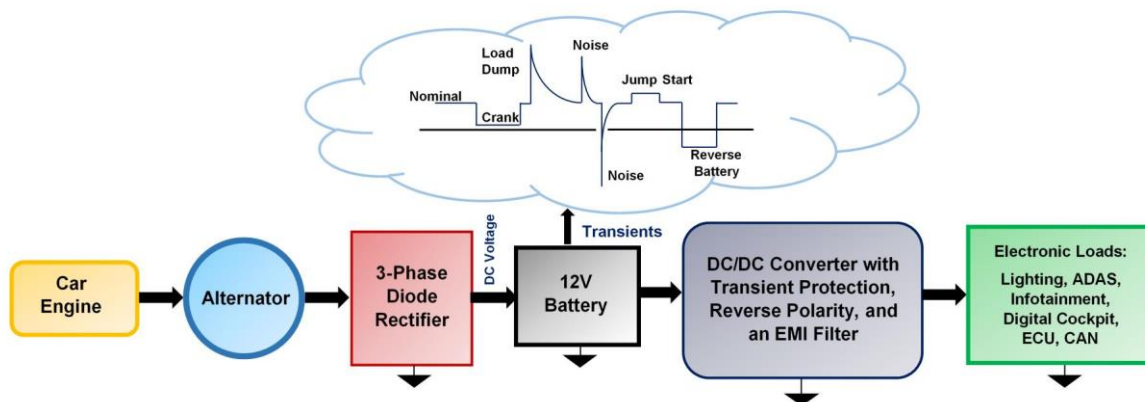


## Introduction

Advances in automotive technology have dramatically increased the number of sophisticated electronic circuits required to improve driving experience and safety in a typical automotive system. New vehicles provide infotainment systems with high-resolution displays, an enhanced user interface, and numerous connectivity options. Improved safety features include LiDAR for collision avoidance, as well as multiple cameras and sensors for driver awareness. Many of these electronic modules are connected to 12V or 24V battery systems, which means they are subject to harsh and dynamic transient environments. These conditions challenge power supply designers to ensure reliable circuit operation in extreme environments.

Figure 1 shows a typical automotive electrical system for a car. Typical loads for the automotive battery system include the infotainment system, ADAS, digital cockpit, lighting, electronics modules (ECUs), and CAN bus.



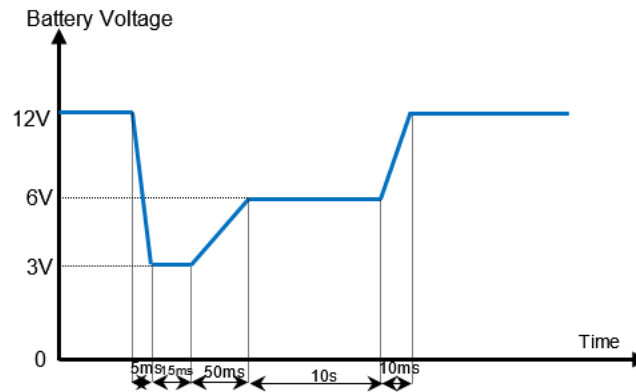
**Figure 1: Typical Automotive Electrical System**

The transients on a traditional automotive power supply range from severe, high-energy transients generated by the alternator to low-level noise generated by the ignition system. This article introduces common automotive transient conditions (e.g. reverse battery, cold crank, warm crank, and load dump), and discusses the causes of these transients in addition to system design challenges.

## Cold Crank

During cold weather conditions, both the car battery and engine can be subjected to extremely cold temperatures. A cold crank pulse occurs when the battery voltage drops after the starter draws a high current to turn on a cold engine. Under cold-crank conditions, the battery voltage can drop below 3V (the worst-case condition) for 15ms to 50ms.

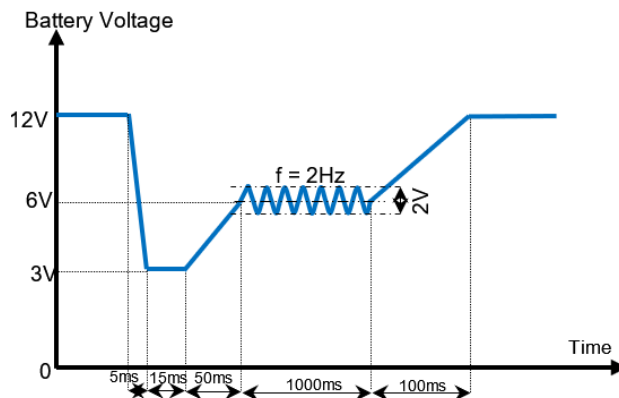
After this period, the battery voltage ramps up to about 6V, where it remains for few seconds before returning to the nominal voltage within a rising time of few milliseconds. Figure 2 shows the battery voltage profile under typical cold-crank conditions at low temperatures. ISO 7637-2, Test Pulse 4 provides details for this type of starting profile.



**Figure 2: Typical Cold-Crank Pulse**

Under typical conditions, the battery starting profiles are very similar for different automotive manufacturers. With respect to the voltage levels and timing, there are variations among different original equipment manufacturers (OEMs).

Depending on the OEM specification, a low-frequency sinusoid may also be included in the starter profile pulse. The sinusoid (e.g. 2Hz) represents the alternator noise during crank. The ISO 16750-2 standard describes several starting profiles using an injected sinusoid, and may be referenced by the OEM specification. This waveform is often referred to as a severe cold-crank pulse (see Figure 3).



**Figure 3: Severe Cold Crank Pulse**

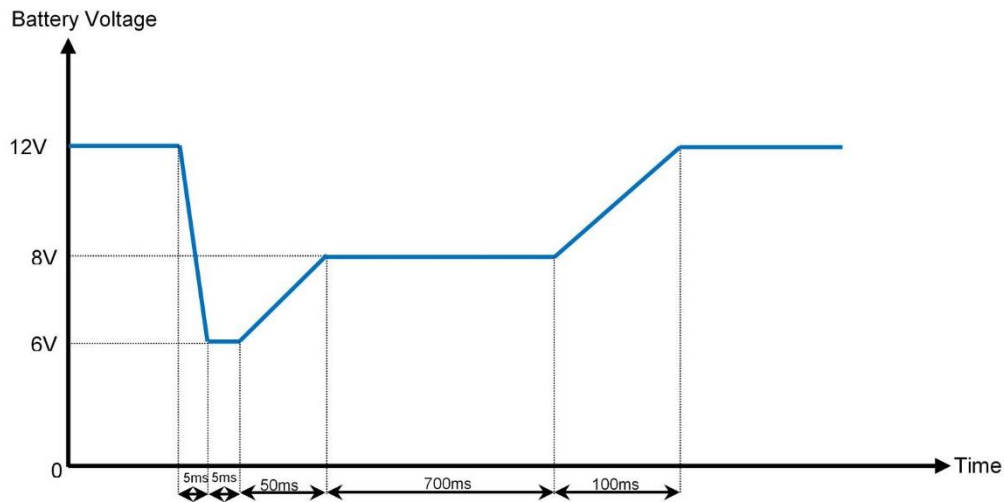
### Cold Crank System Challenges

During a cold crank starting condition, the power solution should ensure that there is continuous, stable output regulation for inputs as low as 2.8V for a short duration. A converter (e.g. a DC/DC buck/boost converter such as the [MPQ8875A-AEC1](#)) with a wide  $V_{IN}$  range can be used to address low input voltages.

### Warm Crank

A warm crank pulse occurs when the battery voltage drops as the starter draws a high current to turn on a warm engine. Although a warm crank pulse is very similar to a cold crank pulse, the voltage drop and shortened pulse duration are typically less severe. ISO 16750-2 and ISO 7637-2, Test Pulse 4 also describe starting profiles for warm cranks.

During a warm crank pulse, the battery voltage can drop to 5V or 6V, and the voltage falling time is often shorter than it is for cold cranks. After a short duration of about 5ms, the battery voltage then ramps up to about 8V, where it remains for less than a second before returning to the nominal voltage. Figure 4 shows the battery voltage profile under warm crank conditions.



**Figure 4: Typical Warm Crank Pulse**

The battery voltage profile for this pulse is very similar for different automotive manufacturers, but there are variations among different OEMs for the voltage levels and timing. An example of a warm crank pulse condition is automotive start-stop, where the engine shuts down at a complete stop when the brake is depressed, then restarts when the brake pedal is released.

### **Warm Crank System Challenges**

Many vehicles require that certain functions continue operating, even during conditions such as warm crank. For example, a car radio should not suddenly stop playing music when the warm engine restarts, and the LCD display panel should not flicker or have a degraded video. It is recommended to use a DC/DC boost or buck-boost converter with a wide  $V_{IN}$  range to address these types of low input voltage conditions, such as the [MPQ8875A-AEC1](#).

### **Reverse Voltage**

A reverse voltage — or reverse battery — condition occurs when the car battery is disconnected from the system and accidentally reconnected with the battery polarity reversed. This creates a negative voltage across the input supply connector, which can damage the power supply and other circuits. Many ICs are rated for only a few hundred millivolts of negative voltage (e.g. -0.3V), and other components may be sensitive to the polarity. A reverse protection diode or MOSFET is typically used to protect circuits against this condition.

Figure 5 shows a set-up in which an ECU is connected incorrectly to the battery. Initially, the 14V battery is connected correctly, then it is disconnected. When the battery is reconnected to the ECU, the battery polarity is reversed, subjecting the ECU to -14V. ISO and OEM tests define the duration during which the negative voltage is applied, which can be longer than 60 seconds. A fuse is often used to prevent over-current damage, depending on the reverse protection circuit. After a reverse voltage is applied for the specified test duration, it is necessary to reapply the correct polarity voltage to confirm that the module still operates normally.

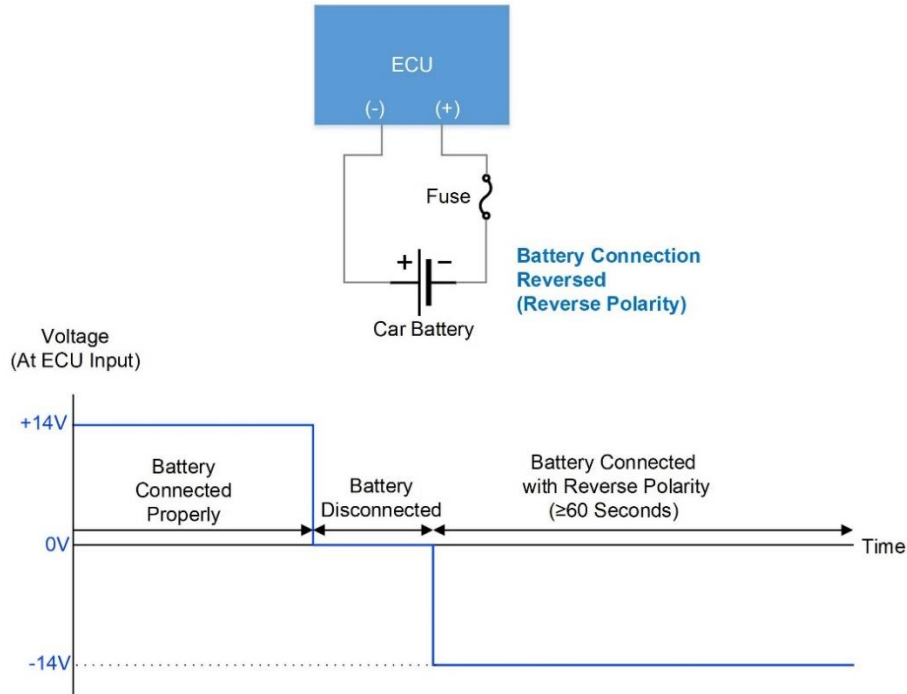


Figure 5: Reverse Battery Condition

### Reverse Voltage System Challenges

It is critical to protect all ICs and components from exposure to negative or reverse voltages. Exposure to these conditions can result in severely degraded or damaged components. It is recommended to use devices such as diodes and MOSFETs to provide these protections. Smart diode controllers, such as the [MPQ5850-AEC1](#), also offer excellent reverse input protection while significantly reducing power losses associated with typical diode and MOSFET protection circuits.

### Load Dump

A load dump transient is the voltage surge generated when the battery is disconnected while the alternator is still connected to other electronic loads (see Figure 6). A load dump can occur when the battery is accidentally disconnected while the vehicle is running. Common instances include when the battery terminals are corroded, have a poor connection, or when the battery cable is degraded.

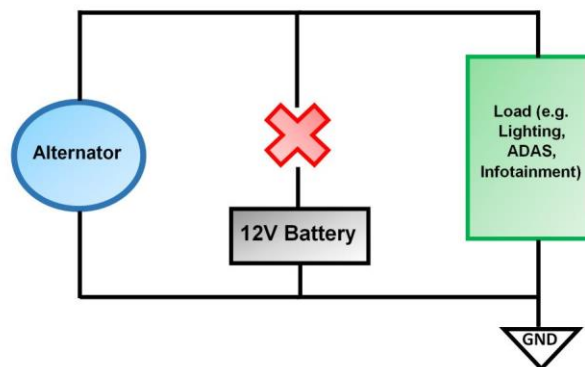
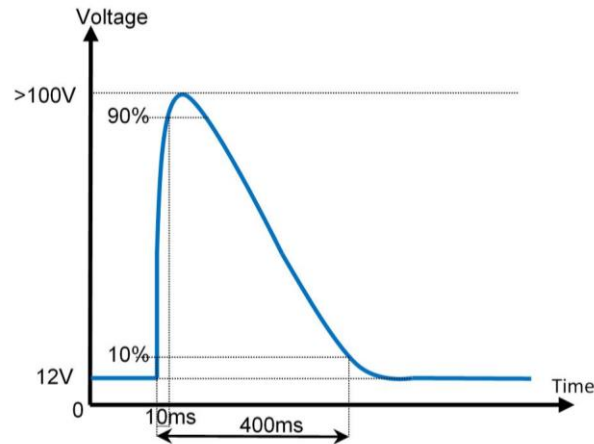


Figure 6: Load Dump Condition

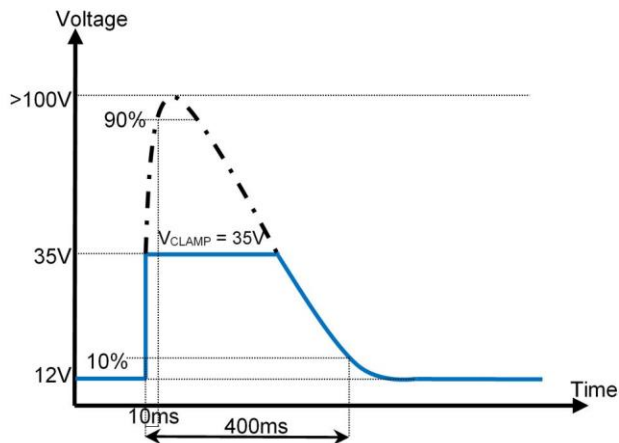
The peak voltage of the surge can exceed 100V, and the surge takes up to 400ms to decay. ISO 16750-2 and ISO 7637-2, Test Pulses 5a and 5b, are typically referenced for specific load dump transient pulses. Each of these standards describe two types of load dump transients.

1. **Unsuppressed:** The high-voltage load dump transient surge occurs when the battery is disconnected and while the alternator still supplies power to the system, which results in an unclamped waveform (see Figure 7). In this case, the alternator has no internal clamping or means of suppression, so modules and devices connected to the alternator are subjected to this large transient.



**Figure 7: Unsuppressed Load Dump Pulse**

2. **Suppressed:** When the load dump transient surge occurs, the waveform is suppressed by avalanche diodes in the alternator’s rectifier. This results in a clamped waveform (see Figure 8). In this scenario, the clamping protection in the alternator suppresses the transient to a lower voltage (typically between 32V and 40V) in most 12V systems.



**Figure 8: Suppressed Load Dump Pulse**

### Load Dump System Challenges

A circuit must survive load dump without damage or degradation. It is recommended to use TVS diodes or other input protections to protect against load dump conditions. For a suppressed load dump, the required clamping protection for a circuit may only need to be rated between 40V and 45V. In this scenario, a wide  $V_{IN}$  buck converter — such as the [MPQ4316-AEC1](#) — can be utilized to meet the system requirements. For an unsuppressed load dump, clamping protection must be rated much higher, which may require a larger and more costly solution.

## Summary

Table 1 shows a summary of the automotive transients and pulse conditions described in this article, including common industry testing standards. It also highlights the system challenges that must be considered by the system designer.

**Table 1: Automotive Input Transients, Common Standards, and System Challenges**

Test	Origin/Occurrence	Reference Standards	System Challenges
<b>Reverse Polarity</b>	When the battery terminals are disconnected, the car battery connection can be reversed by mistake.	ISO 16750-2:2010(E) Section 4.7 Reversed Voltage	Additional protections (e.g. diodes and MOSFETs) are required to protect ICs and passive components.
<b>Cold Crank</b>	Battery voltage reduction caused by energizing the starter-motor circuits of internal combustion engines. Occurs when the starter draws a high current to turn on the engine under cold conditions.	ISO 16750-2:2010(E) Section 4.6.3 Starting Profile ISO 7637 -2 – Section 5.6.4 Test Pulse 4	Ensure that $V_{OUT}$ is continuous and stable while $V_{IN}$ is low for short durations. A DC/DC converter with a wide $V_{IN}$ range is recommended.
<b>Warm Crank</b>	Battery voltage reduction caused by energizing the starter-motor circuits of internal combustion engines. Similar to cold crank, though the voltage drop and duration are not as extreme due to the warm engine.	ISO 16750-2:2010(E) Section 4.6.3 Starting Profile ISO 7637 -2 – Section 5.6.4 Test Pulse 4	Ensure that $V_{OUT}$ is continuous and stable while $V_{IN}$ is low for short durations. A DC/DC converter with a wide $V_{IN}$ range is recommended.
<b>Load Dump</b>	If a discharged battery is disconnected while the alternator generates a charging current, other loads may remain on the alternator circuit.	ISO 16750-2:2010(E) Section 4.6.4 Load Dump ISO 7637 -2 – Section 5.6.5 Test Pulses 5a and 5b	Circuits connected to the battery must survive transients without damage or degradation. Generally, a TVS diode, clamping circuit, or a DC/DC converter with a wide $V_{IN}$ range is required.

## Conclusion

A typical automotive module must address most or all of the transient conditions discussed in this article. A basic understanding of these critical automotive transients is necessary to allow an automotive system engineer to design a robust solution.

While designing a reliable power circuit for extreme conditions can be challenging, robust automotive components such as the [MPQ4316-AEC1](#) (a buck converter with a wide  $V_{IN}$ ), [MPQ8875A-AEC1](#) (a buck-boost converter with a wide  $V_{IN}$ ), [MPQ5850-AEC1](#) (42V smart diode controller), and [MPQ7200-AEC1](#) (an LED driver with a wide  $V_{IN}$ ) offer excellent performance and safety with their ability to handle dynamic environments.

For more details on the content covered in this article, watch the free webinar “[From Cold Crank to Load Dump – A Primer On Automotive Transients](#)” on the MPS website.