Application Brief

Power and Material Optimization in 48V Power Distribution

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Introduction

The adoption of 48V-based architectures in automotive power distribution moves incrementally at a steady yet determined pace. The promise of the 48V domain is to ascend to a higher level of optimization, one where power losses are further minimized and materials (cables, connectors, PCB area) further reduced. However, OEMs and their suppliers have encountered new challenges migrating loads from legacy 12V domains.

For a semiconductor device to align with this mission, the device must offer something in addition to performing the designated task, something that helps optimize power and material. For example, a power distribution switch must have a complete arsenal of power management features as well as something that can help to reduce power and material further. This blueprint comes to reality in TI's first 48V automotive smart eFuse – TPS481HS04-Q1. The TPS481HS04-Q1 is a switch equipped with the tools to manage and reduce power, reduce material and ultimately relieve the pain points of the 48V migration.

Reducing Power Consumption

A mature 48V architecture benefits from reduced power losses migrating from 12V because of the higher voltage, as conduction losses scale with the magnitude of load current. These power savings can be further reduced leveraging the TPS481HS04-Q1's flexible low power mode. This is a mode where the device remains enabled to deliver power at lower currents with greatly reduced quiescent current consumption, as much as two orders of magnitude in reduced consumption.

Table 1. TPS481HS04-Q1 Low Power Mode Quiescent Currents

Specification			I_Q (µA)
Manual	VBB I_Q	Small FET	10
		Large FET	15
	VDD I_Q	Small FET	10
		Large FET	15
Automatic	VBB I_Q		15
	VDD I_Q		15
Normal Operation	VBB I_Q		3300
	VDD I_Q		1650

These values are based on pre-production silicon and may vary from the final production silicon

Two variations are offered: large FET and small FET. Both variations have configurable exit currents so the transition from low power mode to active mode is adjustable based on the needs of the load. The small-FET mode has lower exit currents, which allows it to consume less quiescent current, but comes at the cost of a smaller range of programmable values. The large FET mode has higher exit currents, giving it more range, but consumes higher quiescent current. The large FET low power mode can be configured for automatic entry and exit, which gives the device the autonomy to enter and exit LPM at fixed thresholds. Between these variations, a pathway to significantly reducing quiescent current consumption is shown. Table 1 shows the typical quiescent current consumption based on the FET in use.

Reducing Wire Harness Weight

A 48V power network naturally employs smaller gauge cables than its 12V predecessor. TI's 48V eFuses have a complete I^2T curve with multiple knobs to precisely tailor the overcurrent profile. This curve is a programmable energy threshold representative of a melting fuse's thermal limits. It can align with a melting fuse profile or a wire tolerance profile with more precision due to the integrated current sense. Aligning it with a wire profile can contribute to wire gauge reduction.

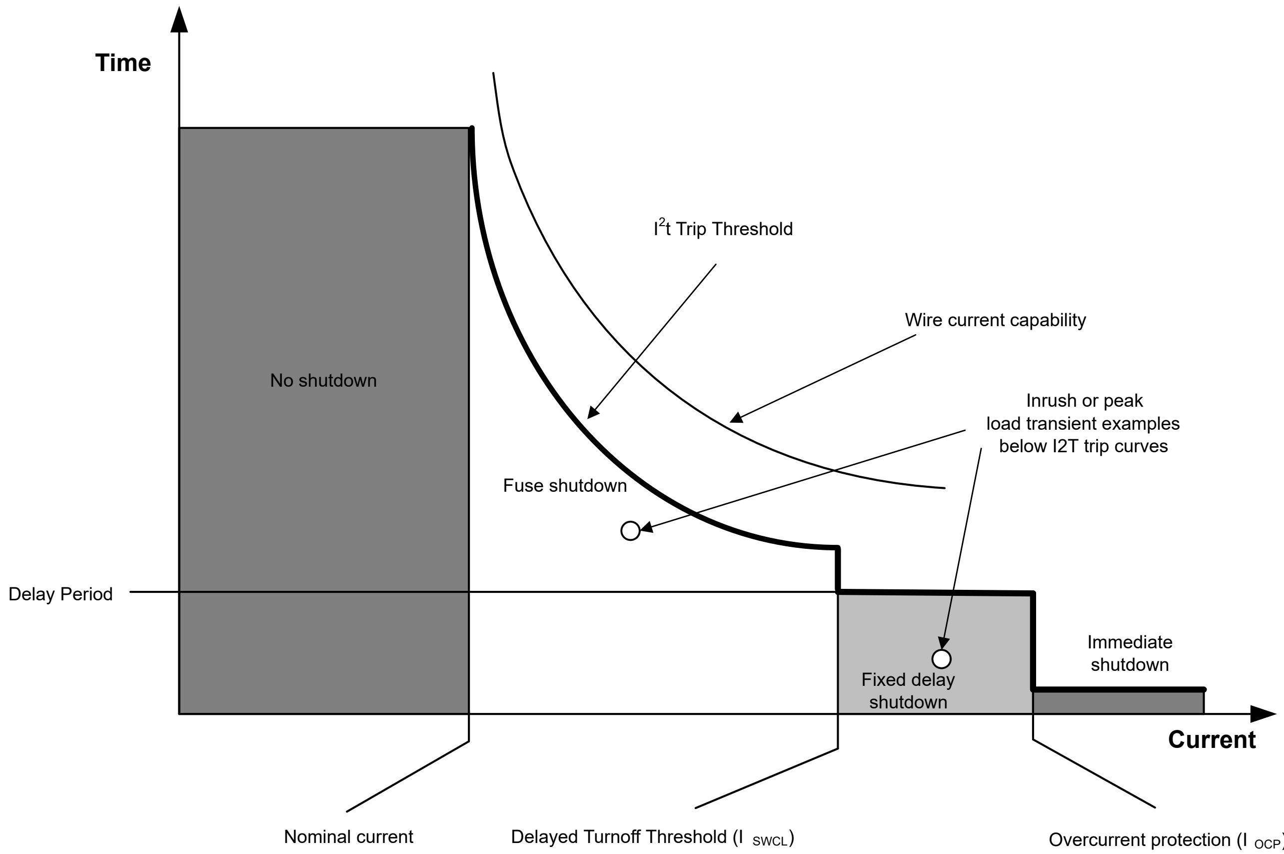

Figure 1. TPS481HS04-Q1's Configurable I^2T curve

The configurable I^2T curve, as shown in Figure 1, has a multivariable construction. There are four regions: the nominal region, the accumulation (I^2T) region, and the delayed shutdown and immediate shutdown region. Each of these plays a different role in the I^2T protection mechanism. The configurable nominal limit is the threshold across which the I^2T accumulation begins. The accumulation is simply the parallel computation of the current against time to determine if the programmed I^2T threshold has been breached. Beyond this, there is a delayed shutdown region where a programmable delay and threshold give another means to define the tolerance for faster and more powerful transients. Finally, the immediate shutdown region allows for a configurable fast trip limit for instantaneous protection. Altogether, these configurations create a complete power curve that will add another layer of protection and enable further cable weight reduction for 48V systems.

All in One Package

One of the central advantages of 48V is material reduction, as already discussed earlier in this document, in reference to cables, connectors, and PCB area. Therefore, the rule for semiconductors must necessarily follow in suit. And while silicon delivers more power per unit area of FET in the 48V domain than the 12V domain, an integrated eFuse component has not been available on the market. Early 48V designs used a gate driver and an external FET for their high-power loads. In these scenarios, the material reduction expectation at a component level was not met. With the TPS481HS04-Q1, the benefit of PCB reduction can be realized.

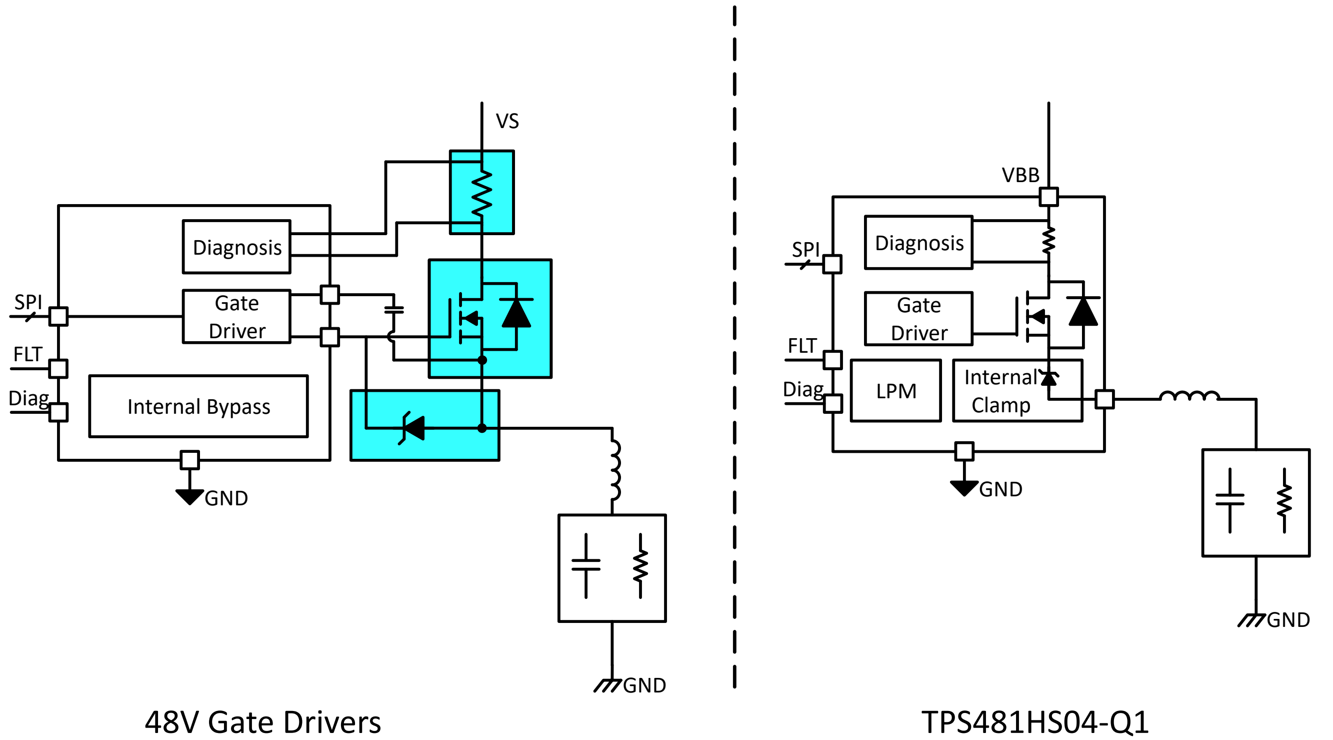

Figure 2. An Integrated Design Contributes to PCB Area Reduction

As shown visually in Figure 2 and tabulated in Table 2, there is a clear advantage with the integrated design. The space reduction can reach as much as 80% for power rails less than 1kW.

Table 2. Area Comparison

Size Comparison (mm2)		
Feature	48V Gate Driver	TPS481HS04-Q1
Controller	25	Integrated
Shunt	50	
FET	64	
Clamp	40	
Total	170	32

Methods of Inrush Management

The feature set of the TPS481HS04-Q1 is shown to push the 48V benefits further. In parallel, this device pushes the boundaries of what a power distribution switch can do as well. Managing inrush current in some form or another is axiomatic of power switching, and the TPS481HS04-Q1 introduces several additional creative methods. This capability is critical in power distribution as most ECUs have input bulk capacitance that must be charged in a controlled manner. With the TPS481HS04-Q1, the immediate shutdown method is available, where if the device enables into a hard short, the FET is disabled after the current breaches a programmed threshold. As discussed before, I^2T serves as a more advanced energy and time-based method, where again, once there is a breach, the FET is disabled. In addition to these two, there are three capacitive-charging schemes available depending on cable, load, or system requirements.

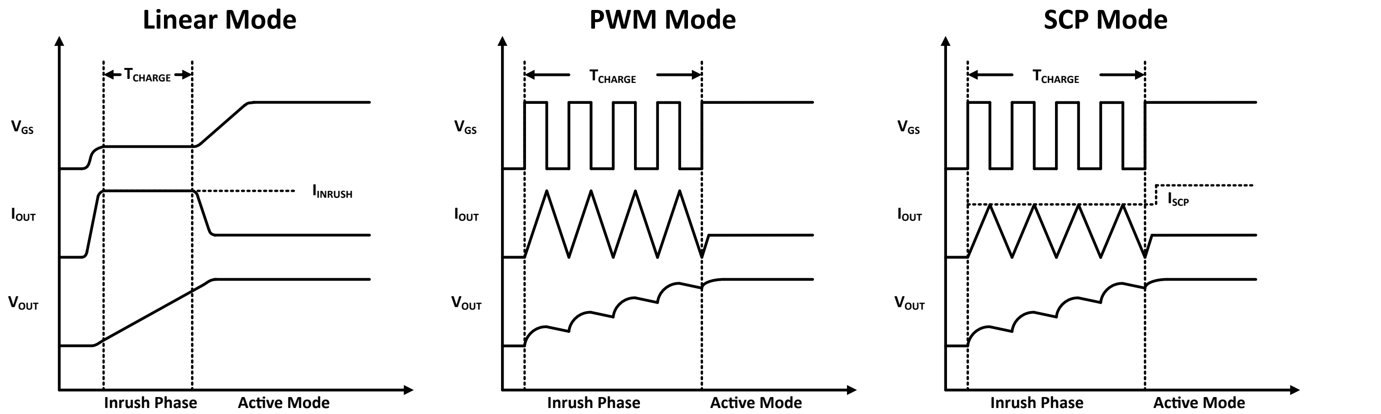

Figure 3. Three Different Capacitive Charge Modes Available

Each mode has different configurable parameters and advantages captured in Table 3. The first method is a linear capacitive charge mode where the inrush current is clamped at a programmed value to charge the load at a fixed rate. Both the limit and the duration of the charge period are configurable. This mode has low switching noise for EMC sensitive applications and is simple to configure. The second mode available is PWM based. The duty cycle and the frequency are configurable in this mode, as well as the duration. This mode can offer better thermal management over the linear mode and allows for a higher degree of configurability. The last mode is a short-circuit based (SCP) auto-retry scheme where the device continuously retries into a lower current limit that forces an immediate shutdown when trespassed. The duration and current limit are again the knobs. The SCP-based mode can be implemented without consideration of the wire-harness inductance, which varies from cable to cable. Together, these charging modes give great flexibility depending on the cable, the load, and the system requirements.

Table 3. Capacitive Charging Methods

Capacitive Charging Methods		
Mode	Configurable Parameters	Advantages
Linear	1. Inrush Current Limit 2. Charge Duration	Simple to configure, low switching noise
PWM	1. Charge Duration 2. Duty Cycle 3. Frequency	Strong thermal performance, highly configurable
SCP	1. Inrush Current Limit 2. Charge Duration	Strong thermal performance, can be set independent of wire-harness inductance

Conclusion

For automakers to reap the rewards of the 48V migration in power and material, they must have the tools that enable such a harvest. Much of the 48V discussion dwells in the power distribution sector and therefore falls disproportionately on the power switch for enablement.

Now, with TI's TPS481HS04-Q1 coming to market, such tools all come in one package. The device is equipped with a highly configurable I^2T curve for protection and cable gauge reduction, a low power mode to bolster power savings, and multiple capacitive charging methods to make this a remarkably versatile power distribution device.

Trademarks

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