APPLICATION NOTE

Design Considerations to Optimize and Expedite Custom Magnetic Prototypes

INTRODUCTION

The application-specific features in today's high frequency power converters and EMI filters have resulted in a growing demand for customized high-power magnetics designs. These types of complex customized designs require an experienced engineering team that can supply both the software (magnetic component design and Finite Element Analysis, or FEA) and hardware (prototyping tools) from a single power electronics laboratory. The cumulative result of being able to supply this combination of engineering expertise in a single location also leads to time-to-market and configuration benefits in expediting a customer's converter prototype design.

This application note presents the additional power advantages that can be achieved in using Finite Element Analysis to identify the optimum winding order prior to building physical prototypes. And, because actual prototype measurements to simulations can vary, the application note also demonstrates why creating prototypes in the same location as the simulation software has become an essential custom design requirement.

Determining the Initial Specification

The initial step in a magnetic component design requires a preliminary specification of the power supply itself including additional information such as the topology, for example, a flyback topology. The manufacturer and power management chip series to be used must also be taken into consideration. A basic electrical block diagram of the system will indicate the number of windings involved.

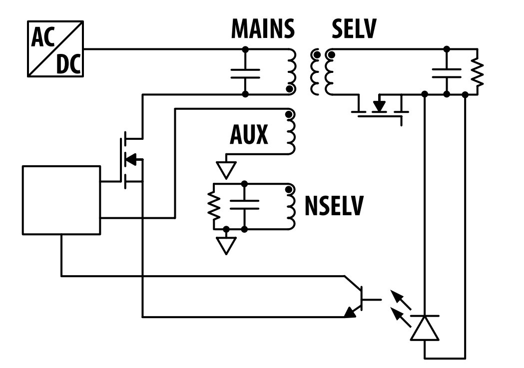

Figure 1. Block Diagram of a Flyback Power Supply

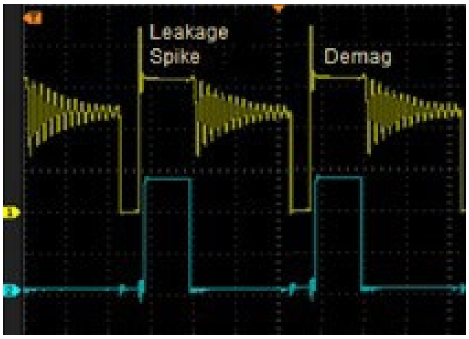

Figure 2. Auxiliary Winding Voltage and Synchronous Rectifier Control Voltage (Blue) in a Flyback Power Supply

Figure 1 shows an isolated AC/DC 70 W flyback power supply with reinforced isolation. The control loop consists of secondary voltage feedback, as well as primary current sensing. The coordination of the MOSFET and synchronous rectifier is done using the auxiliary (AUX) winding and the controller IC for measuring the demagnetization time. In this case, the leakage inductance measurements will determine the length of time that the leakage inductance spike lasts and will determine the cycle time of each oscillation when the secondary is completely demagnetized. Designing the transformer to ensure optimum leakage inductance with multiple windings is important in such a design.

If there is an application note from the power controller supplier, it can help determine the electrical parameters of the transformer including the primary inductance and peak saturation current (in the case of a flyback transformer). For this case study example, the primary inductance will be calculated using the energy equation for a flyback transformer:

$$L = \frac{2\ (V_{out} + V_F) * I_{out}}{f_{sw} I_p^2}$$

Where:

f_{sw} = *Switching Frequency*
I_p = *Peak Current in the Primary*
V_F = *Synchronous Rectifier Voltage Drop*

Determining the Initial Specification *(Continued)*

The dimensions of the transformer will be determined first and foremost by the target power to be dissipated in the transformer, as well as the specified operating temperature range. Also important are the customer's board and enclosure, which are strictly dictated by safety requirements as stipulated by the customer. In Europe, Bourns uses SOLIDWORKS® for mechanical design. Figure 3 shows one example of a Solid Works transformer design. The blue line highlights the shortest distance between a secondary SELV pin and winding. SOLIDWORKS® supports its partners in helping to meet safety standards such as IEC 62368-1 Edition 2.0 2014-02.

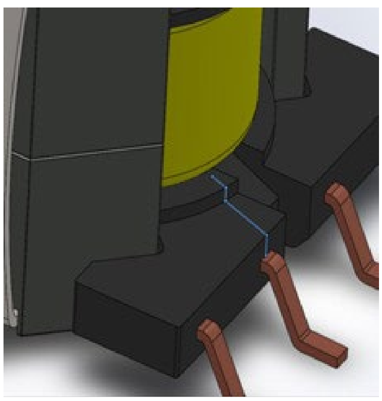

Figure 3. | *Calculation Example for Creepage and Clearance*

Ideal Prototype Support

If a customer requires urgent engineering samples, having all materials in stock is a clear advantage to help avoid delays. Typically, Bourns stocks more than 179 different shapes and sizes of MnZn ferrite cores for new designs. These cores are "un-gapped", although custom laboratory machines can produce a flat uniform gap in less than 30 minutes. In addition, a Formlabs 3D printer is typically able to create various types of plastic bobbins within four hours.

Optimized Simulation Software

The time-consuming trial and error of assembling and testing different prototype variations can be simplified by first relying on tools such as ANSYS for identifying optimum structures. The flyback transformer example in Figure 1 is designed for 12 V /6 A isolated output (SELV) with a non-regulated, non-isolated 12 V/0.18 A output (NSELV).

Some controller manufacturers will have a maximum time allowed for the leakage inductance spike on the AUX winding. Figure 2 (in yellow) shows the AUX winding voltage, which is sampled by the controller. The peak-to-peak variation (ringing) will also have a minimum value and is dependent on the leakage inductance. The coupling between the NSELV in figure 1 and AUX may also need to be controlled. This can be necessary in standby power situations with the NSELV output being switched on or off. The control loop stability could be affected in these situations without optimum coupling between the AUX and NSELV windings. Therefore, placing the NSELV close to the AUX is necessary in this situation to maximize their coupling.

Figure 4 shows three different winding structures that have been analyzed by ANSYS. The leakage inductance is plotted in figure 5 and figure 6.

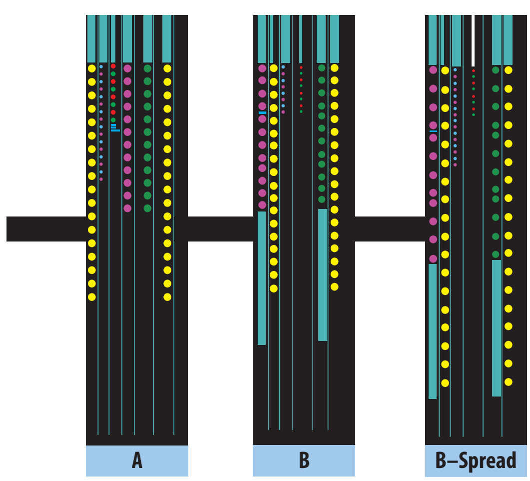

Figure 4. | Diagram of Winding Order for Three Different Scenarios

Table 1: Winding Layers

Winding	Layer	1	2	3	4	5	6
A	Name	Winding Mains	Winding AUX	Winding NSELV	Winding SELV 1	Winding SELV 2	Winding Mains
B & B–Spread		Winding SELV 1	Winding Mains	Winding AUX	Winding NSELV	Winding SELV 2	Winding Mains

Optimized Simulation Software *(Continued)*

The software will optimize the layout of the windings, but also allows for manual placement of the windings, as well. It also allows for insulators such as tape and margin tape that can have an effect on leakage inductance. The isolation requirement between two non-isolated windings (500 Vac) is not possible if the windings are placed side by side, which would be more efficient. They must be separated by at least one layer of tape. The spacing between turns can also be adjusted. The Primary to SELV leakage in a high-power flyback transformer with auxiliary winding using secondary regulation is halved by splitting the Primary winding. This will double the magnetic field path length and the magnetic field intensity will be halved..

Winding Order B provided the optimum balance between the Mains to SELV and AUX to NSELV leakage. Winding Order A has the lowest leakage inductance between Mains to SELV but had a higher AUX to NSELV leakage. Spreading out the windings actually increased the leakage inductance, despite the fact that the path length increases through this approach, hence, lowering the field intensity (Ampere Turns Per Meter). Increasing the distance between the turns allows uncoupled flux to pass into the space between windings. However, there is a trade-off in the space between turns and the overall length of the winding. Therefore, margin tape was used to keep the turns close together when making initial samples. The measured results confirmed that Winding Order B was the better option. The measurements demonstrated that spreading the winding across the bobbin had the opposite effect on the leakage inductance.

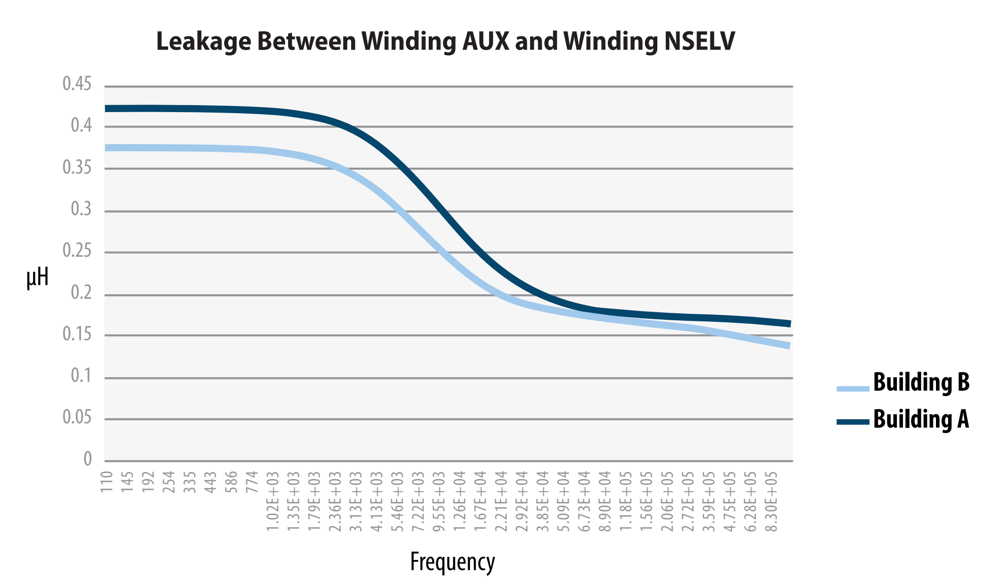

Figure 5. | *ANSYS Finite Element Analysis*

Optimized Simulation Software *(Continued)*

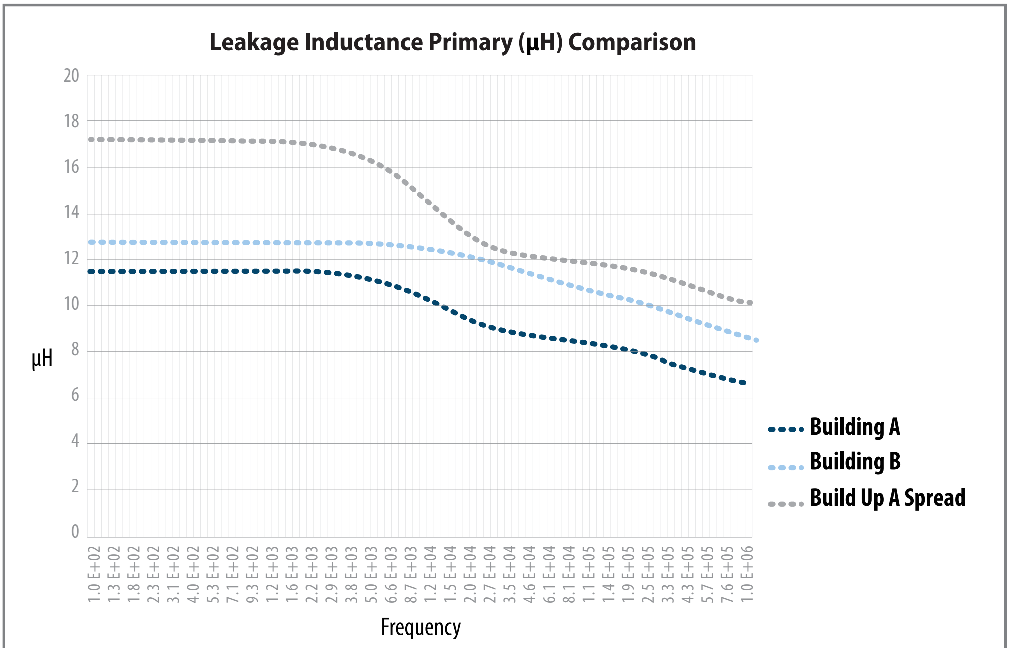

Figure 6. | *ANSYS Finite Element Analysis*

Table 2: Physical Measurements of Prototypes Made with Three Different Scenarios (80 KHz HP 4285)

Winding Buildup	Leakage Primary	Leakage AUX Winding
A	5.1 µH	0.98 µH
B (Margin Tape)	5.5 µH	0.45 µH
B Spread Out	6.5 µH	1.05 µH

The differences in real and simulated measurements of leakage inductance can be partly due to the following factors:

A. Short circuit bar resistance
B. Distribution of coil along surface of bobbin
C. Tolerance in insulation material thickness

It is important to note that while simulation helps to compare different scenarios and select the appropriate winding structure, it is imperative to build a sample and test it thoroughly.

Bourns Power Electronics Laboratory Capabilities

Customers sometimes require transformer testing support on application boards under certain conditions. For instance, Bourns has a license for Altium Designer® for circuit and PCB design. The laboratory has a range of power sources and electronic loads together with a temperature chamber and infrared camera for testing boards. Bourns also can assist customers with EMI board testing.

Key to successful custom magnetics designs, Bourns' production facilities are certified to IATF 16949 with automated manufacturing both for high volume, low power transformers as well as more complicated magnetics assemblies. This includes high-power converters (toroidal or split cores) such as power factor corrected soft switched half bridge converters. The company's experienced application engineers ensure that prototypes are meticulously and efficiently transferred from initial engineering to production using industry standard AQCP (Advanced Quality Control Procedures) so that the design maintains the highest quality levels.

Bourns has set up its power electronics laboratories to best support customers with design, simulation and engineering samples of high frequency power magnetics. Our expertise in advanced software design tools allows us to select the optimum magnetics design for each customer before making engineering samples. Having mechanical and electrical engineering in the same location, as well as available stock of ferrite cores and 3D printing capability allows Bourns the advantage of offering quick, sometimes as fast as 24-hour turnaround on engineering samples. While simulation tools save time by identifying the optimum design, there is still no substitute for testing actual samples and verifying results.

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