BOURNS®

Bourns Magnetics Solutions

for Power and Signal Lines

For more than 70 years, Bourns has worked relentlessly to provide customers with the latest in reliable, quality technology to power the innovations of the future.

In this e-book, we highlight some of our most advanced solutions, including BMS transformers, push-pull transformers, reinforced transformers, advanced network transformers, and planar flyback transformers, as well as provide information about Bourns high-voltage storage solutions and power inductor technology.

This e-book will help you understand how Bourns transformer and power solutions can help elevate your designs and improve your product efficiency, increasing design reliability and lowering your system costs.

Table of contents

The Development of New Amorphous Cores for **High-Frequency Power Application**

INTRODUCTION

Increased electrification is driving the development of more efficient energy solutions for all market segments. Designers of semiconductor technology have developed new methods for switching, such as soft switching or zero-current switching, which have contributed to increased bandwidth and the introduction of devices using GaN and SiC materials. Increased bandwidth helps to reduce the size of magnetic components as the magnetizing inductance increases, yet core materials can struggle to dissipate less power as the frequency increases. Typically, materials with high flux density and low coercivity exhibit excess core losses as the frequency approaches 1 MHz. »»»

This section introduces new core material research published at APEC 2019 and PCIM 2019 by Bourns in collaboration with Tyndall Research Institute. The purpose of developing new magnetic materials is to achieve minimal core losses at high switching frequencies. This section provides an overview of core material terminology and describes the results obtained from new material produced by Bourns, with a discussion on the application of these results and future work planned.

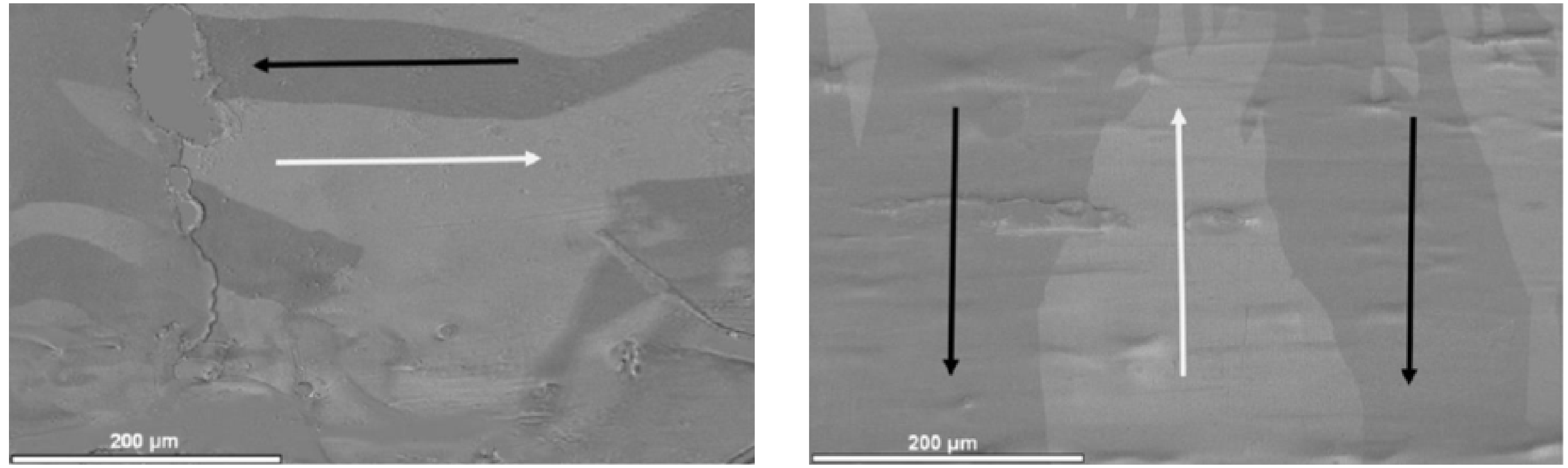


Figure 1: Electron microscope image of amorphous material with domain wall movement (left) and domain rotation (right)

Advanced Magnetic Materials Terminology

Magnetic materials differ from non-magnetic materials by the way they react when a magnetic field is applied. If a magnetic field is generated, the atoms in magnetic materials will experience a torque proportional to the flux density in the field by a vector quantity called the magnetic moment. A strip of magnetic material can be described furthermore by groups of magnetic moments, known as domains, wherein every domain has a different direction. Once a field is applied, the domains will align along the direction where the least amount of energy is lost (called the easy axis, as shown in Figure 1). All magnetic materials have these qualities, although some have higher anisotropic energies (the energy required to rotate the magnetic domains to a saturated state at which the applied field has no effect) than others, and a few materials enable better performance at different switching frequencies compared with others.

Figure 2 shows the saturation flux densities of various commercially available materials on the market. Nickel–iron alloy (NiFe) cores are commonly used in power inductor applications, as they offer good coercivity compared with ferrites and have higher flux densities as well.

The chart in Figure 2 shows that amorphous materials have a good mixture of coercivity and

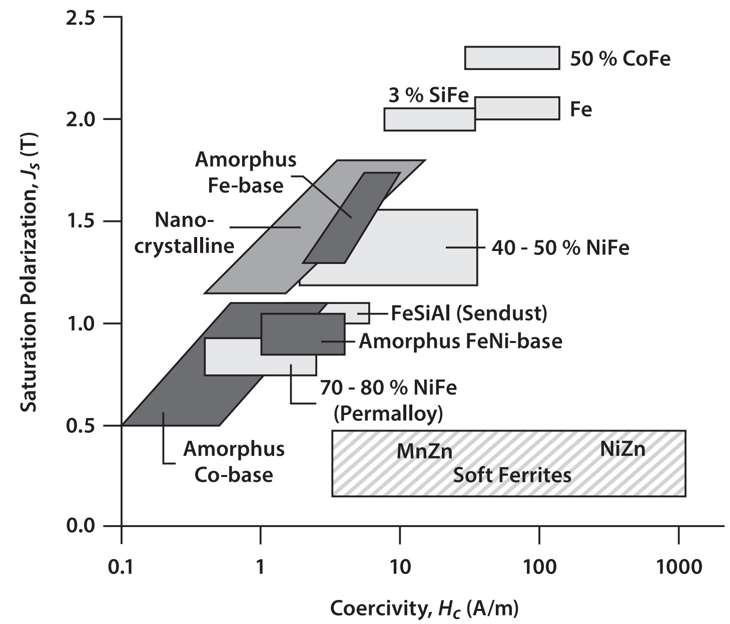


Figure 2: Overview of different materials categorized by coercivity and saturation flux density

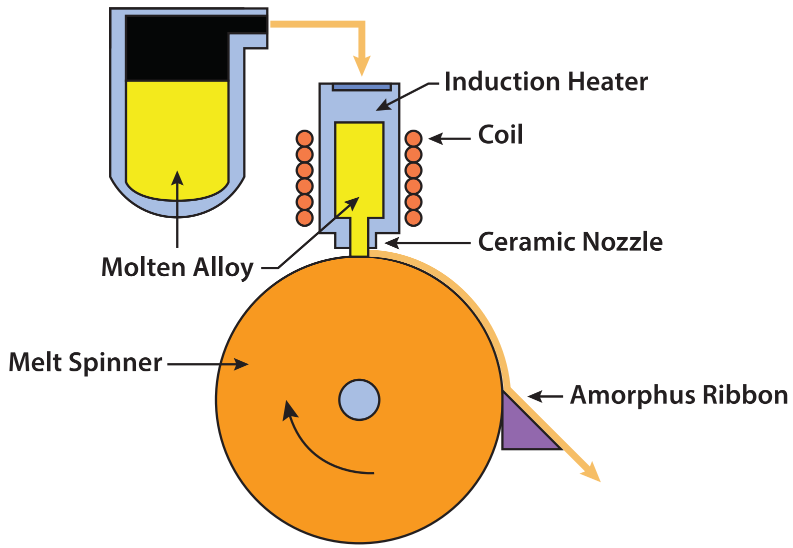


Figure 3: The first stage of production as quenched samples of amorphous material

saturation flux density. The composition of amorphous materials consists of trace elements such as cobalt and iron together with mixtures of silicon and other elements such as niobium. One of the objectives of this research was to prepare and test amorphous material, which did not depend on traditional elements and resulted in reducing the material cost by 30%.

The experimental material used in this research was based on cobalt and iron and other elements. To prepare the material, the elements were carefully weighed and arc-melted at temperatures of 4,000˚C in an arc furnace producing 1-g ingots. The ingots were subsequently put into an induction heater and the molten liquid ejected onto a spinning disk and cooled at a very severe rate (1 million degrees per second), producing 20-μm–thick, 1-mm–wide ribbons into a quartz vial. Figure 3 illustrates the steps taken in the first stage of making the material.

The ribbons, once gathered in the quartz vial, are known as "quenched." The B-H loop of this material was gathered using a B-H loop tracer and is shown in Figure 4 (black line). The curve is known as the magnetization curve. The magnetic domains are aligned in the longitudinal direction and the magnetization is known as domain wall movement. The core losses of amorphous material with domain wall movement magnetization are high and are dominated by anomalous losses. This is corrected by applying magnetic annealing (up to 5T magnetic field)

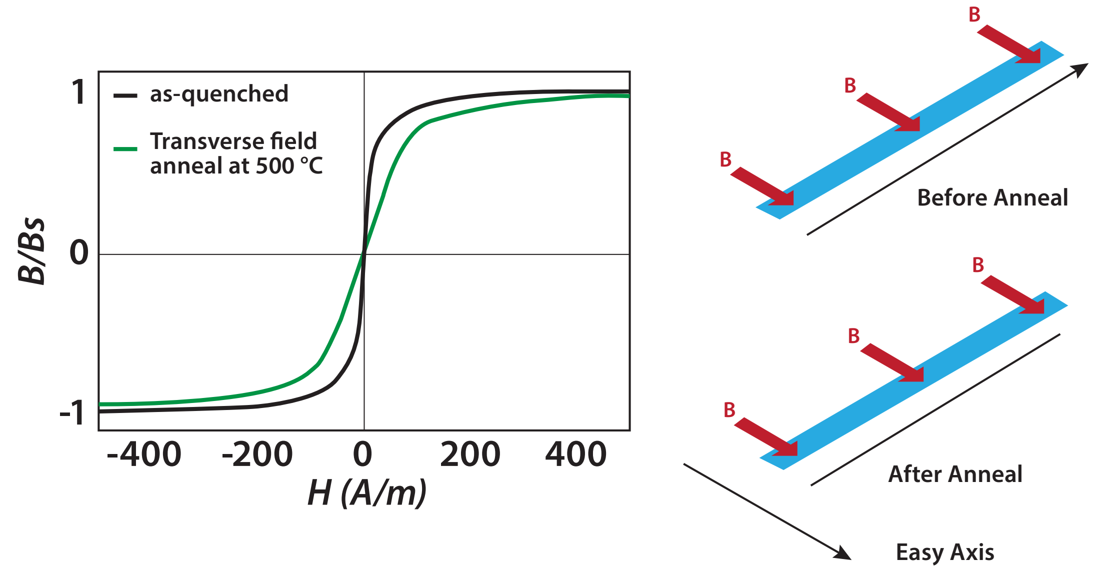


Figure 4: B-H curve of Bourns amorphous material before and after annealing

in a transverse direction to the easy axis at different temperatures starting from 500˚C. The effect of magnetic annealing is to change the magnetization process from domain wall movement to domain wall rotation. Domain wall rotation reduces anomalous core losses significantly. The B-H loop of magnetically annealed samples can be seen in the green curve in Figure 4. There is an obvious difference in the slope of the B-H curve with magnetization requiring a larger field (H) and, hence, higher anisotropic energy.

Calculation and Measurement of Core Losses

Core losses can be divided into three categories as follows:

A. Hysteresis losses (Ph): This is a function of the B-H curve of the material and is proportional to the product of the AC magnetic field, the flux density, and the frequency, as shown in Equation 1:

$$P_h = 4fB^2 \frac{H}{B_{sat}} \text{ : Equation 1}$$

B. Eddy current losses (Pe): Eddy currents induced in the core material are affected by the resistivity of the material. The resistivity, in turn, is affected by the skin depth at the switching frequency.

Where ω represents angular speed (radians per second, or 2πf); δ represents skin depth; σ is the electrical conductivity; a and b refer to the sheet thickness and width; and l is the overall length. Eddy current losses are, therefore, proportional to the square of the switching frequency. Pe can be reduced by keeping a as close to the skin depth as possible.

$$P_e = \frac{\omega^2 \phi^2 \sigma b \delta}{8l} \left(\frac{\sinh\frac{a}{\delta} - \sin\frac{a}{\delta}}{\cosh\frac{a}{\delta} + \cos\frac{a}{\delta}} \right) \text{ : Equation 2}$$

C. Anomalous loss: The anomalous loss is about 70% of the losses in amorphous cores. It is caused by variations in the demagnetization curve due to fluctuations in the domain wall rotation. Anomalous loss is calculated by measuring the core loss of the material, then calculating hysteresis and eddy current losses using Equations 1 and 2 and then subtracting them from the measured core loss.

Core Loss Measurements

To measure core losses, the research team used a 5-cm solenoid (5-mm radius) with 150 turns of copper wire connected to an LCR meter. The 150 turns completely filled the solenoid so as to ensure a uniform magnetic field inside the solenoid. The impedance of the solenoid was measured with and without the material sample. The core loss is the difference in impedance multiplied by the square of the current injected by the LCR meter, as shown in Equation 3.

$$P_{loss} = R_e\{Z_c - Z_a\}I^2 \text{ : Equation 3}$$

Where ƒ and S are the measurement frequency and cross-sectional area of the sample magnetic material inside the solenoid.

Figure 5: Photograph of the test fixture used to measure core loss

The resultant core loss measurements were then recorded and plotted on Figure 6 and shown in comparison with commercial-grade NiFe material at a frequency of 1 MHz. As the graph shows, there was a vast improvement in the power losses with the tested Bourns material. It was at least 30% lower than the NiFe material. Furthermore, the permeability was measured from the B-H curve as 770, compared with typical values of 100 or less with NiFe cores. Assuming

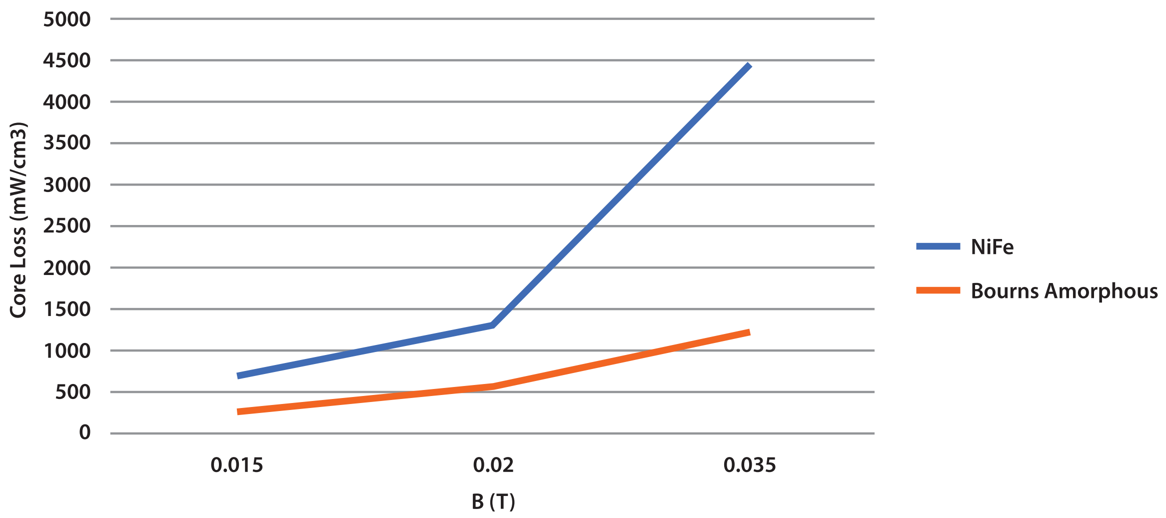


Figure 6: Core loss density measurements of Bourns material and NiFe material

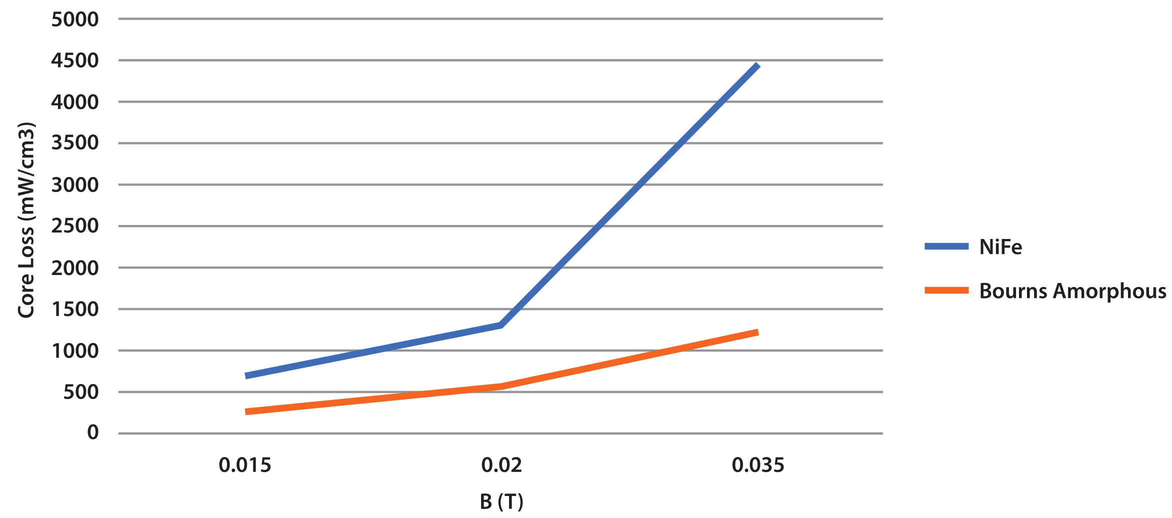


Figure 7: Change in permeability (%) over operating temperature of Bourns material compared with NiFe and ferrite

an NiFe core with an initial permeability of 77, the ratio of extra turns required to reach the same inductance value compared with the Bourns amorphous material would be 3.16. The amorphous material had a strong advantage over NiFe when it came to form-factor reduction, as fewer turns would be needed, and it would be more efficient, as thicker wire with lower copper losses could be introduced.

The temperature stability of this material is also very strong and comparable with NiFe cores, giving a strong advantage in electromagnetic interference (EMI) filtering applications in which inductance drift with temperature can affect the insertion loss of common-mode filters. However, the tenfold increase in permeability allows this material to be used where inductance values typically requested are higher than what NiFe can typically provide without increasing significantly in form factor.

Figure 7 illustrates the similarity in temperature drift between NiFe and the Bourns amorphous material. It also shows the stability of a commercial off-the-shelf ferrite material. The only way to reduce the ferrite material's temperature instability would be to introduce a gap into the core. The Bourns material's permeability was calculated by creating a toroidal magnetic component and recording the magnetizing inductance in a temperature chamber at different temperatures. Figure 8 shows a photograph of the prototype magnetic device (push-pull transformer) on a test board.

Summary

The work here to create an amorphous core material using less exotic trace elements for high switching frequencies has produced some interesting initial results. At 1 MHz, the core losses were much lower than other materials with similar coercivity, such as NiFe. More research is still needed to evaluate the amorphous material for alternative high-frequency cores in high-power converters or filters requiring low coercivity, good temperature stability, and high permeability. ■

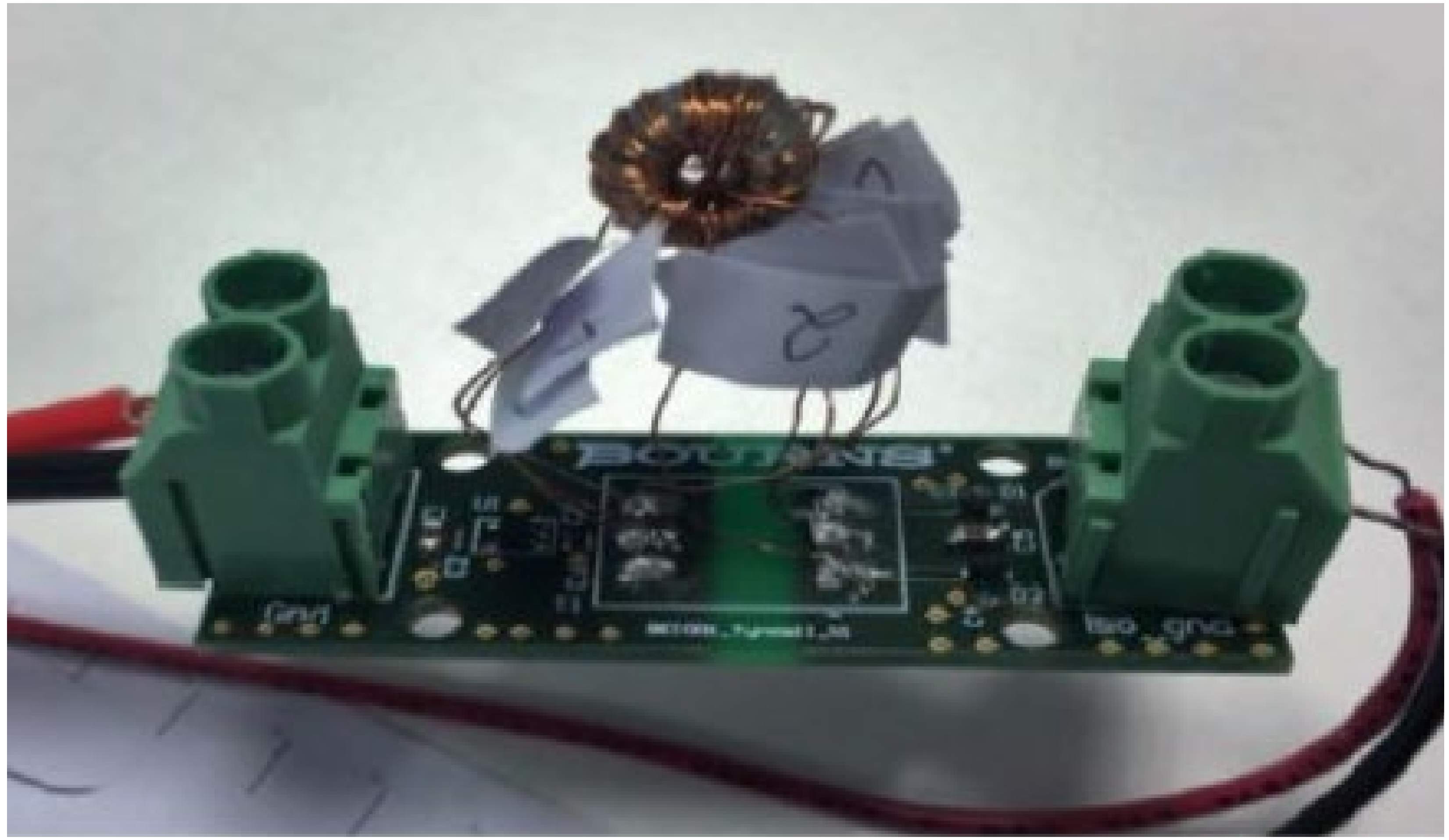
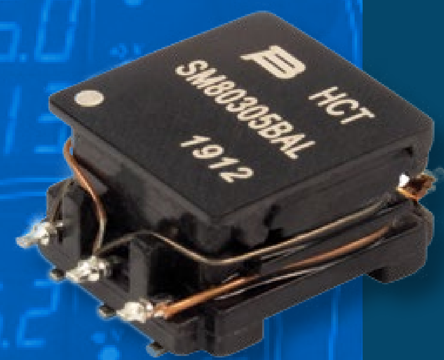


Figure 8: Photograph of prototype transformer made with Bourns amorphous core

Using
Push-Pull Transformers
to Isolate Power in 12-V Applications



INTRODUCTION

DC/DC converters produce very efficient circuits by utilizing high-frequency switching and energy storage components such as the inductor and the capacitor. DC/DC converters have many high-voltage applications such as ultra-capacitor energy banks, motor drives, high-voltage battery systems, and solar inverters.

DC/DC converters are important elements of power designs and are used to “condition” voltage from one level to another; i.e., they can either step up or step down a voltage. Push-pull DC/DC converters are becoming more and more common in electric vehicle applications in which galvanic isolation is a requirement. They produce low EMI emissions, are high-efficiency, and occupy a small footprint, so they are extremely attractive for automotive applications. The push-pull configuration can be used to produce power for BMS, on-board chargers, and traction inverters that need to isolate high-voltage circuits from low-voltage circuits.

This application note will highlight why the Bourns Model HCTSM8 series transformers are excellent solutions to isolate power in DC/DC converter systems. It will cover the benefits of the push-pull topology and how Model HCTSM8 transformers can also be used to supply the bias voltage for an isolated insulated gate bipolar transistor. »»»

Bourns HCT transformers are qualified to be used with Texas Instruments' SN6501 and SN6505B transformer drivers, which have a maximum operating voltage of 5 V for isolated power supplies. In theory, the Model HCTSM8 series can operate at much higher voltages. This application note examines how this is achieved using the SN6501 IC chip. The solution involves inserting a pair of FETs in between the transformer and the SN6501, which protects the chip from experiencing high voltages within the specified design limits.

Push-Pull Converter Background

Figure 1 shows a typical application in which a push-pull transformer is used to generate the ±15 V to turn the IGBTs on and off. One disadvantage of this power supply is that the input supply voltage is limited to 5 V, and consequently, this limits the range of applications that operate above 5 V, such as 12 V or 24 V.

DC/DC converters are a necessity in industrial environments, and examples of this include interface/bus isolation and isolation of digital circuits. 12 V is a common industrial voltage, and the proposed application could be used for a DC/DC 2:1 12-V power rail in a communication interface system. Here, the DC/DC converter system would provide galvanic isolation between the signal isolation unit and the transceiver unit.

The push-pull converter is a two-switch topology that has very high efficiency. It requires a transformer, so it transfers power from primary to secondary in each switching cycle. Figure 2 shows the switching operation. When switch M1 is closed, current flows through coil L1. At the same instance, current is flowing through coil L4 and diode D4 is conducting. The opposite occurs when M2 is closed and M1 is open; current flows through L2 and D1 starts conducting through L3. It is worth mentioning that there is a dead time wherein both switches are turned off to prevent the chance of a short-circuit occurring.

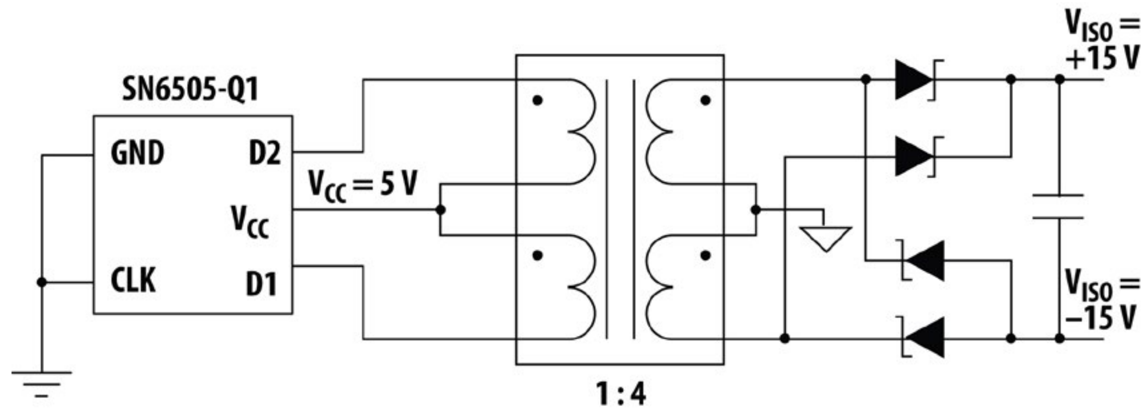


Figure 1: Isolated bias supply for gate driver of IGBTs.

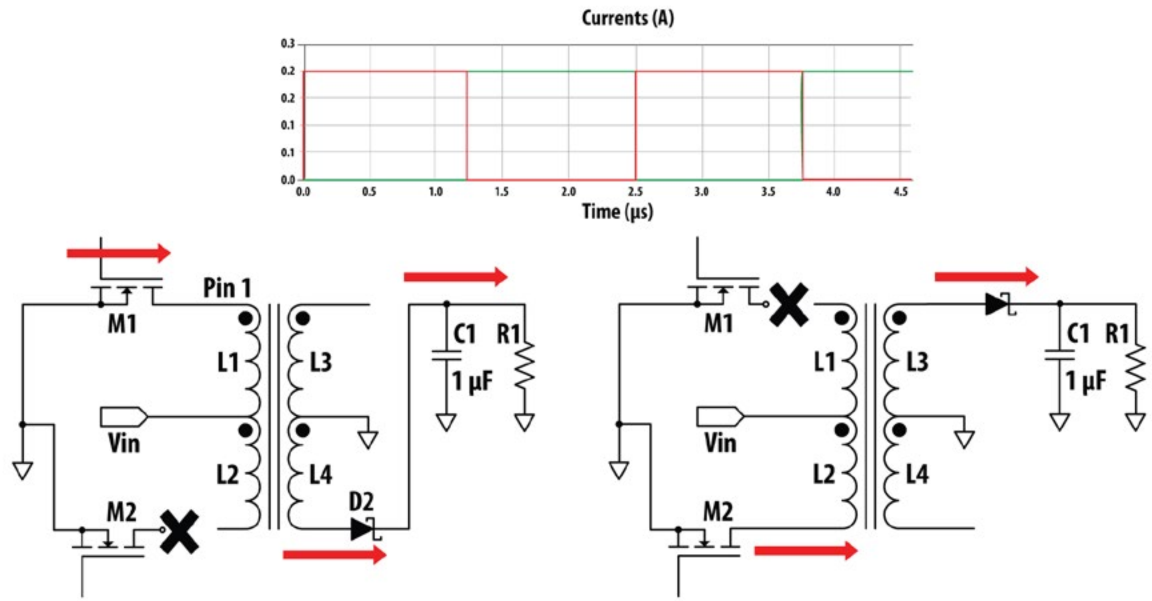


Figure 2: Operation of a push-pull converter with the red lines indicating output current

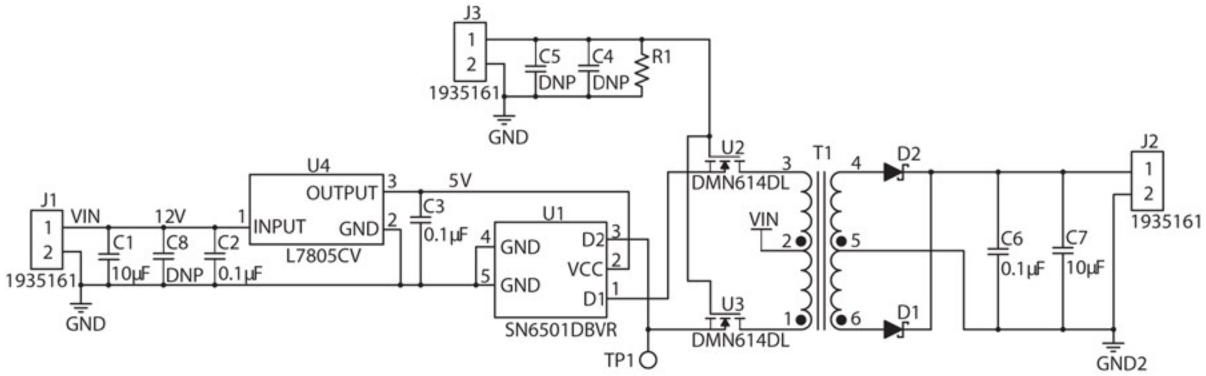


Figure 3: Model HCTSM8 higher-voltage application schematic

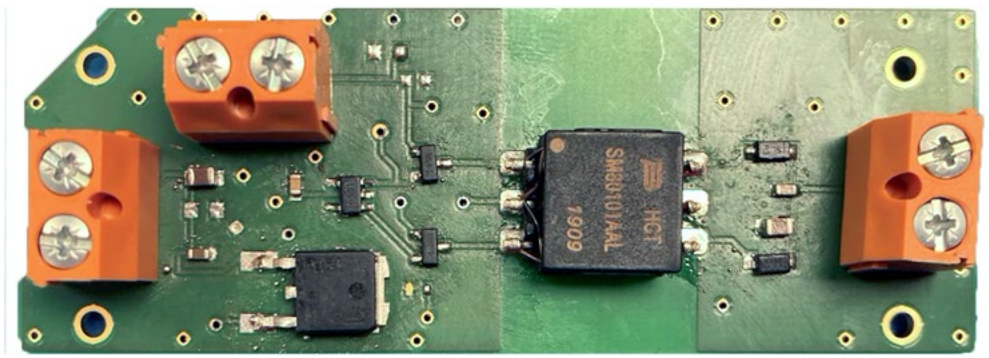


Figure 4: Model HCTSM8 board

Electrical and Mechanical Advantages

The Bourns HCT series transformers have many electrical and mechanical advantages. For example, they provide high efficiencies at a stable input and output current. The series' push-pull transformer design is used in open-loop configuration, so it requires no feedback, thus permitting a simpler design. In addition, the transformer offers good core utilization, as it draws current from both halves of the switching cycle. Plus, it has low EMI emissions due to the push-pull converter's balanced configuration. This feature is an advantage in automotive applications in which there are strict regulations on EMI.

Moving to the mechanical advantages, the HCT series has a small footprint, and it boasts a high-clearance and high-creepage design. Its innovative design maximizes the creepage distance. The transformer's core is located in a special compact housing that increases the path length for current to flow between the primary and secondary. For a transformer with a small footprint, the creepage distance is similar to a flyback transformer that has a much larger footprint.

Circuit Description

Shown in the circuit schematic in Figure 3, the FETs are located between the transformer primary winding and the drains of the internal FETs of the TI SN6501 device. The FETs will protect the chip from voltages above 5 V while not affecting the efficiency of the circuit.

A linear regulator is used to supply the voltage to the SN6501 driver from the input voltage, and a separate voltage source is used to bias the gates of the FETs.

The gate voltage is set to 5 V to maximize efficiency. Higher gate voltage results in higher drain current and requires more current draw from the input voltage source. Additionally, it is advised to carefully select a FET with low output capacitance and low RDS(on). If the FET's output capacitance is too large, the voltage on the drain of the SN6501 device will start to float up and this phenomenon may damage the chip. A FET with low RDS(on) must be chosen, as the FETs are in a continuous on state. The lower the RDS(on), the more efficient the circuit.

Bourns performed circuit testing in the company's magnetic design center using a DC power supply, a DC electronic load, and an oscilloscope. Table 1 includes a list of the equipment used. The turns ratio of the transformer and the applied input voltage dictate the output voltage. Two transformers with different turns ratios were used: a 1:1 and a 2:1 configuration. The input voltage applied throughout the testing was 12 V and 15 V. The results of the Bourns internal tests are provided in the next section.

Equipment	Manufacturer	Part Number
Oscilloscope	LeCroy	WaveACE101
DC Power Supply	Powerbox	PB3100
DC Load	BK Precision	8540
Digital Multimeter	Fluke	179

Table 1: Equipment

Bourns Circuit Test Results

Bourns engineers performed two tests using the same transformer but with different turns ratios: 1:1 and 2:1. The circuit test setup was performed as described in the previous section.

Test 1 used the 1:1 configuration, and the transformer was tested at an input voltage of 15 V. Figure 6 displays the efficiency of the circuit over a

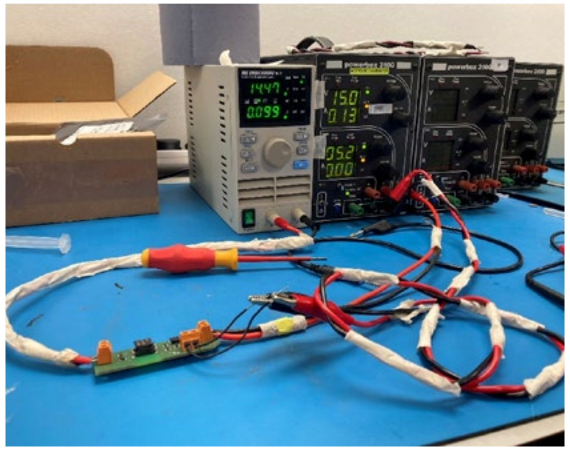


Figure 5: Testing setup

load current of 0 to 100 mA. The optimal efficiency occurs at the largest load current of 100 mA. For efficiency improvements, designers should select a FET with low RDS(on) to minimize power loss, as the FETs are always on.

Figure 7 shows the output voltage versus the load current. The output voltage remains relatively stable as the load current increases and it doesn't drop below 14.5 V. There is no closed-loop control or LDO used, so it is normal to see the output voltage slightly drop as the load current magnitude is increased.

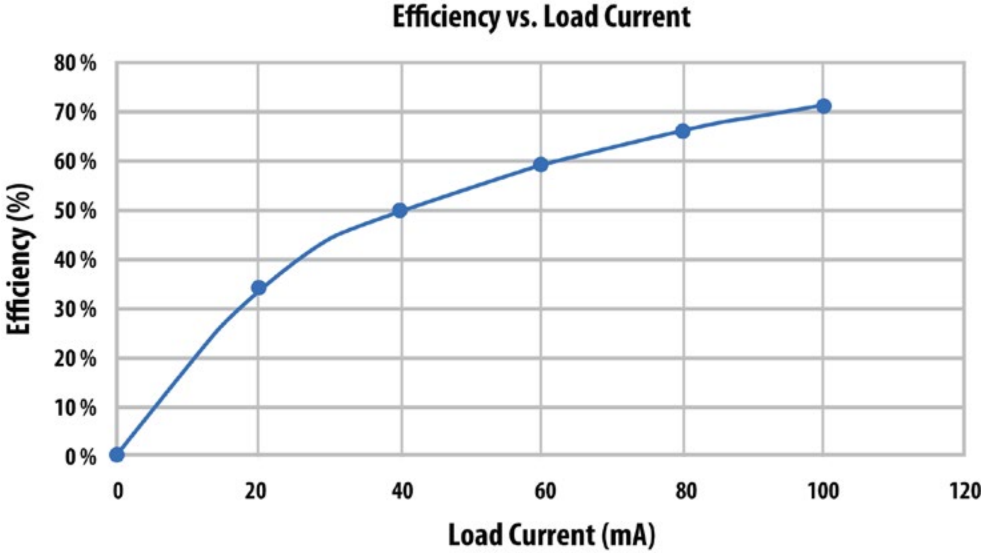


Figure 6: HCT series 1:1 efficiency versus load current plot

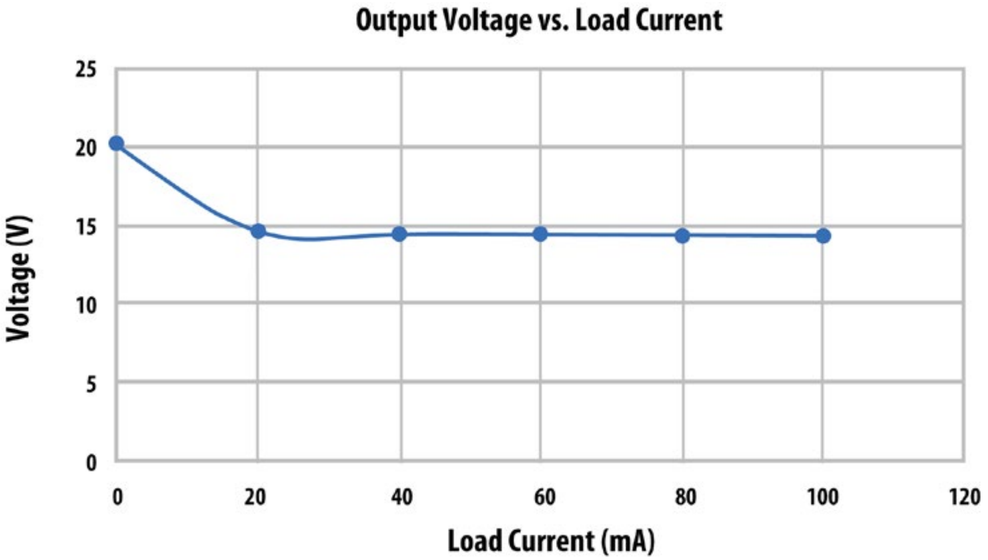


Figure 7: HCT series 1:1 output voltage versus load current plot

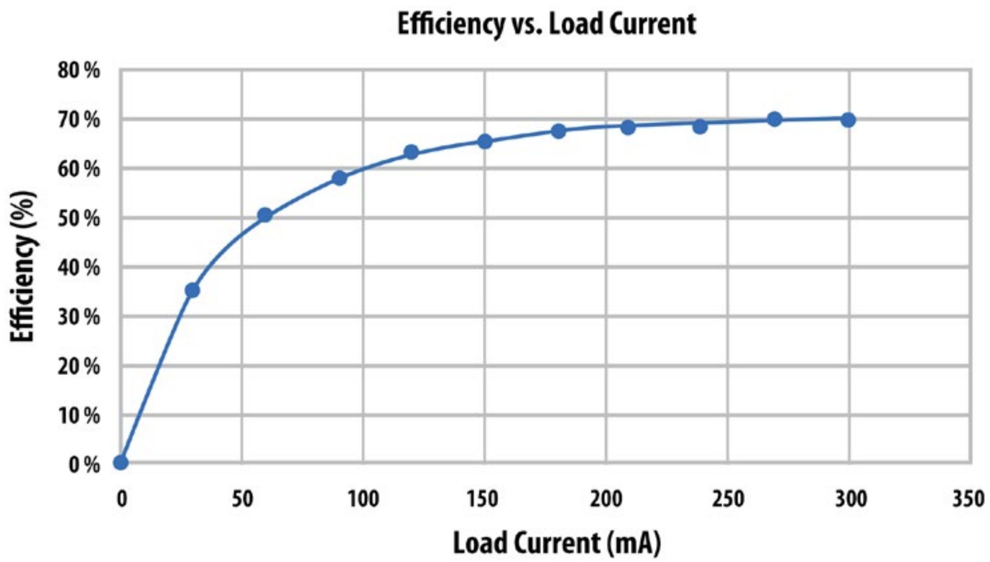


Figure 8: HCT series 2:1 efficiency versus load current plot

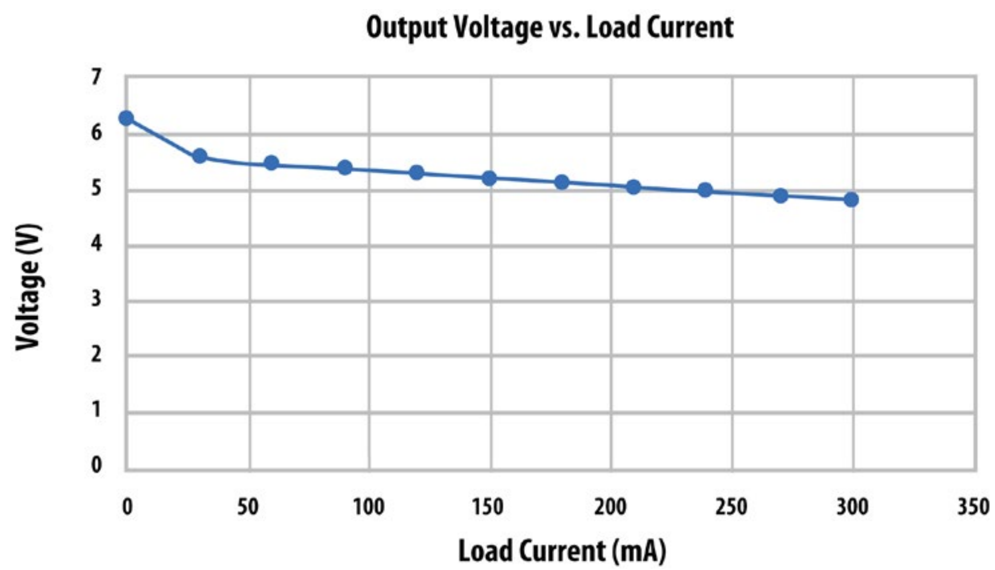


Figure 9: HCT series 2:1 output voltage versus load current plot

Model HCTSM8 Series Transformers in 2:1 Configuration

The second test uses the same transformer with a 2:1 turns ratio. The input voltage applied is 12 V, and it is very similar to a 12-V rail in a communications power supply. The load current was increased from 0 to 300 mA and the results were recorded. This test showed similar efficiency results to the previous one. Figure 8 illustrates where the highest efficiency at the largest load current is achieved. Additionally, Figure 9 shows that the output voltage tapers slightly with the load current.

Conclusion

The test results illustrate adequate performance for both push-pull circuits. They also show that the addition of the FETs has little impact on the efficiency, but it is still important to choose a FET with low RDS(on) or efficiency will decrease. Demonstrated with the proposed circuit, it shows that the TI SN6501 chip can be used at higher voltages than 5 V. The examples provided also highlight that the combination of the Bourns Model HCTSM8 series transformers along with the TI SN6501 drivers are ideal solutions to isolate a 12-V bus rail in a communications system or a power supply for the switching of IGBTs. ■

References

1A. Kamath, "Push-pull converter simplifies isolated power supply design in HEV/EV systems" Analog Design Journal, Texas Instruments, accessed 13/11/2020

2C. Sheehan, "How to Select the Right Reinforced Transformer for High Voltage Energy Storage Applications," Application Note, Bourns Electronics, accessed 13/11/2020

Selecting the Right Power Inductor
for DC/DC Converters

INTRODUCTION

Buck and boost converters (Figures 1 and 2) are common forms of DC/DC converters used in a wide variety of consumer automotive and industrial applications. Bourns PQ series power inductors are ideally suited for DC/DC converters operating at power greater than 100 W. This design note provides a guide to selecting the right power inductor by providing design rules and key inductor values as well as the equations needed to determine peak and RMS currents. »»»

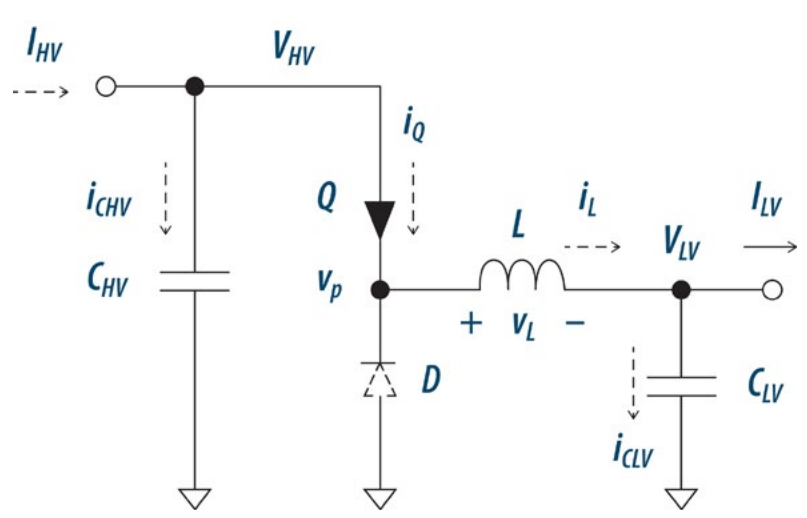


Figure 1: Buck converter

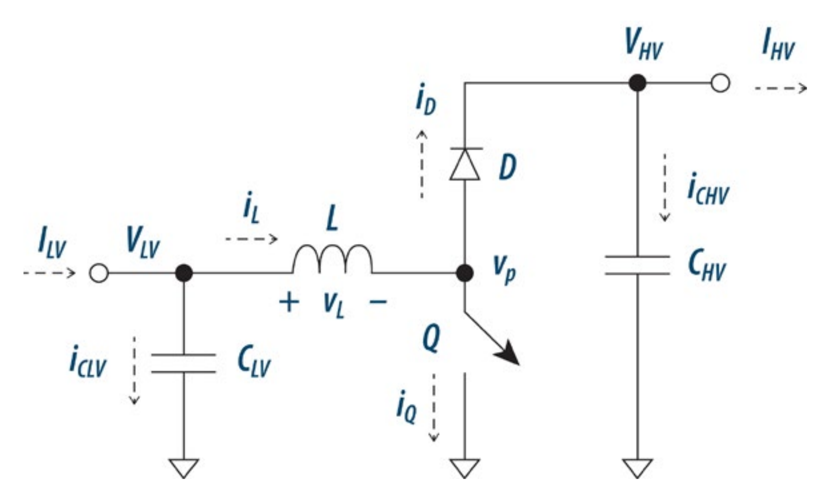


Figure 2: Boost converter

Key Parameters Required and Design Steps

The following questions need to be answered in order to calculate the correct inductor value:

1. Operating frequency (Fsw) (kHz)
2. Output power (W)
3. Input and output voltages (V)
4. Ripple current in inductor (ΔIpp) (A)
5. Operating mode (CCM, BCM, DCM)

The calculations and steps below are necessary to determine the inductor that best meets the application requirements:

1. Calculate average current (Iout) (A)
2. Calculate duty cycle D (Equations 1, 2, 8, 10)
3. Calculate the inductance value (μH) (Equations 3, 9)
4. Calculate inductor max. current (A) (Equations 4, 5)
5. Calculate inductor RMS current (A) (Equations 6,7)
6. Search for suitable inductor with correct inductance, Isat, and RMS currents

Buck Converter Design Example

The following inductor characteristics are typically required for a buck converter:

1. Fsw = 200 kHz
2. Power = 264 W
3. VIN = 48 VDC, VOUT = 12 VDC
4. Ripple current = 50 A
5. Operating mode = DCM (DCM2 = 0.1)

Calculating a Solution

Design Steps 1 through 6 are shown in Table 1 with the provided equations:

Calculate Average Current I_{out}	$I_{out} = \frac{264}{12} = 22\ A$			
Calculate Duty Cycle D (Equations 1, 2, 8, 10)	$D = \frac{12}{48(1 - 0.1)} = 0.3125$			
	$Dcm1 = 1 - 0.3125 - 0.1 = 0.587$			
Calculate the Inductance Value (Equations 3, 9)	$L = \frac{(48 - 12) * 0.3125}{(50 * 200{,}000)} = 1.1\ \mu H$			
Calculate Inductor Max. Current (Equations 4, 5)	$I_{max} = 50\ A$			
Calculate Inductor RMS current (Equations 6,7)	$I_{rms} = 50\sqrt{\frac{0.3125 + 0.587}{3}} = 27.37\ A$			
The Optimum Power Inductor that Meets Inductance, I_{sat} and RMS Current Requirements	Part Number	Inductance	RMS Current	Peak Current (I_{sat})
	PQ2614BLA-1R5K	1.5 µH	30.0 A	100 A

Bourns PQ Series Power Inductors

Bourns designed the following features into the PQ series power inductors to deliver considerable application benefits for high-power buck and boost converters:

Features	Benefits
Coil Made with Stamped Flat Wire	Low DC and AC Resistance
High Frequency Ferrite Core	• Low Core Losses at High Frequency • High Permeability Material Requiring Fewer Turns than Iron Powder which means lower DC resistance
Automated Production Line	High Quality
Available for Selection in LTpowerCAD®	Recognized by Leading Power Vendors

Summary of Equations and Waveforms

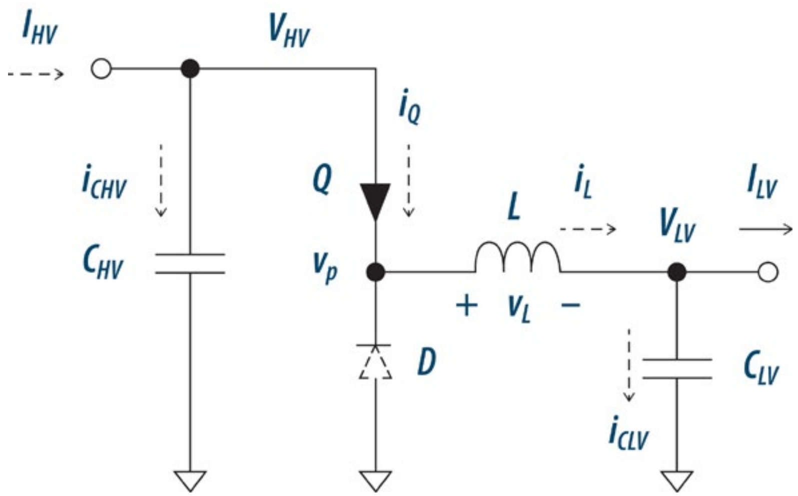


Figure 1: Buck converter

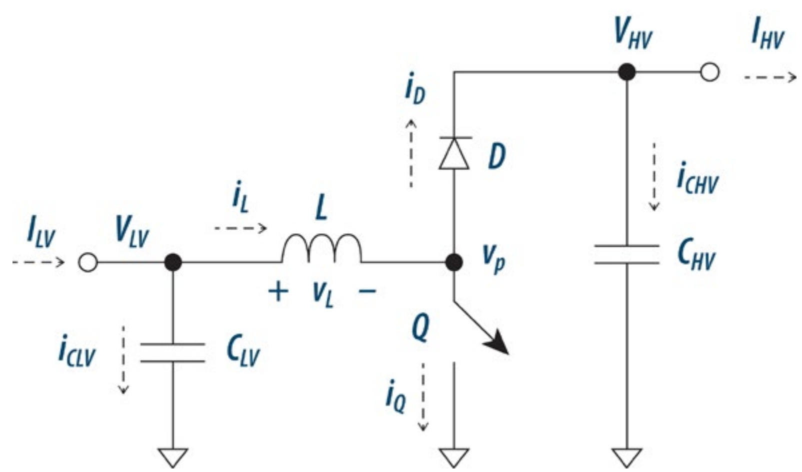
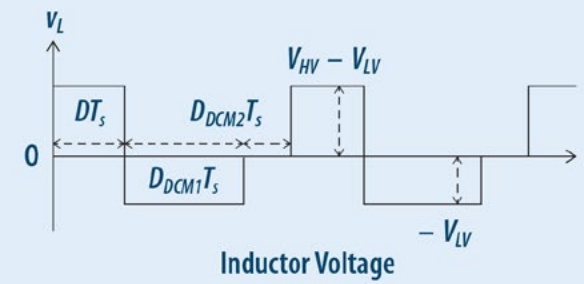
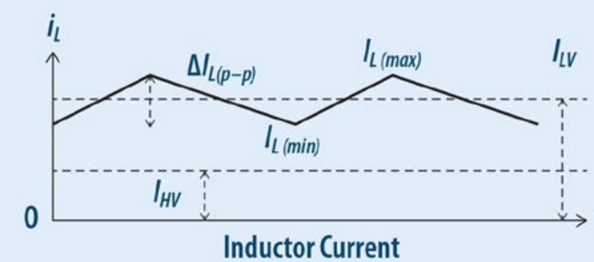
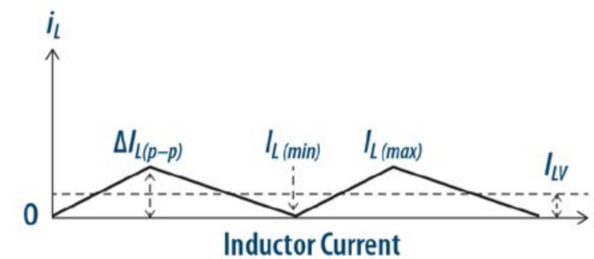


Figure 2: Boost converter

Reference	Equation	Description	Waveform (if applicable)
1	$D = \frac{V_{out}}{V_{in}}$	Duty Cycle Buck in CCM and BCM	
2	$D = \frac{V_{out}}{V_{in}(1 - Dcm2)}$	Duty Cycle Buck in DCM	
3	$L = \frac{(V_{in} - V_{out}) * D}{F_{sw} * \Delta I}$	Inductance	
4	$I_{Lmax} = I_o + \frac{\Delta I}{2}$	Max. Current CCM	
5	$I_{Lmax} = \Delta I$	Max. Current CCM and DCM	

Summary of Equations and Waveforms (continued)

Reference	Equation	Description	Waveform (if applicable)
6	$I_{Lrms} = \sqrt{I_o^2 + \frac{\Delta I^2}{12}}$	RMS Current CCM and BCM	
7	$I_{Lrms} = \Delta I \sqrt{\frac{D + Dcm1}{3}}$	RMS Current Buck DCM and Boost DCM	
8	$D = 1 - \frac{V_{in}}{V_{out}}$	Duty Cycle Boost Converter	
9	$L = \frac{V_{in} D}{F_{sw} \Delta I}$	Inductance Boost Converter	
10	$Dcm2 = 1 - \frac{V_{out} D}{V_{out} - V_{in}}$	DCM Duty Cycle	

How to Select
the Right Reinforced Transformer for High-Voltage Energy Storage Applications

INTRODUCTION

Providing isolated low-voltage bias power to ICs such as microcontrollers, analog-to-digital converters, isolated gate drivers, or voltage-monitoring ICs in high-voltage systems is usually accomplished with an isolated DC/DC converter. If the high-voltage system is spread out over several modules, the architecture may call for a parallel DC bus on the low-voltage side with multiple isolated low-power DC/DC converters for each module. Because it is used multiple times in this scenario, an efficient and cost-effective topology is the best approach.

This application note highlights the design benefits of using push-pull transformers that are proven solutions for these situations. Used as an example is the Bourns Model HCTSM8 series transformer, which is AEC-Q200–compliant and available with a wide range of turns ratios as standard. Multiple turns ratios are an important feature enabling the same basic circuit topology to be replicated across a system with the same components and PCB layout. With a transformer series like the Model HCTSM8, designers can select the right reinforced transformer part number based on the specified output voltage for powering a microcontroller or an isolated IGBT gate driver. »»»

Why Push-Pull Transformers Are an Optimal Choice: Electrical Advantages

Push-pull transformers are known to operate well with low voltages and low variations in input and output. This characteristic is ideal for a microcontroller bias or gate driver IC that has constant power levels and input voltages. Unlike typical flyback and forward topologies, the push-pull topology offers high efficiency at a stable input and output current. Any variations in input and output current tend to waste energy, as the power dissipated in the switches remains constant.

In addition, flyback transformers can cause EMI problems and often require closed-loop control for stable operation even though they can efficiently handle wide input ranges. Conversely, a push-pull transformer can operate very simply in open loop. Compared with the number of components required for closed-loop control, open-loop control requires only a combination of a driver with a fixed duty cycle along with two MOSFETs, a transformer whose turns ratio is selected to suit the desired output, two Schottky diodes, and two ceramic capacitors. In fact, the driver can be a microcontroller that may already be in use. If a microcontroller is used as the driver, then additional NPN transistors and resistors are necessary to provide the gate drive of the push-pull MOSFETs.

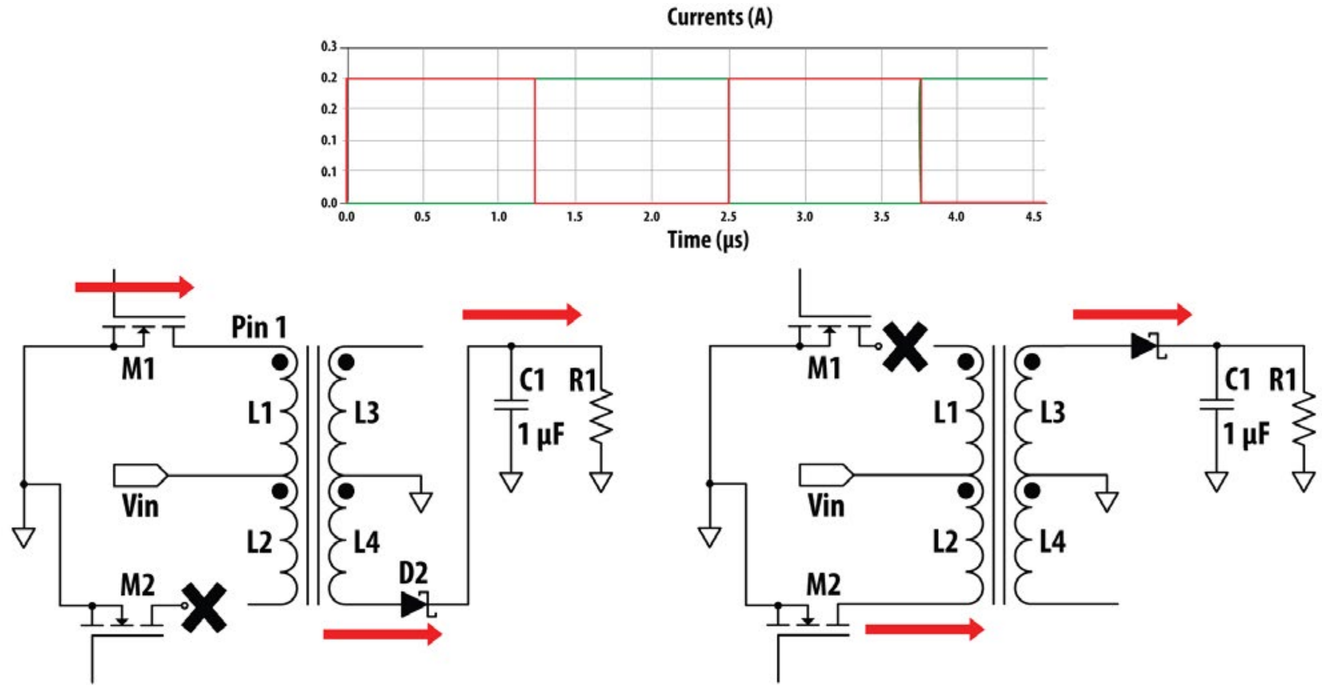


Figure 1: Illustration of the operation of a push-pull converter with the red and green lines indicating output current

There are other reasons that justify the choice of a push-pull transformer. The shape of the output current is regular and not pulsating, which tends to stress the diodes and capacitors. For a relatively low-current solution, diodes offer a cost-effective addition that can help ensure compensation and balancing of the transformer. If the magnetizing current is imbalanced, the additional current in the winding will cause the drain-to-source resistance of the driver MOSFET to increase. This increases the voltage drop across the MOSFET and reduces the voltage across the winding, thereby equalizing the imbalance.

Why Push-Pull Transformers Are an Optimal Choice: Mechanical Benefits

Space Saving

Specifying a push-pull transformer for low-voltage applications offers several space-saving benefits. They typically are offered in a smaller footprint than flyback transformers. And because push-pull transformers are designed as "pure" transformers, they usually have physically smaller ferrite cores compared with flyback transformers. Plus, there is no gap required in the ferrite core of a push-pull transformer, and therefore, the effective permeability remains high and the magnetizing inductance can be quite high for a low number of turns.

Given a sufficiently high switching frequency and low DC voltages, the flux generated (volt-seconds per turn) remains well below the saturation point. Contrast this result with the split ferrite core in a flyback transformer in which more turns are needed to ensure that the current does not saturate the transformer. If there are tight space considerations and restrictions, the DC resistance will inevitably increase with the higher number of turns, resulting in reduced efficiency.

It is advised to look for a push-pull transformer with a toroidal core. What makes them a good choice is that there is no need for a gap, and a toroidal core is well-known for providing good coupling between windings. This is because the flux has a short distance to travel and there is little dispersion between windings. The relatively high inductance factor of a push-pull transformer with a toroidal core means it is possible to achieve high magnetizing inductances without a high number of turns. Plus, a coil former is not required, as the wires are wound directly on the ferrite, which feature a high dielectric protective coating. Coil formers add extra space, as does the fact that the ferrite split core is exposed on the top and bottom if the transformer is an SMD device.

A toroid core can be enclosed in a housing separating the core from the circuit board. This difference automatically minimizes the footprint on a PCB in high-voltage applications in which safety distances (creepage and clearance) are required as defined by the standards for insulation (IEC 60664) and communications equipment (IEC 62368) that mandate a specified distance between the high-voltage hazardous side of the PCB and the low-voltage side. If the core is exposed, the clearance will be significantly reduced, which will need to be compensated by additional width or height of the plastic carrier.

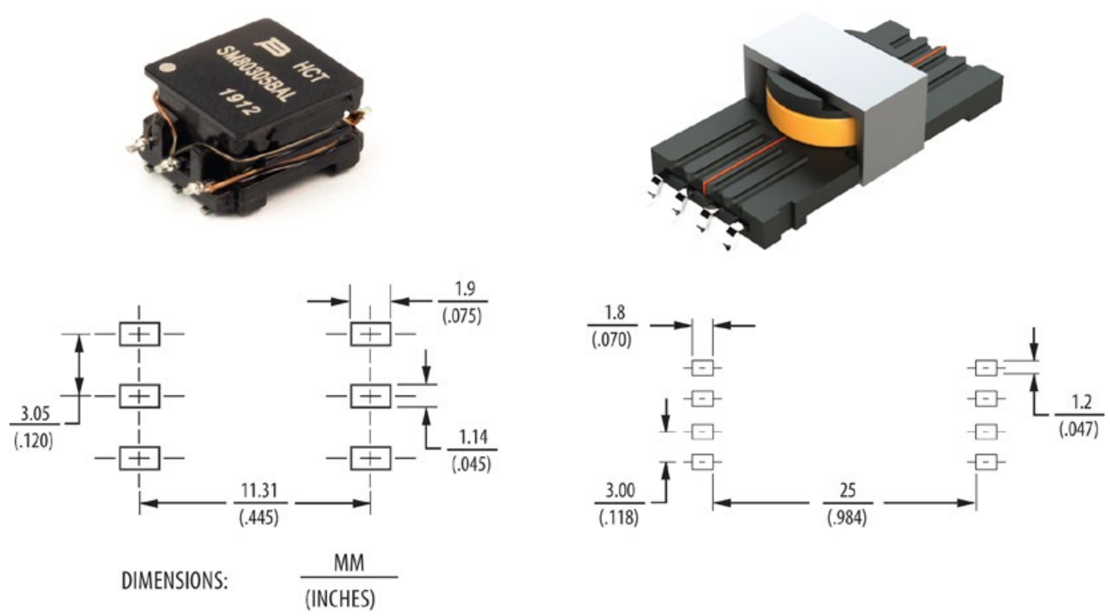


Figure 2: Comparison between Bourns Model HCTSM8 push-pull transformer and a typical split core transformer, both with 8 mm of creepage

Figure 2 shows a comparison in terms of dimensions between the Bourns Model HCTSM8 transformer and a transformer with a split core such as an E13. The figure illustrates that the E13 solution requires 90% more room on the PCB to meet the same isolation level of the Bourns HCT transformer. Furthermore, the leakage inductance of a transformer with an extended bobbin needs at least 200% more space on the PCB compared with a transformer with a tightly coupled toroid, even with the primary wrapped around the outside of the housing.

Better Insulation

The Bourns Model HCTSM8 has reinforced insulation, which, according to standards, must consist of either triple-insulated wire (three separate layers of insulation on the wire) on one winding or insulation on both windings (double insulation). Double insulation is not efficient from an electrical point of view. The time to strip the insulation from the start of the coil during the winding process will be twice that of a triple-insulated transformer. The effective space for conductors is reduced in a double-insulated system, as both coils have at least 0.08 mm of insulation, compared with 0.02 mm for pure magnet wire with enamel. The time required to wind a toroid with insulated wire is higher compared with enamel-coated wire. Therefore, double insulation is less efficient and more expensive. However, to some customers, double insulation has the advantage of offering real redundant insulation compared with triple-insulated wire.

Using the HCTSM8 series transformer example, the secondary winding consists of FIW, which is considered as strong as triple-insulated wire but without safety agency recognition (for many types). This is particularly relevant in a transformer with a toroidal core. The concern is the effect of triple-insulated wire, which could degrade and cause a short to the core and also from the core to the non-insulated wire. This risk can be mitigated using FIW wire on the secondary side.

Figure 3: The construction of the Bourns Model HCTSM8 transformer with a toroidal core showing the lid and primary wire wrapped around the housing to extend the distance from the pins to the core

Maximum Creepage/Clearance

The Bourns HCTSM8 push-pull transformer makes full use of the enclosure around the ferrite core to maximize creepage and minimize the footprint. The core is not visible from the pins of the design, so the clearance pin to core will be measured up the wall of the device and down the joint between the lid and the side wall. The effective tracking distance over the insulated wire from pin to core is maximized by running the insulated wire around the outside of the component. By using this breakthrough design that features a press fit of the lid against side wall and the wraparound insulated wire, the Model HCTSM8 series can obtain a creepage and clearance of 8.0 mm despite having a nominal height of just 6.5 mm and a distance from pad to pad on the PCB of 11 mm max.

In addition, the Model HCTSM8 uses plastic material classified as Class I, which means it is the least conductive of all plastics to high voltages. It features triple-insulated wire on one winding (primary). Consequently, by taking 8.0 mm as creepage and clearance distance and consulting Table F.4 of IEC 60664, this transformer offers a working voltage of 800 Vrms. As a result, inverters and battery packs with RMS voltages of up to 800 Vrms requiring reinforced insulation could use the HCTSM8 for the following two energy storage applications:

1. Isolated DC voltages for a gate driver for an IGBT or SiC MOSFET
2. Isolated DC power for a microcontroller or voltage-monitoring IC or transceiver

Typical Application Usage

To generate plus and minus voltages for a gate driver, a circuit configuration similar to that shown in Figure 4 represents why Bourns Model HCTSM8 is a valid solution. In this example, the device is driven by an integrated Texas Instruments SN6501 push-pull driver. The Texas Instruments device operates at a high frequency (400 kHz) and has a fixed duty cycle (50%). The output relationship in a push-pull driver with input VIN and output VOUT and duty cycle D is as follows:

$$VOUT = 2 \times D \times n \times VIN$$

Where n is the turns ratio from secondary to primary.

Model HCTSM8 has 11 different standard turns ratios. Because the Texas Instruments SN6501 device uses internal MOSFETs whose maximum voltage rating is 5 V, VIN cannot exceed this level. And in order to generate 12 V, which is required to switch on an IGBT, it requires a turns ratio of 2.5.

It is not possible to push D beyond 50% in a push-pull transformer, as the time to magnetize and demagnetize the core must be balanced or saturation will occur. The negative voltage can also be generated from the same transformer by attaching a shunt reference between the ground rail and a negative output. Given that the Model HCTSM8 series is a catalog product with AEC-Q200–compliant quality levels, it provides an efficient and cost-effective isolated power source compared with a customized transformer. A customized solution typically requires multiple outputs involving soft tooling and hard tooling, as well as the additional costs to develop.

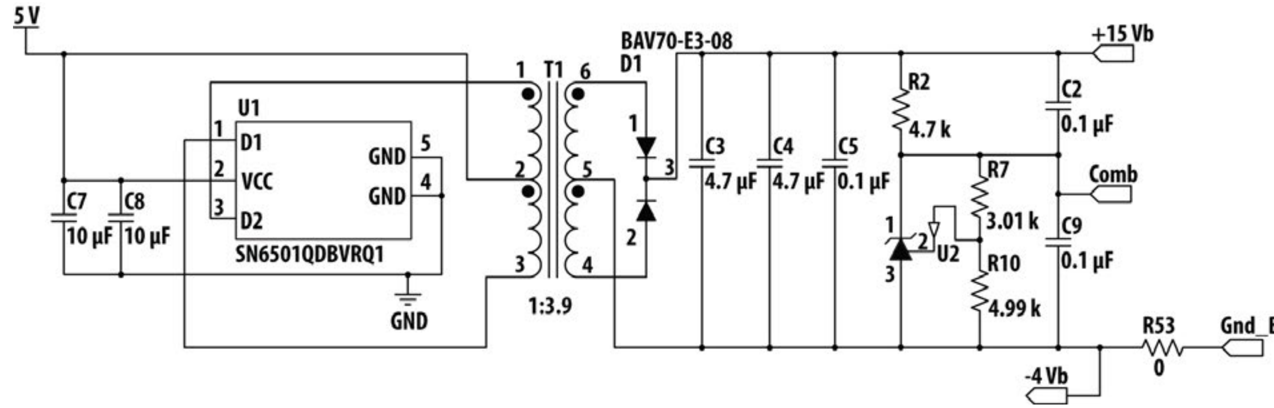


Figure 4: Typical circuit-generating diagram showing plus and minus voltages when using the Model HCTSM8 transformer

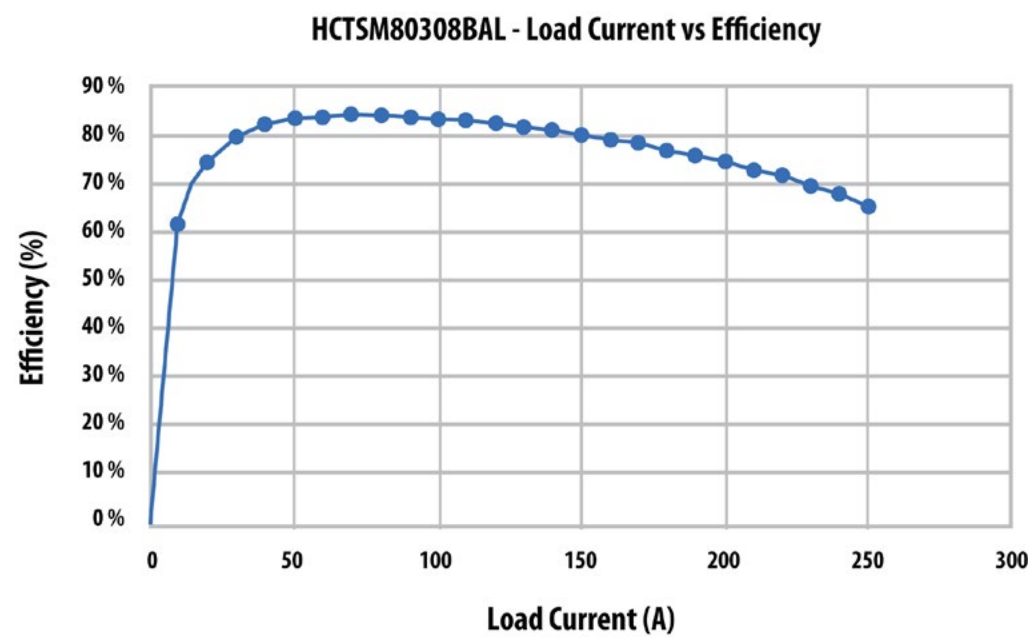


Figure 5: Graph demonstrating the efficiency of the Bourns Model HCTSM8 transformer with 3:8 turns with the Texas Instruments Model SN6501 driver

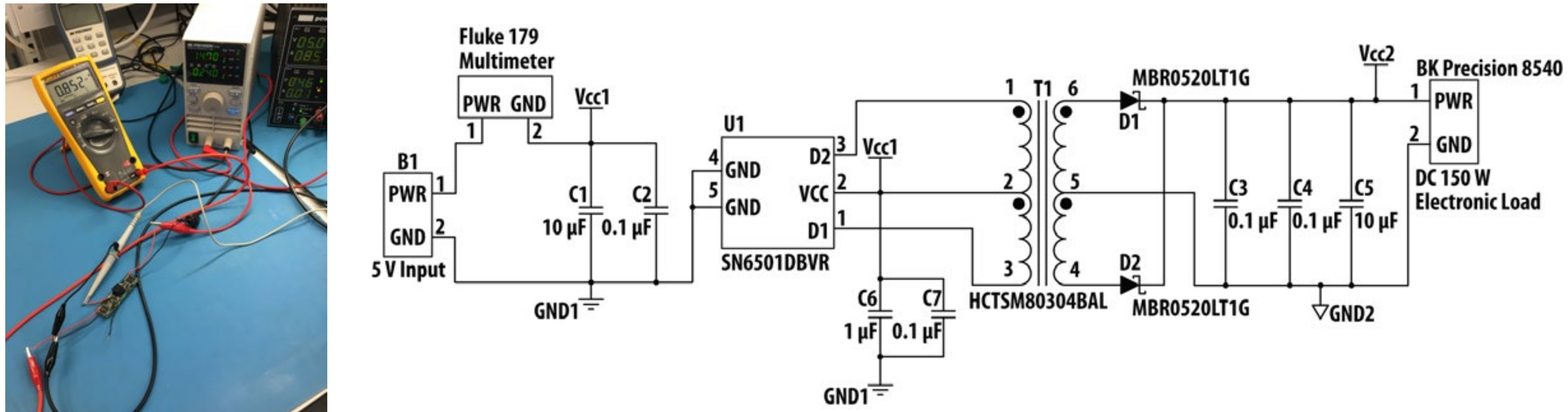


Figure 6: Model HCTSM8 series has been fully validated.

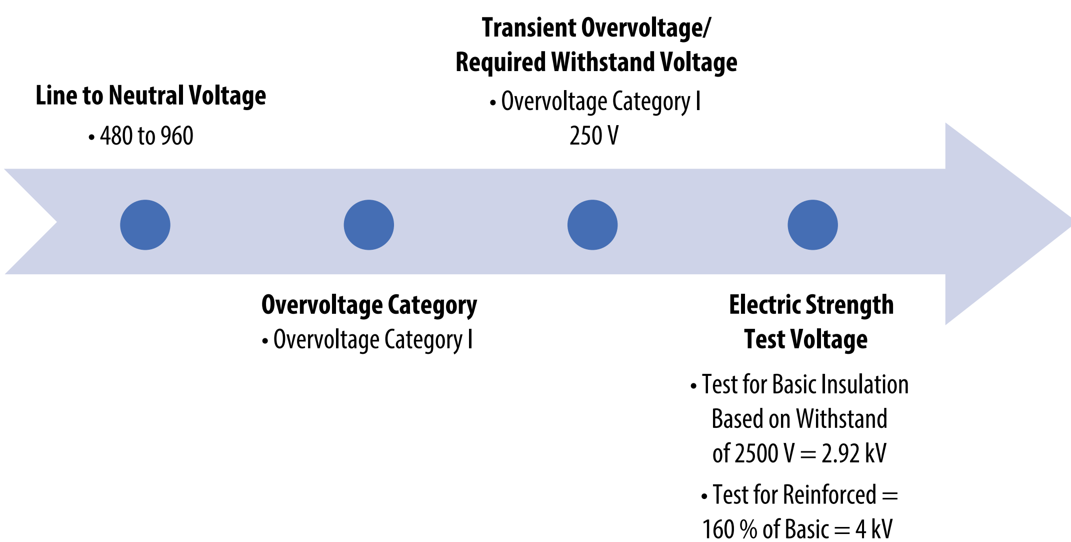


Figure 7: Decision flowchart specifying Model HCTSM8 isolation test voltage

Figure 5 shows the efficiency of a circuit when using Model HCTSM80308BAL, which is an ideal solution to provide the 15 V needed for an isolated gate driver IC. The optimum operating point for this application is between 100-mA and 150-mA output current.

Figure 6 shows the test circuit used to validate the HCTSM8 series and highlights the test board and equipment used for calculating overall power efficiency.

BMS Transformer Safety Testing

The question of ensuring that the transformer's insulation will remain intact from the tape in which it is delivered to the board and during the lifetime of the application is answered by complying with accepted industry standards.

Bourns designed and tested its Model HCTSM8 series to survive identified solder-reflow conditions and can be reflow-soldered three times without degradation of the insulating wire. The insulation strength was tested using a Hi-POT tester applying 4 kVrms for up to 60 seconds. Shown in Figure 7 is the criteria that Bourns used when it defined the electrical isolation specification.

Determining the overvoltage category depends on where the power supply is located. If there is no risk of a transient from the mains hitting the power supply, such as where the voltage source is located relative to the battery, then the application may be categorized as Category I.

If there is an isolated connection to the mains supply, it is permitted to move from Category II to Category I. The Hi-POT test is used to check the solid insulation in the transformer, but it can also be used to verify that the clearances comply with the standard.

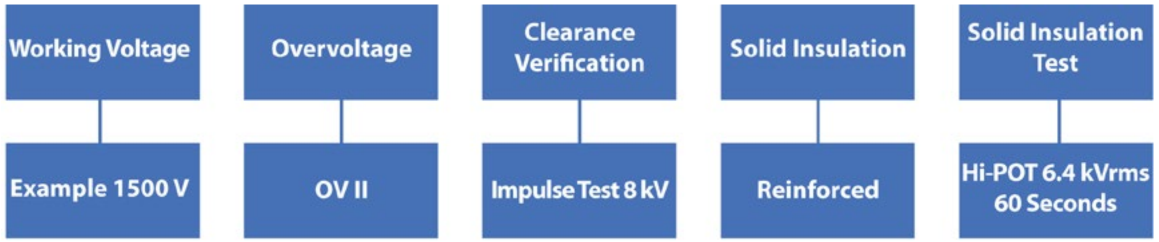


Figure 8: Electrical insulation test voltages for a 1,500-V battery

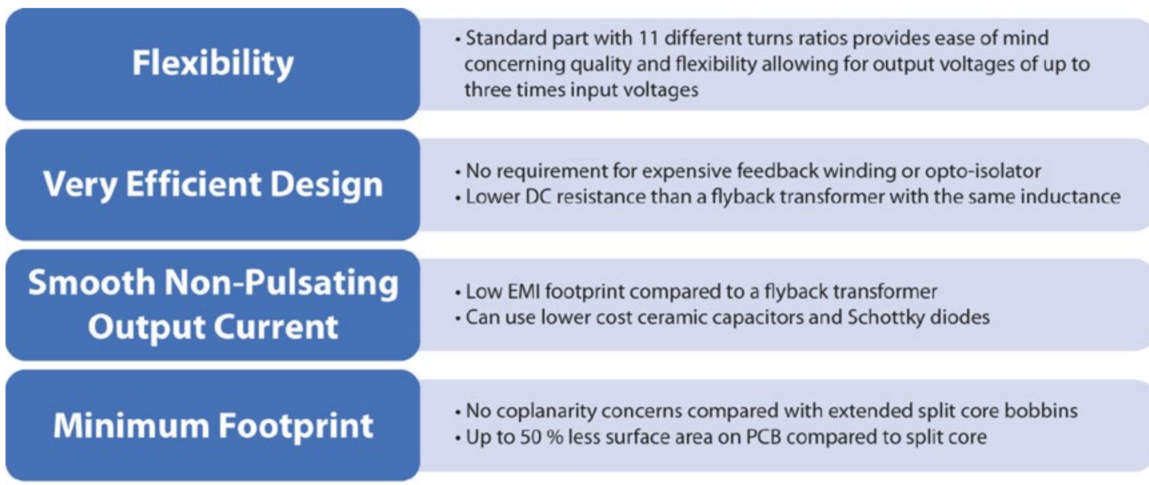


Figure 9: The benefits of selecting a standard catalog transformer like the Model HCTSM8 series

Any signs of arcing or corona discharges will be a clear failure. The Model HCTSM8 is designed for 800 Vrms at a 2,000-meter altitude. For higher altitudes, the working voltage must be derated, as the breakdown voltage or corona of air decreases as the air becomes thinner.

Future Trends

Working voltages of 1,000 V and 1,500 V for transportation applications, as well as energy storage in industrial installations, require isolation testing with various levels of test voltages, according to the relevant standards as shown in Figure 8. The IEC 60664 standard also refers to using partial discharge testing to ensure there are no defects in the insulation such as tiny pinholes, which would expand over time under a strong electric field. In fact, complying with IEC 60664 requires that designs pass the standard of partial discharge if the electric field between primary and secondary exceeds 1,000 V/mm and if the working voltage exceeds 750 V.

Design Advantages

This application note illustrates the advantages that designers can leverage by using the Bourns HCTSM8 series transformers for module hardware energy storage applications. The flexibility, efficiencies, low EMI, and space-saving benefits present a compelling solution for these designs.

The Bourns HCT series has been tested and approved by Texas Instruments in their Model SN6501 and SN6505 series of push-pull drivers. As the range of applications for high-voltage–driven equipment in transportation and other markets increases, so, too, will the demand for stable, high-quality, and standardized isolated power designs in applications such as modules in high-voltage battery or ultra-capacitor packs. Bourns offers 11 different fully tested and AEC-Q200–compliant Model HCTSM8 series push-pull transformer part numbers for the Texas Instrument drivers. Based on Bourns's advanced power transformer design, the HCTSM8 series delivers the right combination of isolated power with low voltages for energy storage gate drivers, microcontrollers, battery management ICs, and many more applications. ■

Achieving **Higher Efficiency** Using Planar Flyback Transformers for **High-Voltage** AC/DC Converters

INTRODUCTION

The emphasis on improving industrial power supply efficiencies is both environmentally and economically motivated. Even incremental improvements in efficiency can result in electrical usage savings that contribute to cost reductions and the ability to minimize heat and thus wasted energy in the application.

Adding to the challenge of making power supplies more efficient is the fact that today's designs are becoming more integrated, packing an increasing amount of functionality into smaller and smaller form factors. These complex, higher-density applications create a much larger power envelope that is more difficult to manage effectively. »»»

AC/DC power supplies of less than 100 W typically use flyback topologies to convert electrical power efficiently, as they are the simplest and lowest-cost of all isolated topologies. Planar magnetics are commonly the high-frequency application converter of choice for designs because they offer a low number of turns in helical windings and very low resistance. Using a planar transformer in a high-voltage application provides several advantages, including a reduced or lower mechanical profile. However, there are technical challenges to overcome with this approach that include considerations for high inductance values and the level of isolation needed for safety reasons.

This section describes a planar flyback transformer designed by Bourns to meet the efficient conversion needed in high-voltage applications. This customized planar transformer was tested on an AC/DC adaptor with an output of 5 V and delivered a peak efficiency of 91.05% in this test.

Planar Magnetic Advantages

Planar transformers have some distinct advantages over wound transformers. The cores have wider surface areas than traditional E, EC, or EP cores, which allows for smaller numbers of turns in the windings. The wider core areas also enable lower DC resistance of the copper.

The rigid structure of the planar transformer's PCB (standard thickness of 1.3 mm) eliminates the need for a plastic carrier or bobbin. Therefore, it can be made thinner and lower in profile than wound transformers. Another benefit is the repeatability allowed in PCB manufacturing that ensures higher tolerances in transformer specifications, such as inductance, resistance, and turns ratios.

There are disadvantages to planar transformers as well. Typical PCB substrates like FR4 are not considered as meeting safety requirements for insulation in high-voltage applications. Differential surges can also jump across from vias to cores, causing damage. Also, implementing multiple layers can be problematic in the design phase as well as expensive, especially if thick copper plating is required.

Planar Transformer Design Considerations

Winding Structure

Bourns designed its custom planar flyback transformer for applications such as a USB power delivery system, which can deliver up to 100 W (20 V, 5 A) with the understanding that a continuous conduction mode is recommended for power greater than 10 W. This is to avoid peak currents that can cause high switching losses and overheating of the core. Using the Bourns planar transformer solution, the main contributing factor to losses will be from the copper and not the core. An optimum primary inductance value of 530

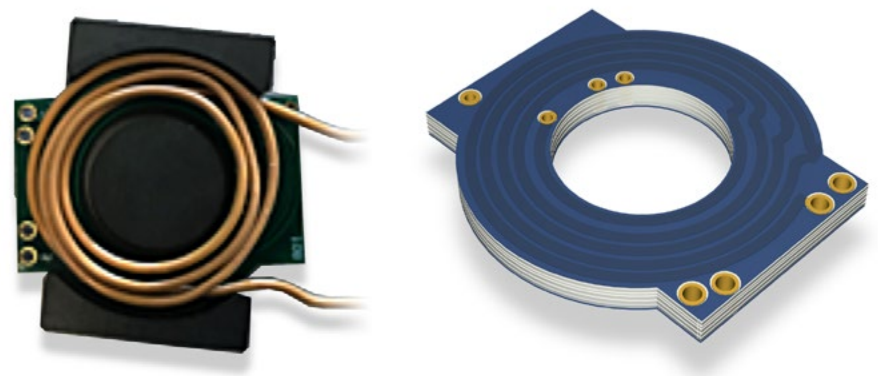


Figure 1: Secondary winding and isometric view of planar primary PCB

μH was selected to keep peak currents to under 2.3 A, so as not to overstress the external 650-V MOSFET. The number of turns of 30, on the primary side, was calculated based on the saturation current, inductance value, and area of the core (EC26).

The design uses 12-layer winding incorporating a primary and secondary winding produced using 2-oz. copper and FR4 material and two identical substrates (shown in Figure 1). The planar transformer PCBs form a split primary winding enclosing the secondary made from triple-insulated wire.

The triple-insulated wire on the secondary side provides the reinforced insulation between the primary and secondary windings. As the design uses just four turns, it fits in a spiral shape around the core and between the two PCBs, as shown in Figure 1.

Core Losses

The flux density is highest at the edge of the core, as shown in Figure 2. The flux must travel through the side wall of the core to complete its path. Therefore, the flux density will increase at the side. However, the flux density in the center leg is well below saturation.

Leakage Inductance

The leakage inductance is a source of energy waste in a flyback converter and needs to be kept to a minimum to increase overall efficiency. The inductance value of this leakage depends on the magnetic field between the primary and secondary winding. According to Ampere's Law, the ampere turns across the interwinding region is the same as the ampere turns in either winding. In the Bourns planar transformer, the winding width was kept at a maximum to reduce the field strength (H) in this region.

$$H = \frac{IN}{Wb}$$

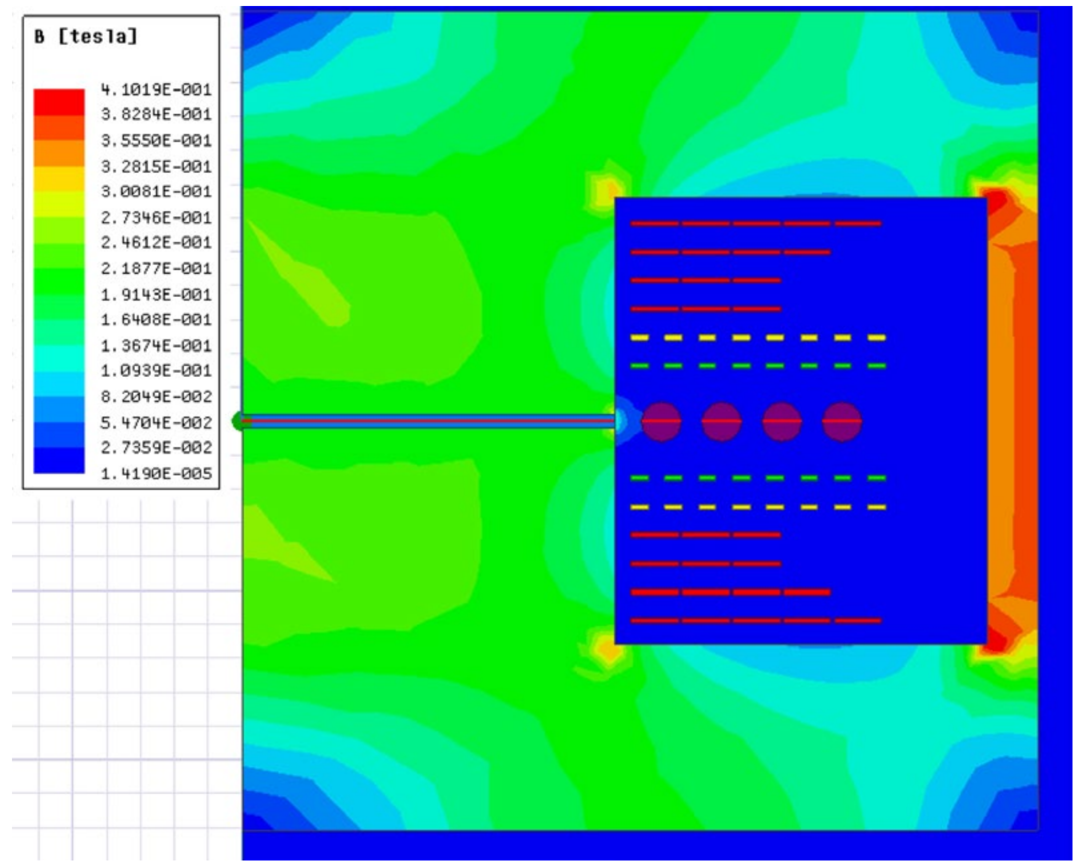


Figure 2: Flux density in transformer using 2D FEA

The permeability of the interwinding region is that of air (4π × 10–7), and so the flux density in this region is as follows:

$$B = \mu H$$

The energy density in this interwinding region is, therefore:

$$\frac{Energy}{Volume} = \frac{BH}{2}$$

Energy is calculated at energy density multiplied by the interwinding volume, but it can also be shown as:

$$Energy = \frac{1}{2} LI^2$$

Therefore, the inductance value of this region is estimated by:

$$L = 2\frac{Energy}{I^2}$$

In the Bourns transformer design, the volume of the interwinding region was kept as small as possible to reduce leakage. Increasing the winding breadth (Wb) also reduces leakage inductance.

The effective winding breadth can be increased by interleaving the layers, if possible, which is what has been done in this transformer. For this particular design, there are four turns on the secondary, implemented using insulated wire on a single layer. This eliminates the need for creepage and clearance distances between the primary and secondary windings. The secondary was interleaved with the primary, which effectively doubles the winding breadth of the primary and, therefore, cuts the leakage inductance value in half.

The interwinding volume could be better-controlled if the secondary was also implemented in the PCB material, though using insulated wire on the secondary removes the need for creepage and clearance distances between the primary and secondary windings. This is particularly important in high-voltage applications. Furthermore, interwinding capacitance is adversely affected as their distances decrease. This is a serious concern for high-voltage applications, as it worsens the coupling of AC power line noise through to the power supply output.

The leakage inductance on the Bourns planar flyback transformer was recorded by shorting the secondary wire and measuring the primary inductance. The leakage was recorded as 14 μH at 130 kHz in this test.

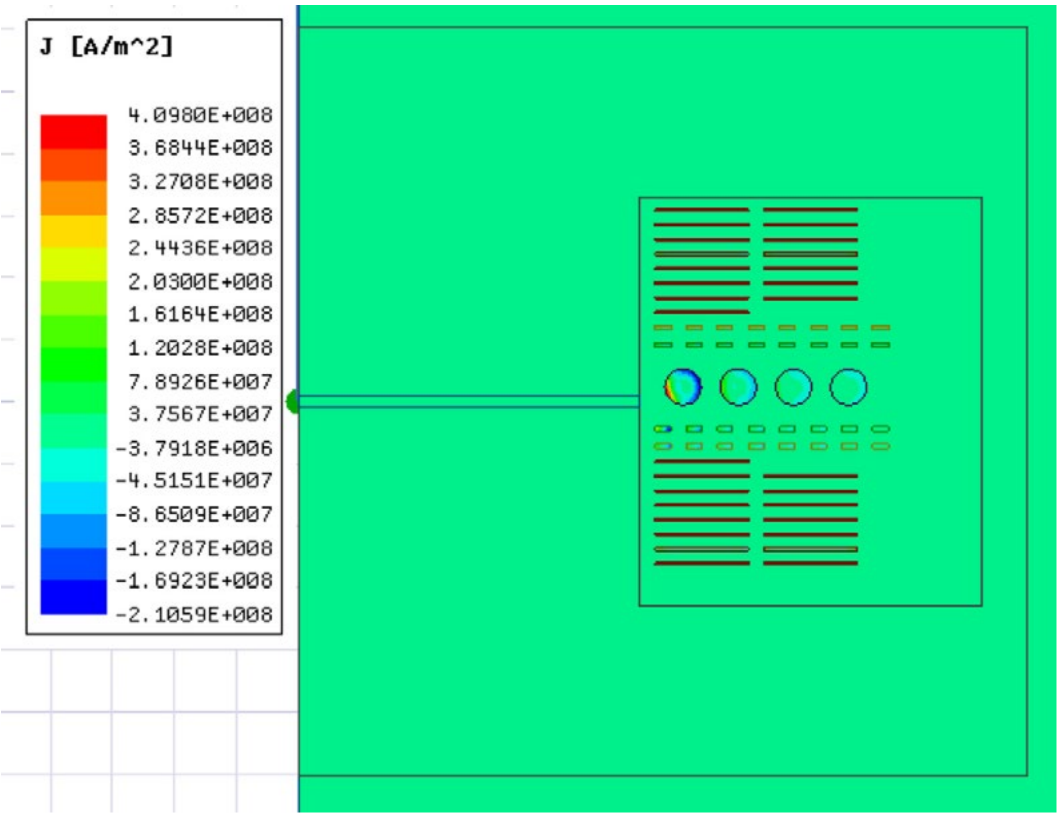


Figure 3: Current density in transformer using finite element analysis

AC Losses

In a flyback transformer, there is no benefit to the AC resistance in interleaving the primary and secondary windings, as these windings are out of phase. If they were in phase, the magnetic field strength would dip to zero at every boundary, which would keep AC resistance low in an interleaved structure. The AC resistance on the primary side can be controlled by keeping the copper at less than the skin depth at the switching frequency. In this case, the skin depth is 0.2 mm, while the thickness of copper is 0.07 mm.

At maximum load, the secondary AC current is 7.3 A due to the pulsating nature of current on the secondary side. This would lead to copper losses of 1.5 W on the secondary side due to the thickness of the wire (0.8-mm diameter).

Finite element analysis (FEA) shows that the conductor closest to the gap experienced a hot spot due to the high circulating AC currents and eddy currents induced by fringing effects, as shown in Figure 3.

Bourns found that to reduce the copper losses at high frequencies, the insulated secondary wire would have to be replaced with a helical winding. As FR4 is not considered safe in this application, a barrier such as mylar or polyimide tape must be bonded to the PCB substrate.

Satisfying International Safety Standards

Bourns followed the IEC 61558 international safety standard for its design. IEC 61558 specifies the creepage and clearance between primary and secondary windings according to:

- Working voltage
- Level of insulation (functional, basic, reinforced)
- Degree of pollution
- Material group

The design complies with IEC 61558 through the following features:

- The secondary winding is made of UL-listed triple-insulated wire. According to the standard, there is no requirement for extra clearance or creepage between the primary, secondary, and auxiliary.
- The secondary winding is a flying lead. The required creepage and clearance between the conductive pin of the secondary and the conductive core with a working voltage of 300 V is 5.5 mm. The insulated secondary wire is kept at least 5.5 mm from the core.

IEC 61558 also specifies the dielectric isolation (also known as Hi-POT) between the primary and secondary windings, which was also followed.

AC/DC Adaptor Application Example

The Bourns planar flyback transformer was tested on an AC/DC adaptor shown in Figure 4. The design is based on a discontinuous conduction mode (DCM) flyback converter topology with valley switching and synchronous rectification. Both the valley switching and synchronous rectification reduce power losses in the external MOSFET and rectifier, respectively. Operating in DCM mode meant that there would be zero ampere turns in the transformer for a period every switching cycle.

The operating mode of the transformer is shown by the voltage across the drain of the MOSFET. Figure 6 shows the drain voltage and secondary pulse-width–modulation waveform of the Bourns AC/DC adaptor. The voltage across the drain consists of the bulk voltage across the primary plus the reflected output voltage from the secondary. However, once the secondary current reaches zero, there are no more ampere

Figure 4: View of an AC/DC adaptor with a planar transformer and other Bourns components

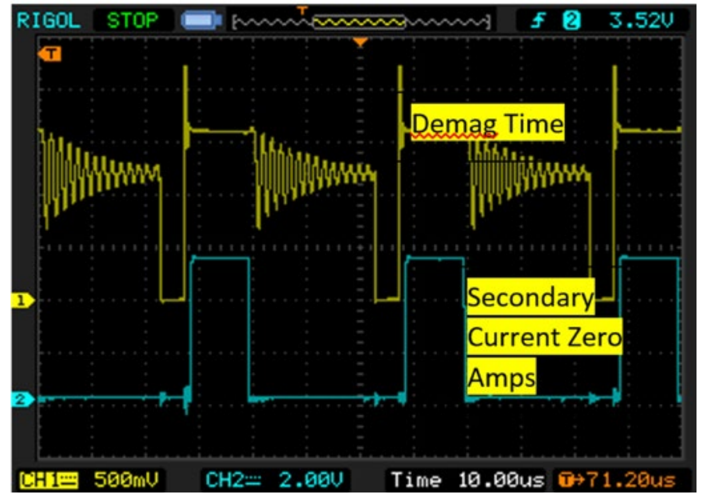


Figure 6: Drain voltage and secondary rectifier activation waveforms

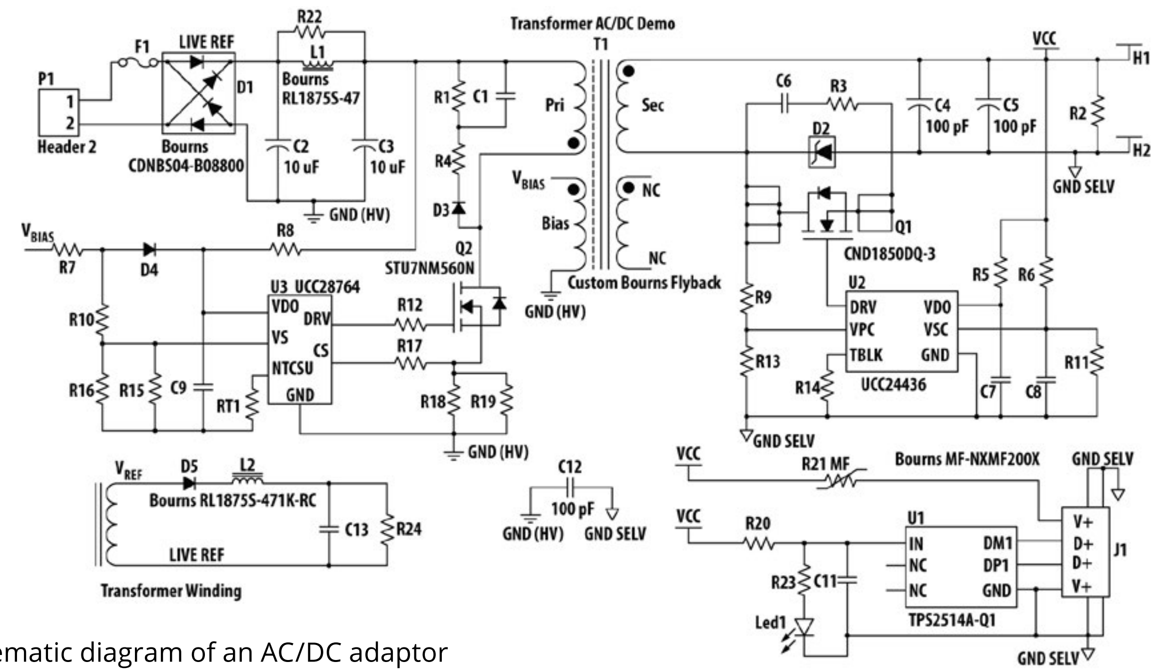


Figure 5: Schematic diagram of an AC/DC adaptor

turns in the windings, meaning the mutual inductance collapses. This leads to a period of oscillation around the bulk input voltage. The controller IC senses this from the auxiliary voltage and switches off the synchronous rectifier (blue line in Figure 6) to save energy. If the load is increased, this period of resonance is reduced until it disappears, and the converter passes into continuous conduction mode.

Increasing Power Supply Efficiency

In this example, the power supply operated at 115-VAC input with a 5-V output. Bourns measured the efficiency at different output powers, as shown in Figure 7.

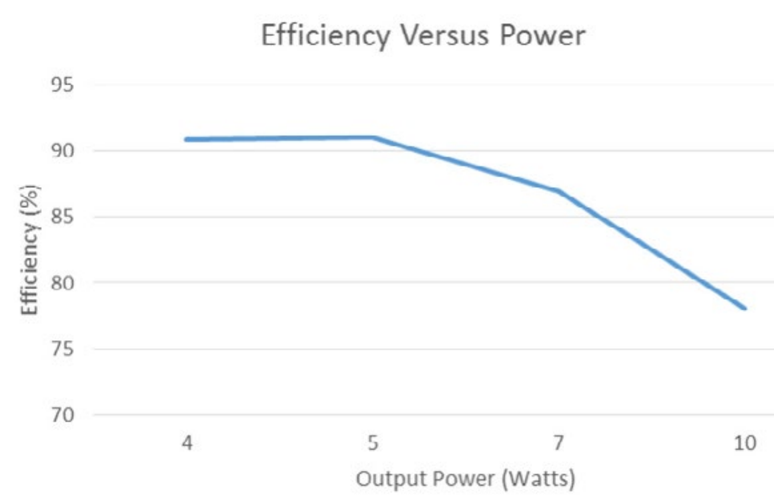


Figure 7: Efficiency versus power curve of an AC/DC adaptor

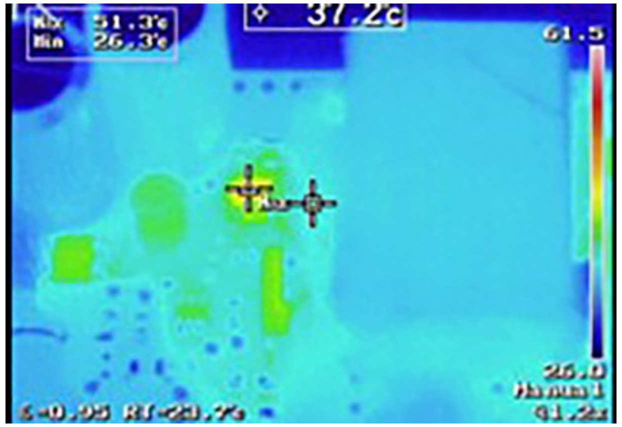


Figure 8: Thermal image of an AC/DC adaptor during testing

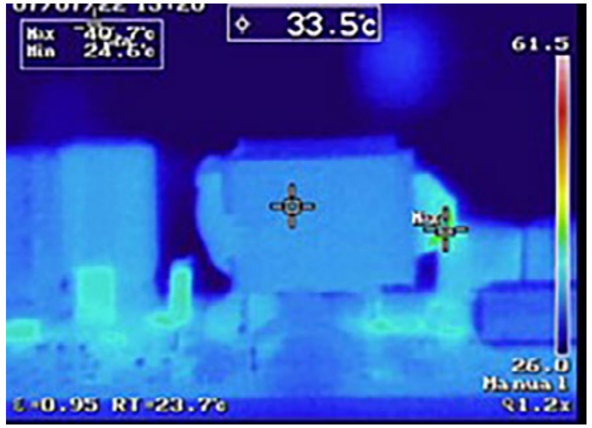


Figure 9: Thermal image highlighting the heat from the snubber diode

The thermal image shown in Figure 8 captures where the inefficiencies lie at 10 W, where the external MOSFET, inductor, and the secondary winding of the transformer are at their warmest state.

The biggest loss came from the snubber diode. The image in Figure 9 shows it is the hottest component, reaching 51.3˚C. Optimization of the snubber resistor value and reduction of the leakage inductance in the transformer will help to improve power loss in this area.

Conclusion

Using the Bourns planar flyback transformer design in this e-book has illustrated that planar magnetics can be optimal conversion solutions for high-frequency, high-current applications, including high-voltage applications such as AC/DC adaptors. The planar transformer example provided the advantages of a compact, low-profile design combined with PCB construction for high-quality manufacturing.

Bourns developed this planar transformer with reinforced insulation, which was created by splitting the primary into two PCBs and sandwiching a four-turn secondary using triple-insulated wire, providing a necessary barrier between the primary and the secondary. Because the leakage inductance of a transformer is a source of wasted energy in a power supply, Bourns split the primary, resulting in a leakage reduction of 50%. Using this structure and testing it on an AC/DC flyback in DCM mode with 5-V output provided a peak efficiency of 91.05% in the test conducted by Bourns.

The AC currents circulating in the secondary coil generate losses that could be mitigated if planar coils embedded in PCBs were used. By controlling the distances between the primary and secondary PCB, reductions in leakage inductance can also be achieved. Further transformer design improvements can be realized by focusing on reducing leakage inductance.

Bourns has extensive experience in supporting customers with custom transformer design for any topology in switch-mode power supplies. The company's extensive use of 2D FEA allows them to achieve optimal magnetic and thermal performance in the design phase. Bourns's state-of-the-art laboratory enables its team to quickly assemble prototypes and test (Hi-POT, climatic, EMI, impedance) according to customer specifications. Layout and test application board capabilities are also available to support customers, and Bourns's manufacturing facilities are TS16949-certified. ■

Figure 10: Test bench showing input and output power (91.05% efficiency)

Selecting **BMS Transformers** for Isolated Communications in **High-Voltage Energy Storage**

INTRODUCTION

Battery management systems (BMS) connect to high-energy battery packs and manage the charging and discharging of the pack. They also monitor essential safety factors including temperature, state of charge, and the pack's state of health. Providing additional application protection, the BMS can connect the battery and disconnect it from the load or charging source as required.

This application note provides an overview of the key features of battery-monitoring integrated circuits (ICs) typically specified in BMS. It includes background information on battery cell chemistries as they relate to the requirements for communications in high-voltage BMS. An application example will be used to explain the technology benefits that Bourns transformers deliver to meet these specifications. »»»

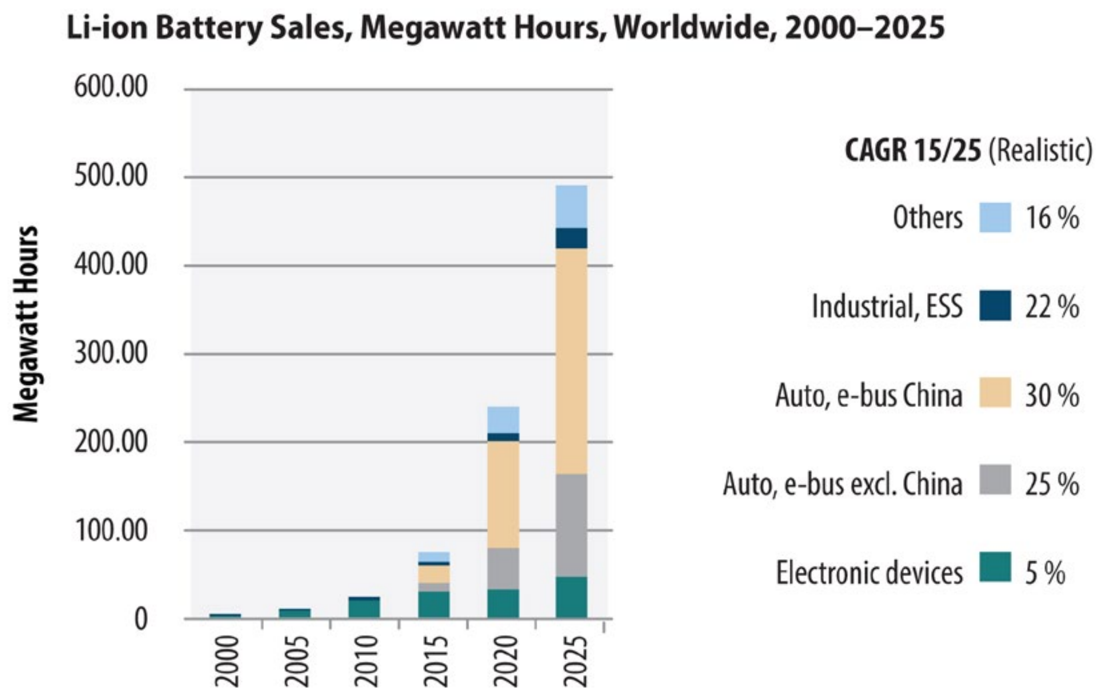


Figure 1

Table 1: Summary of Most Common Li-ion Chemistries for Battery Applications

Cathode	Anode	Energy Density	Cell Voltage	Charge Rate
NMC	Graphite	150 – 220 Wh/Kg	3.6 – 3.7	1 C Max.
LFP	Graphite	100 –120 Wh/Kg	3.2 – 3.3	1 C Max.
NMC	LTO	50 – 80 Wh/Kg	1.8 – 2.5	5 C Max.
LMO	LTO	100 – 150 Wh/Kg	2.4 – 2.6	3 C Max.

Table 1: Summary of most common Li-ion chemistries for battery applications

Overview of Lithium-Ion Battery Chemistries

Consulting and market research firm Avicennes1 has predicted that the usage of lithium-ion (Li-ion) battery cells for energy storage and automotive applications will continue to grow significantly through 2025, with compound annual growth rates up to 30% forecasted in China's transport sector. As Li-ion usage grows and expands into new applications, it is important to understand the nature and use of various battery chemistries.

Table 1 shows a summary of the most popular chemistries by energy density, cell voltage, and charge rate for 48-V and higher-voltage battery packs. These next-generation packs match the power density required to drive new electronics and motor designs. The latest battery cell developments in different chemistries deliver the increased power energy over longer periods of time necessary for full electric battery power.

There are several factors to consider when choosing the chemistry for a battery-powered application. As can be seen in Table 1, lithium nickel manganese cobalt (NMC) with graphite has the highest energy density among the commonly used chemistries. This is advantageous for heavy loads such as consumer energy storage or plug-in electric vehicles. The

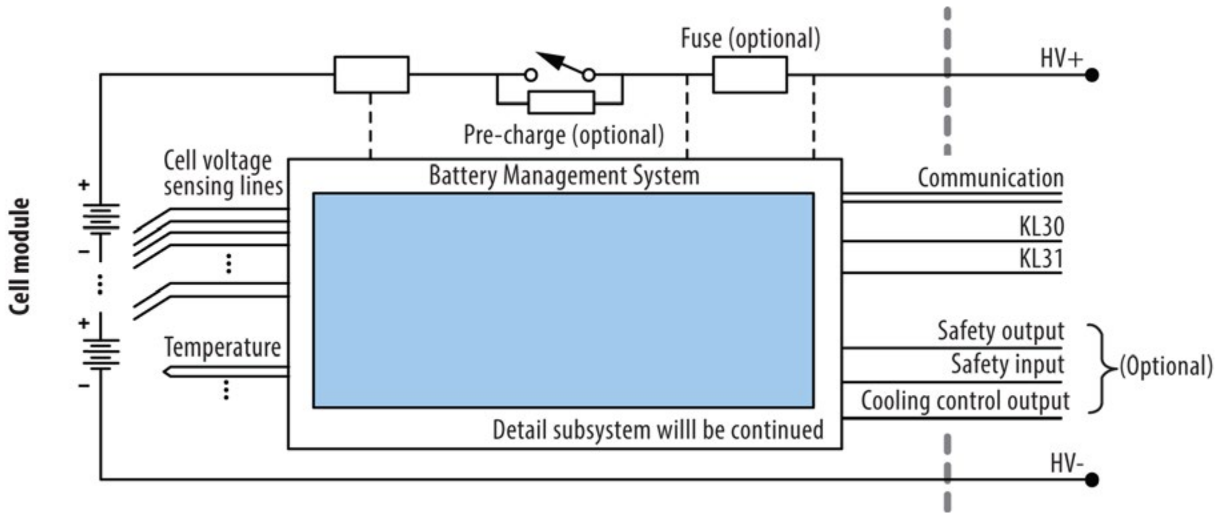


Figure 2: Block diagram showing the battery management system in relation to the battery pack

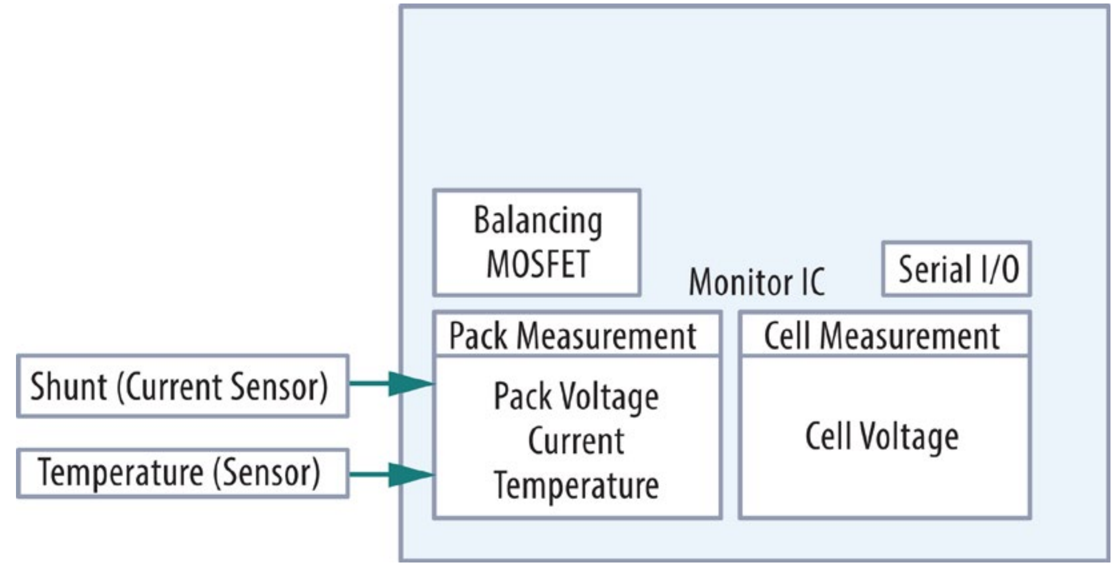


Figure 3: Block diagram of BMS IC

disadvantage, however, of this chemistry is that it creates a higher risk of lithium plating on the anodes, which can reduce battery life and lead to thermal runaway (fire or explosion). The potential for these harmful conditions can be exacerbated with today's faster-charging connectors.

Lithium titanate (LTO) has a lower energy density than NMC and does not suffer from the problem of cracking graphite, which together improve the estimated battery life. The lower internal resistance of LTO facilitates faster charging rates, making this battery chemistry beneficial for plug-in electric vehicles. The downside is the higher cost for heavier battery packs, as more cells are needed to provide the necessary energy in kilowatt hours (kWh).

Lithium chemistries have very narrow operating temperature ranges, typically from 20˚C to 40˚C. Operating outside these temperatures leads to a loss of capacity and a shorter lifespan. Elevated temperatures can also cause further degradation and a thermal runaway condition. A paper by NASA,2 which studied the protection within 18,650 cells, found that the interrupt devices in all the cells connected in series and parallel were not as effective as single cells in preventing thermal runaway during fault conditions. This study illustrates the strong need for a battery management system when multiple cells are interconnected.

Overview of Battery Management ICs and Transformers

A typical battery monitor IC (shown in Figure 3) measures cell voltage and pack temperature and

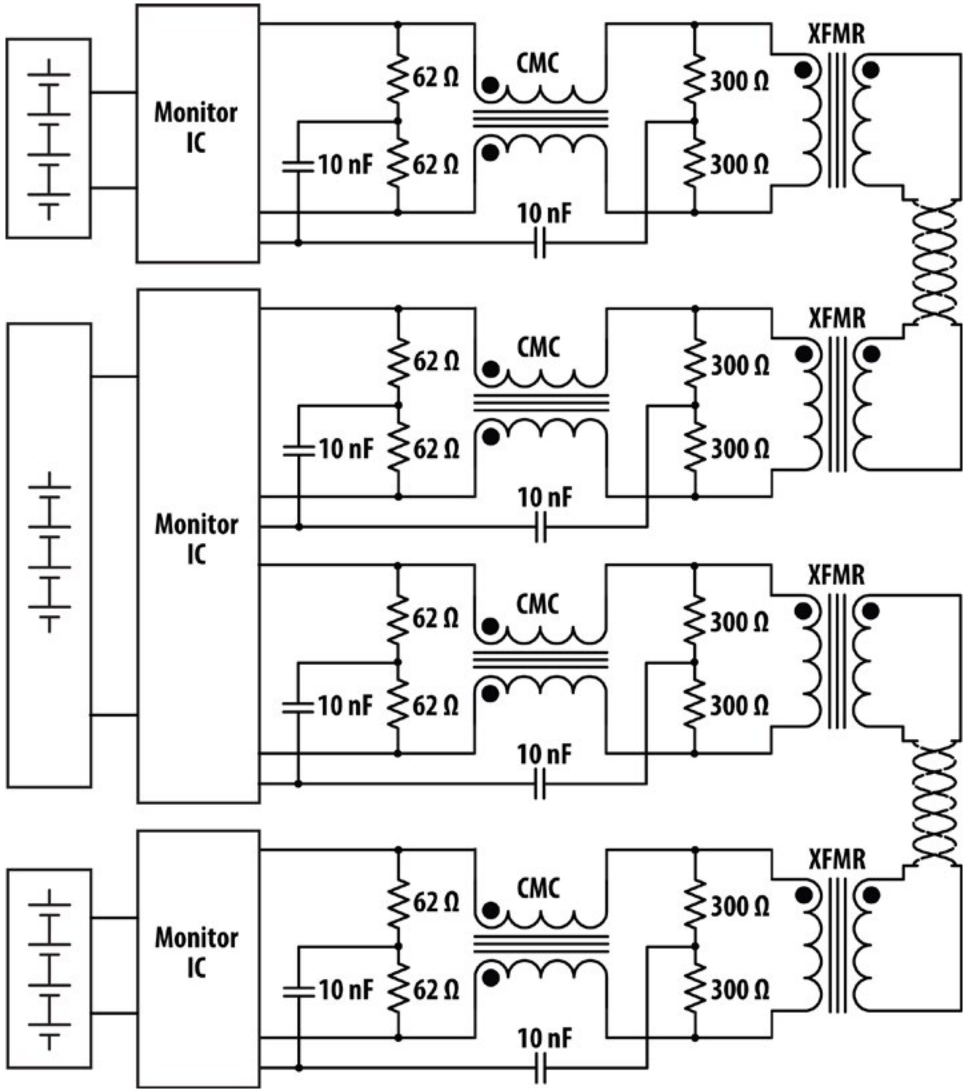


Figure 4: BMS transformer with center-tapped capacitor and resistor. Right: Image of SPI signal.

performs cell balancing. In some models, there is also a current-sense input port for shunt-based current measurement. Including this feature makes sense in 48-V systems that use a limited number of battery cells and do not experience hazardous voltage levels and, hence, monitoring ICs.

Conversely, it does not add a lot of value to integrate a current-sense function into an IC for high-voltage battery packs. These packs require only one current-sensing chip and several monitoring ICs to monitor the individual cells in the pack. For instance, the 2011 Nissan Leaf has a working voltage of 360 V and energy of 24 kWh (NMC technology).3 The structure of the pack is 96S2P (192 cells). A simpler way to put it: If each monitoring IC can check 10 cells, then at least 20 monitoring ICs will be needed. Another consideration in high-voltage battery packs is that the BMS IC module or board must be located on top of the shunt resistor, which may pose a mechanical design challenge.

BMS High-Voltage Communications

The BMS typically has two ports for isolated communications, allowing battery-monitoring modules to be daisy-chained throughout the battery pack. The source and sink currents of the serial port drivers are balanced, enabling the IC to drive a transformer without saturating it. The transformer, with a rated working voltage of several hundred volts, provides the necessary protection of the communications line from any hazardous voltage coming from the battery pack. Furthermore, the drivers on the IC encode a four-line serial peripheral protocol into the differential signal needed for isolated communication from board to board.

Serial peripheral interface (SPI) is an interface bus commonly used to send data whereby one device or “master” transmits a clock pulse and control bit to a series of slaves. On each clock pulse, the slave either reads a command from the master or, if the control bit is inverse, transmits its data on the data line. In this way, a central battery controller IC (master) can interrogate each monitoring IC (slave) in turn and retrieve necessary voltage and temperature information from the whole pack. In addition, the transformer and integrated common-mode choke filter out common-mode noise from the daisy-chained network.

Although BMS ICs have balanced currents on their I/O pins, most manufacturers recommend a center-tapped transformer. These have been found to improve common-mode noise rejection if a filter capacitor and termination resistor are used, as shown in Figure 4.

Bourns BMS Transformer Safety Features

The windings inside the Bourns Model SM91501AL transformer use enameled, fully insulated wire (FIW) that passes the dielectric strength (Hi-POT) test of 4.3 kV (1 mA, 60 seconds). Per Table 2N of IEC 60950,[4] the minimum creepage distance for Material Group I, Pollution Degree 2 of functional insulation for a working voltage of 1,600 V is 8 mm. The Bourns Model SM91501AL transformer datasheet shows a minimum 10-mm creepage distance. This is because the actual tracking distance over the surface of the transformer and chokes has been calculated at 10.4 mm in the samples measured.

The replacement test for IEC 60950 (IEC 62368-1),[5] which becomes mandatory in June 2019 for audio/video, information technology (IT), and communication equipment, will recognize FIW in the future.

The use of FIW may qualify the device as having reinforced insulation with a lower working voltage (depending on the standard) of approximately 800 V. This may allow the device to meet UL Listing requirements and may enable its use in additional applications, such as consumer energy storage, that mandate reinforced insulation.

Recommended Electrical Characteristics

The recommended primary inductance values by some IC manufacturers will depend on the voltage of the communication signals, pulse widths, and frequency. Bourns designed its Model SM91501AL transformer with a primary inductance span between 150 μH and 450 μH over an operating temperature range of –40˚C to 125˚C. The inductance is directly proportional to the permeability of the core. The permeability of the ferrite core of a transformer is temperature-dependent and tends to increase with temperature. Therefore, the primary inductance in the Bourns model will drift up toward 450 μH at the upper end of the temperature range. This is the reason for the large variation in the inductance value, as specified on the datasheet.

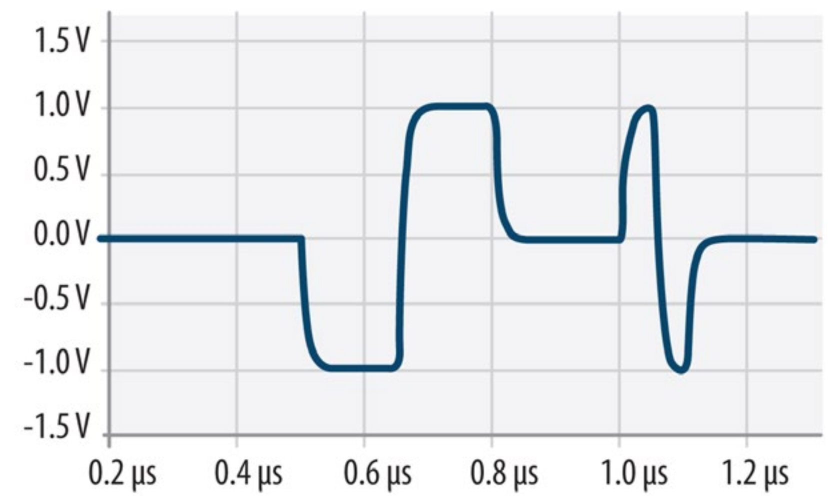


Figure 5: Bourns Model SM91501AL transformer on Bourns's BMS demonstration board

The noise immunity of the BMS IC and transformer can be evaluated using a bulk current injection (BCI) test. The BCI test injects current into the twisted-pair lines at set levels over a frequency range of 1 MHz to 400 MHz with the bit error rate being measured. A 40-mA BCI test level is sufficient for most industrial applications. The 200-mA test level is typically used for automotive testing. The Bourns Model SM91501AL and SM91502AL have been evaluated by certain BMS IC manufacturers for select automotive applications and have successfully passed requirements for BCI.

Summary and Conclusion

The demand for Li-ion battery power is predicted to grow at a CAGR of 20% to 30% over the next eight years.[1] Battery management systems that integrate isolated communications are expected to be an important part of the safety and security of the battery system. An effective and reliable BMS will help increase the lifespan of Li-ion cells while also enhancing safe operation for end users.

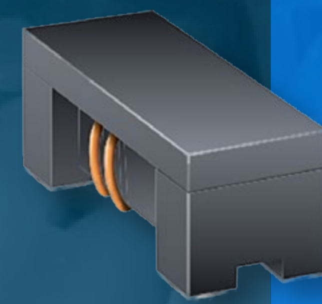
Offering an optimal protection solution for isolated communications in industrial and consumer BMS applications, Bourns engineered its latest Model SM91501AL and SM91502AL BMS transformers with the higher working voltages of 1,600 V and 1,000 V, respectively. They feature an inductance value of 150 μH and 450 μH over an operating temperature range of –40˚C to 125˚C, which meets higher-voltage BMS requirements. Additionally, the transformer windings use fully insulated wire passing the dielectric strength (Hi-POT) test, further increasing electrical insulation protection for overvoltage transients.

Bourns Model SM91501AL and SM91502AL have been tested by several BMS IC companies in their test laboratories who found them to function well with their chipsets, passing the necessary BCI tests. ■

References

1. Avicennes, Christophe, Pillot, Rechargeable Battery Market 2017–2025 The Battery Show, Hannover, May 15, 2018
2. NASA, Jeevarajan, Judith A., Safety Limitations Associated with Commercial 18650 Lithium-ion Cells presented at Lithium Mobile Power and Battery Safety 2010, Boston, MA
3. Hayes, J. G., & Goodarzi, G. A. (2018). Electric powertrain: Energy systems, power electronics and drives for hybrid, electric and fuel cell vehicles. Hoboken, NJ: John Wiley & Sons.
4. International Electrotechnical Commission, Information technology equipment – Safety – Part 1: General requirements IEC 60950-1 Edition 2, 2005
5. International Electrotechnical Commission, Audio/Video, Information and Communication Technology Equipment- Part 1: Safety Requirements IEC 62368-1 Edition 2.0 2014-02

Bourns Advanced Network Transformer



INTRODUCTION

The growth in the use of Ethernet for a diverse range of IT systems is well-known. Ethernet allows companies to leverage increased bandwidth capabilities to support future networking and real-time data-sharing needs. This has led to the increasing integration of Ethernet-based transformers in connected communication applications primarily for isolation and signal conditioning. The high reliability mandated in communication systems can be threatened by coupling signals from devices that work with different power specifications. If there is a fault operation in one device, it can potentially spread to other connected devices, compromising the overall performance and reliability of the network. »»»

Component suppliers are also tasked with meeting ongoing IT equipment manufacturability trends that include miniaturization, higher manufacturing yield rates, and strict product quality metrics. Therefore, it is important that all components within a system contribute to facilitating greater levels of automated production.

This section will present a new type of Chip-LAN transformer solution for Ethernet-based IT equipment. Details of the component's discrete, center-tapped construction, drum core winding, and ferrite plate cap will be explained along with the benefits from its toroid core magnetic path design. This section will also outline the technology advancements that make smaller-form–factor solutions with consistent feature sets possible while also delivering high-quality signal-conditioning performance in a device designed for fully automated production.

LAN Transformer Background

A local area network (LAN) transformer is a magnetic module designed to link the interface between the physical layer (PHY) transceiver and the RJ45 connector. A typical LAN circuit with the PHY transceiver is shown in Figure 1.

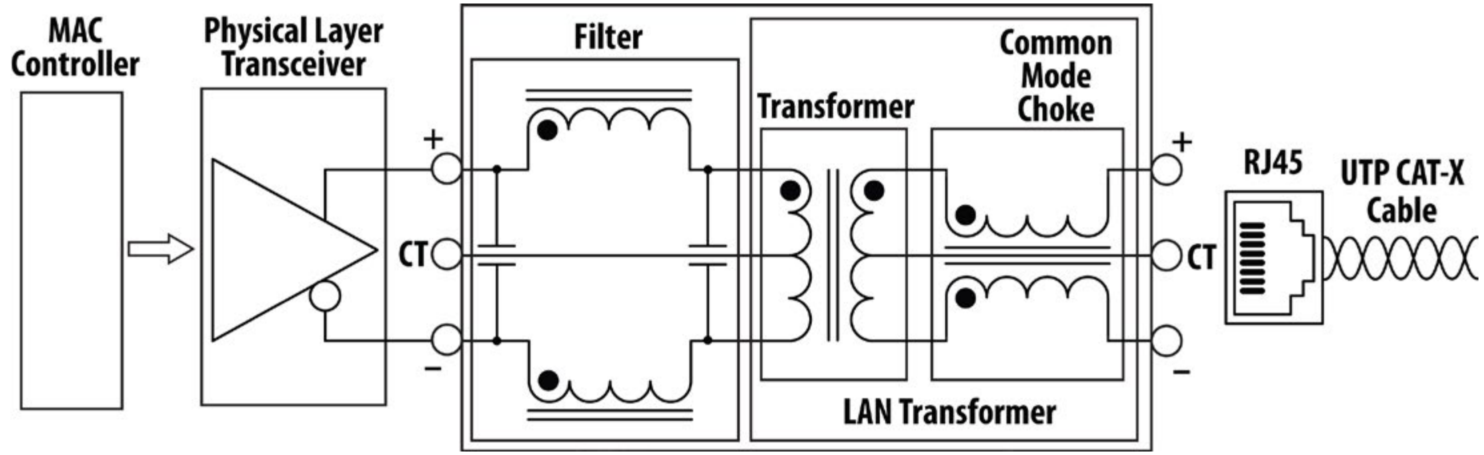


Figure 1

The purpose of a LAN transformer is to convey pulse signals at high speed and at the same time provide other functionality, such as isolation between the input and output. Theoretically, the circuit will include a pulse transformer and common-mode choke coils that will allow it to transmit and receive signals, providing the essential functions of coupling, matching, isolation, and filtering. These capabilities all contribute to transmission quality.

The Benefits and Disadvantages of Traditional LAN Transformers

Traditional LAN transformers are commonly a combination of at least two parts: a pulse transformer (T1) and common-mode choke (T2), shown below in Figure 2. These combined parts deliver a 1:1 turn ratio on both the transmit and receive paths.

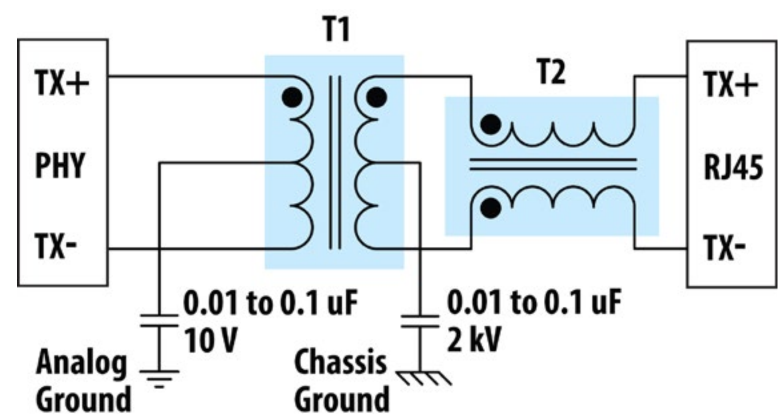


Figure 2

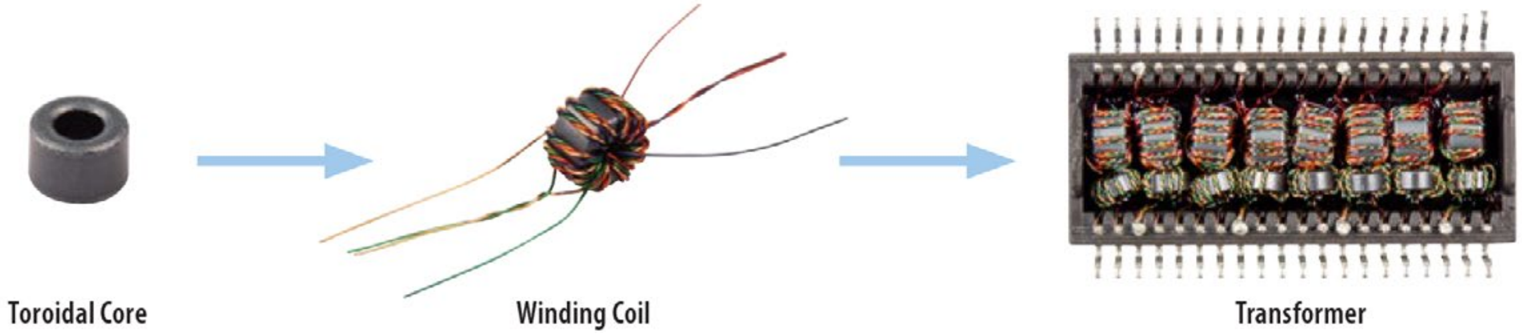


Figure 3: Structure of traditional LAN transformer

Traditional LAN transformers typically have a toroidal shape core (T-core) and are used on T1 and T2 lines because of their superior electrical performance. The advantage of the T-core is that, due to its symmetrical closed-loop core, the amount of magnetic flux that escapes outside the core, known as leakage flux, is low. Therefore, the T-core is more efficient and provides the advantage of radiating less EMI.

Further benefits are achieved by the LAN transformer's structure (Figure 3) consisting of a plastic case with terminal pins, a toroidal ferrite core, enamel copper wiring, and special adhesive materials.

Traditional manufacturing of a LAN transformer typically utilizes a great deal of manual labor in the winding process, which can result in higher production costs and less consistent quality. The T-core structure is difficult to automate, and manufacturers cannot easily control its electrical consistency from expected variations due to the manual process of winding. Therefore, traditionally manufactured LAN transformers can exhibit unevenness in transmission quality and have long lead times.

Advantages Gained from New Chip-LAN Transformers

Production automation and feature consistency are becoming more important requirements in light of the growing trend of transferring ever-larger amounts of data at ultra-fast transmission rates. Based on their ability to be produced using fully automatic manufacturing that contributes to higher device uniformity and improved reliability, newly available Chip-LAN transformers (T1, T2) can be an optimal solution.

Unlike traditional LAN magnetics built with multiple

Table 1 - Evaluation of Typical Features

REQUIREMENT	TRADITIONAL TRANSFORMER	CHIP-LAN MODULE	CHIP-LAN (DISCRETE)
IEE Features	Good but inconsistent	Good	Good
Manufacture	Manual	Automatic	Automatic
EMI debug	Spend time; Inflexible	Save time; Flexible	Save time; Flexible
Cost	Higher	Medium	Lower
Quality	Can be inconsistent	Consistent	Consistent
Delivery Period	Long delivery cycle common	Short delivery cycle	Short delivery cycle

toroidal core transformers and common-mode chokes in a single module, the Chip-LAN transformer is a discrete, center-tapped component wound on a drum core and capped with a ferrite plate to emulate the result of the close magnetic path of a toroid core. A common-mode chip inductor pairs with a Chip-LAN transformer to provide EMI suppression.

The innovative design of a Chip-LAN transformer allows the magnetic flux to travel through the interior of both cores, providing the functional equivalent of a toroidal core, which is illustrated in Figure 4.

In addition, the Chip-LAN transformer design employs advanced circuit technology with precision automated winding technology to produce surface-mount magnetic components and uses mature surface-mount technology, making it a fully automated production product. Chip-LAN transformers largely eliminate the drawbacks experienced with traditional network transformers with lower product stability and requiring extensive manpower to manufacture. Furthermore, the new design structure of a Chip-LAN transformer is compliant with a customer's SMT process, enabling enhanced product quality and consistency. Time to market is also streamlined by decreasing lead times.

Figure 4: Chip-LAN transformer and its associated LAN module

Advantages of Chip-LAN Architecture

- Optimized for design and debug development
- Reduces EMI and IEEE debug time and resources
- Three PCB options provide additional manufacturing flexibility:
    - *Pulse transformer only*
    - *Common-mode choke only*
    - *Pulse transformer + common-mode choke*
- Saves PCB space
- Drop-in replacement for traditional LAN transformers
    - *100% pin-for-pin replacement (mechanical)*
    - *10/100/1,000 Mbps, 2.5 Gbps available (electrical)*
- Allows production to be fully automated

Summary

The added manufacturability and reliability delivered with the Bourns Chip-LAN transformers make them ideal solutions for many applications in the communications market. Bourns developed its new Chip-LAN transformer family to be fully compliant with IEEE 802.3/802.3u and 802.3ab, which optimizes it for the Ethernet market. The integrated features in Chip-LAN transformers create options that make it easier for engineers to design a system solution. ■

Additional Resources

Please contact your local Bourns applicaton engineer or Bourns sales representative for additional information. Visit Bourns online at www.bourns.com.