

CAD/CAE Software Aids Converter Design

By **Dennis Owsiany**k, Integrated Engineering Software, Winnipeg, MB, Canada; and **Peter Van Duijsen**, Simulation Research, The Netherlands

Typically, power supply design involves electronic and magnetic components. Using a flyback converter example, let's see how CAD/CAE tools aid the engineer in both areas, reducing prototyping costs and providing insights into system performance.

Before the availability of computer-aided engineering (CAE) software designed to run on PCs, engineers had little choice but to simplify assumptions for "ballpark" estimates of system performance. This was especially true in the areas of electromagnetic field modeling and system transient performance. As a result, magnetic circuit analogies were used in place of true field analysis, and frequency response methods were used to evaluate stability in place of actual transient analysis.

Advances in PC speed now permit more accurate simulations of physical systems. Electromagnetic CAE software provides exact solutions to the field differential equations inside magnetic components. System transient performance using PCs involves solutions to the network time-dependent differential equations subject to the initial conditions of devices that store energy, such as inductors and capacitors.

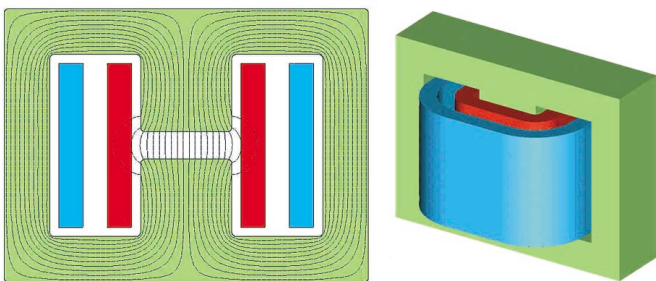


Fig. 1. A 2-D magnetic model (left) and a 3-D rendered model of a flyback transformer (right).

Power converter engineers can benefit from simulation advances by predicting transformer and inductor parameters using field solver software. They can then use parameters from the field analysis to construct the equivalent transformer circuit model for transient analysis by simulation software. Results presented here were obtained using CAE software packages MAGNETO®, AMPERES®, and CASPOC®.

Magnetic Simulation

To demonstrate this simulation, we've used a flyback transformer consisting of a primary and a single secondary con-

centrically wound around the center leg formed by two cores. For the purpose of illustration, we've created a large gap in the center leg, and have loosely wound both windings so there's considerable space between the coils.

Our first approach used MAGNETO, a 2-D analysis package, to simulate the transformer. **Fig. 1** shows a 3-D rendering and the 2-D cross-section MAGNETO model overlaid with a field line plot. We modeled the windings as simple volumes (neglecting skin or proximity effects), and nonmagnetic components (such as the bobbin) are omitted. **Fig. 1** shows that a large gap in the center leg results in fringing flux that is only partially linked by the primary coil. This reduces the coefficient of coupling between primary and secondary windings.

Besides field analysis, MAGNETO can calculate the inductance matrix of the transformer. The results of the inductance analysis are then multiplied by the square of the number of coil turns and (in the case of a 2-D simulation) by the stack height to approximate actual inductance values. This approach ignores 3-D or "end effects" that occur in the actual physical device. These effects can be significant in transformers and inductors that contain air gaps.

Fig. 2, on page 48, shows a graphical demonstration of end effects, the results of a 3-D analysis from the AMPERES program. An arrow (vector) plot represents the magnetic field. Color-coded according to the field's magnitude, the arrows point in the direction of the field. The scale at the right of the plot relates the magnitude of the flux density (in Gauss) to the arrow color.

The 3-D analysis calculates the inductance due to all flux paths. As a result, the matrix values need only be multiplied by the square of the number of coil turns for actual inductance values. For coupled coils that have unequal turns in the primary and secondary, you multiply the mutual inductance by the product of the individual coil turns to obtain the actual value.

Fig. 3 shows the equivalent circuit of the flyback transformer obtained from the field analysis. L1 and L2, respectively, are the inductance of the primary and secondary. The block designated as K1 represents the magnetic coupling of

the windings. The coupling coefficient between the primary and secondary coils is relatively low due to fringing around the air gap.

Areas of high flux concentration in the core can lead to hot spots. You can easily identify them by examining a color contour plot of the magnitude of the flux density in the middle of the core, as shown in Fig. 4.

Flux tends to concentrate in the vicinity of sharp corners, as shown by the bright spots in Fig. 4. Calculating the peak field values would be very difficult without field analysis software.

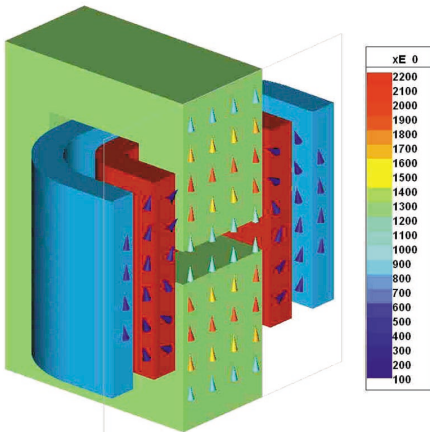


Fig. 2. 3-D plot showing the magnetic field arrows in the cutting plane.

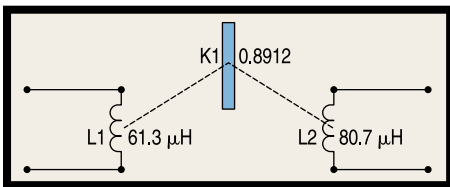


Fig. 3. Transformer equivalent circuit obtained by electromagnetic simulation.

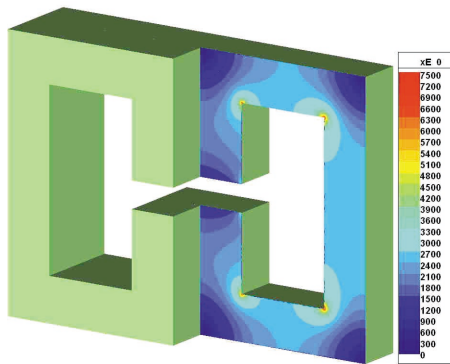


Fig. 4. Color contour plot of the flux density in the middle of the core; bright spots at corner points indicate regions of high flux concentration.

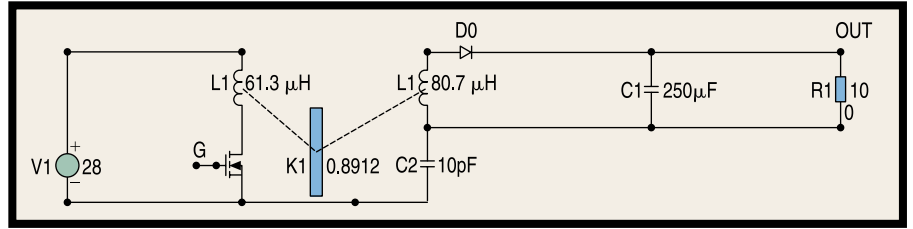


Fig. 5. Flyback converter using transformer equivalent circuit obtained from field solver.

We can now turn to an analysis of the power supply system using CASPOC (computer aided simulation of power converters), a software package specifically designed for power electronic simulations.

Fig. 5 is the schematic of the flyback converter. The transformer primary input is 28Vdc. A MOSFET controls the primary current. A 250μF capacitor C1 filters the output voltage to the 10Ω load resistor, R1. A 10 pF capacitor, C2, models the capacitive coupling between the primary and secondary.

The objective of the converter design is to supply the load resistor with regulated 12Vdc. The feedback control circuit (Fig. 6) provides the trigger signal to the MOSFET gate. A 12V reference is the first input to a proportional plus Integral (PI) controller (the block PICTRL). The second input to the controller is a voltage probe block, whose output equals the voltage at the node labeled OUT in Fig. 5. Comparing the output from the PI controller with a 50 kHz sawtooth produces a PWM signal that controls the MOSFET gate (node G).

Fig. 7 illustrates the transient analysis of the complete regulated converter system as modeled in CASPOC, which allows the designer to insert thumbnail size “scopes” at appropriate places. These scopes can have multiple inputs, and can be opened as separate windows for a detailed examination of system waveforms. The enlarged view of SCOPE1 shows the current in the primary and secondary inductors. The enlarged view of SCOPE2 shows the transient startup of output voltage.

The simulation in Fig. 7 calculated half-million-time steps in about 32 sec (on a PC running with a 667-MHz clock). The simulation timeframe is 5ms with a calculation step size of 10 ns. **PEtech**

References

1. Yildir, Y.B., B.W. Klimpke, and K.M. Prasad, “Three-D Analysis of Magnetic Fields Using the Boundary Element Method,” ICWA—International Coil Winding Conference, Boston, Mass., October 1991.
2. Integrated Engineering Software, “Superior Solutions for Electromagnetic Field Designs: The Boundary Element Method,” Winnipeg, MB, Canada, September 1995.
3. Lascu D.F., Kolar J.W., “Animation of Power Electronics and Electrical Drives,” Proceedings of the 43rd Power Electronics Conference (PCIM 2001), Nuremberg, Germany, June 2001, pp. 145-150.
4. van Duijsen, Peter J., “Simulation and Animation of Power Electronics and Electrical Drives,” PCIM Europe, December 2001, pp. 26-28.
5. Mohan, Ned, Tore M. Undeland, and William P. Robbins, “Power Electronics: Converters, Applications, and Design,” 2nd Edition, ISBN 0471584088.

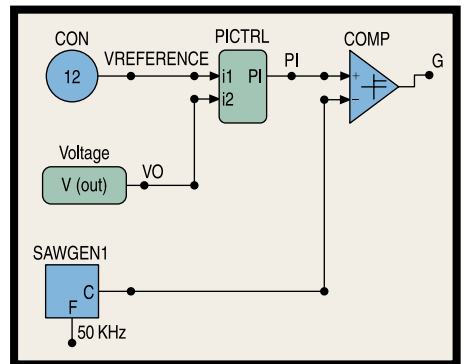


Fig. 6. Feedback control circuit for the gate signal of the MOSFET.

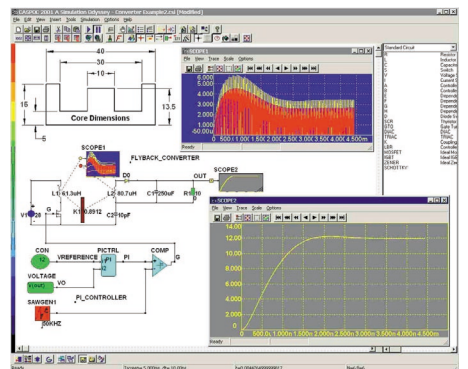


Fig. 7. Regulated supply modeled in CASPOC.