APPLICATION NOTE

Magnetic Challenges and Success Factors for Transformer Design

Bourns® Model HCT Series Transformers

INTRODUCTION

Engineers looking to provide a particular dimensional footprint or requiring superior performance in terms of operational frequency or overall efficiency in their transformer will want to consider a custom design. Yet, designing a transformer for a particular function or application can be a complex endeavor. This application note presents the primary elements designers need to consider and how those elements affect one another.

PARASITICS AND SIGNAL INTEGRITY

One of the key challenges when designing a transformer for any application is signal integrity, which has to do with the management of the parasitic elements of the coil windings and the magnetizing inductance of the transformer. All transformers exhibit parasitic signals such as capacitance and inductance between windings. For example, distributed capacitance and magnetizing inductance determine Self-Resonant Frequency (SRF), and contributions of SRF plus leakage inductance can affect EMI and EMC performance. Signal integrity involves analyzing the pulse wave of your coil design, and includes the contributions of parasitic elements from the magnetic device (see Figure 1).

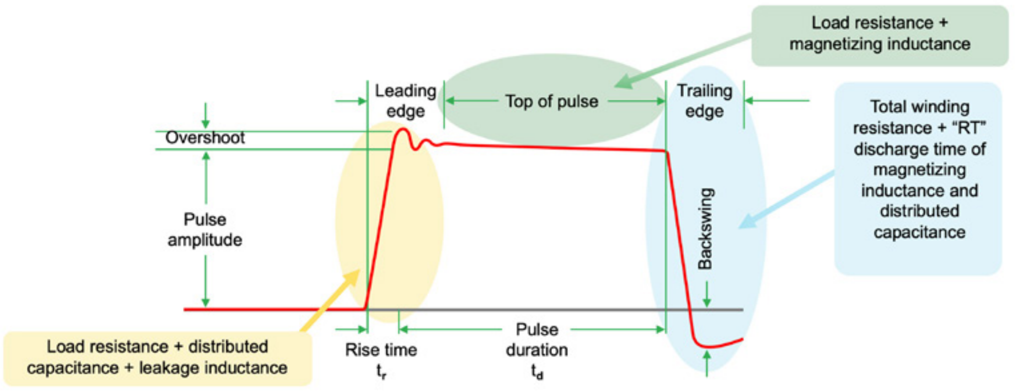


Figure 1. The leading edge of a standard pulse train shows the overshoot caused by the distributed capacitance and leak conductance of the coil design.

The leading edge of a standard pulse train illustrates how parasitic capacitance, leakage inductance, and winding resistance contribute to overshoot at the leading edge of the signal output waveform. Distributed capacitance is a component of the coil winding and leakage inductance is the coupling loss between the electrical energy of the coil being converted to magnetic energy (primary side transfer), and then back to electrical energy (secondary side transfer). Overall, lower leakage inductance is achieved when there is tighter coupling between primary and secondary windings. Fewer turns or greater spacing between wire turns can provide reduced distributed capacitance.

Bourns® Model HCT Series Transformers

PARASITICS AND SIGNAL INTEGRITY (Continued)

Droop in the waveform's top of pulse region in Figure 1 is due to load resistance and magnetizing inductance. The trailing edge backswing, as seen in the drawing, is a combination of total winding resistance along with the discharge time between the magnetizing inductance and secondary distributed capacitance of the coil. Combined together in one illustration, the integrity trade-offs we are discussing are shown.

One more thing to consider is interwinding capacitance, which happens between the primary and secondary windings of the transformer. Lower interwinding capacitance typically results in lower conducted emissions between primary and secondary windings. This can also reduce the Y capacitance that's needed in the circuit. It is important to evaluate the tradeoffs between all of these parasitic elements when designing a transformer.

MINIMIZING LOSSES AND REDUCING SIZE

While parasitics are important for signal integrity, it is necessary to take into account how to minimize total losses through the transformer to gain the highest power supply efficiency. The physical size of the transformer is limited by material dynamics and the physics considerations of the design calculations.

Magnetic component design begins with a full understanding of the electrical inputs and criteria for the construction of the finished product. Peak working voltage is the highest input voltage at the primary side of the transformer. If transient conditions are to be added to the normal operating voltage range, this may require overvoltage category consideration. Overvoltage categories may include greater isolation requirements such as creepage and clearance distance.

For a transformer to comply with a given safety standard or standards, there are physical distances that need to be incorporated into the device construction. Clearance is the distance between two surfaces with an air gap between them. Creepage is the distance between two bodies but along a surface (see Figure 2). Both types of distance must be met in accordance with the specific standard or standards and can include IEC, UL, CSA, VDE or a combination of these.

Bourns® Model HCT Series Transformers

MINIMIZING LOSSES AND REDUCING SIZE (Continued)

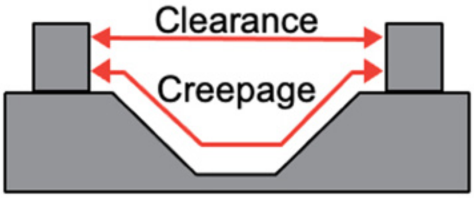


Figure 2. Depending on the specific needs of the user, the standard distance between two surfaces in air and between two bodies but along a surface must meet a number of electrical standards for transformer design.

This is also the point at which design engineers need to consider the level of insulation to use. For example, will the device be operating in circuit with only a functional level of user protection, or will the device need to be reinforced with several layers of insulation for user protection? In addition, designers should consider environmental-based conditions such as pollution degree levels, location, temperature, and more, which might require specific testing for reliability.

SAFETY AND ISOLATION

Physical distance is key in meeting safety regulations and this is also where different configurations for different transformers comes into play. There are times when a designer chooses a particular distance for safety and applies this to both the primary and secondary sides of the transformer. Such a design looks uniform as opposed to having all of the safety distance incorporated on one side of the transformer (see Figure 3).

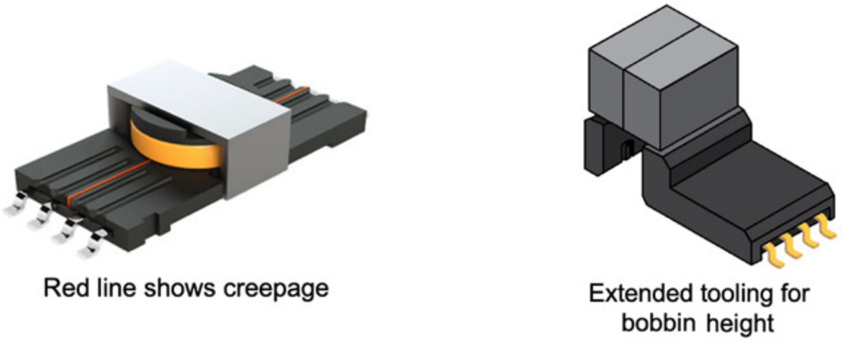


Figure 3. In transformer design, safety distances can be achieved by keeping the rail between the center coil and core assembly for a uniform look (left), or incorporating the safety distance on one side of the transformer (right).

Bourns® Model HCT Series Transformers

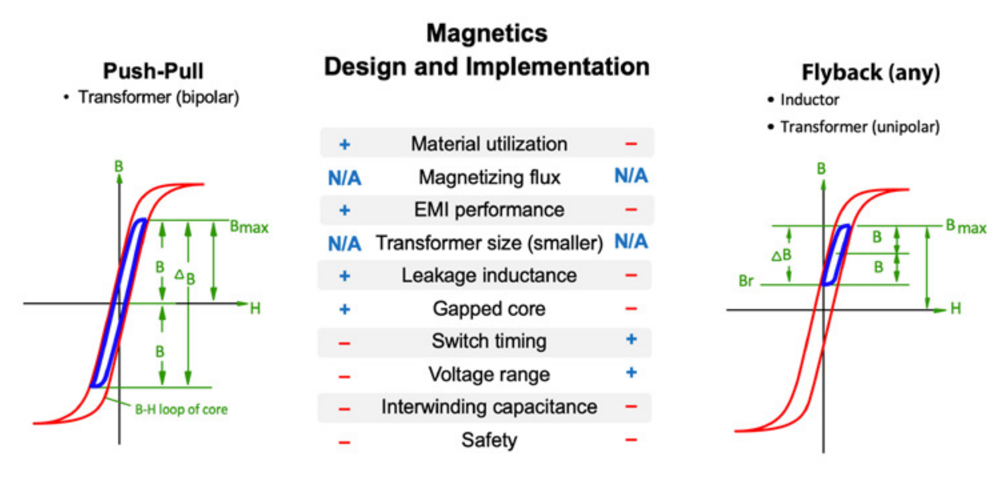
SAFETY AND ISOLATION (Continued)

Annex exceptions included for some standards allow for materials to replace physical distance. These substitutions include Triple Insulated Wire (TIW) and Fully Insulated Wire (FIW) that provide extruded layers of material insulation over the copper wire. Layered tape between primary and secondary windings can be used to meet distance requirements for a particular standard. Other techniques for using insulating material in place of physical distance are sealed joints and encapsulations around portions or even the whole finished good. Finally, a PC board can include its own air gaps to create spacing between components or have dams put between components to create the distance requirements of a standard.

Different safety standards require different types of testing. Hi-Pot testing evaluates all insulations and spacings used for the entire makeup of the transformer. Dielectric testing identifies leakage currents and arcing between insulating materials. If values are too high, the transformer will fail the test, which then requires design modifications. Instead of a single high voltage test, impulse and surge testing can be completed by putting the transformer through the test multiple times at a specific voltage. This ensures that the transformer will survive under abnormal conditions. A stepped voltage test looks for different discharge rates between insulation layers where small pinholes and voids along the surface can cause a transformer to fail.

COMPARING TOPOLOGIES BETWEEN ISOLATED POWER CONVERSION DRIVERS

In comparing the different transformer topologies, there is no right or wrong topology. Each topology has a particular operational mode that might align better with a given application. In determining a topology, the primary concern at this point is with the hysteresis loops for the material as opposed to the operational mode for each type of topology (see Figure 4).



Push-Pull	Magnetics Design and Implementation	Flyback (any)
+	Material utilization	−
N/A	Magnetizing flux	N/A
+	EMI performance	−
N/A	Transformer size (smaller)	N/A
+	Leakage inductance	−
+	Gapped core	−
−	Switch timing	+
−	Voltage range	+
−	Interwinding capacitance	−
−	Safety	−

Figure 4. This illustration shows the hysteresis loops (in red) for the material opposed to the operational mode (in blue) for each type of topology.

Bourns® Model HCT Series Transformers

COMPARING TOPOLOGIES BETWEEN ISOLATED POWER CONVERSION DRIVERS (Continued)

The push-pull operation practically uses the entire hysteresis loop whereas the flyback transformer uses a smaller portion of the hysteresis loop. The flyback transformer is considered to have a single quadrant operation mode. For a more specific comparison based on topology see Table 1.

Table 1. This general comparison provides some background for engineers with specific design requirements.

Parameter	Conventional Flyback	PSR Flyback	Open-Loop Push-Pull	Closed-Loop Push-Pull	Isolated Power Module	Isolated Power with Digital Isolator
Output Power Level	Flexible (Transformer and PWM controller dependent)	5 W to 7 W	5 W	Flexible (Transformer and PWM controller dependent)	0.5 W	0.65 W
Input Voltage Range	Up to 42 V/65 V	Up to 42 V /65 V	Up to 5.5 V	Up to 75 V	Up to 5.5 V	Up to 5.5 V
Output Regulation	1 % or less	1 %	5 to 10 %	1 % or less	1.5 %	1 %
Number of Discrete Components	More than 30	21	10	46	Less than 10	Less than 10
Isolation Rating	Flexible (Transformer dependent)	Flexible (Transformer dependent)	Flexible (Transformer dependent)	Flexible (Transformer dependent)	5000 V_{rms} reinforced	5000 V_{rms} reinforced
Emission	High	High	Low	High	Low	Moderate to High

Bourns® Model HCT Series Transformers

BOURNS® PUSH-PULL TRANSFORMER SOLUTIONS

For both unregulated and regulated power conversion modes for push-pull operation as well as end solutions for signal line drivers used in battery management systems, Bourns has introduced their HCT line of products. These very small footprint transformers offer a large amount of creepage and clearance corresponding to multiple standards where designers are working with voltages up to 800 VAC.

Although the transformer was originally designed for the TI SN6501 and SN6505 push-pull driver chipsets, the Bourns® Model HCTSM110103HAL HCT Transformer works with any IC chipset with input and output voltages and power levels corresponding to the TI chipset family. HCT 200 compliancy means that the transformer is automotive ready and meets EHNS requirements for RoHS, reach, halogen free and lead-free operation with extended temperature range.

The Model HCT Series meets safety and isolation standards through a unique design of the header. The lid wall is inserted over the top of the core and coil assembly to create a sealed environment between the primary and secondary pins. In this way, it creates a creepage and clearance distance that is typically very small. This maintains approximately a 10 mm creepage in clearance to allow users to simply size the header for the longer pin distance versus having to redesign the header to meet the 10 mm requirement.

Overall, the transformer is designed for a very high working voltage. Options also include different turns ratios than most competitive products on the market — while still meeting the Hi-Pot capacity and large creepage and clearance distances required. (See Figure 6a and 6b to better understand the basic operation of the Model HCT Series push-pull transformer design.)

Bourns® Model HCT Series Transformers

PUSH-PULL TRANSFORMER DESIGN BASICS

A review of a basic push-pull driver schematic shows the split winding configuration of the transformer in the center. Figure 6a illustrates how the transformer works. Note that when Q1 is closed and Q2 open, the split winding of the primary side is energized which moves the transfer of energy to one half of the split winding on the secondary side. When Q1 is open and Q2 closed, the opposite happens so that the other half of the split-point primary side receives energy which is transferred to the other split winding half of the secondary side. This operation sets up timing configurations for what would be unregulated operation. The result is a square wave input for circle A and circle B and a normalized output for circle C (see Figure 6b).

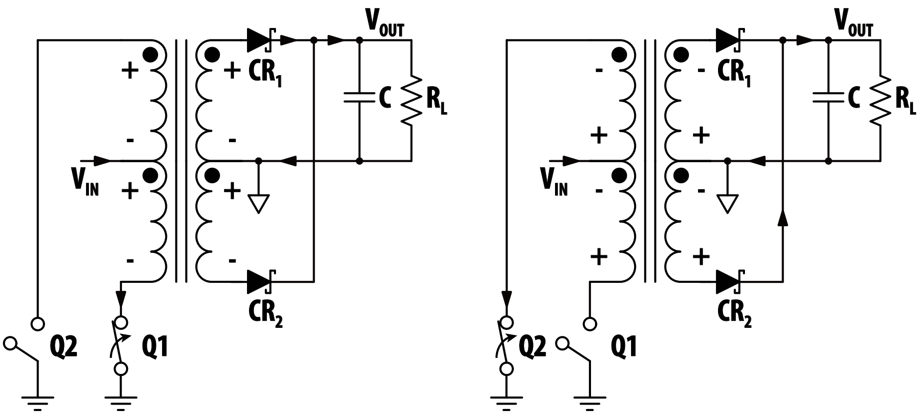


Figure 6a. This schematic of a push-pull converter shows how the split winding operates when under power.

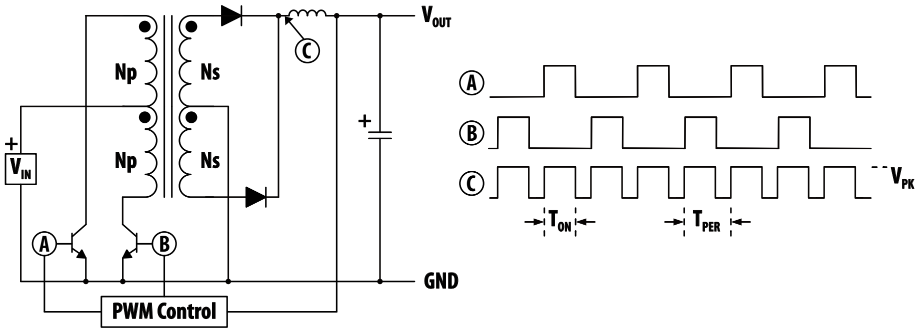


Figure 6b. Note that alternating inputs (circle A and B) provide a consistent square wave output (circle C).

However, a push-pull transformer can be operated in a regulated situation by adding an LDO (low dropout) regulator or an output inductor to the secondary side of the circuit. It results in a DC output voltage with very little current ripple.

Bourns® Model HCT Series Transformers

CONCLUSION

The magnetic design of a transformer involves multiple trade-offs that can affect the overall size and performance of the component. Safety and isolation play a large part of the design process. In particular, battery management systems require a certain level of isolation and separation between the low voltage and high voltage circuits. This can be implemented in different ways, but most often it is done through the transformer selection. Bourns offers a multitude of solutions to meet any of the performance and safety requirements described in this Application Note.

Bourns offers both off-the-shelf standard transformers as well as full custom capabilities to match unique application specifications.