Application Brief

Quickly Detecting Overcurrent Faults With Low-Side Current Shunt Measurement Required for SiC or GaN Switches

Rachel Scheller, Charles Barsh *High-Speed Amplifiers*

As the electrification of automobiles rapidly increases, more advanced systems are integrated into vehicles. These electrified vehicles contain sensitive GaN and SiC switches that are susceptible to overcurrent conditions. Therefore, there is a need to implement a current-monitoring circuit that must react to peak overcurrent conditions, and in many cases, shut down in less than 1µs to prevent damage to the switches. Figure 1 illustrates how this need is addressed with a minimal delay time using a high-speed amplifier and comparator-based current-shunt monitoring circuit.

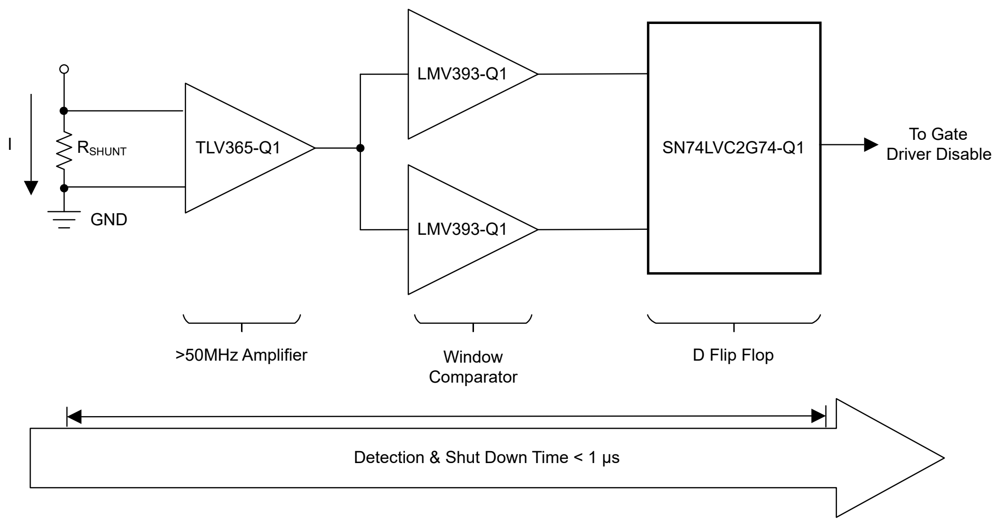

Figure 1. Typical Current-Detection Circuit

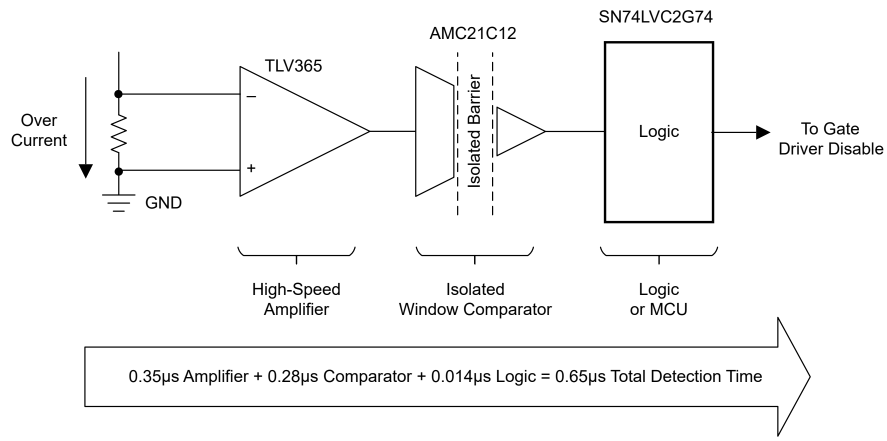

Figure 2. Typical Current-Detection Circuit With Isolation

What is a High-Speed Amplifier and Why Use One?

The propagation delay of a circuit varies drastically based upon the components selected. If a DC/DC converter uses average current control for power factor correction, for example, then a slower amplifier can be used. However, if there is a need to detect peak current, or if the system needs to react and shutdown in less than 1µs, then a high-bandwidth amplifier is required. In Figure 3, the current waveforms of peak detection and average detection are overlaid. The reason using a higher-bandwidth amplifier for peak detection is necessary is the fact that the transient current spikes occur very quickly – when measuring average current, these spikes remain undetected.

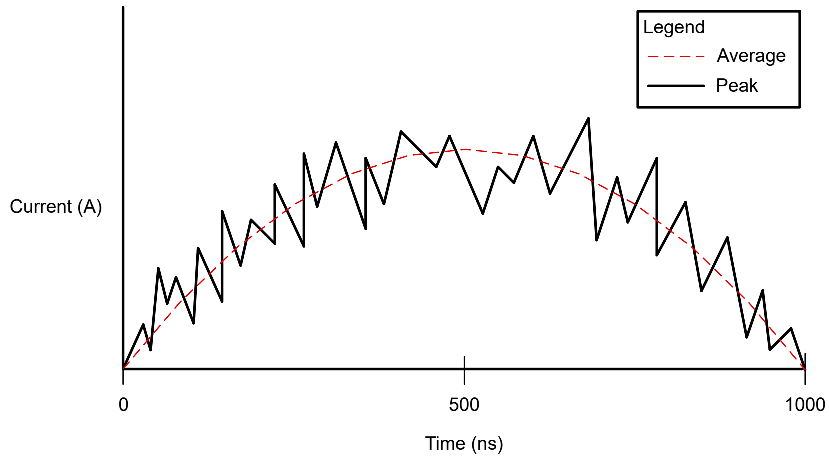

Figure 3. Average Current vs Peak Current Waveforms

Newer implementations of onboard chargers, DC/DC converters, and traction inverters take advantage of the reduced power consumption and faster switching frequencies provided with Gallium Nitride and Silicon Carbide switches. Many GaN switches are susceptible to failure from current spikes over 54A and at a duration of as little as 1µs. In Figure 4, the rise times of a 10MHz and a 50MHz op amp are compared, showing that a high-bandwidth 50MHz op amp reduces propagation delay by 0.8µs. This allows for ample time to detect and respond to an overcurrent condition.

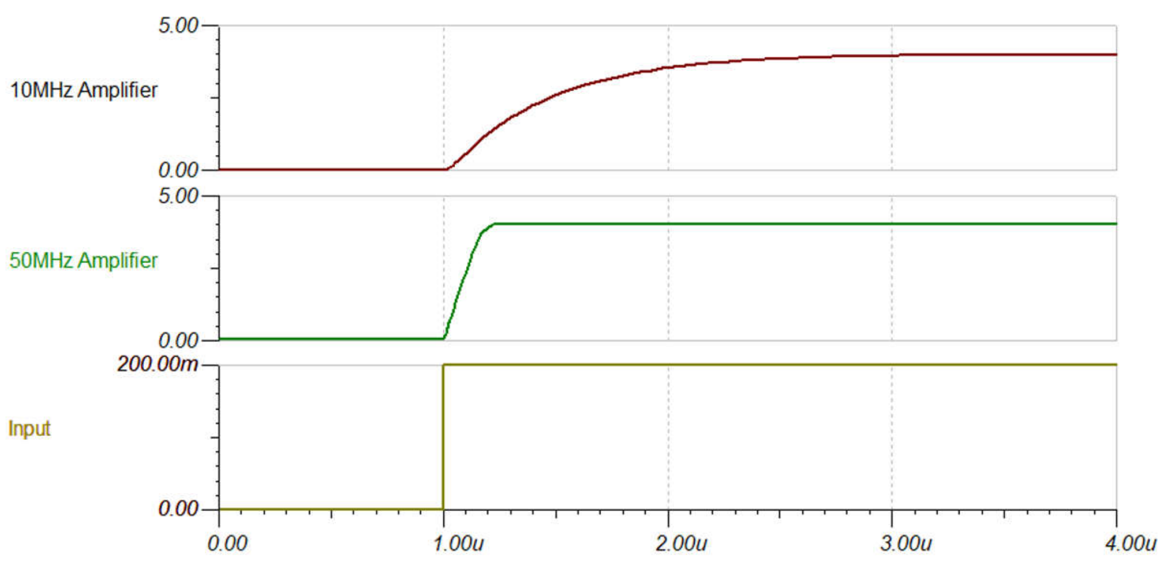

Figure 4. 10MHz Ideal Rise Time vs 50MHz Ideal Rise Time

To achieve detection and shutdown in less than 1µs, allocate 35% of the total response time to the amplification stage. If the amplifier requires a gain of 1V/V, then the required bandwidth of the amplifier is 1MHz; however, most shunt-based current monitoring circuits require gains in the range of 50V/V to reduce the power consumption of the shunt resistor. To achieve this level of gain, an amplifier with at least 50MHz is required, as Equation 1 demonstrates.

$$T_{response} = 35\% \times 1\mu s = 0.35\mu s$$

$$\text{Bandwidth}_{(Hz)} = \frac{0.35^{[1]}}{T_{response}} = \frac{0.35^{[1]}}{0.35\mu s} = 1MHz$$

$$GBW = \text{Gain} \times \text{Bandwidth} = 50\frac{V}{V} \times 1MHz = 50MHz \quad (1)$$

[1] 0.35 is a constant value used to approximate bandwidth.
This is related to the time required for a capacitor to charge from 10% to 90%.
See the *Op Amp Slew Rate* – *TI Precision Labs* video for more details.

Texas Instruments (TI) offers a variety of amplifiers for different system requirements. Figure 5 is a graph demonstrating rise times of several amplifiers with increasing bandwidth, and Table 1 is a comparison chart of the rise time.

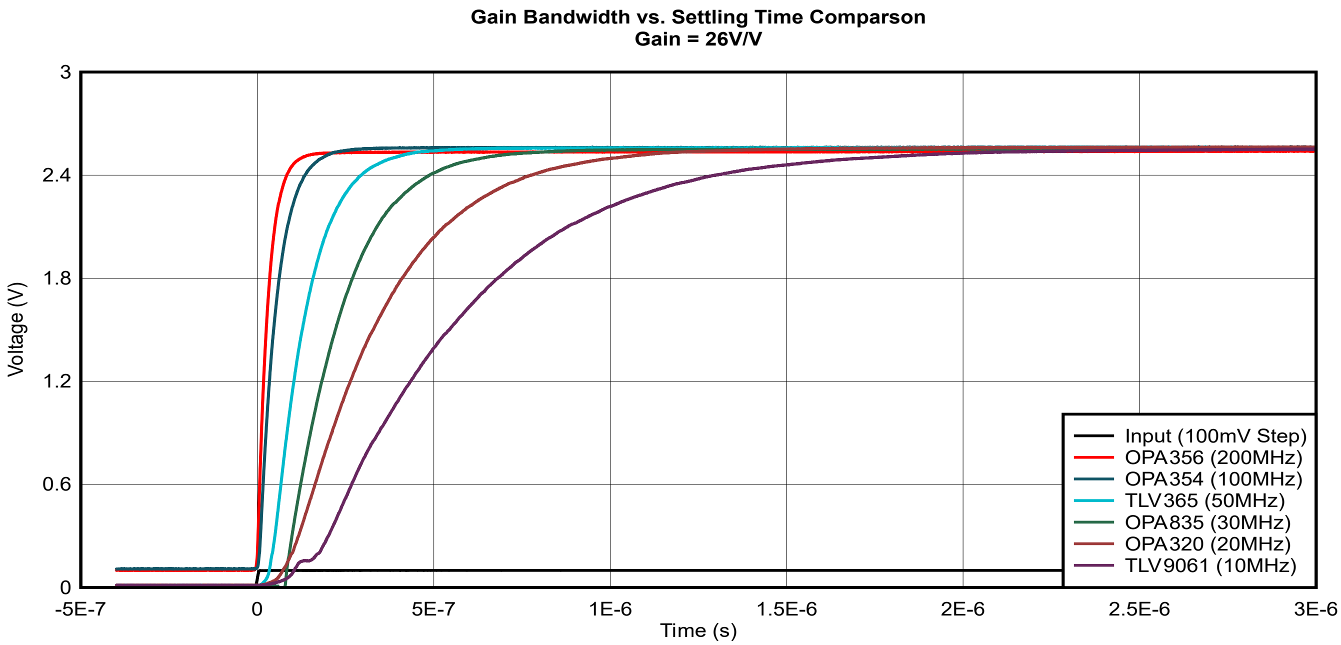

Figure 5. Rise Times of Several TI Amplifiers

Table 1. Rise Time Comparison Chart

Device	Gain Bandwidth	Change in Rise Time
TLV9061	10MHz	2000ns
OPA320	20MHz	1100ns
OPA835	30MHz	715ns
TLV365	50MHz	475ns
OPA354	100MHz	225ns
OPA355	200MHz	150ns

Some designers choose to cascade two or more lower-bandwidth amplifiers with different amplification stages to achieve the same amplification at a reduced cost. Using multiple lower-bandwidth amplifiers adds additional propagation delay and requires more space on the circuit board. High-bandwidth amplifiers historically were perceived to be costlier alternatives; however, with modern manufacturing capabilities at TI, these newer devices are able to be priced more competitively and are comparable to using multiple lower-bandwidth amplifiers.

Single Shunt versus Multi-shunt Current Sensing

A further way to reduce board space and potentially reduce cost is to implement a single shunt as opposed to using multiple shunts in a system. For a system in which multiple average current measurements are taken, utilizing a higher-bandwidth amplifier and tying these measurements together can reduce the number of amplifiers required. However, there are cases in which a multi-shunt configuration is required. For example, if measuring the individual current phases in a three-phase traction inverter is desired, then implement multiple high-bandwidth amplifiers to measure the peak current faster. Figure 6 and Figure 7 show typical setups of a single-shunt traction inverter and multi-shunt traction inverter.

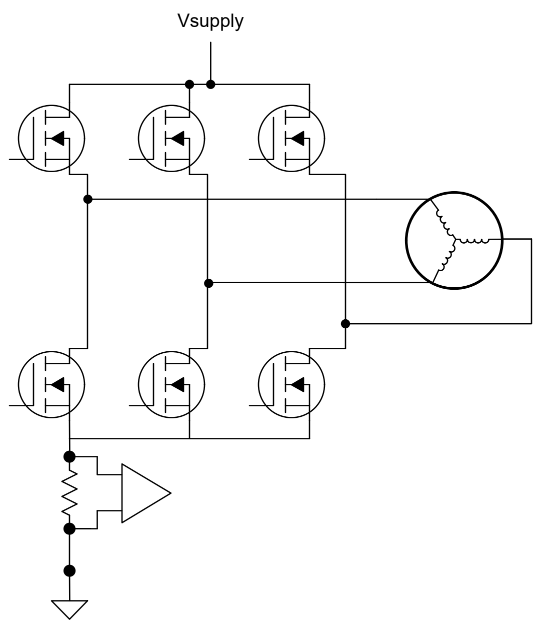

Figure 6. Single Shunt Implementation; Three Phases Tied Together

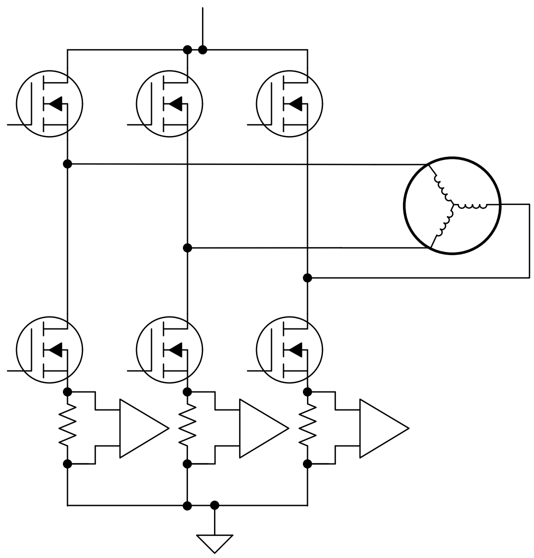

Figure 7. Multiple Shunt Implementation; Each Phase Current Measured Separately

Conclusion

Detecting and responding to overcurrent conditions in electrified vehicles in Sub-1µs is becoming increasingly important as more efficient GaN and SiC switches are implemented in these systems. When designing a system, choosing the right amplifier can help save board space, money, and reduce delay times. See TI's broad portfolio of automotive-qualified high-speed amplifiers that include a wide range of bandwidths and precision.

Table 2. Recommended Devices for Automotive Current-Sensing Applications

Device	Channel Count	Supply Voltage Range (V)	Gain Bandwidth Product (MHz)	Slew Rate (V/µs)	Minimum Stable Gain (V/V)
TLV365-Q1	1	2.2–5.5	50	27	1
OPA607-Q1	1	2.2–5.5	50	24	> 6
OPA2607-Q1	2	2.2–5.5	50	24	> 6
OPA354A-Q1	1	2.2–5.5	100	150	1
OPA2354A-Q1	2	2.2–5.5	100	150	1
OPA4354-Q1	4	2.2–5.5	100	150	1
OPA2863-Q1	2	2.7–12.6	50	105	1

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