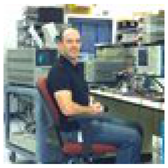
Technical Article

Buck-boost Regulator Benefits Automotive Conducted Immunity



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An automotive battery's steady-state voltage ranges from 9V to 16V depending on its state of charge, ambient temperature and alternator operating condition. However, the battery power bus is also subject to a wide range of dynamic disturbances, including start-stop, cold crank and load-dump transients.

Each automotive manufacturer has a unique and extensive conducted immunity test suite in addition to the standardized pulse waveforms given by industry standards such as International Organization for Standardization (ISO) 7637 and ISO 16750. Table 1 identifies several undervoltage and overvoltage automotive transient profiles.

Table 1. Automotive battery continuous and transient conducted disturbances with related test levels

Transient	Cause	Amplitude & Duration	Relevant Standard
Load dump	Disconnection of discharged battery from alternator at high output current	Clamped to U_S* = 35V, subject to alternator's centralized clamp and voltage regulator's response time	ISO 16750-2:2012 section 4.6.4
Cold crank	Battery voltage reduction and subsequent recovery upon energizing the starter motor	Initial low-voltage plateau (U_{56}) as low as 2.8V for 15ms during a cold-crank period	ISO 16750-2:2012 section 4.6.3 (OEM variants of this also)
Double-battery jump start	Jump-start from commercial vehicle with a dual-battery electrical system	24V for 2 minutes	ISO 16750-2:2012 section 4.3.1
Alternator regulator failure	Alternator's voltage regulator malfunction, causing full application of charging current to the battery	18V for 1 hour	OEM specific
Reversed voltage	Negative voltage applied by misconnection at the battery terminals	–14V for 1 minute	ISO 16750-2:2012 section 4.7
Inductive loads	Switching or disconnection of high-current inductive loads (fans, window motors, braking system, etc.)	–150V for 2ms (pulse 1) +150V for 50µs (pulse 2a)	ISO 7637-2:2011 pulses 1, 2a, 2b, 3a, 3b
Superimposed alternating voltage	AC voltage riding on DC battery voltage due to alternator's 3-phase bridge-rectified output voltage	1V to 4V amplitude at 50Hz to 25kHz sweep over 2 minutes duration	ISO 16750-2:2012 section 4.4

Alternator-induced Noise

One particularly troublesome source of noise within the audio frequency range is an automotive alternator causing a residual alternating current on its output, leading to alternator "whine" and supply modulation issues. ISO 16750-2 section 4.4, mentioned in Table 1, describes a ripple voltage on the alternator's output in the frequency range of 50Hz to 25kHz, with a peak-to-peak amplitude (V_{PP}) of 1V, 2V and 4V depending on the test pulse severity level. See Figure 1.

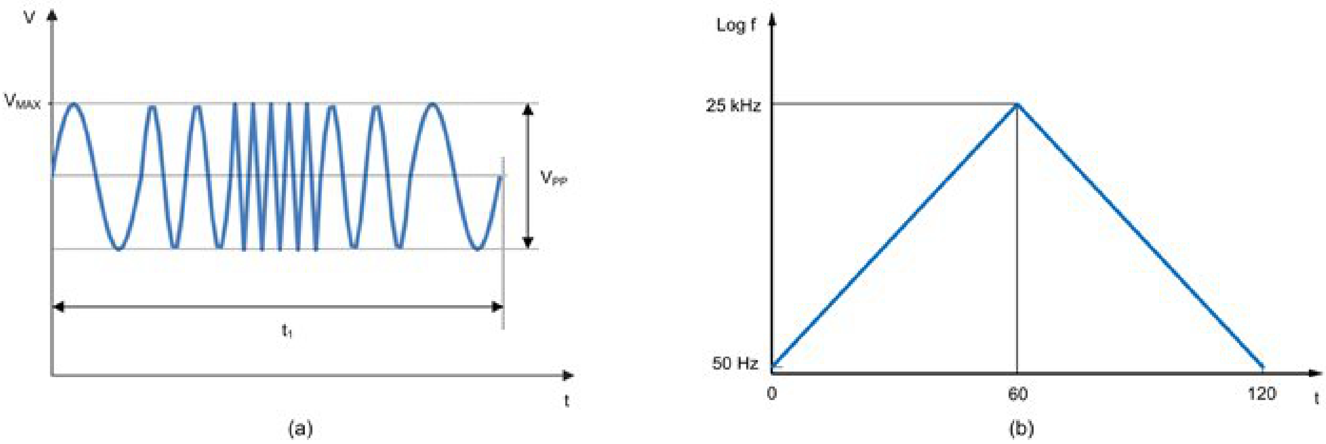

Figure 1. An ISO 16750-2 Superimposed Alternating Voltage Test (a); a Log Frequency Sweep Profile from 50Hz to 25kHz over a Two-minute Sweep Duration (b)

In many vehicles, a centralized passive-circuit-protection network consisting of a low-pass inductor-capacitor (LC) filter and transient voltage suppressor (TVS) diode is used as a first line of defense for transient disturbance rejection. Automotive electronics located downstream from the protection network are then rated to survive transients up to 40V without damage. However, the required cutoff frequency of the LC filter to attenuate low-frequency disturbances makes the filter inductor and electrolytic capacitor quite large. What's required is an active power stage that eliminates the bulky passive filter components and provides a compact and cost-effective solution for tight voltage regulation and transient rejection.

Four-switch Synchronous Buck-boost Regulator

The benefit of a wide V_{IN} buck-boost regulator solution lies in its high power-supply rejection ratio (PSRR), offering excellent transient dynamics to attenuate input voltage transients. With that in mind, I recently wrote an article, "Automotive front-end buck-boost regulator actively filters voltage disturbances," that describes a high density solution for automotive applications.

Figure 2 shows the schematic of a four-switch buck-boost regulator designed to output a tightly regulated 12V rail. This solution is ideal for critical automotive functions including drive trains, fuel systems, and body and safety subsystems where loads must remain powered without glitches during even the most severe battery-voltage transients. This easy-to-use design tool streamlines regulator design and implementation for faster design-in and time to market.

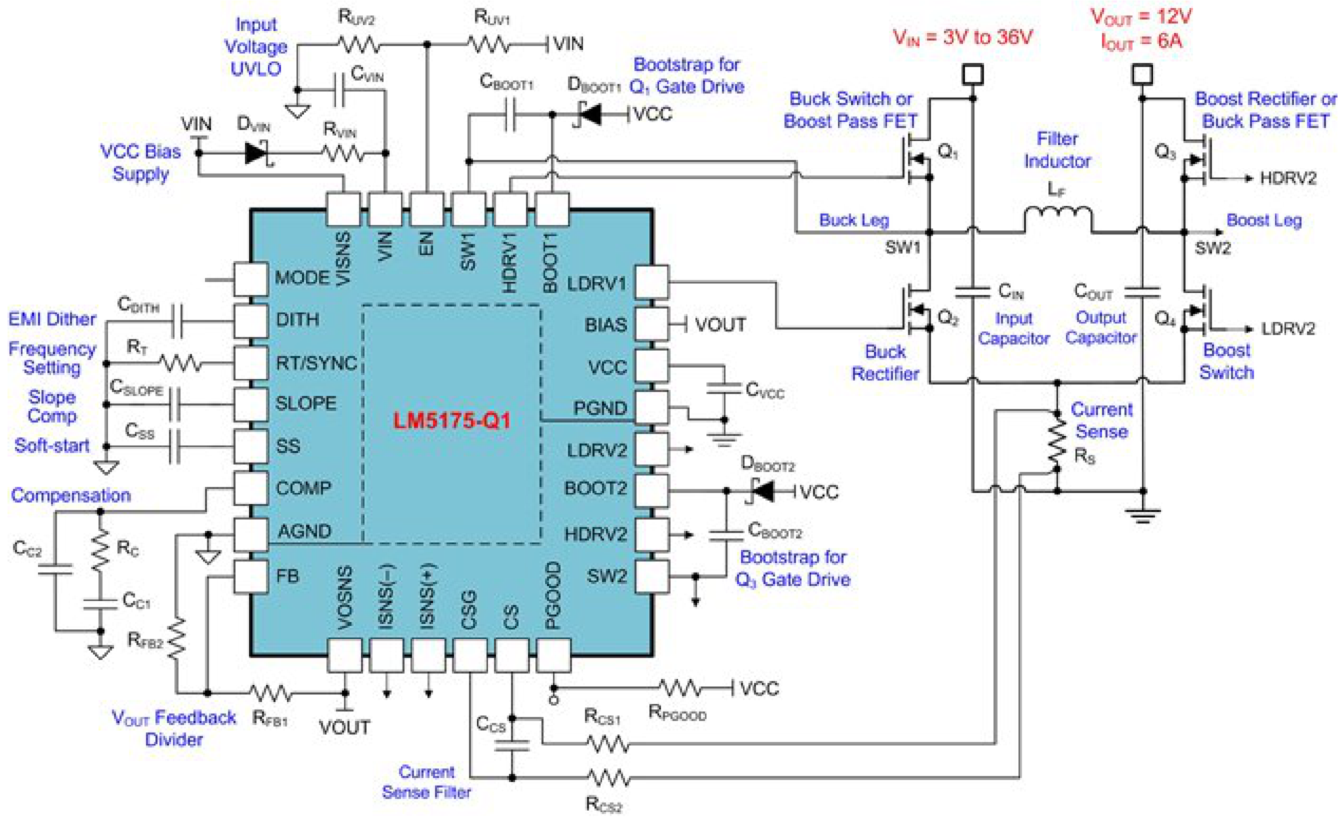

Figure 2. Four-switch Synchronous Buck-boost Solution with a Wide V_{IN} Range of 3V to 36V

Figure 3a shows the buck-boost regulator's output voltage waveform when a DC input of 9V has a superimposed sinusoidal ripple with a peak-to-peak amplitude of 1V and a frequency of 1kHz. The input ripple is attenuated by approximately 40dB. Figure 3b shows the output voltage during a cold-crank transient down to 3V for 20ms using an automotive cold-crank simulator. The four-switch buck-boost converter regulates seamlessly through the cold-crank profile.

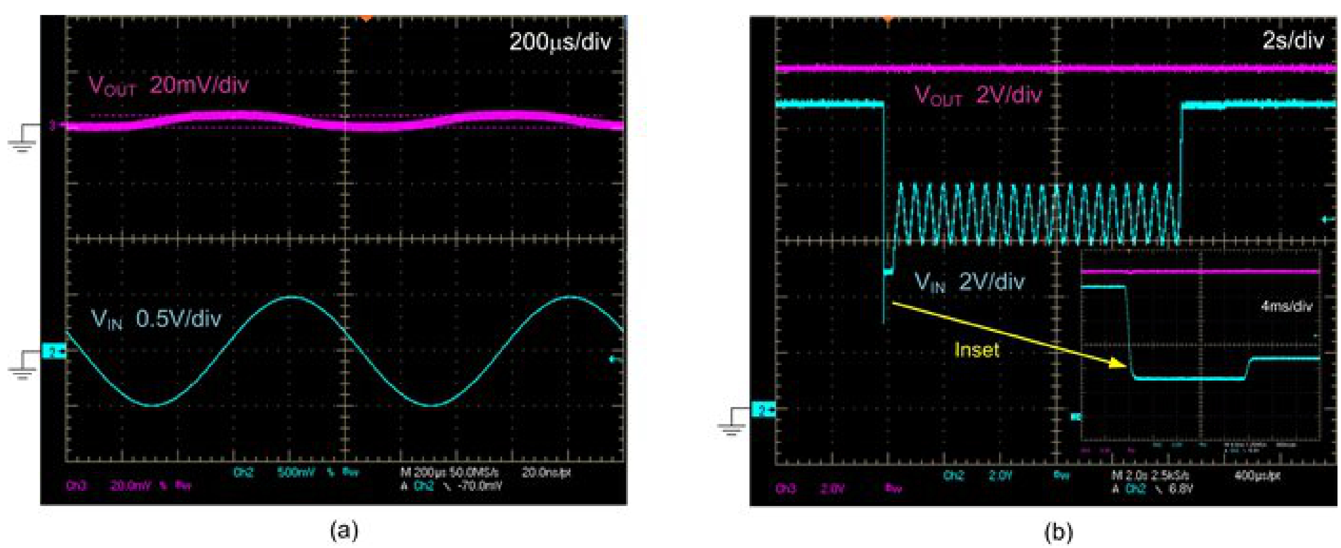

Figure 3. Measured Four-switch Buck-boost Converter: Ripple Rejection at a 9V DC Input (a); Cold-crank Performance (b)

Summary

With its high PSRR, high efficiency and low overall bill-of-materials cost, a four-switch synchronous buck-boost like TI's LM5175-Q1 current-mode controller offers a useful solution for mitigating transient disturbances in automotive applications. This buck-boost controller is automotive qualified to facilitate its integration into vehicular 12V single-battery and 24V dual-battery systems.

Additional Resources:

- Check out the "Under the Hood of a Non-Inverting Buck-Boost DC/DC Converter" topic from TI's 2016-2017 Power Supply Design Seminars.
- Read "Designing the front-end DC/DC conversion stage to withstand automotive transients" in the 1Q17 edition of TI's Analog Applications Journal.
- Order an evaluation module for the LM5175-Q1 buck-boost controller.
- Peruse the ever-expanding repository of wide V_{IN} automotive power solutions in the TI Designsreference design library, for example:
  - Automotive Wide V_{IN} Front-End Power Reference Design with Cold Crank Operation and Transient Protection.
  - Front End Power Supply Reference Design with Cold Crank Operation, Transient Protection, EMI Filter.

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