



# Selecting Inductors for DC-DC Converters and Filters in Automotive Applications

## APPLICATION NOTE



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### INTRODUCTION

While automotive manufacturers are doing their part to offer alternative powered vehicles to consumers, the market for them has not grown as rapidly as hoped. It has been discovered that some of the advancements employed in hybrid and electric vehicles can be adopted by their Internal Combustion Engine (ICE) counterparts. A newer technology that is gaining momentum is “start-stop” engine technology to improve fuel economy in ICE vehicles. However, implementing a start-stop design can affect electronics in the entire automotive system and introduces several development challenges. Direct Current (DC)-DC conversion becomes more complicated since the voltage level in start-stop is not inherently consistent. Though the surge requirements and Electromagnetic Interference (EMI) emissions requirements may vary based on vehicle model, it is still a mandatory requirement to meet them. Successful implementation will depend on the quality, construction and characteristics at the electronic component level. One key solution lies in the advances achieved in high current inductor technologies which provide compact components for power conversion and supply circuits.

This paper presents the basics of the start-stop powertrain in ICE vehicles along with associated automotive electronics tests for this type of design. Also presented will be a discussion of the many design considerations and advancements in inductor technology. Specifically, one solution will be provided to show the advantages of using a highly conductive inductor which employs a flat, rather than, a round shape. Bourns offers enhanced solutions for high frequency, high current start-stop automotive applications through its extensive portfolio of approximately 2,000 inductors, featuring flat wire conductors, powdered iron cores molded directly to the wire and a wide range of inductance values.

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## DIFFERENTIATING BETWEEN HYBRID, ICE AND START-STOP DESIGNS

Automotive designers use various methods to conserve fuel in alternatively powered vehicles. A hybrid vehicle, for example, utilizes specific triggers to transition between charging the battery while consuming fuel and operating under battery power to conserve fuel. Contrarily, in traditional ICE vehicles, fuel is always being consumed when the engine is on. A start-stop ICE design differentiates a vehicle's moving and stopped states to cause the engine to run only when necessary. Each time the automobile is stopped, the start-stop engine goes into shutdown mode. When the car prepares to move, the engine must start again.

## THE BASICS OF ICE START-STOP POWERTRAINS

Automotive electronics are typically designed to operate from a 12 V battery with a 14 V nominal voltage. The battery voltage in an ICE vehicle drops to as low as 7 V any time the engine is switched to the on-state. Even this short drop in the voltage level can cause other electronics that expect a steady 12-14 V to malfunction, so reserve batteries need to be added to the design. A schematic that shows a high-level start-stop example circuit is shown in figure 1. Any time the engine is running, the main battery powers electronics, and the reserve battery is isolated from the rest of the vehicle by a switch. When in the stop-state, and during the transition to the start-state, the switch is open so the reserve battery can supply the needed consistent level of power to the electronic circuits, such as those used for infotainment features.

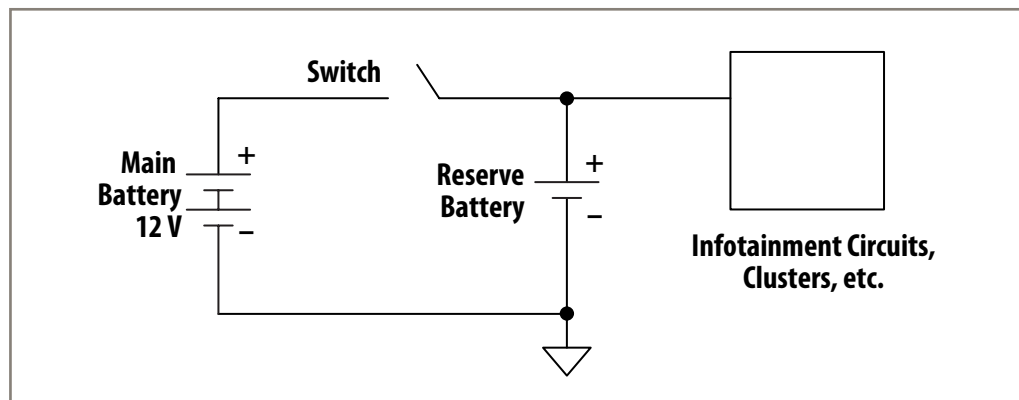


Figure 1. | This schematic illustrates the start-stop circuit that switches to a reserve battery when an ICE turns off, in order to keep the power level consistent to run electronics.

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## THE BASICS OF ICE START-STOP POWERTRAINS (Continued)

DC-DC conversion occurs between the battery and the onboard electronics. If the reserve battery voltage is lower than the main battery, then a boost DC-DC converter is necessary between the reserve battery and onboard conversion circuits. A typical DC-DC converter design employs an output capacitor and a switching inductor as shown with the power source, voltage-controlled switch and load in figure 2. If the switch is on, the inductor charges while the current is turned into magnetic flux and stored in the inductor. When the switch is turned off, magnetic flux collapses and is transformed back to electrical current to provide power to the load. The conductor wire is in use at all times, and it is essential to have an efficient conductor wire design in this high power, high frequency application.

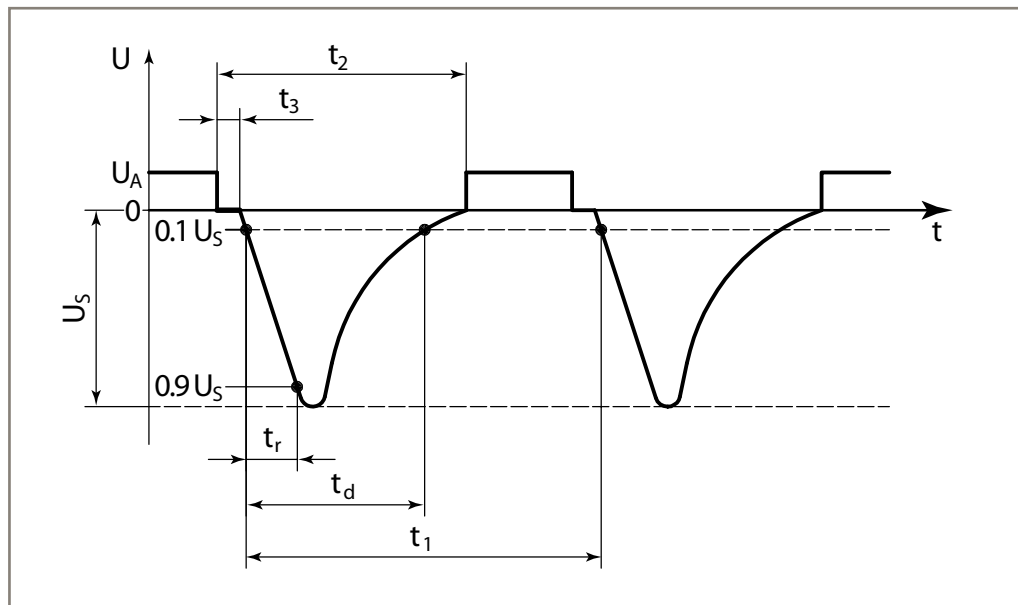


Figure 2. | The components in the DC-DC converter are the power inductor, the controller chip/switch, a diode and a bulk capacitor.

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## CONTENDING WITH SURGE AND EMI REQUIREMENTS

Another crucial parameter that makes a start-stop design challenging is the surge voltage that all automotive electronics must withstand. Specific and well-defined automotive tests are conducted to ensure engine operation is maintained during surge events. All automotive circuits, including power supplies, must be pulse-tested with the transients described as part of the design process per the ISO 7637 and ISO 16750 standards. The specified test pulse is applied at regular intervals, and the electronics must be capable of operation within its parameters. In addition, ISO 7637 specifies bench tests for electrical transient compatibility of equipment installed on passenger cars and light commercial vehicles fitted with a 12 V electrical system or on commercial vehicles fitted with a 24 V electrical system. The characteristics of the test pulse are shown in figure 3 and described in table 1.

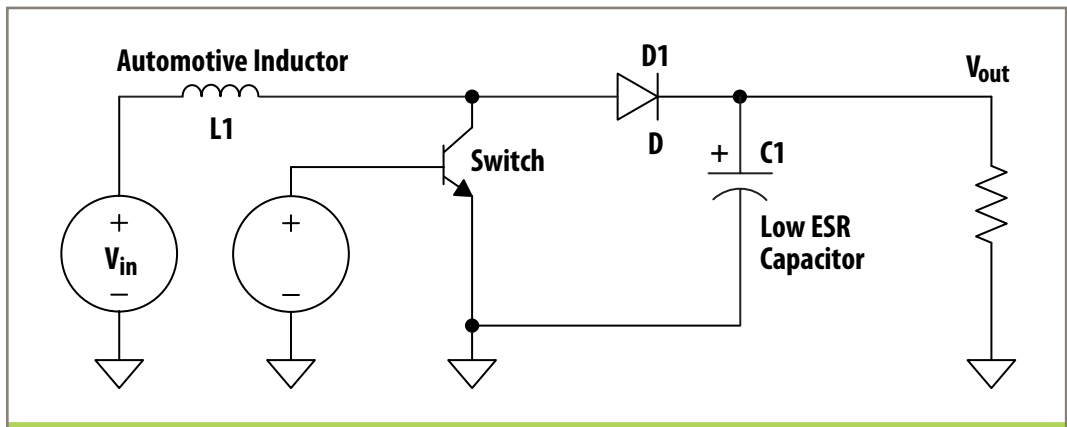


Figure 3. Automotive Test Pulse 1 – Source: ISO 7637 Manual

Table 1. Parameters for Test Pulse 1 – Source: ISO 7637 Manual

Parameter	12 V System	24 V System
$U_s$	-75 V to -100 V	-450 V to -600 V
$R_i$	10 $\Omega$	50 $\Omega$
$t_d$	2 ms	1 ms
$t_r$	1 $\mu$ s	3 $\mu$ s
$t_1^a$	0.5 s to 5 s	
$t_2$	200 ms	
$t_3^b$	<100 $\mu$ s	

a.  $t_1$  shall be chosen so that the DUT is correctly initialized before the application of the next pulse.

b.  $t_3$  is the shortest possible time necessary between the disconnection of the supply source and the application of the pulse.

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## CONTENDING WITH SURGE AND EMI REQUIREMENTS *(Continued)*

Car manufacturers have separate specifications for EMI emissions. The most common international standard is EN55022 Class B which requires attenuation of frequencies above 230 MHz to be a minimum of 37 dBuV/m. Controller boards used in electric motors to power various features throughout the vehicle provide an example of the design overhead introduced by EMI emission requirements. Motor controllers have a Pulse-Width Modulated (PWM) drive, and the switching action of its power transistors typically leads to high noise generation. Power inductors are used as part of a filter to attenuate this high frequency noise. Figure 4 shows a pair of inductors used as filters between the battery and the inverter connected to the 3-phase AC motor. Since electric motors can introduce heavy Amp loads, large inductors are needed to carry the current physically.

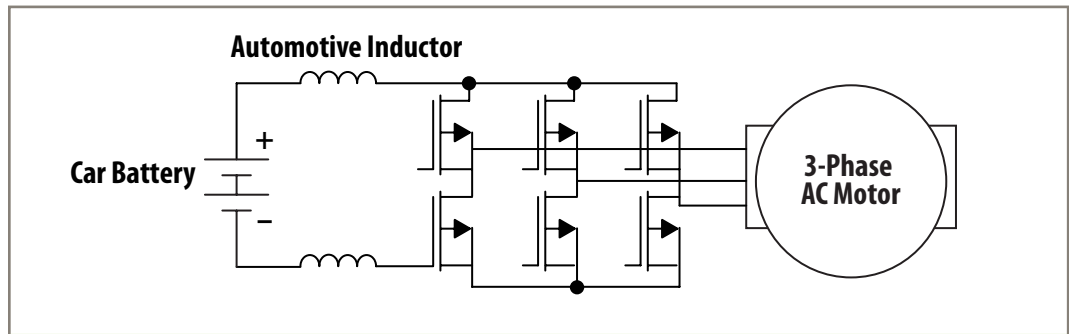


Figure 4. | An inductor is used as a filter in an electric motor controller

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## IMPORTANT DESIGN CONSIDERATIONS

When it comes to selecting the type of inductor to use in an automotive design, there are several major factors to consider such as core type, frequency rating, current, saturation, temperature, EMI and wire type. While a ferrite core-based inductor may suffice for some designs, today's high current, high frequency automotive designs would be well-served with the Bourns® Model SRP Series flat wire power inductor's higher saturation capabilities. Bourns offers detailed test results and data sheets to help designers determine the right inductive component for a given application.

A crucial consideration for power supply designers is to avoid selecting an inductor that would saturate the given specifications of an application. Motor drives can have high DC current values and would require large inductance values to effectively filter emissions. Similarly, DC-DC converters, as in start-stop systems, may also have very high DC currents that generally require physically large components to carry the current, without overheating or saturating. To determine if a ferrite inductor will meet an application's specifications and to test for core saturation, designers can use a high transient pulse test specified by ISO 16750-2:2012 load dump A and B. This test is designed to simulate disconnecting a discharged battery while the alternator is generating charging current (also known as load dump), using a very high pulse of up to 174 V.

All automotive powertrain electronics are required to perform in the high temperatures associated with the automotive environment, typically as high as 150 °C. The operating temperature of each component must be examined to ensure that it is rated to the requirements of the car manufacturer. Ferrite cores have to derate their saturating flux density based on temperature, while an iron powder core's saturation point is not affected by temperature. This means that at high temperatures, iron powder inductors can operate at even higher currents than ferrite inductors.

In DC-DC converters, low EMI and low-ripple voltages are important considerations. The overall ripple voltage is a function of the ripple current in the inductor and the Equivalent Series Resistance (ESR) of the capacitor. Ripple voltage,  $\Delta V_{out}$ , can be calculated by the following equation:

$$\Delta V_{out} = ESR \left( \frac{I_{out}}{1-D} + \frac{\Delta IL}{2} \right)$$

Where  $I_{out}$  is the output current,  $\Delta IL$  is the ripple in the inductor current,  $D$  is the duty cycle, and ESR is the output capacitor's equivalent series resistance. These calculations must be done to ensure the selected components meet the requirements.

The Bourns® Model SRP Series offers features that are especially advantageous for start-stop engine applications:

- Flat wire technology allows for a compact footprint
- Capable of handling high frequency switching
- The combination of flat wire technology with a powdered iron core reduces wasted space in the package and increases the conductivity of the conductor when operating at high frequencies

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## IMPORTANCE OF SELECTING THE RIGHT INDUCTOR

Borrowing from alternative fuel vehicles, a start-stop powertrain architecture in ICE vehicles offers a marked improvement in fuel efficiency, but presents several challenges since all of the vehicle's electronics must be considered. A successful design requires attention to the components used for the DC-DC converter design. It is vital that designers specify robust, high-quality components that can handle high amounts of current and frequency at extended operating temperatures, throughout the automotive start-stop system. Furthermore, a start-stop design must be able to withstand surges of current in order to pass various Original Equipment Manufacturer (OEM) requirements. Bourns® Model SRP Series Inductors offer an optimal application solution for start-stop powertrain applications. Their flat wire, iron powder core construction and high frequency capability provides the needed high DC current bias and temperature stability. This allows them to operate at high temperature and high currents without saturating, thus meeting many of the stringent requirements of automotive design.

## ADDITIONAL RESOURCES

For more information and further technical support, visit Bourns online at:

**[www.bourns.com](http://www.bourns.com)**

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