Employing Reliable Protection Methods for Automotive Electronics

WHITE PAPER

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BACKGROUND

Automotive systems continue to become more sophisticated with the introduction of new, modified and improved features every year. Each feature must be powered, protected and connected to its respective interface within the overall automotive system. Direct current (DC) to DC converters are necessary to convert the main 12 V automotive battery supply to a range of voltage levels required for operation of these various features. DC-DC converters are used to provide DC power to heavy loads in hybrid and electric vehicles, and for lighting, displays, infotainment and any other electronics in all types of vehicles. Once powered and operating, the automotive electronics are subject to various transient events and must be tested to ensure they comply with standards such as ISO 7637. With protection in place, the electronics can be connected to the system using various standard interfaces such as CANbus. It is important to ensure the system reliability of these interfaces in terms of Electromagnetic Compatibility (EMC) and Common Mode Noise (CMN). The protection of the system has to be re-examined after all interfaces are in place to ensure adequate isolation and protection. Finally, Electrostatic Discharge (ESD) considerations must be made since the electronics are subject to ESD events beginning as early as circuit assembly and continuing throughout the lifetime of the vehicle.

Effective and reliable circuit protection can be achieved by implementing a variety of resistors and magnetics for DC-DC converters, Polymer Positive Temperature Coefficient (PPTC) devices for transient protection, common mode chokes and chip varistors for EMC and interfaces, and multilayer varistors and clamp devices for ESD protection. This paper will describe the power supply, transient, interface, and ESD requirements for components in the automotive environment. It also will introduce the various technologies and product families that have been found to be effective in protecting automotive electronics.

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TOUGH REQUIREMENTS FOR AUTOMOTIVE SYSTEMS

Electronics are replacing mechanical couplings in a broad range of systems such as engine controllers, safety systems, chassis control, diagnostic systems, infotainment, and many more. A diverse set of network interfaces including CAN, Flexray and Ethernet connects each Electronics Sub-Assembly (ESA) to the system and other ESAs, which then are susceptible to interference or reliability issues caused by other ESAs. Given the range of possibilities it seems on the surface there are few commonalities, yet regardless of the function the electronics all must be powered from a single automotive battery and withstand well-defined tests, surges and performance requirements throughout the lifetime of the vehicle. Along with a robust power conversion design, circuit protection is necessary to ensure that the electronics are not affected by outside surges, other electronics in the system or human interaction. Designing a stable and reliable system begins with understanding the needs and specifications for conversion, interfaces and threats. Components then can be selected to address the requirements and meet or exceed the level of performance and protection in each part of the automotive system.

Stabilizing Voltage Levels for Power Supplies

DC-DC converters are used in electronics to convert between voltage levels and provide a stable and accurate supply. The nominal voltage in a car that runs on a 12 V battery is 14 V. Some infotainment circuits require a reduction to voltages of 5 V or 3.3 V. Conversely, LED lighting strings require a boost to 60 V, and permanent magnet DC motors like those used in hybrid and full electric vehicles present larger loads of several hundred volts. For these conversions, the power supply circuit typically will include a MOSFET, inductor (L), resistor (R), and capacitor (C). A switch, as shown in figure 1, can represent the MOSFET. In this circuit, the parasitic inductance of the wiring combined with capacitance of the MOSFET can interfere with the normal operation of the circuit. Components must be chosen or inserted to minimize the risk of this interference and maintain stable operation of the converter and the system, regardless of whether or not the converter design boosts or reduces the voltage supplied to the load.

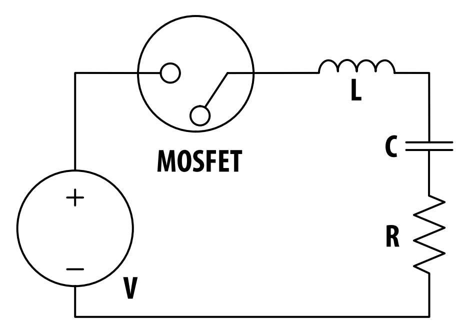

Figure 1. | *Equivalent Circuit of Power Supply*

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TOUGH REQUIREMENTS FOR AUTOMOTIVE SYSTEMS *(Continued)*

Transient Event Protection

A great deal of consideration is given to protecting automotive electronics from various transient events. The transient surges that threaten automotive electronics are well-known and classified by ISO 7637 according to the type of event. These events can last up to several seconds and generate several hundred amps. Table 1 details the ISO 7637 test specifications, where R_i indicates the internal resistance of the voltage generator. Each ESA must be designed to pass tests according to ISO 7637. Designers need to comply with the requisite level of protection by adding components to limit the surge or clamp the voltage.

Table 1. *ISO 7637 Test Specifications*

Test	Simulation of	Peak Voltage (12 V)	Peak Energy (24 V)
1	Disconnection of battery from power supply	-100 V (R_i = 10 Ω)	-600 V (R_i = 50 Ω)
2a	Surge induced by wiring harness after current switched off	+50 V (R_i = 2 Ω)	+50 V (R_i = 2 Ω)
2b	DC motors acting as generators after ignition switched off	+10 V (R_i = 0.05 Ω)	+20 V (R_i = 0.05 Ω)
3a, 3b	Induced currents through inductance in wiring	-150 V (R_i = 50 Ω)	-200 V (R_i = 50 Ω)
4	Surge caused by energizing starting motor	-7 V (R_i = 0.05 Ω)	-16 V (R_i = 0.05 Ω)
5a, 5b	Disconnecting discharged battery while the alternator is generating charging current (load dump)	87 V (R_i = 0.5 Ω)	174 V (R_i = 1 Ω)

System Interfaces Bring Additional Challenges

Adequate protection as a standalone unit is the starting point for introducing an ESA to the automotive system. Once connected to the system through an interface, an ESA may contribute to a rise in the network voltage. For instance, most ESAs connected to a CANbus network will contain a common mode inductor to limit unwanted high-frequency noise on the communication bus, improve the immunity of the transceiver to EMC, and reduce Electromagnetic Interference (EMI). With all its benefits, the common mode inductor also can induce a high voltage across the CANbus transceiver, as seen in the disconnection from the supply in ISO 7637 Test 1. This voltage then needs to be clamped by a suppressor such as an automotive varistor to protect the ESA from damage that the overvoltage condition could cause.

The type of core, wire and construction of the chosen inductor as well as the amount of current will have a bearing on the electromagnetic emissions from the ESA. The emissions must remain within the specified guidelines of the vehicle manufacturer. On some occasions, the guidelines can be tougher than the international EN55022 Class B specification, for which the emissions level is 30 dB (mV/m) over the frequency range 0 - 230 MHz, and 37 dB (mV/m) for 230 MHz - 1 GHz.

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TOUGH REQUIREMENTS FOR AUTOMOTIVE SYSTEMS (*Continued*)

Protection Against Electrostatic Discharge Events

Finally, automotive electronics must be protected from ESD damage. The risk of ESD events is increasing with the availability of the Universal Serial Bus (USB) for infotainment. There are three categories for the classification of malfunctions caused by the current and voltage surge of an ESD pulse: (i) temporary errors corrected automatically by the circuit or its operating software; (ii) temporary errors requiring operator intervention to recover and resume normal operation; and (iii) permanent damage requiring partial repair or replacement entirely.

As with transient compliance, the automotive industry uses a well-known standard for ESD protection guidelines. This Human Body Model (HBM) characterizes the current versus time curve and electrostatic surge as shown in table 2. It simulates the energy transmitted by contact with people during handling on the assembly line. In testing, a surge generator can replicate the HBM curve by a connecting a voltage source to a 1.5 kΩ resistor and 100 pF capacitor, as shown in figure 2. These tests will help designers to include the appropriate voltage suppression in their designs, such as Bourns® ChipGuard® chip varistors.

Table 2. Tests for Human Body Model

Applied Voltage (kV)	Peak current (A) Human Body Model
2	1.33
4	2.67
6	4.00
8	5.33
10	6.67

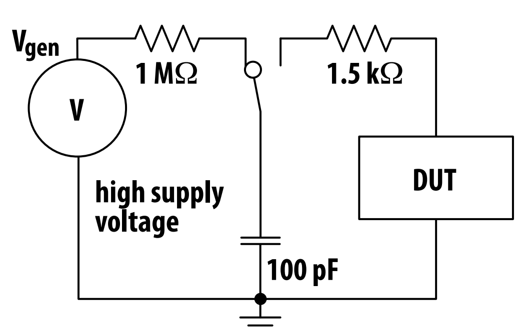

Figure 2. Test Circuit for Human Body Model

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SOLUTIONS THAT HELP ENSURE RELIABILITY

Resistors in Power Supplies

The first component to be inserted in the power supply for protection is a resistor. If the MOSFET is switched voltage is induced across the capacitor: $V - V * \cos(\omega t)$ where $\omega = \sqrt{\frac{1}{LC}}$. The peak amplitude of this sinusoidal wave is twice the supply voltage, and this could damage the MOSFET transistor. Adding a Resistor R in series with the MOSFET dampens these oscillations and protects the MOSFET. The type of resistor used depends on the output power of the converter. A resistor's suitability for a design can be determined from several factors. First, its average power dissipation can be calculated from the following equation: $P_{av} = P_{pk} * D$, where $D = \frac{T_{pulse}}{T_{period}}$; T_{pulse} is the pulse length of the surge; and T_{period} is the time between surges. The total thermal resistance of the resistor and board is given by: $R_{th} = R_{th}(\text{Resistor}) + R_{th}(\text{Circuit Board})$. The temperature rise for the circuit is given by: $\Delta T = P_{av} * R_{th}$. Finally, a graph of the energy that the resistor can handle in Joules versus surge time. To calculate the energy in the surge, the peak power of the surge is multiplied by the duration of the surge and by the relative area of the surge compared to a square pulse.

Bourns' fixed resistor product portfolio includes AEC-Q200 qualified PWR series power resistors in a variety of packages. These thick film non-inductive resistors are electrically isolated from the back plate and available with power ratings up to 50 W. Bourns® Models PWR163 and PWR263 have a low inductance, making them ideal for high frequency applications, and their excellent pulse characteristics support current limiting or capacitor discharge applications. Bourns® Model 4816P SOIC resistor network is available with isolated, bussed, and standard termination options with a tolerance as low as 0.5 %.

As an example of evaluating a resistor for use in the power supply circuit, assume $P_{av} = 9.2$ W and the operating temperature is 90 ˚C. Using Bourns® Model PWR263S-35 for the power resistor and a typical high performance copper-clad circuit board with heat exchanger, the respective thermal resistances of 3.5 ˚C/W and 2.5 ˚C/W total 6 ˚C/W. The temperature rise is 55.2 ˚C. The overall temperature of the component is given by the sum of the temperature rise and operating temperature. In this example, the resistor temperature would be 145 ˚C, which is less than the maximum temperature of 155 ˚C on the Bourns® Model PWR263S-35 data sheet. The time versus energy curve available on the data sheet will indicate whether the part is capable of handling the instantaneous power of the surge. If the resistor meets all of these specifications, it can be incorporated in the design.

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SOLUTIONS THAT HELP ENSURE RELIABILITY (*Continued*)

High Intensity Discharge Lamps

Another application for DC-DC converters is to supply the necessary lighting circuits in the car. High Intensity Discharge (HID) lamps require a very high ignition voltage pulse of several thousand volts followed by a constant voltage. A transformer coil and a spark tube create the high ignition voltage as illustrated in figure 3. Bourns produces a range of high voltage spark tubes called Sparctube™ Switching Spark Gap Devices for HID automotive lamp circuits. Bourns® Sparctube™ ST Series is designed specifically for voltage controlled switching of capacitive discharge circuits where high energy, low loss and a fast rate of switching are required. This series performs in high temperatures and offers long-term reliability. Most commonly used in automotive are the 800 V and 840 V parts, Bourns® Model ST-0800-Bxx-STD and Bourns® Model ST-0840-Bxx-STD, respectively.

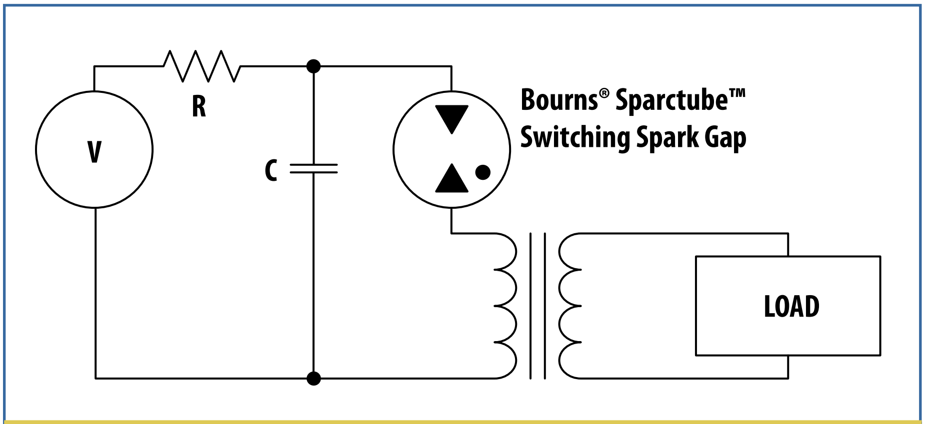

Figure 3. | Application of Bourns® Sparctube™ Switching Spark Gap

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SOLUTIONS THAT HELP ENSURE RELIABILITY (*Continued*)

Implementing Effective Transient Protection

Bourns® Multifuse® PPTC devices are ideal for transient protection. A Bourns® Multifuse® device is a thermistor with a nonlinear resistance-versus-temperature characteristic. Selection of a Bourns® Multifuse® PPTC device depends on the operating voltage, which typically is 16 V for a nominal voltage of 14 V, the operating current for the ESA application and the time-to-trip defined in the specification. During normal operation, the device has an extremely low resistance and remains essentially invisible to the circuit. When the PPTC operating current reaches the trip current, the device temperature increases and the resistance jumps quickly to a very high value.

Different polymer blends during component manufacturing can be used to produce specific features in the device such as high current capability (low resistance), high operating voltage or high operating temperature. While the PPTC devices typically have a maximum operating temperature of 85 ˚C, some Bourns® Multifuse® devices are rated to 125 ˚C. Bourns® components allow for a more stable resistance over a wider temperature range. This is a great advantage in situations where the resistance of the thermistor plays a role in the circuit. One such example is the differential line of a camera module. The bandwidth of the module can be affected by changes in the PPTC resistance, so it is important to select a component that will not interfere with normal operation of the circuit or trip prematurely.

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Achieving Low EMI Levels with Common Mode Inductors

In a Common Mode Noise (CMN) choke, each inductor winding is connected in series with an input line. The connections and phasing of the inductor windings are arranged so that the flux created by each winding appears to cancel the flux of the other winding. The insertion impedance of the inductor to the input signal is thus zero, except for small losses in the leakage reactance and the DC resistance of the windings.

Instantaneous current is shown in figure 4 as proceeding in one direction; in one input line and returning through the other input line. The opposing flux generated in the core ensures that virtually no voltage is induced in either winding, so the input current can pass through the common mode choke with almost no power loss. Unwanted high frequency current called Common Mode Noise (CMN), can appear in one or both input lines as seen in figure 5. The CMN current returns to the noise source through the ground connection. Since it is not cancelled by an opposing return, this current sees the full impedance of either one or both windings of the CMN inductor. The CMN voltages must be attenuated in the windings of the common mode inductor to reduce the unwanted noise on the lines.

Inductors used in the power supply interface and at the CAN transceiver should be shielded surface mount components capable of handling high current. Bourns offers a large selection of inductors in its SRP family. Their shielded housing helps achieve the low EMI levels required of automotive design. Bourns® SRP family of inductors combines flat wire technology and a powdered iron core to achieve a compact, efficient package. The flat wire has increased conductivity due to maximizing the use of its surface area, and thus is capable of handling high frequency switching.

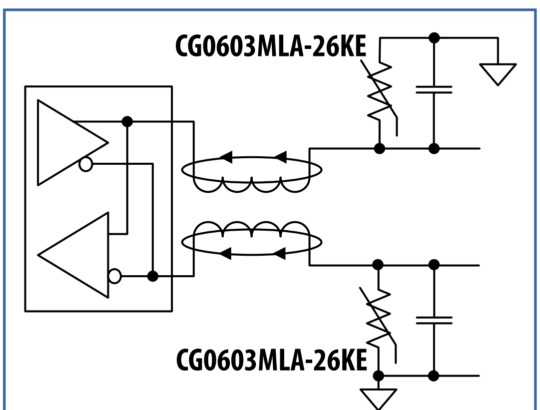

Figure 4. | *Flux Generated by Signals in Common Mode Choke*

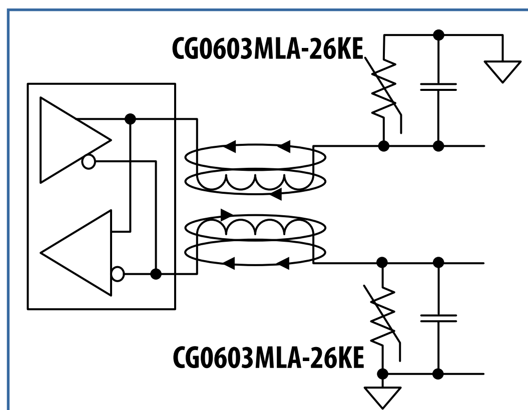

Figure 5. | *Flux Generated by Signal and Common Mode Noise*

SOLUTIONS THAT HELP ENSURE RELIABILITY (*Continued*)

Avoiding Overvoltage Damage

In addition to performing as clamping devices in other areas of the automotive system, Bourns® ChipGuard® multilayer varistors are designed to provide optimal ESD protection. With low capacitance and leakage characteristics, these devices are virtually invisible to the circuit during normal operation and can withstand multiple ESD events. When an overvoltage condition arises, the Bourns® ChipGuard® varistor clamps the voltage to a safe level to protect the ESA from overvoltage damage.
The suppressor shown in figure 6 is connected across the terminals of the ESA to protect the electronics from ESD occurring during board mount or throughout its lifetime. AEC-Q200 qualified varistors such as Bourns® Model CG0603MLC are qualified using tests 1-3b of ISO 7637. Selecting the correct Bourns® ChipGuard® device depends on the specific characteristics of the ESA, so that the voltage and trip characteristics of the part meet the requirements of the application.

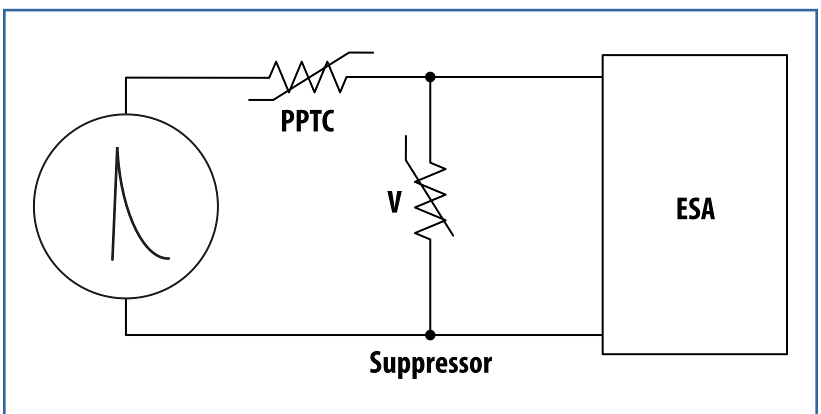

Figure 6. | *Representation of Protection Circuit*

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PROVEN COMPONENTS FOR AUTOMOTIVE ELECTRONICS

Bourns has been a trusted supplier of electronics components for decades. Their resistive, magnetic, PPTC and fuse components meet the needs of automotive electronics designers in DC-DC converter design, transient and ESD protection, and interface and system stability. All Bourns® components that are approved for automotive applications are manufactured in facilities that are fully certified to TS16949. The components have been tested and qualified using AEC-Q200, a well-known specification for passive components. As the components are integrated into automotive electronics designs, Bourns works with its automotive customers throughout the approval process, providing the necessary documentation to obtain approvals, while continuing to work toward meeting quality targets. With a proven track record for quality, customer service, and innovation, Bourns helps to ensure that designers can maintain focus on the design.

ADDITIONAL RESOURCES

For more information about Bourns' complete line of circuit protection solutions, please visit:

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