Optimizing Custom Magnetics Design

Author: Cathal Sheehan, Bourns, Inc.

To meet application-specific feature specifications, many high frequency magnetics designs must now be customized. What has proven successful for customization is where experienced engineering teams can supply both the software (magnetic design and FEA) and hardware (prototyping tools) portions of the design from one power electronics laboratory location. And, being able to supply this combination of engineering talent provides time-to-market and configuration benefits in supporting a customer's initial converter prototype design.

The article highlights the power advantages gained in using Finite Element Analysis to identify the optimum winding order before proceeding with physical prototypes. The article also points out how actual prototype measurements to simulations can vary, so having the ability to create prototypes in the same location as the simulation software is a critical requirement.

Initial Specification Case Study

The first steps in creating a magnetic component involve a preliminary specification of the power supply itself including additional information such as the topology (example: Flyback) as well the manufacturer and identifying the power management chip series. A basic electrical block diagram of the system will indicate the number of windings involved.

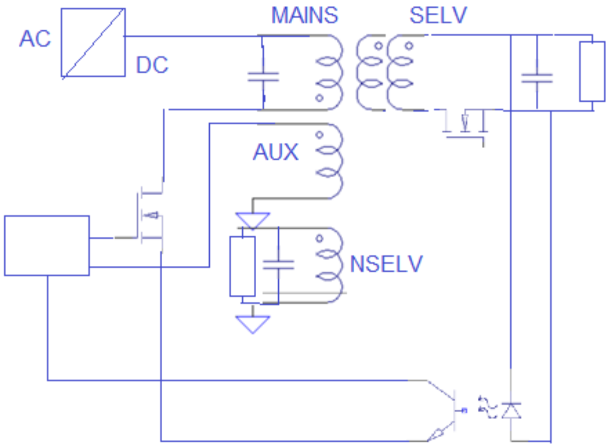


Fig 1: Block diagram of a Flyback Power Supply

Figure 1 shows an isolated AC/DC 70W 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 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 will be important for such a design.

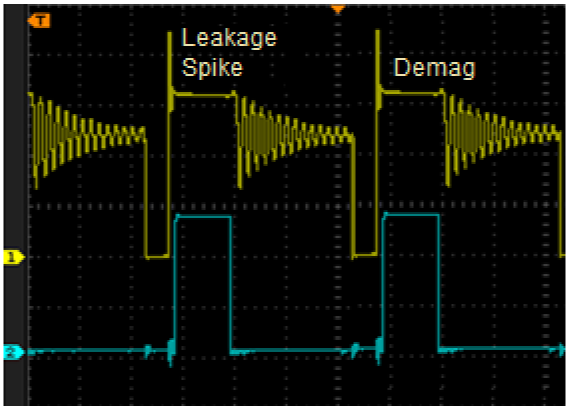


Fig 2: Auxiliary winding voltage and synchronous rectifier control voltage (blue) in Flyback power supply

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). For this case study example, the primary inductance will be calculated using the energy equation for a Flyback transformer:

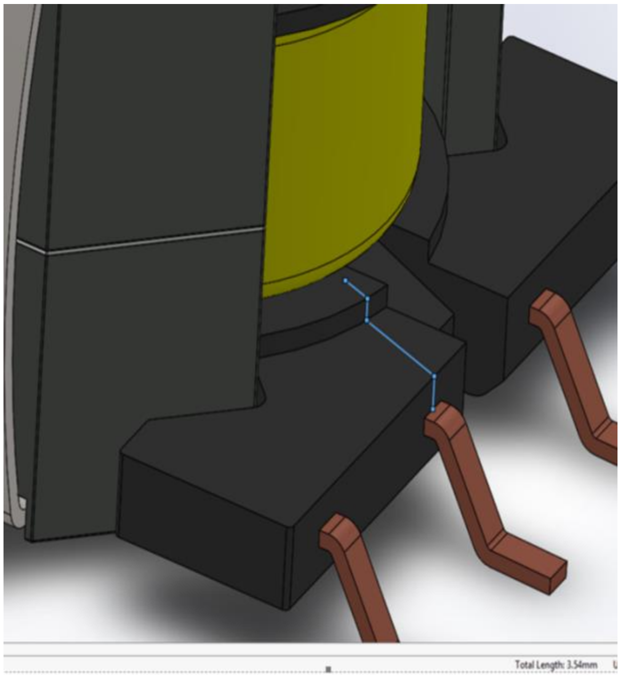
$$L = \frac{2(Vout + VF) * Iout}{fswIp^2}$$

Where:

$$fsw = Switching\ Frequency$$

$$Ip = Peak\ Current\ in\ the\ Primary$$

$$VF = Synchronous\ Rectifier\ Voltage\ Drop$$



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 temperatures. Also important are the customer’s board and enclosure that are strictly dictated by the safety requirements as stipulated by the customer. Bourns in Europe uses Solid Works for mechanical design. Figure 3 shows one example of a Solid Works transformer design. The blue line highlighted is measuring the shortest distance between a secondary SELV pin and winding. Solid Works supports its partners in helping meet safety standards such as IEC62368-1 Edition 2.0 2014-02.

Figure 3: Example Calculation for Creepage and Clearance

Ideal Prototype Support

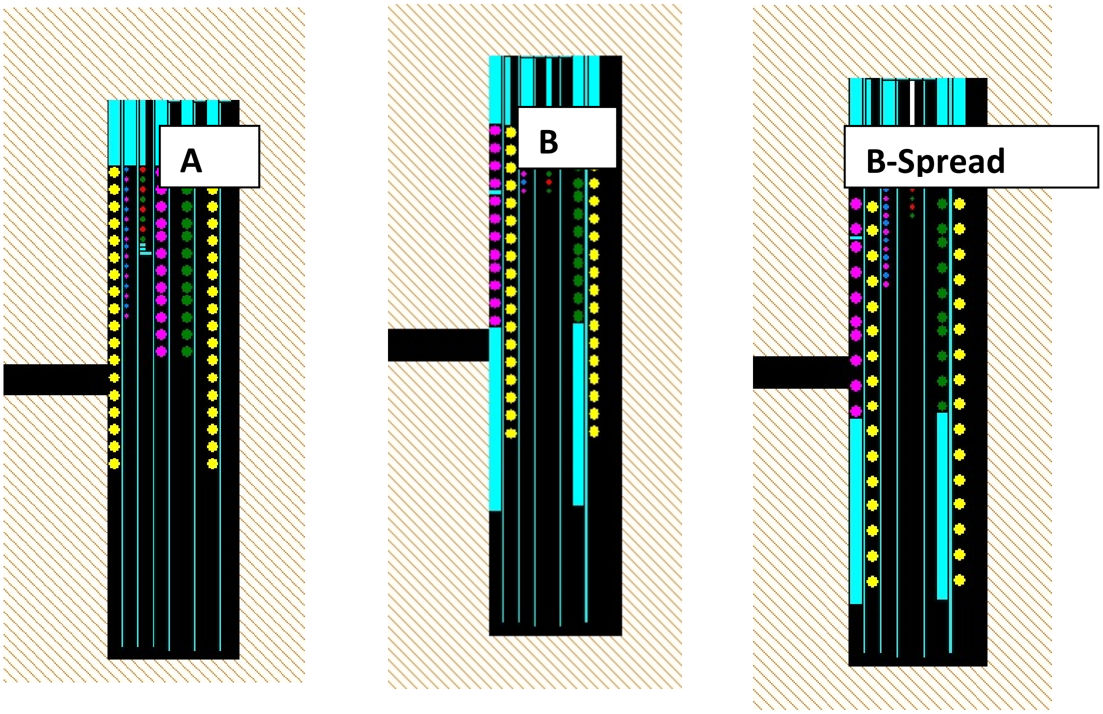
If a customer requires engineering samples urgently, then having all materials in stock is a clear advantage as it helps avoid delays. Typically Bourns stocks more than 179 different shapes and sizes of MnZn Ferrite cores for new designs. These cores are “un-gapped”, although custom laboratory machines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

Optimized Simulation Software

The time-consuming trial and error of assembling and testing different 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 12V /6A isolated output (SELV) with a non-regulated, non-isolated 12V/0.18A 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 NON SELV in Figure 1 and AUX may also need to be controlled. This can be necessary in standby power situations with the Non SELV 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 NON SELV 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 with the leakage inductance shown plotted in Figure 5 and Figure 6.



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

Figure 4 Diagram of Winding Order for Three Different Scenarios

The software will optimize the layout of the windings but 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 have to 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 with auxiliary winding using secondary regulation is halved by splitting the primary winding. This will double the magnetic field path length and halve the magnetic field intensity.

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 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, using margin tape to keep the turns close together was used 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.

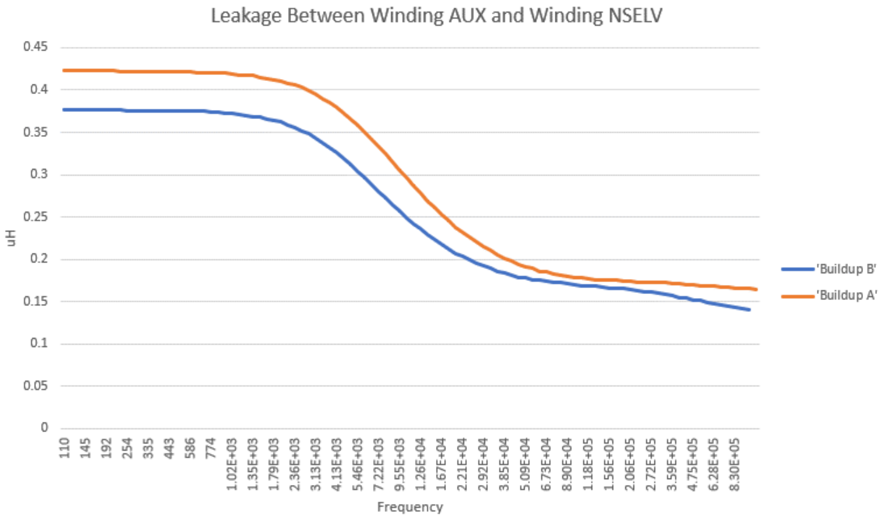


Figure 5 ANSYS Finite Element Analysis

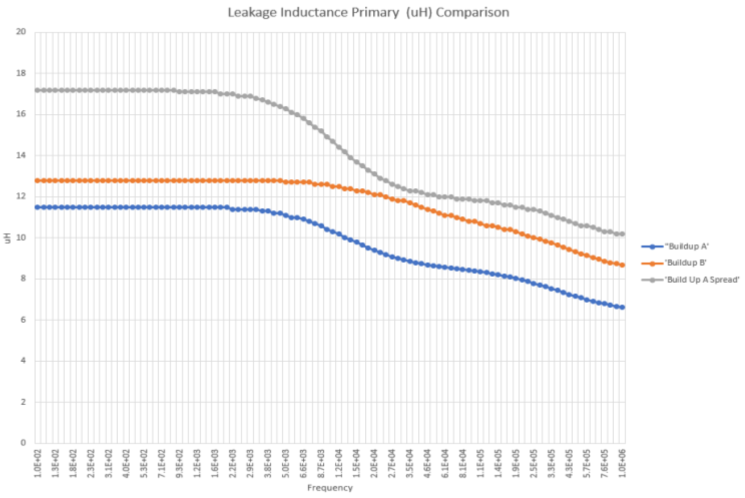


Figure 6 ANSYS Finite Element Analysis

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

Made at 80kHz using a HP 4285 LCR

Figure 7: Physical Measurements of Prototypes made with Three Different Scenarios (80KHz HP 4285)

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.

Power Laboratory Capabilities

Occasionally, customers might require support with testing transformers 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.

Ideally, custom magnetics suppliers should also have production facilities that are certified to IATF16949 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. Experienced application engineers are needed to ensure prototypes are successfully transferred from initial engineering to production using industry standard AQCP (Advanced Quality Control Procedures) so the design can maintain the highest quality levels.

The most efficient power electronics laboratories are set up to support customers with design, simulation and engineering samples of high frequency power magnetics. They also need to have expertise with advanced software design tools that will allow them to select the optimum magnetics design for the customer before making engineering samples. Having mechanical and electrical engineering in the same location, as well as available stock of ferrite cores and 3D printer allows for a quick, (sometimes as fast as 24-hour), turn-around 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.