the space requirements for each solution based on these assumptions:

- Typical op amps and comparators use the SOT23 package with a 2.8-mm x 2.9-mm footprint
- Many current-sense amplifiers (such as the [INA199](#)) use a SC-70 package with a footprint of 2.1 mm x 2.0 mm
- The INA300 comes in a space-savings, dual-flat no-lead (DFN) package that measures 2 mm x 2 mm
- The 0603 size (2.35 mm x 1.45 mm) is used for all non-shunt resistors
- For the shunt resistor, use the same 2512 size for all implementations: 7.25 mm x 3.85 mm

	Op amp + comparator	CSA+ comparator	INA300
Op amp	8.1	n/a	n/a
Comp	8.1	8.1	n/a
CSA	n/a	4.2	n/a
INA300	n/a	n/a	4.0
Shunt	27.9	27.9	27.9
Discrete Rs	30.7	17.0	10.2
R-area	3.4	3.4	3.4
#of Rs	9	5	3
Area	74.8	57.3	42.1
% Savings	n/a	23%	44%
			36%

Table 1. Overcurrent detection schemes footprint comparisons

Figures 6 and 7 shows the estimated board layout savings offered by the INA300 solution over the op amp and comparator solution.

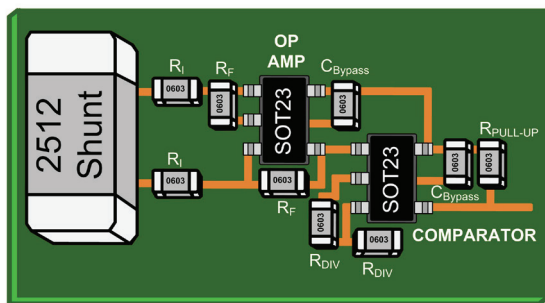


Figure 6. Footprint for an op amp and comparator overcurrent detection scheme.

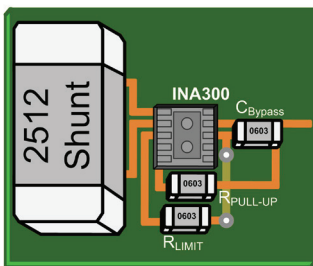


Figure 7. Footprint for an integrated over-current detector.

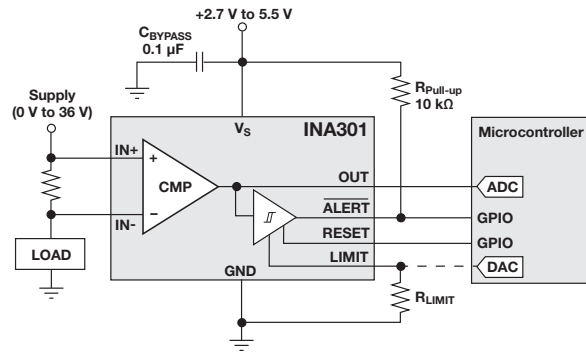


Figure 8. Overcurrent detection implementation using a fully-integrated current-sense amplifier and high-speed comparator.

Integrated current monitoring and overcurrent comparator

Extending the functionality of the dedicated overcurrent comparator to include monitoring of the current level addresses the shortcomings of a dedicated overcurrent comparator solution. The [INA301](#) (Figure 8) integrates a precision current-sense amplifier with a high-speed comparator. It takes the best of the current-sense amplifier and comparator implementation and the dedicated current-sense comparator implementation and wraps them into a small package that only needs a single external limit resistor. This allows the system implementer to enable both overcurrent detection and full-current monitoring in a very small and simple-to-implement method.

The system management controller does not need to monitor the current unless an overcurrent event triggers, at which point the controller can start monitoring the current to determine the required corrective action, if any. Further extensions of this implementation could include dual-overcurrent comparators or window comparators. Dual-overcurrent detection enables the implementation of more complex schemes, such as the lower limit being used to trigger the system management

controller to start monitoring the current while the second, higher alert could be used for critical system shutdown. A window comparator allows for detecting both undercurrent and overcurrent conditions. It also can be used to measure current flowing in both directions, for example in battery-powered devices when the battery is powering the system, or if the battery is being charged.

Digital power monitors with ALERT functionality

An additional option is that many newer digital power monitors, such as the [INA226](#) or [INA230](#), have an integrated ALERT function. Typically, these power monitors measure the current via a shunt voltage input, as well as measure the bus voltage. Many can calculate power consumption by multiplying the current level times the power level. ALERT options usually include overcurrent or undercurrent, overvoltage or undervoltage, and over power. Since the comparison of the inputs to the limits happens in the digital domain after the integrated analog-to-digital comparison, response times are slower than that achievable by the analog solutions discussed already. However, this digitization allows for more flexible ALERT options without increasing implementation cost, because no additional comparators are required.

Summary

Monitoring a system's current provides a leading indicator of potential issues. Whether the concern is system performance, system reliability, or basic safety concerns, knowing as early as possible of a potential issue enables minimizing system downtime or worse. Overcurrent detection is the simplest method of monitoring the current load in a system. While a fuse is a very simple and low-cost method for detecting and responding to such overcurrent conditions, using a fuse as a protection component does not provide information on the system's actual operating conditions. This is where other options for system protection via overcurrent detection can be employed. There are many overcurrent detection solutions that can be optimized based on the key concerns of a particular application – whether that be based on cost, solution size, measurement accuracy, or alert response time.

References

- [Getting Started with Current Sense Amplifiers](#), Texas Instruments Training Series
- [Automotive Precision eFuse Reference Design](#) (TIDA-00795), TI Design, Texas Instruments
- Download these data sheets: [INA199](#), [INA226](#), [INA230](#), [INA300](#), [INA301](#)

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