Keywords: power management, power modules, aftermarket transportation electronics, industrial electronics, power supply, power architecture, fault protection, protection ICs, DC-DC regulators

APPLICATION NOTE 6613

HIGHLY EFFICIENT POWER-MANAGEMENT ARCHITECTURES FOR AFTERMARKET TRANSPORTATION ELECTRONICS

Abstract: This application note covers the key market trends and customer needs that are presenting new challenges for power-supply design for aftermarket technologies and transport infrastructure automation. Equipment supporting this market must be robust against transient conditions like overvoltage, overcurrent, reverse voltage, reverse current, and overtemperature. This piece presents solutions to these challenges, with a particular emphasis on power architecture. A similar version of this application note appeared on Electronics for U on December 21, 2017.

Introduction

Electronics for the industrial transportation market includes a variety of applications. There are aftermarket additions for automation and entertainment in cars, trucks, trains, planes, and ships. There's also infrastructure automation for roads, sea lanes, trains, and air traffic control to move people and goods more efficiently.

Aftermarket automotive products have driven quite a bit of innovation in areas ranging from infotainment and telematics to advanced driver-assistance systems (ADAS) over the last few decades. Consider technologies that are being designed into cars and trucks, such as GPS, audio, seat-back video, rear-view cameras, parking sensors, charging ports, and keyless entry. There is also a continuous rollout of novel aftermarket technologies being developed by companies worldwide. Recent innovations include fleet management, on-board diagnostics, heads-up display (HUD), gesture-controlled navigation, network gateways, driver assistance, keyless/biometrics-based entry/exit/driving, and freight control/monitoring. We're seeing these technologies in cars and trucks, as well as in trains, ships, avionics, and defense applications.

Transport infrastructure automation to move people and goods more efficiently includes HOV lane control, parking/toll, fare meters, traffic control, and others. Faster movement, on-time schedules, and fewer accidents are now possible thanks to engineering ingenuity.

Trends in Industrial Transportation

Fleet management and logistics represents one of the most dynamic applications in industrial transportation today. Tracking goods is big business, given that goods are being manufactured and shipped from various regions, states, countries or even overseas. For example, transported perishables must be kept under regulated temperature, pressure, or other parameters throughout their journey. Similarly, secure goods require sensors to track location and entry access. Driver safety is also important and ensuring this safety calls for data from cameras monitoring driver alertness and GPS systems tracking vehicle location. This data is logged using wireless networks and cloud infrastructure, and complex algorithms synthesize the data to make real-time decisions on route and/or driver safety. Several GPS navigation companies are now providing hardware and software products and services for the fleet-management market. North America, Europe, Japan, and Korea each have a long history of advanced fleet-management systems. More recently, Latin America, China, and India are adding this capability, presenting a huge growth opportunity. Interestingly, Israel has several players that develop products for consumption in Israel, Africa, Europe, and the rest of the world.

Some may believe that there isn't too much more innovative technology to bring to the infotainment space, since we already have so many audio/video, smartphone, and navigation options becoming standard features. Yet, trends in this area include integration beyond a simple smartphone interface to add HUD that projects the phone screen onto the windshield glass with gesture control to navigate between maps and video calls, or other salient features like weather, stock ticker, calendar, etc. Seat-back screens to mirror the phone screen for rear passengers is also an active product development area.

ADAS solutions continue to be a growing market. Aftermarket ADAS technologies include parking sensors, rear-/extended-view cameras, lighting, traffic warnings, car-to-car (vehicle-to-vehicle) interface, and others. Several manufacturers are working on solutions that enable drivers to avoid unintended lane departures, collisions, pedestrians, and road hazards, as well as drive within the speed limit.

Considering how much time people are spending in cars in highly congested urban cities, many OEMs are adding wireless gateways to cars and buses. Passengers can then continue their work during long commutes between home and office/school.

Typical System Architecture

Figure 1 shows is a typical fleet tracking/management system architecture.

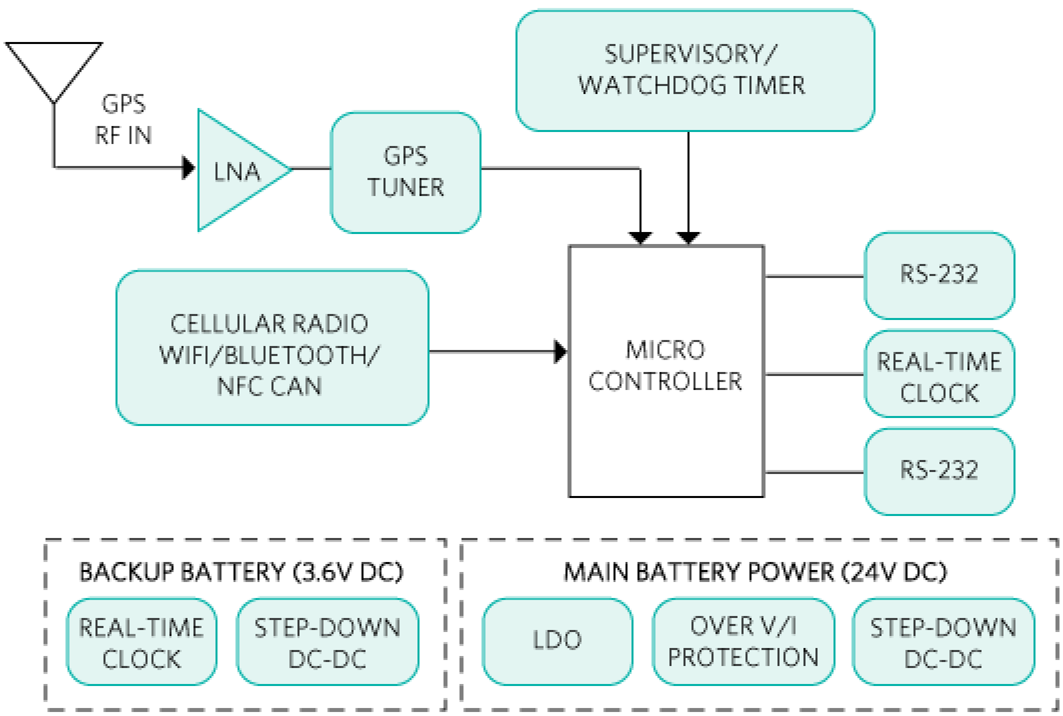


Figure 1. Typical fleet tracking/management system architecture.

Power Architecture Overview

The fleet tracking/management device is powered by the vehicle battery, typically 12V in cars and 24V in many trucks. As an aftermarket add-on, it faces a much harsher power-management environment than a well-bounded OEM device. Most devices also have a rechargeable backup battery, typically 3.6V; this backup battery is meant to last just a few days when the main battery power is lost. From the main battery source, the front-end electronics are protected against transient and fault conditions. The protected voltage is converted to usable, lower voltages (3.3V, 2.5V, 1.2V, etc.,) by step-down DC-DC converters and LDOs to power various digital logic and analog ICs. **Figure 2** shows a typical fleet tracking/management power architecture.

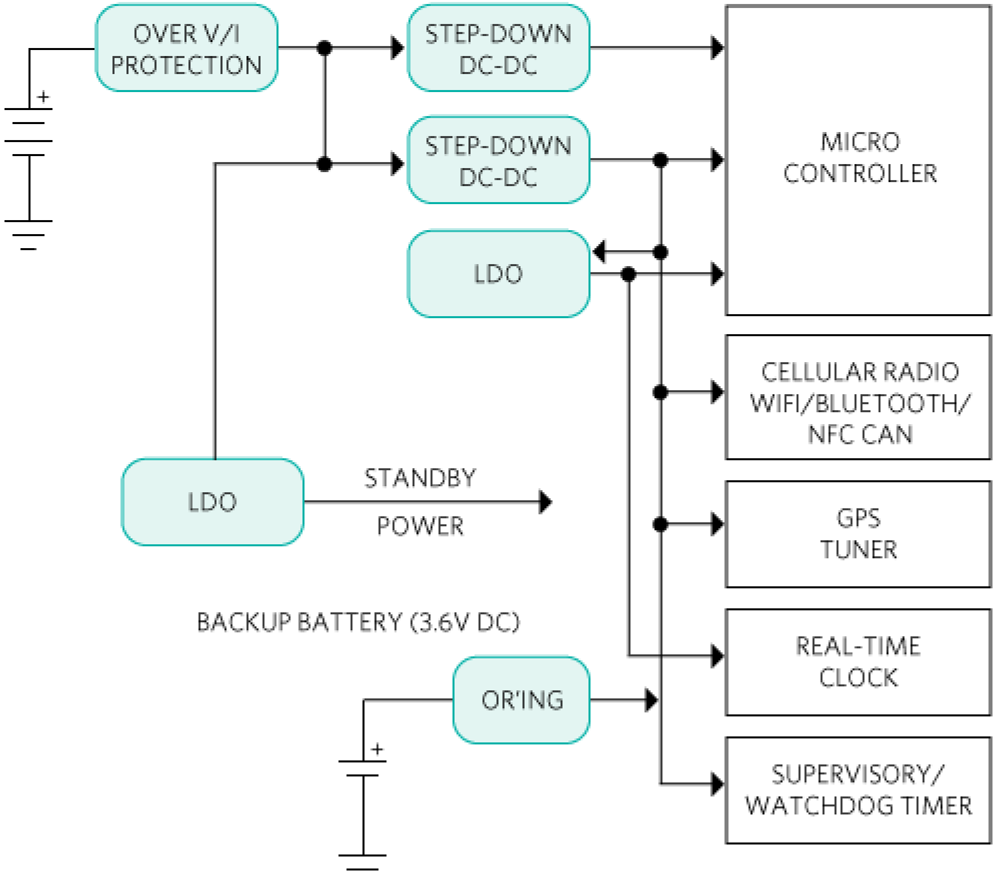


Figure 2. Typical fleet tracking/management power architecture.

Fault Protection

As with many other electronics that draw power from a vehicle battery, the fleet tracking/management device must also be protected from voltage surges commonly known such as load dump, regenerative braking, long cable ringing, etc. Load dump occurs when the battery cable is suddenly disconnected while the alternator is spinning, putting high energy back to the vehicle power cable where there is nothing to absorb it, causing high voltages that could destroy unprotected electronics. Regenerative braking occurs in an electric vehicle when the driver applies the brake; the vehicle kinetic energy is captured by the motor and sent back to charge the battery. High-voltage ringing is associated with regenerative braking because of the high energy, high di/dt nature of this activity.

Long-cable ringing occurs when there is a high di/dt event, such as when a device is plugged into an on-board diagnostic connector. The surge current charging the device's on-board capacitors or backup battery resonates with the cable’s inductance, causing high-voltage ringing. Longer cables, with higher parasitic inductance, exhibit more severe voltage ringing. The new OBD-II standard dictates that the diagnostic connector be within two feet (0.61m) of the steering wheel while the main battery is far away under the hood or on a side of a truck. This new requirement makes the cable from the battery to the OBD-II connector longer and more prone to high-voltage ringing.

High-Voltage Faults from Cable Ringing

Figure 3 depicts a lab setup to demonstrate cable ringing. A 24V DC power source is used to emulate a 24V DC battery from a truck. A 10-foot cable connects the power source to a ceramic capacitor (either 1µF or 10µF) to emulate an input capacitance of a fleet tracking device.

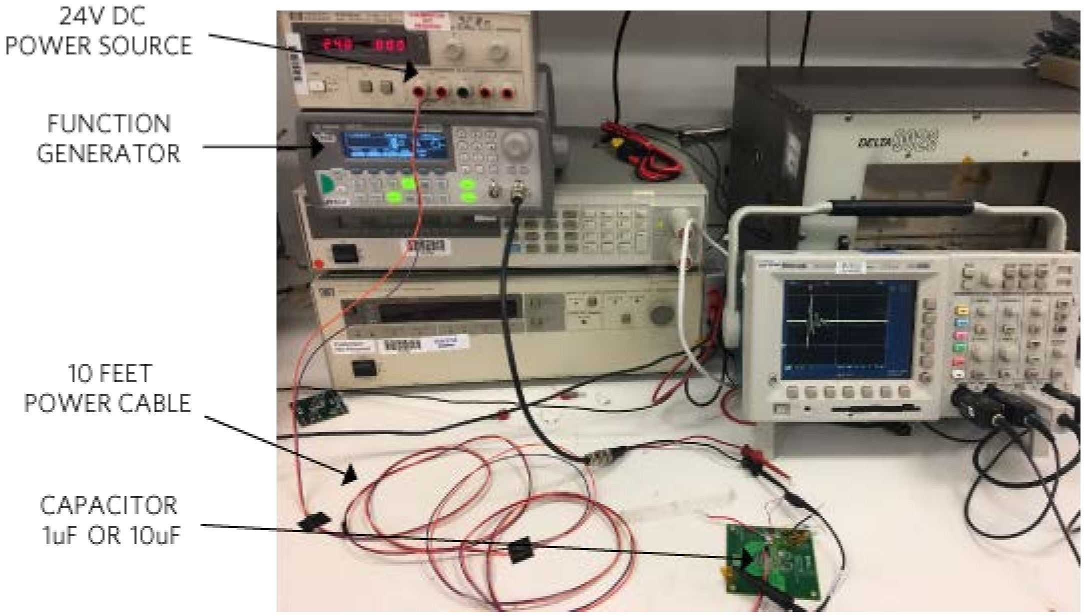


Figure 3. Cable ringing test setup.

Figure 4 shows our first test, emulating cable ringing at initial plug-in when the in-rush current charging the capacitor (previously discharged) built up through the cable parasitic inductance resonates with the board input capacitance. With 10µF input capacitance, the peak ringing voltage is 32V with a voltage spike at 42.6V. With 1µF input capacitance, the peak ringing voltage is at 40V.

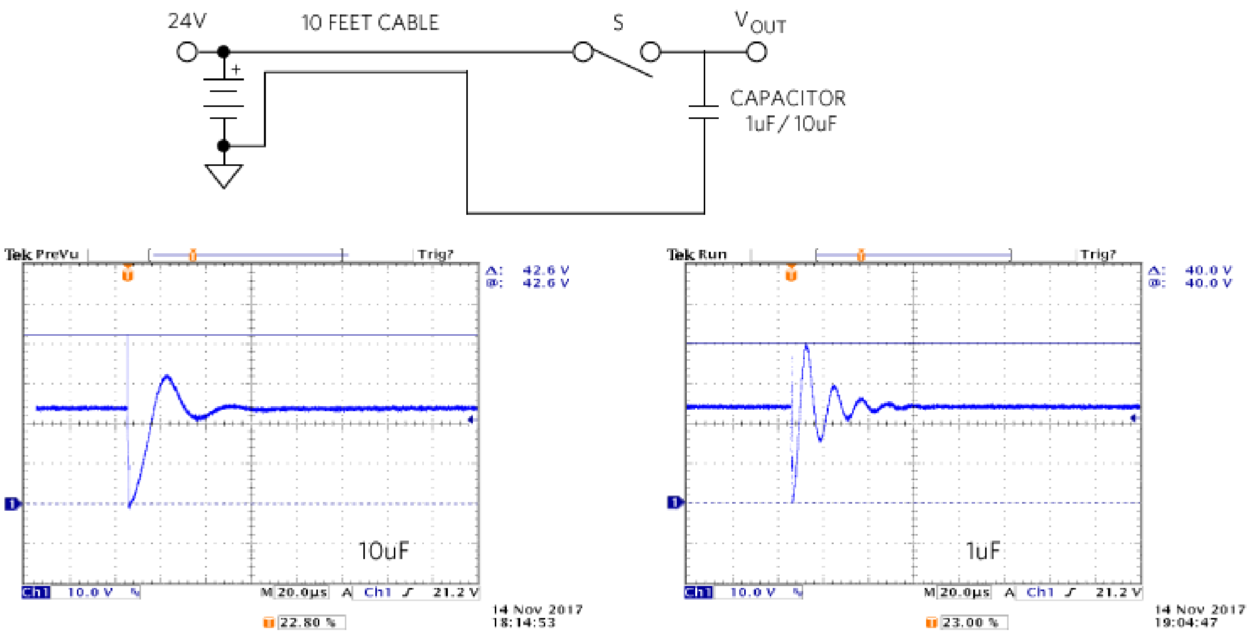


Figure 4. Cable ringing at initial plug-in.

Figure 5 shows our second test, where we emulate a brief short-circuit condition across the cable. Once the short is removed, the short-circuit current built up through the cable parasitic inductance resonates with the board input capacitance. With 10µF input capacitance, the peak ringing voltage is 40V. With 1µF input capacitance, the peak ringing voltage is at 50.4V, more than doubling the source voltage of 24V.

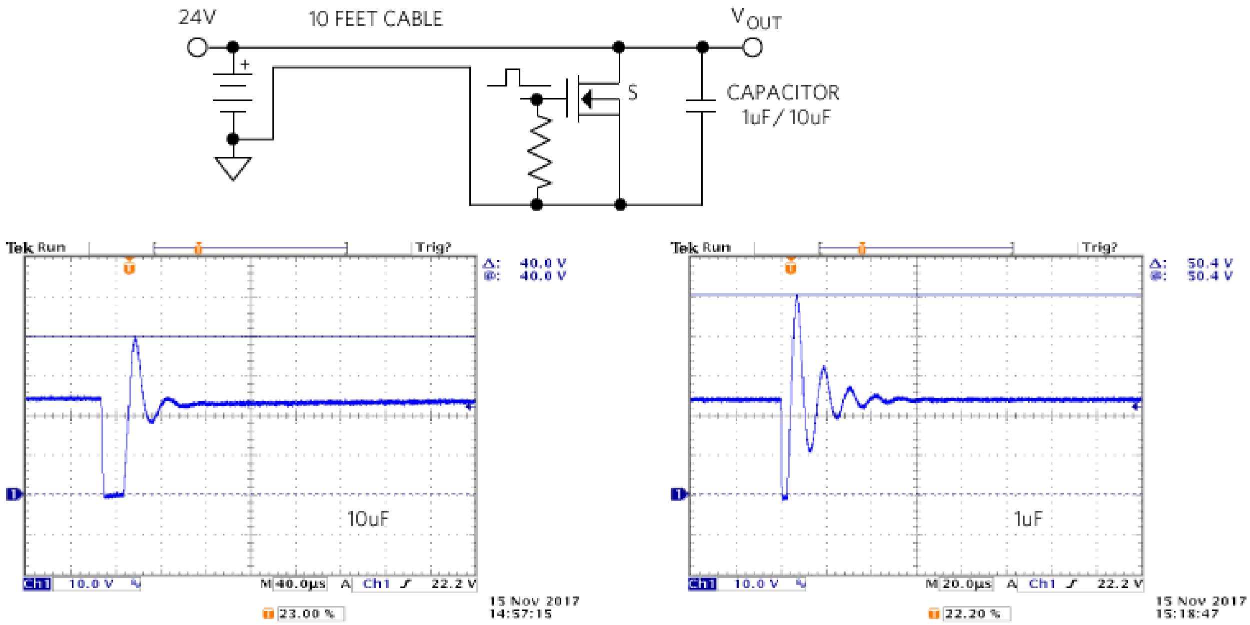


Figure 5. Cable ringing after a brief short-circuit condition.

This experiment uses 10 feet of cable—a reasonable estimation of the truck cable length from its battery to an OBD-II connector to demonstrate that the peak ringing voltage can easily double the input voltage source. The high-peak ringing voltage can occur at different cable lengths and at different device input capacitance. In fact, peak-ringing voltage can be calculated as:

$$V_{PK} = I_{PK}\sqrt{L / C}$$

where I_{PK} is the peak short-circuit current and $\sqrt{L / C}$ is the characteristic impedance of the system. L in this case is the cable parasitic inductance and C is the device input capacitance.

Other Faults Types

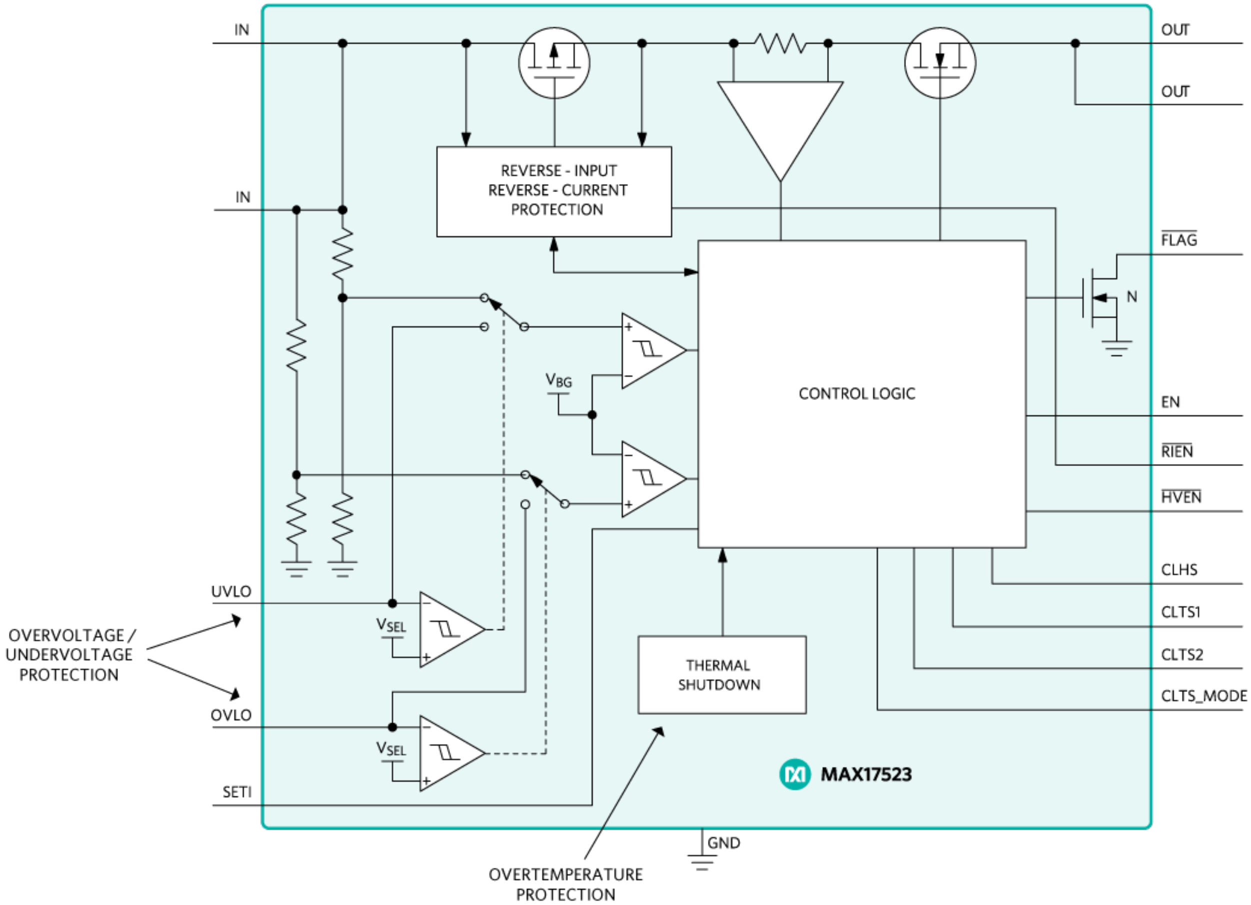
Short-circuit and/or overcurrent protection circuitry is essential in electronic components to prevent fire hazards and also to isolate the power cable from a failed short device. When the ambient temperature become excessive or if there is some other fault (overcurrent, etc.,), the overtemperature protection prevents permanent damage by either scaling down the power dissipation or shutting down the device completely. Overtemperature protection prevents system overheating and fire hazards and ensures that the system operates within its defined temperature limits. Reverse-voltage fault occurs when the battery is connected in reverse or the power cable is installed backwards. While unlikely to happen, reverse-voltage fault usually produces expensive damage to the power cables and electronic devices connected to the cable without proper reverse-voltage protection.

Clearly, there's a valid need to protect the fleet tracking/management device from many possible faults. However, implementing fault protection circuits with discrete components can be quite tedious, expensive, and not always fool-proof. The solution is large due to the high number of components, and circuit performance must be verified and guaranteed over time. System inflexibility when responding to a fault (open a switch, shut down the system, which requires a technician to restart) drives up total cost ownership.

Figure 6 illustrates a modern protection IC from Maxim's Olympus family of devices, the 36V/1A MAX17523. This highly integrated IC brings together all needed protections in a single, tiny 16-pin TQFN (3mm x 3mm) package. Simple to use while rugged enough to support 12V transportation electronics, the MAX17523 includes features such as the following:

- High input-voltage tolerance (+4.5V to +36V operating range)
- Reverse-voltage protection (tolerates -36V negative input voltage)
- Reverse-current protection

- Short-circuit, overcurrent protection
- Overtemperature protection



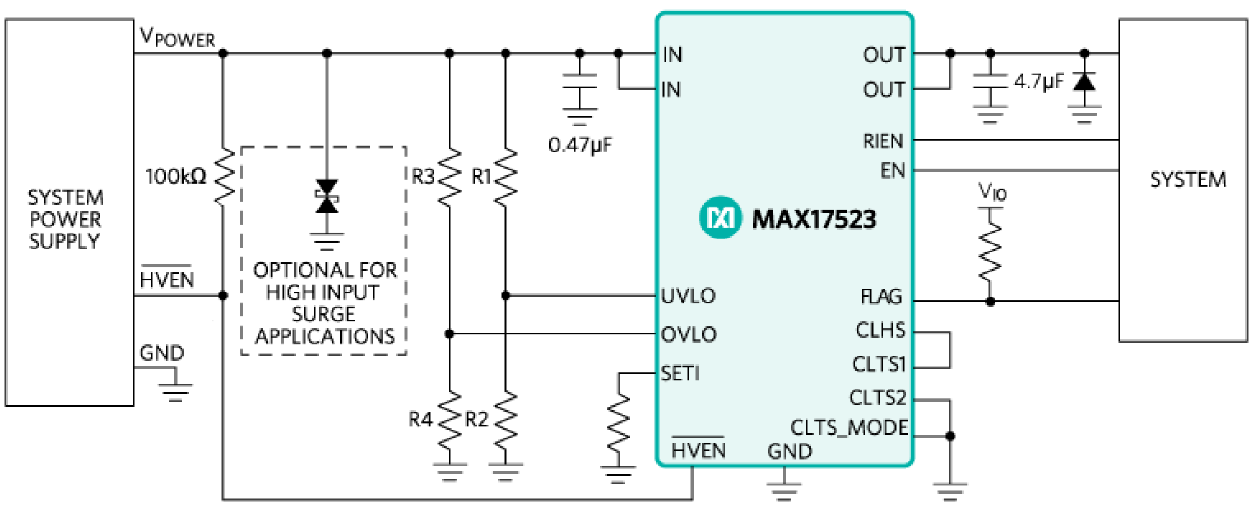


Figure 6. MAX17523 typical application schematic.

For 24V transportation systems, a higher voltage rating protection IC is needed. This is where a solution like Maxim's MAX17525 Olympus protection IC (+5.5V to +60V, 0.6A to 6A) comes in. Available in a space-saving 20-pin TQFN (5mm x 5mm) package, the MAX17525 includes features such as the following:

- High input-voltage tolerance (+5.5V to +60V operating range)
- Reverse-voltage/current protection (tolerates -60V negative input voltage)
- Short-circuit, thermal foldback current-limit protection

- Overtemperature protection
- Adjustable OVLO, UVLO, startup current, and forward-current limit

How Modern DC-DC Regulators Meet Size and Temperature Range Requirements

The fleet tracking/management device, like other transportation electronics, is physically small, so a high level of integration is needed to fit the power circuit into the small space. It's also challenging to remove heat dissipation from the device to keep its temperature within range. Modern DC-DC power solutions that effectively integrate the power MOSFETs, compensation circuit, and other external components help reduce the circuit size. Combining small solution size with efficient synchronous rectification technology helps reduce the power dissipation. The MAX15062 (4.5V to 60V, 300mA), from Maxim's Himalaya family, is an example of such a device, providing 92% peak efficiency in a tiny 8-pin TDFN (2mm x 2mm) package.

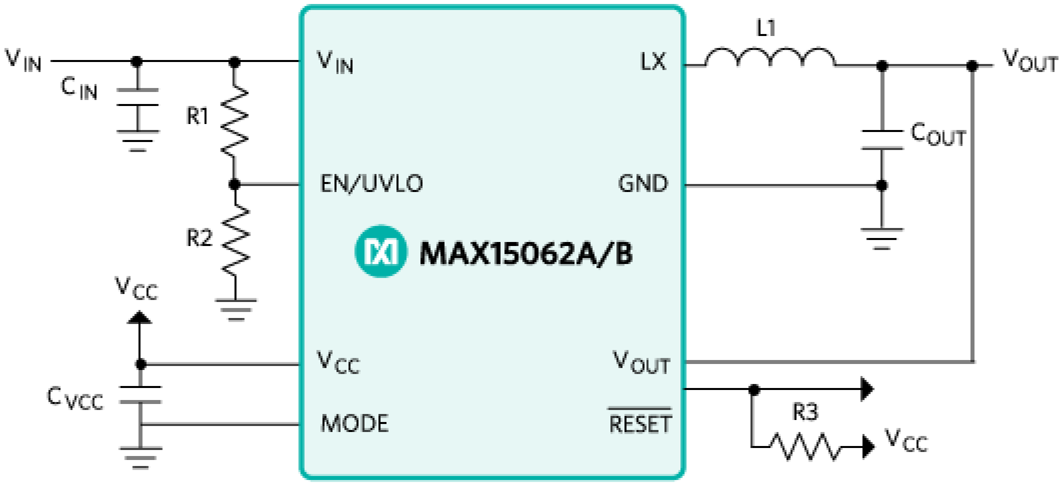


Figure 7. MAX15062A (3.3V V_{OUT})/MAX15062B (adjustable V_{OUT}) typical application schematic.

To further increase integration, Himalaya power modules also integrate the power inductor, resistors, and capacitors with a DC-DC regulator. The results are easy-to-use, easy-to-design, and quick time-to-market power module solutions that only require an input capacitor, an output capacitor, two small voltage-setting resistors, and an optional soft-start setting capacitor to complete the power solution. MAXM17545 (4.5V to 42V, 1.7A) and MAXM17575 (4.5V to 60V, 1.5A) are good examples of Himalaya power modules.

Today's automobiles as well as intelligent transport automation systems boast hundreds of sensors that are being housed under extremely tight space constraints. Powering these sensors requires even higher integration. MAXM17532 uses revolutionary packaging technology to miniaturize a 42V, 100mA power solution into a 2.6mm x 3mm x 1.5mm power module. This highly efficient synchronous DC-DC buck power module also minimizes the sensor's heat dissipation and features the following:

- 4.0V to 42V V_{IN} range
- 0.9V to 5.5V V_{OUT} range
- 100mA continuous current

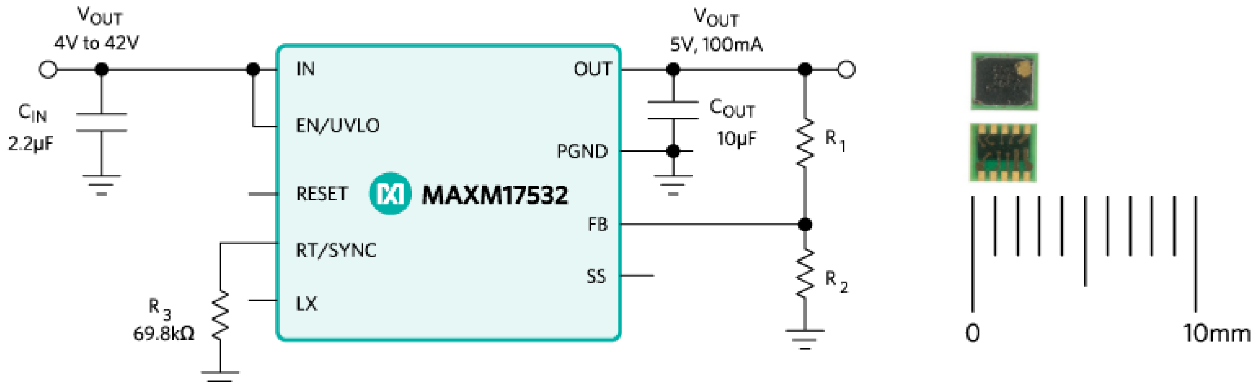


Figure 8. MAXM17532 typical application schematic.

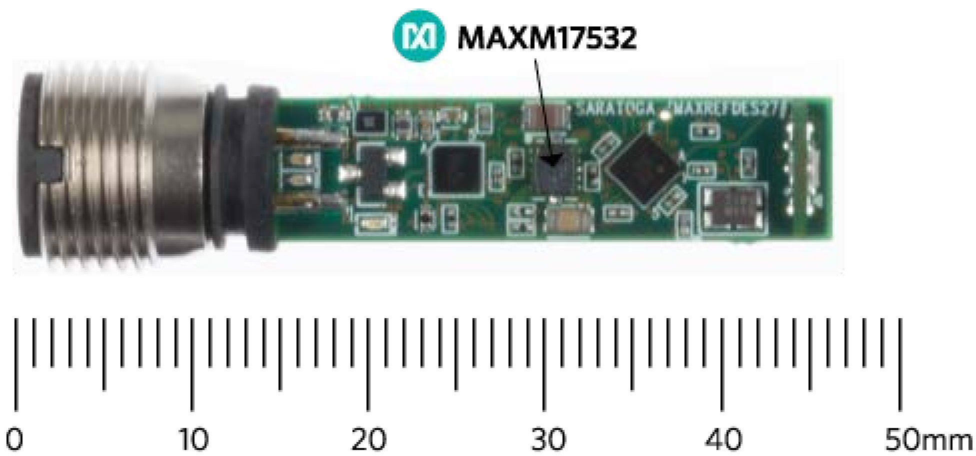


Figure 9. MAXM17532 power module in a tiny proximity sensor.

Now, you might consider powering the sensor using an LDO, since it is generally low cost and very simple to use. However, LDOs also have high power dissipation, which is a key drawback. For example, a traditional simple digital/analog sensor might need 5V at 20mA and has 24V input (nominal). The power dissipation across the LDO is (24V – 5V) x 20mA = 0.38W (nominal). Newer sensors are packed with more intelligence, more functionality, and more flexibility—all of which also require more power, say 100mA. Keeping the same input/output voltages, the power dissipation across the LDO would be (24V – 5V) x 100mA = 1.9W. This significantly higher power dissipation must be dissipated in the same sensor's physical form factor. In addition, there are many more circuitries added to the sensor, requiring smaller size and higher integration. A power module that can address size and power dissipation requirements while delivering great efficiency would be appropriate here. Low power dissipation means lower system operating temperature and higher long-term reliability.

Summary

Aftermarket transportation electronics must be robust against transient conditions such as overvoltage, overcurrent, reverse voltage, reverse current, and overtemperature. These protections can be provided by highly integrated protection ICs, which also simplify the design over discrete solutions. As equipment continues to gain increasing functionality while shrinking in size, higher integration is needed. With highly efficient power-management solutions, you can mitigate thermal dissipation challenges and enhance your system's long-term reliability.

Related Parts		
MAX15062	60V, 300mA, Ultra-Small, High-Efficiency, Synchronous Step-Down DC-DC Converters	Free Samples

MAX17523	1A Adjustable Overcurrent and Overvoltage Protector with High Accuracy	Free Samples
MAX17525	High-Accuracy, Adjustable Power Limiter	Free Samples
MAXM17532	4V to 42V, 100mA, Himalaya uSLIC Step-Down Power Module	Free Samples
MAXM17545	4.5V to 42V, 1.7A High-Efficiency, DC-DC Step-Down Power Module with Integrated Inductor	Free Samples
MAXM17575	4.5V to 60V, 1.5A High-Efficiency, DC-DC Step-Down Power Module with Integrated Inductor	Free Samples

More Information
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