Technical Article

Create a Cost-effective Boost Power Supply with True Load-disconnect Functionality

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The fast-growing consumer electronics market brings opportunities as well as challenges for boost converters. The huge volume drives the market to be very cost-sensitive, so you will need to make trade-offs between solution cost and performance.

The Need for True Load-disconnect Functionality

A boost converter does not have a native mechanism for load disconnection. The rectifier diode or body diode of the synchronous field-effect transistor (FET) passes the battery voltage to the load even when the boost converter is not operating. This leads to continuous battery drainage, even though the leak current may be small.

Many applications require the complete load disconnection and elimination of battery-current leakage when the circuit is not operating. For instance, a boost converter in an electric shaver only needs to operate when it is in use, to boost the battery voltage up for the LED backlight and the motor. Because the electric shaver is off most of the time, disconnecting the loads (the LED backlight and motor in this example) can avoid draining the battery and extend the shaver's service time between charging or battery replacement.

Obviously, a boost converter with an integrated load-disconnect function is a solution, but the cost of such a device is much higher than a converter without one. This is because a true load disconnect has to be implemented with two high-side power metal-oxide semiconductor field-effect transistors (MOSFETs) in a back-to-back connection, or with a single power MOSFET that can turn off the FET's body diode. Both implementations can greatly increase the cost of the boost converter integrated circuit (IC). In contrast, a boost converter like the TPS61322xx with an external load disconnect switch offers a cost-effective solution.

True Load-disconnect Configuration Options

You can implement a load-disconnect function by placing an external switch Q1 in the input power path of the boost converter, as shown in Figure 1. A mechanical switch, p-channel FET, p-channel n-channel p-channel (PNP) transistor, n-channel FET or n-channel p-channel n-channel (NPN) transistor can serve as the disconnect switch.

A popular choice is a mechanical switch, which doesn't require any extra control logic circuit but loses the ability to be controlled by the system microcontroller (MCU). Solid-state semiconductor devices are more controllable and robust, though. P-channel or n-channel FETs are usually preferable to PNP or NPN transistors because the latter two consume continuous base current to drive.

Between the n-channel FET and p-channel PFET, the $R_{DS(on)}$ of the n-channel FET is less than half the p-channel FET for the same size, and cheaper as well. However, it is challenging to design the printed circuit board (PCB) layout for an n-channel FET because you have to use it to break the ground path. Pay careful attention to the ground routing in these systems. Some applications prohibit the interruption of ground routing, because the broken ground leaves the load circuit energized, which can be a big risk.

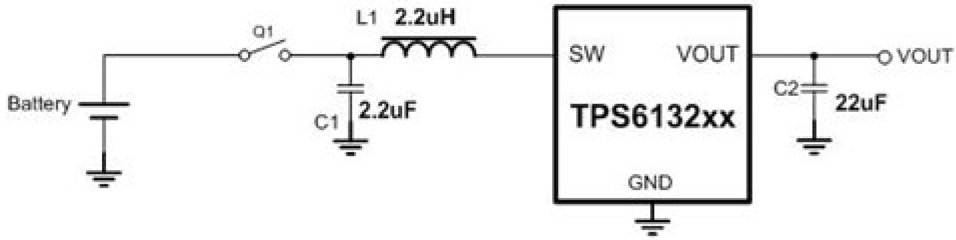

Figure 1. Load disconnection by mechanical switch

Another popular solution is to use a p-channel FET on the high side of the power path, which doesn't interrupt the system ground routing. Figure 2 shows a circuit configuration when the supply voltage of the MCU is higher than the battery voltage, and where the MCU directly controls main switch Q1. If the MCU's supply voltage is lower than the battery voltage, the general-purpose input/output (GPIO) voltage will not be high enough to turn off Q1 successfully. The solution is to use the configuration shown in Figure 3, where introducing a small n-channel FET or NPN transistor (Q2) helps control Q1.

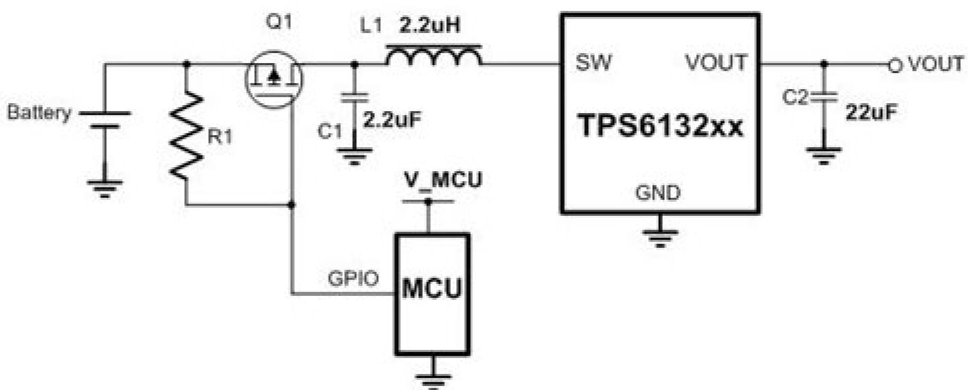

Figure 2. Load disconnection by p-channel FET, V_MCU > $V_{Battery}$

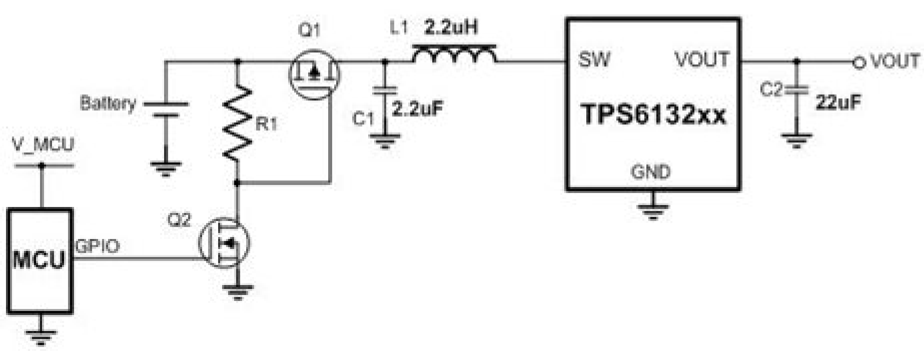

Figure 3. Load Disconnection by P-channel FET, V_MCU < $v_{Battery}$

If the ground routing is not a concern, an n-channel FET or NPN transistor can fulfill the load-disconnect function, as shown in Figure 4. This approach is simpler than the p-channel FET configuration, and the MCU controls Q1 directly.

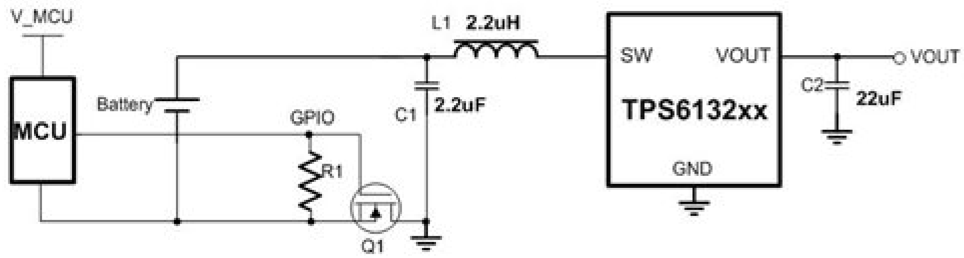

Figure 4. Load Disconnection by N-channel FET

Switch Considerations

It is very important to select a suitable load-disconnect switch. Unlike the MOSFETs of DC/DC converters, the load-disconnect switch is either on or off without frequent switching. Therefore, the gate charge Qg and the parasitic capacitances of the disconnect switch are not a main concern in component selection. Do pay attention to two things, however:

- The rated voltage of the switch should be higher than the battery voltage.
- Assess the $R_{DS(on)}$ of Q1 by allowing about 1% total solution efficiency loss under the maximum load. Use Equations (1) and (2) to calculate the power loss of the disconnect switch:

$$IIN_{RMS} = \frac{VOUT * IOUT * Efficiency}{VIN} \quad (1)$$

$$P_{SWITCH} = Rds(ON) * IIN_{RMS}^{2} \quad (2)$$

where IIN_{RMS} is the root-mean-square (RMS) value of the input current and $R_{DS(on)}$ is the on-resistance of the switch.

As an example, selecting an MOSFET with an $R_{DS(on)}$ < 25mΩ for 3V-to-5V conversion under a 500mA load causes about 1% loss in overall efficiency. The gate threshold should be less than the minimum battery voltage in order to guarantee operation in the entire range of the battery voltage. Q1 should support in-rush current during startup, during which the battery will charge both the input and output capacitors, and there are not many current-limit factors except for the $R_{DS(on)}$ of Q1 and the boost converter's internal synchronous FET. This in-rush current is not only related to the slew rate of Q1's gate voltage, but also affected by the input and output capacitors.

Test Results

I conducted a test with the TPS613222ADBVR, a fixed 5.0-V output voltage boost converter. The conditions were V_{IN} = 1.8V, 2.7V, 3.6V, 4.2V, L = 2.2µH.

As Figure 5, Figure 6 and Figure 7 show, the efficiency differences are very small between the circuit with and without a load-disconnect switch. The worst case is at a heavy load under a low V_{IN} condition, because if V_{IN} < 1.8V, Q1 will not have an adequate gate voltage to fully drive the FET. The $R_{DS(on)}$ will increase and hurt the efficiency.

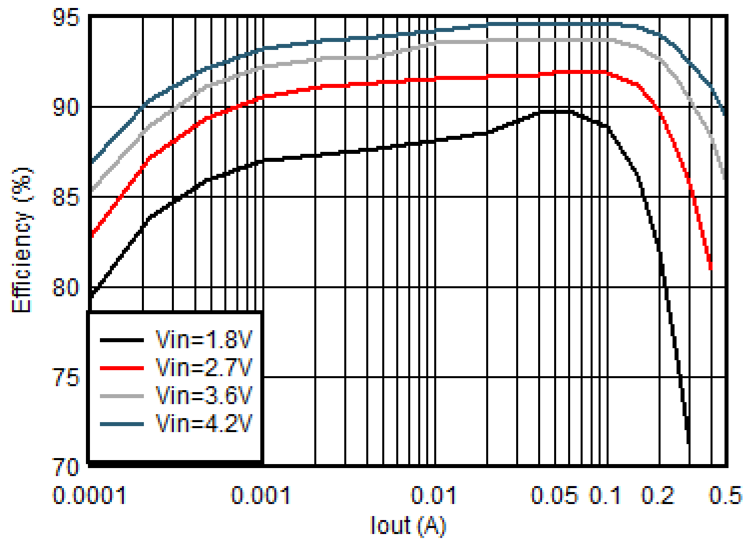

Figure 5. TPS613222A Efficiency without a Load-disconnect Switch

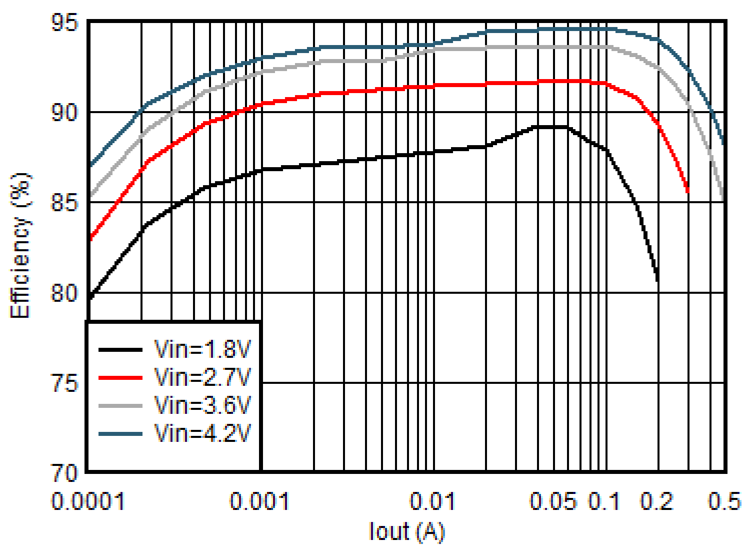

Figure 6. TPS613222A Efficiency with N-channel FET Disconnect Switch (FDN337N, $R_{DS(on)}$ = 82mΩ at v_{GS} = 2.5V)

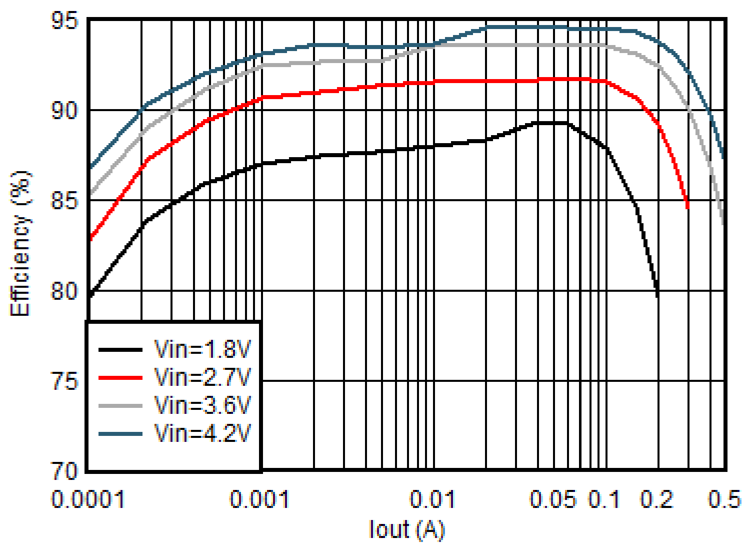

Figure 7. TPS613222A Efficiency with P-channel FET Disconnect Switch (FDN306P, $R_{DS(on)}$ = 50mΩ at v_{GS} = -2.5V)

Conclusion

A device like the TPS613222A provides a cost-effective solution to applications requiring a true load-disconnect function. You can decide to add the appropriate type of switch according to your end-application requirements. True load disconnection is easy to achieve and the total cost can still remain very competitive. For further information, **r**ead the blog post, "How to Select a MOSFET – Load Switching."

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