Designing a 12.5W 50kHz Flyback Transformer

Magnetics Designer is a versatile tool that designs all types of layer wound transformers and inductors. It is unique in the marketplace. The frequency range of the magnetics that can be designed extends from DC to over 5MHz. Unlike finite element analysis (FEA) programs Magnetics Designer is a synthesis tool as well as an analysis tool. With FEA based tools you must enter far more information about the design than you usually have, especially if you are in the initial design stages. In addition, the FEA analysis times can be quite lengthy, even hours. This negates the interactive nature of the design process. Magnetics Designer, on the other hand, operates virtually instantly allowing far more optimizations and "what-if" scenarios to be explored.

With Magnetics Designer all you need to design a transformer is the operating frequency, temperature rise, core type, and the desired voltage and current for each winding. Magnetics Designer does the rest through it sophisticated synthesis algorithms. The result is a fully designed and characterized magnetic meeting all of your specifications.

Here we will take a look at how Magnetics Designer can be used to design a flyback transformer. Although it's called a transformer, the principal magnetic component in a flyback regulator is actually an inductor. It is best described as an inductor because energy is intentionally stored in the core or core gap. Therefore, we will use the inductor design features of Magnetics Designer to create a flyback transformer.

The first step is to determine the specifications. A flyback regulator is designed to operate in the discontinuous mode. That is, the flux in the flyback transformer (inductor) returns to 0 on every cycle, as evidenced by the fact that the current on both the primary and secondary are equal to zero during a part of the switching cycle. During the "on" time of the transistor, energy is stored in the inductor. During the "off" time of the transistor, energy is released to the output.

The required parameters for the (inductor) flyback design are: core type and material, operating frequency, Edt (volt-seconds), primary and secondary (AC and DC) currents, required inductance, and the peak primary current.

The type of core we will use is the EI Ferrite from TDK. Magnetics Designer includes a database of over 7000 cores and dozens of materials including newly developed exotic materials.
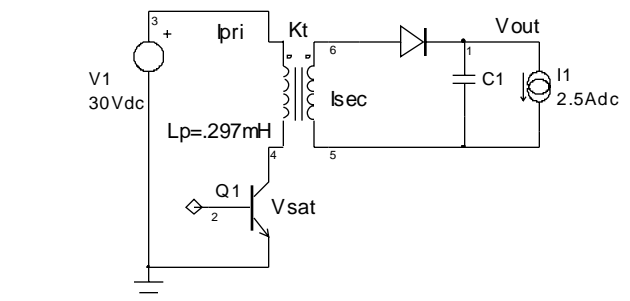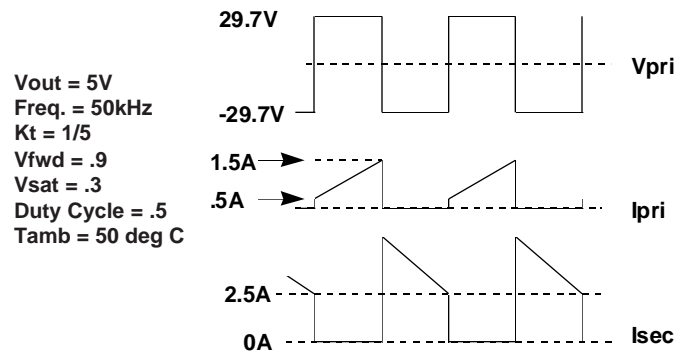

Figure 1, The basic voltage and current waveforms and structure of a flyback regulator.

The Edt across the primary winding is found from the equation:

$$Edt = \frac{DVpk}{fsw} = \frac{(.5)(29.7)}{50kHz} = 2.97x10^{-4}V - \sec$$

Although, the primary winding peak current (see Figure 1) is 1.5 Apk, the switching regulator usually has a current limit which is 10 to 20% greater than the maximum load condition. Therefore, we choose Ipk = 1.8 Apk. Since the turns ratio is 1/5, the peak current reflected to the secondary is 9 Apk. The average (DC component of current) on the primary is:

$$Idc(pri) = \frac{D(Ipk + Imin)}{2} = \frac{.5(.5 + 1.5)}{2} = .5Adc$$

On the secondary, the average current is

$$Idc(\sec) = \frac{(1-D)(Ipk+Imin)}{2} = \frac{5(7.5+2.5)}{2} = 2.5\,Adc$$

It can be shown that the RMS value of a trapezoidal waveform is found from the following equation:

$$Irms = \sqrt{D\left[\left(Ipk \cdot Imin\right) + \frac{1}{3}\left(Ipk - Imin\right)^2\right]}$$

Likewise, using principles derived from Fourier analysis,

$$I^2 rms = I^2 dc + I^2 ac$$

where Iac is the RMS value of the AC component of current (i.e. the RMS value of I(t)-Idc).

Using the Irms equations above, the RMS current for the primary and secondary windings is calculated to be .746 and 3.68 Arms respectively. Solving for Iac, the AC currents were calculated to be .54 and 2.7 Arms respectively.

The inductance on the primary was originally specified as .297 mH. Also the turns ratio was defined to be 1/5. Therefore, the inductance on the secondary is 11.9 H.

The requirements were entered on the Inductor screen (Figure 2). The ambient temperature was set to 50C in the Options tab. The maximum allowed temperature rise is set 30 degrees C. Litz wire was chosen due to the high operating frequency.

After the Apply button is clicked the program performs thousands of calculations. It tries different stranding arrangements, different wire sizes, and so forth, in an effort to generate a design with the minimum power losses in the smallest core possible, that still
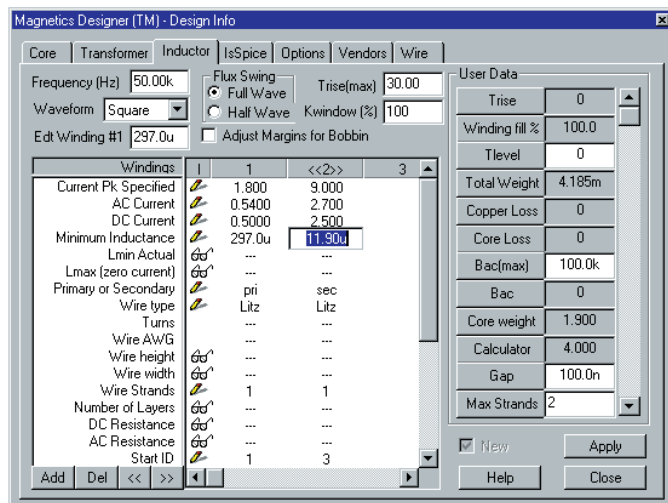

Figure 2, The inductor screen with frequency, Edt, maximum allowable temperature rise, current peak, AC/DC current, and minimum inductance entered. The Apply button generates the rest of the flyback design.
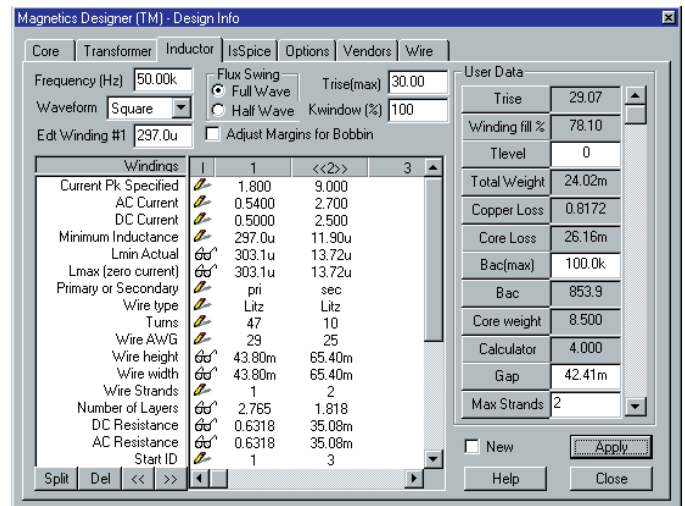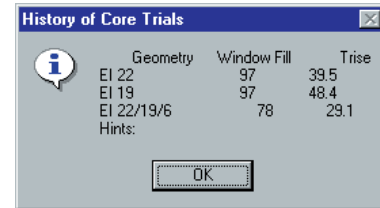

Figure 3, The initial design using Litz wire. The information for each winding is shown in the center of the screen under "Windings 1 and 2". The performance of the whole design is shown on the right side.

meets the fill and temperature rise specifications. Magnetic Designer provides a list of the cores it tried along with their respective fills and temperature rises. The last geometry is the one the program finally settled on. The total time to calculate the full design specifications on a Pentium 133 is under 1 second! The initial design, shown in Figure 3, generally met the design requirements with the exception that the turns ratio was not exactly 1/5.

The window fill algorithm calculates the build assuming that two windings will not share space on a single layer. That is, if a winding has 1.1 layers, the build algorithm calculates the height of that winding as if it consumed two full layers. Since the primary winding occupies 2.765 layers and the secondary occupies 1.818 layers the window is not utilized to its fullest efficiency.

Turns are always rounded to the nearest integer by the program. Therefore, some slight adjustments are required to achieve exact turns ratios. For example, if the program calculates that 46.5 turns are required on the primary and 9.6 turns are required on the secondary, the primary will have 47 turns and the secondary will have 10 turns. The designer would then have to adjust the turns on the primary to achieve and exact turns ratio of 5/1.

Several design changes were tried to improve the inductor design. It was originally assumed that Litz wire was necessary to avoid excessive losses due to potential high frequency AC resistance problems (skin and proximity effects). To test this assumption, heavy formvar (HF) wire was substituted for the Litz wire. This resulted in a significant temperature rise increase. After closely reviewing the results, it was determined that this problem was primarily due to increased AC resistance on the secondary side. Therefore, foil windings were substituted for the magnet wire on the secondary. Foil windings typically have very low AC resistance since the thickness required to achieve the desired cross-sectional area is usually much thinner than the skin depth of corresponding wire. Since a foil winding was used, the program adds layer insulation, wrappers, and end margins to prevent shorts between turns and other windings.

Next, the number of turns on the primary was set to 45 so that the turns ratio from primary to secondary would be exactly 5/1. To maintain the inductance at approximately .3 mh, the Gap was increased to .044 cm. The result of these changes are shown in Figure 4.

The final design meeting all specification is shown in Figures 4 and 5. It has a slightly lower peak flux, lower temperature rise, lower AC and DC resistance, and uses a smaller geometry than the initial design.

At this point you explore the design further by splitting windings or trying different materials. A winding sheet and design summary report can be printed out or copied to Microsoft Excel. As shown in Figure 6, Magnetics Designer can also produce a SPICE model
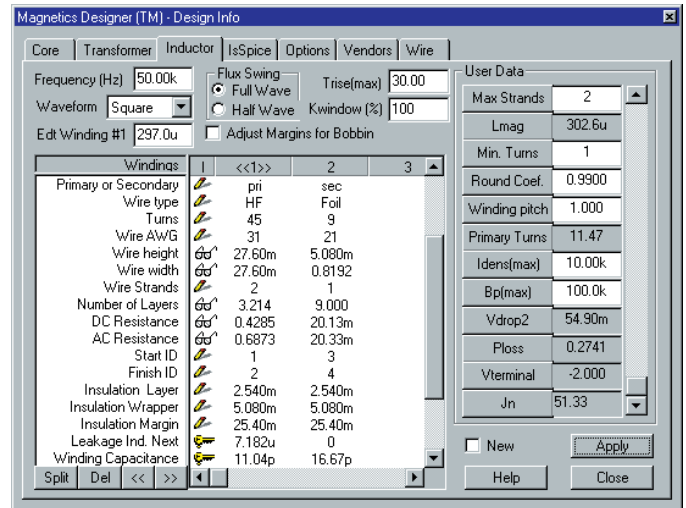
Figure 5, Both the Winding and User Data fields scroll revealing more information like leakage inductance, winding capacitance, weight per winding, magnetizing inductance and more.

and schematic symbol for the magnetic. This allows you to simulate the device while it is being built. The SPICE model can be used with ANY SPICE program.

Magnetics Designer provides a simple and fast way to design custom transformers and inductors, a key part of virtually all electronic systems and many EMI filtering applications. The software even designs planar magnetics, an important part of many new high frequency applications. Magnetic design is an art that is slowly being lost as experienced designers retire. Products like Magnetics Designer help fill the void by providing intelligence and design expertise in a software tool.
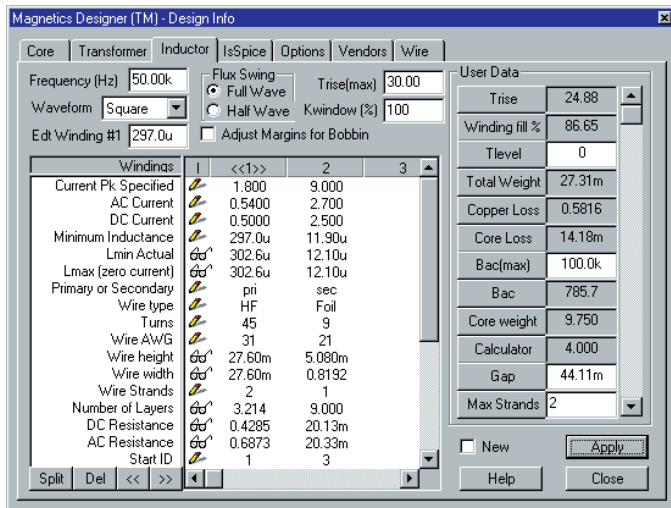
Figure 4, The flyback design using heavy formvar and Foil windings. Here, the Windings window show the required turns, wire size, strands, layers, and AC/DC resistance. The User Data fields show the temperature rise, fill, weight, losses, and flux density.
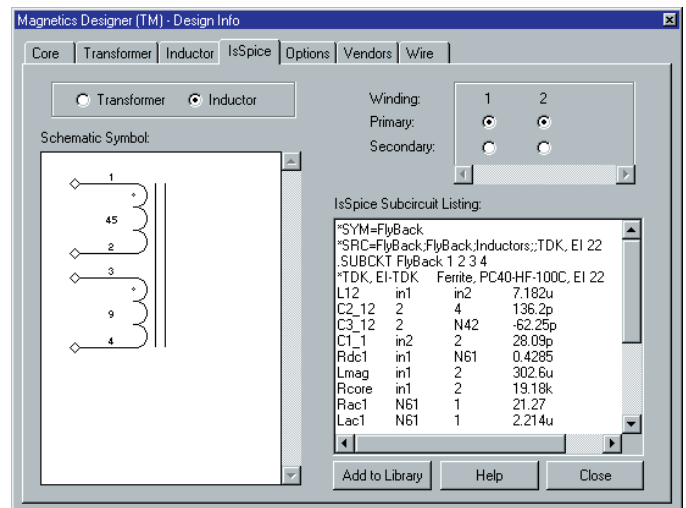
Figure 6, A SPICE model (SPICE 2G syntax) can be produced along with a reconfigurable schematic symbol.