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Modeling of Integrated Magnetics Components*

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The use of magnetic components containing windings on different core legs is a common practice that enables integration of a transformer and an inductor on the same magnetic core (integrated magnetics). Integrated magnetic techniques allow designers to reduce component size, losses, and flux ripple. However, the design of these components is not a trivial task because the selection of the core, air gaps and winding setup is not obvious.

Ansoft's PExprt software is capable of creating accurate models for these complex components, allowing the designer to select the appropriate winding strategy without time consuming prototyping iterations. PExprt uses powerful finite element analysis techniques to generate frequency-dependent models of integrated magnetic components, which include the materials and winding layout of the magnetic component. In this article, we demonstrate how to use PExprt to model a push-pull forward converter with integrated magnetics for a 48-V Voltage Regulator Module with a 1.2-V and 70-A output.

Introduction

In this structure, all magnetic components including the input filter inductor, stepdown transformer and output filter inductors are integrated into a single EI or EE core. The transformer windings (called primary 1 and primary 2) as well as the inductor winding (called secondary) are wound on the two outer legs. The interleaving winding technique is used to minimize the leakage inductance of the integrated transformer. The core structure has an air gap in the center leg and no air gap in the two outer legs.

Figure 1 shows the topology selected for this example. Figure 2 shows the integrated magnetics structure. Figure 3 shows different waveforms that will be used later for comparisons with the simulated results.

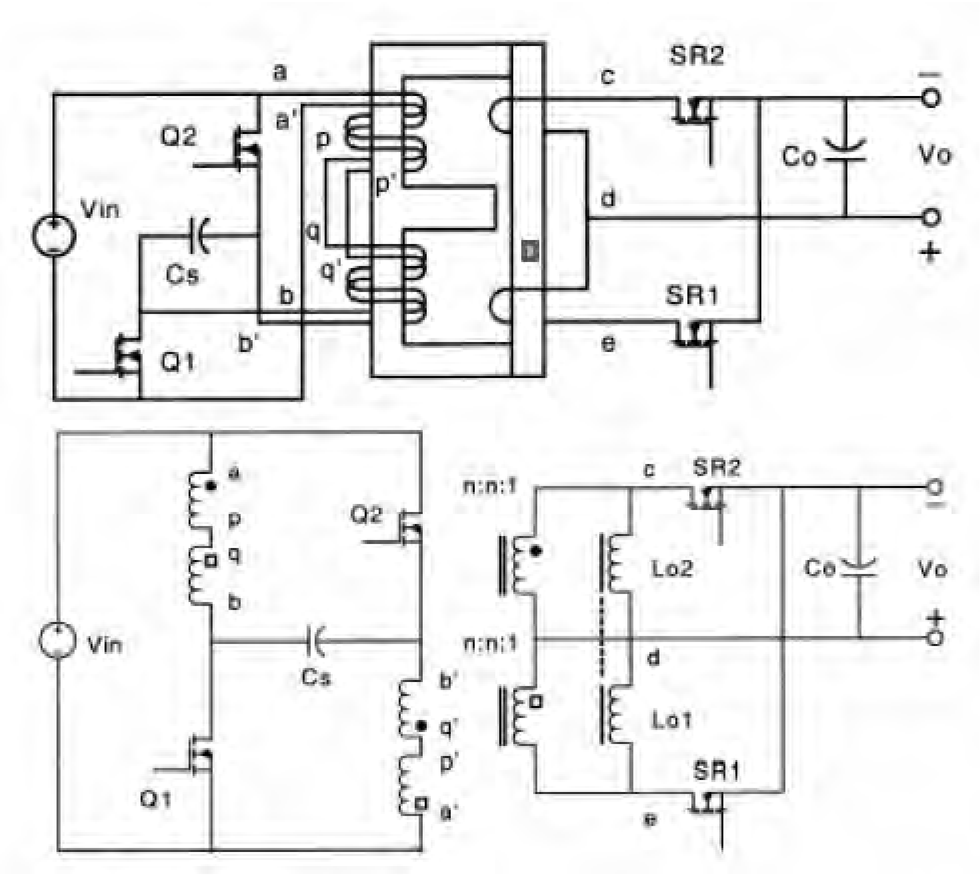


Figure 1. Push-pull converter with integrated magnetics. Shown here are an implementation (top) and the equivalent electrical circuit (bottom).

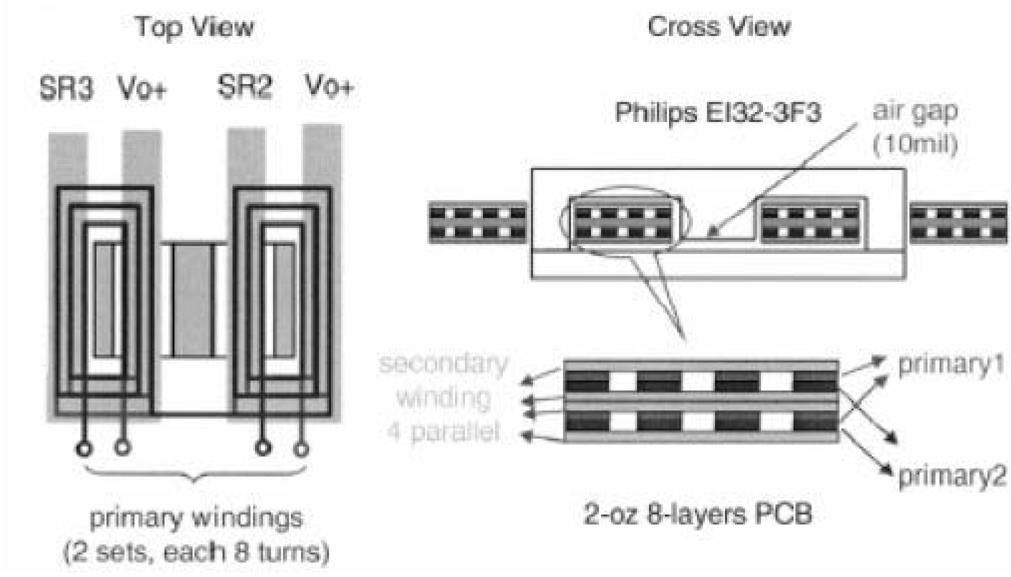


Figure 2. Integrated magnetics design.

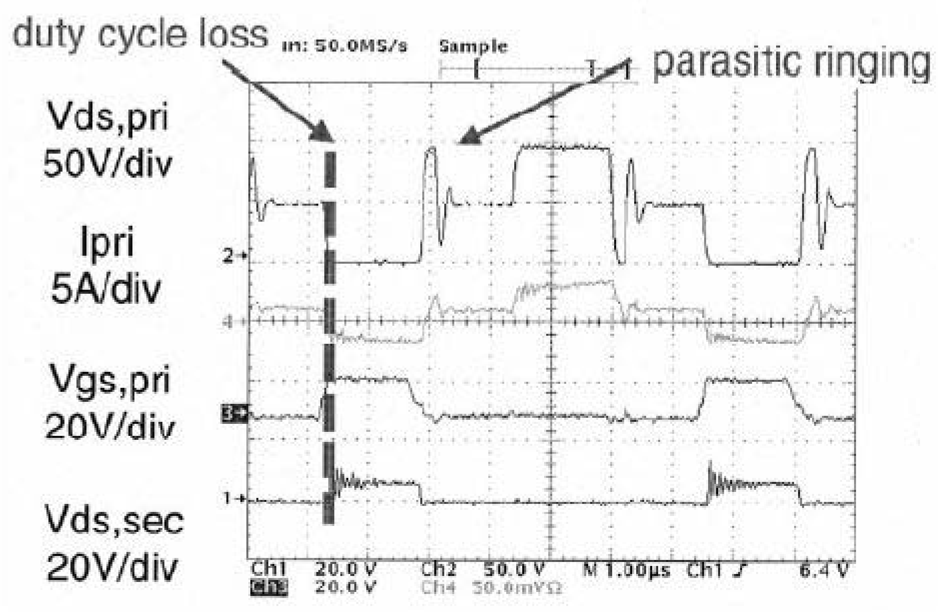


Figure 3. Experimental waveforms.

Model Basis

The use of virtual models aids the designer in selecting the appropriate constructive parameters in order to obtain the expected behavior without the time and expense of build-test iterations. PExprt provides a straightforward design procedure for generating a model from the FEA field solution.

Based on the geometry of this device, a 3D simulation is preferred. However, 3D FEA solvers are not as efficient as 2D FEA solvers in terms of computation time for devices with a high number of turns. As an alternative, PExprt uses a novel 2D approach based on the application of the “Double 2D” technique [1] to increase computation speed yet preserve accuracy.

The generic model structure is based on the one presented in [1] and [7]. The structure of the model is shown in Figure 4 for a three-winding component (assuming one winding in each core leg). There is an electric submodel (top) coupled with a magnetic submodel (bottom).

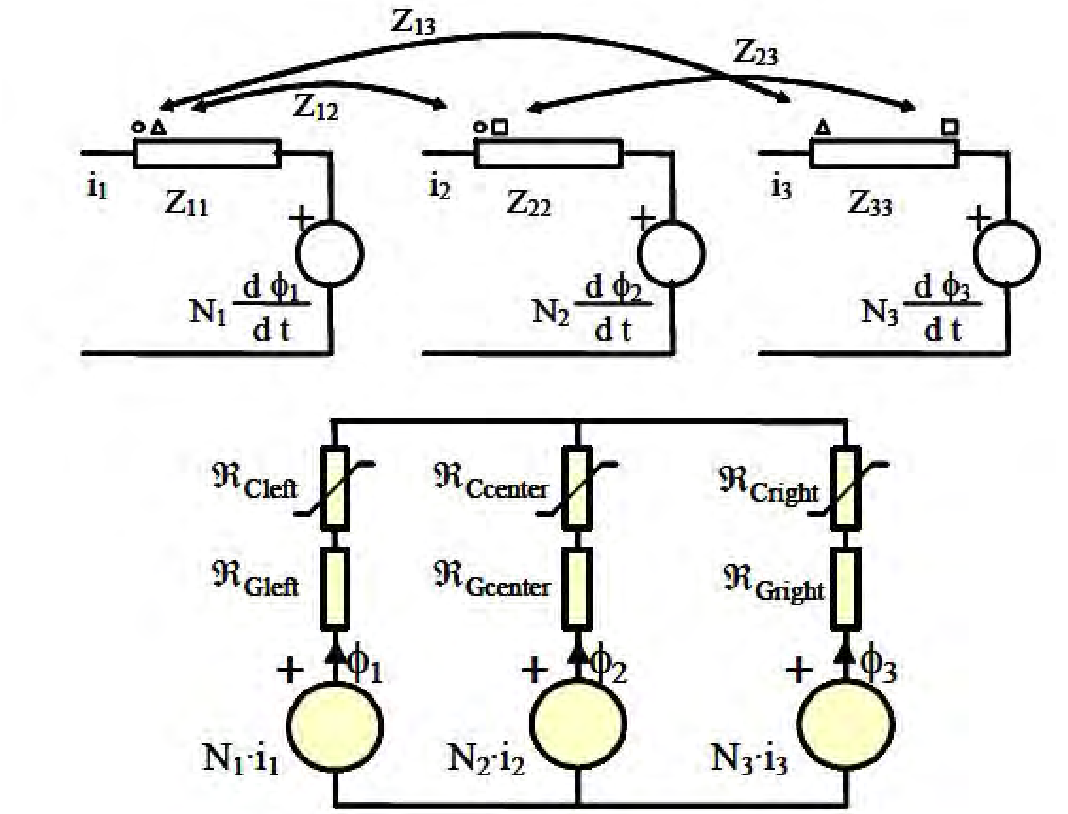


Figure 4. Model structure consists of a windings model (top) and a core model (bottom).

To utilize 2D FEA solvers instead of 3D solvers, the simulation procedure proposed in this work is based on the "Double 2D" approach presented in [2]. This approach is based on the division of the windings of the magnetic component into two parts. Each part produces field distribution in different planes of the space. In this way, it is possible to use 2D FEA solvers to study these 3D structures. Figure 5 shows the actual 3D structure and the double 2D simulations needed to simulate it. The double 2D process requires simulation of four 2D structures. However, the simulations that account for the field distribution in the air for each leg (side views) are very simple. Therefore, the solution time for these three cases is very short.

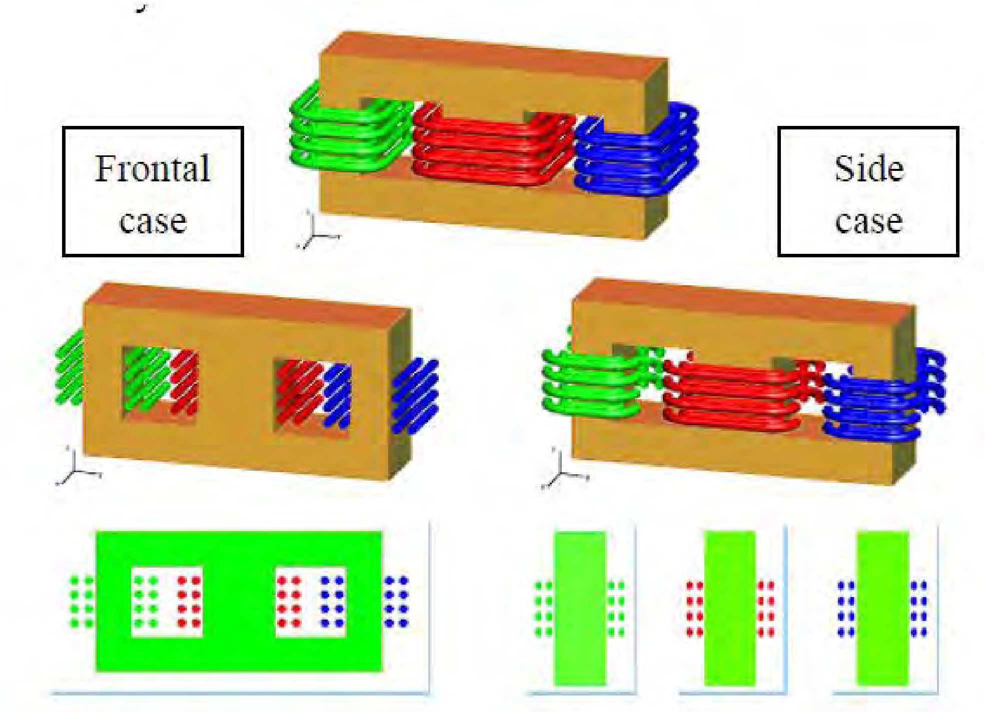


Figure 5. "Double 2D" procedure application.

The main advantages of the FEA model can be summarized as follows:

- Since it is based on FEA calculations, it is accurate (error below 10% for most of the application range) and 2D effects (like the fringing flux effect around the air gap) are considered.

- The model is frequency dependent and is valid for non-sinusoidal waveforms.

- The couplings between each pair of windings are accurately calculated.

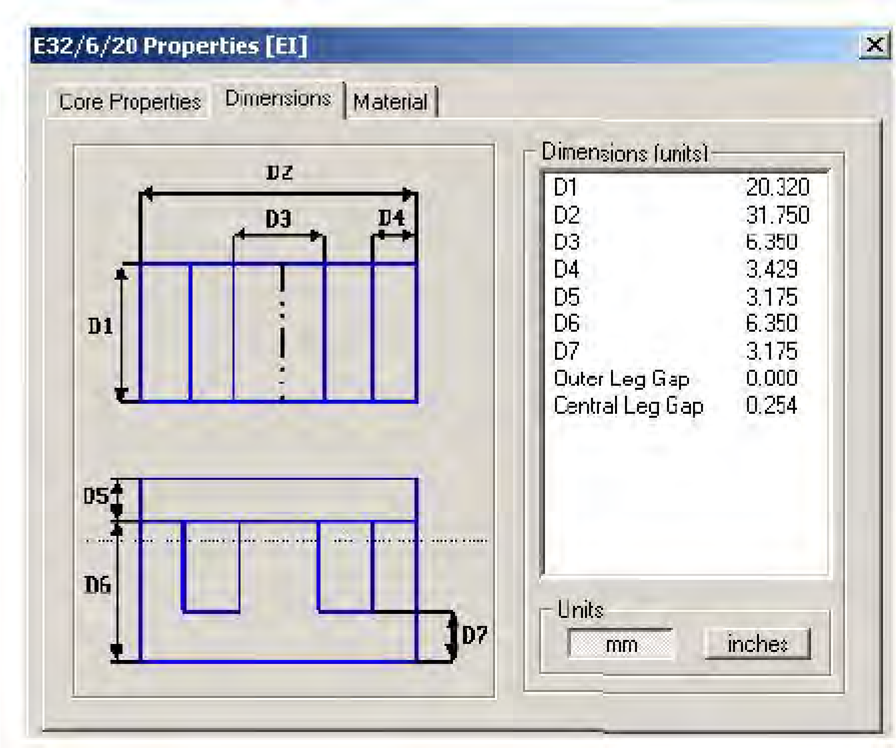
- The solution time is very fast (average time for common components is less than 15 minutes)

- The model generation is completely implemented in PExprt; the user does not need to learn how to use the FEA solver. PExprt creates the FEA project automatically and solves the fields.

Generating The Model With PExprt

Defining The Core Shape, Size And Material

The selection of the core shape and size is very simple. PExprt provides libraries containing most commercially available cores. The appropriate core shape for an integrated structure can be directly selected from the library. An EI shape is selected for this example as shown in Figure 6.



Dimensions (units)

D1	20.320
D2	31.750
D3	6.350
D4	3.429
D5	3.175
D6	6.350
D7	3.175
Outer Leg Gap	0.000
Central Leg Gap	0.254

Figure 6. Core shape and size selected from PExprt library.

Defining The Winding Setup

Once the core is selected, the winding setup for each core leg should be defined. PExprt provides a very flexible user interface that allows the user to define any winding connection. The turns can be connected either in parallel or series creating any possible interleaving structures. A different winding strategy can be defined and assigned for each core leg. Once the winding setups are created and assigned to each core leg, a cross-sectional view of the component can be visualized as shown in Figure 7. For this example, all windings are on the outer core legs only.

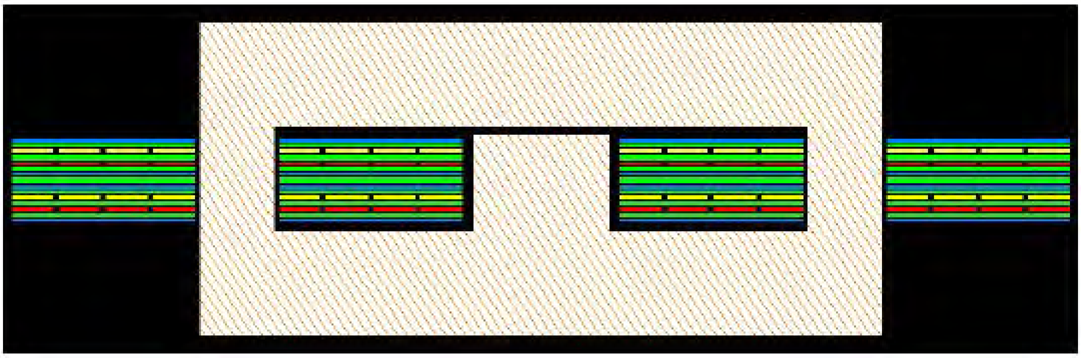
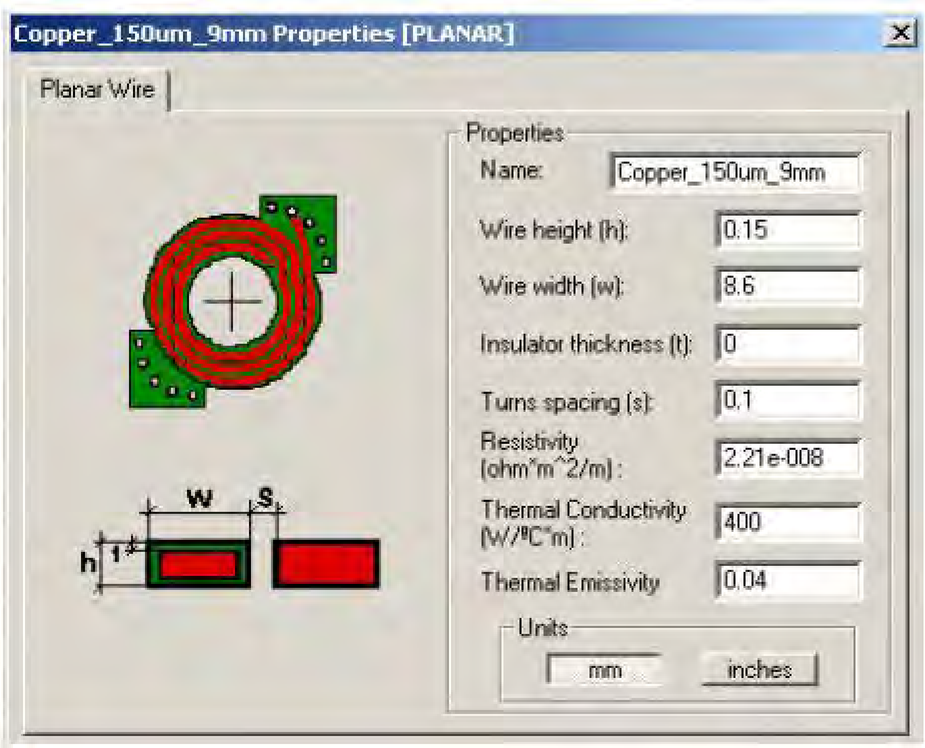


Figure 7. Cross-sectional view of the component.

Defining The PCB Conductors

The thickness and width of each planar track can be easily defined to obtain the real behavior (resistance, coupling, leakage and magnetizing inductances and capacitive effects) of the component. The PCB conductors are defined through easy-to-use menus as shown in Figure 8.



Copper_150um_9mm Properties [PLANAR]

Properties

Name: Copper_150um_9mm

Wire height (h): 0.15

Wire width (w): 8.6

Insulator thickness (t): 0

Turns spacing (s): 0.1

Resistivity (ohm*m^2/m): 2.21e-008

Thermal Conductivity (W/ºC*m): 400

Thermal Emissivity 0.04

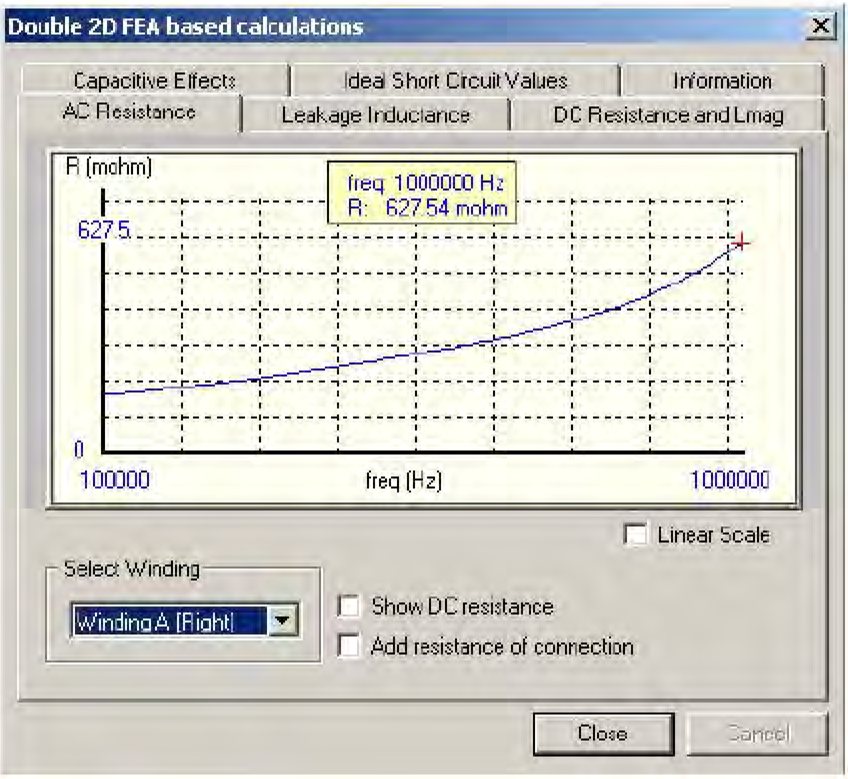
Units

Figure 8. PCB conductor definitions.

Exploring The Results

PExprt contains a powerful model-generation engine that connects the FEA solver with the equivalent circuit model. Once the model is obtained, it can be exported to a circuit simulator (Simplorer, PSpice,…) or it can be used in PExprt to explore the small-signal behavior of the component.

The resistance and leakage inductance as a function of the frequency can be plotted using the tool. The dc resistance, magnetizing inductance and parasitic capacitive effects can be obtained as well. Figure 9 shows the resistance as a function of the frequency.



freq 1000000 Hz
R: 627.54 mohm

☐ Linear Scale

Select Winding: Winding A (Right)

☐ Show DC resistance

☐ Add resistance of connection

Figure 9. Resistance as a function of the frequency.

Simulating The Circuit With Simplorer

Once the integrated magnetic model is generated with PExprt Modeler, you can use that circuit model in Simplorer to explore the waveforms in your circuit. The resulting schematic is represented in Figure 10.

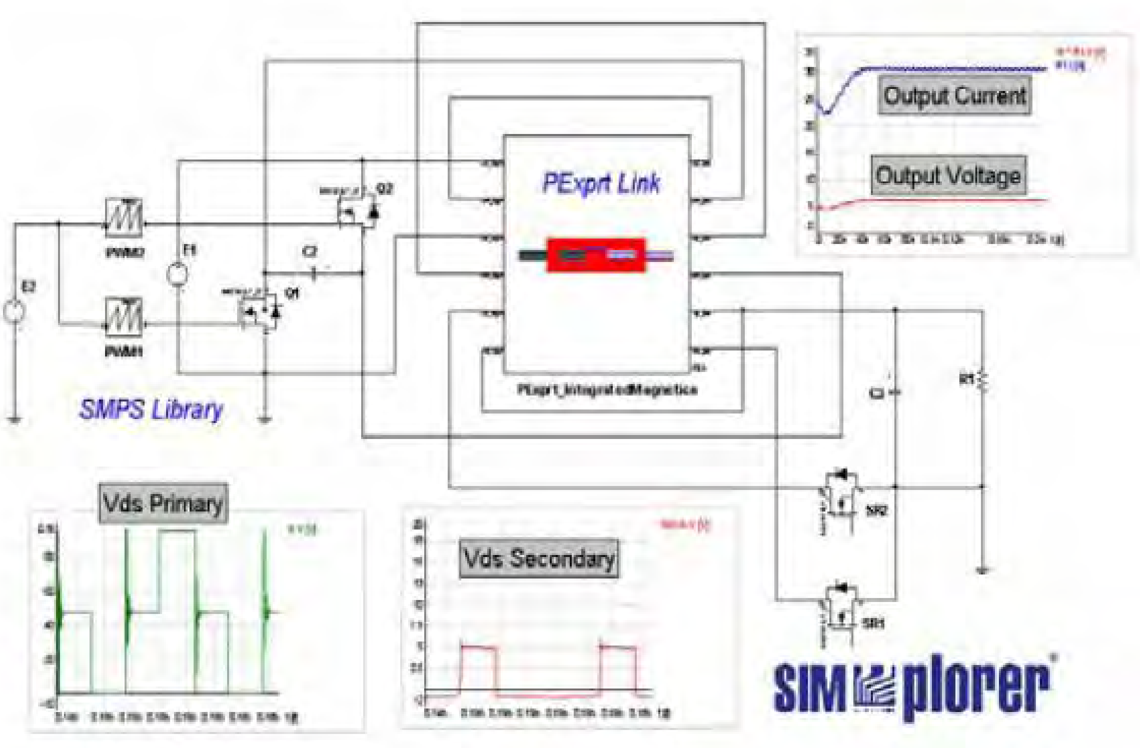


Figure 10. Simplorer schematic.

Since Simplorer includes a PExprt Link element, the user can simply drag this element and drop it on the schematic. The symbol of the model is also generated by PExprt, creating an actual representation of the winding setup of the magnetic component (Figure 11).

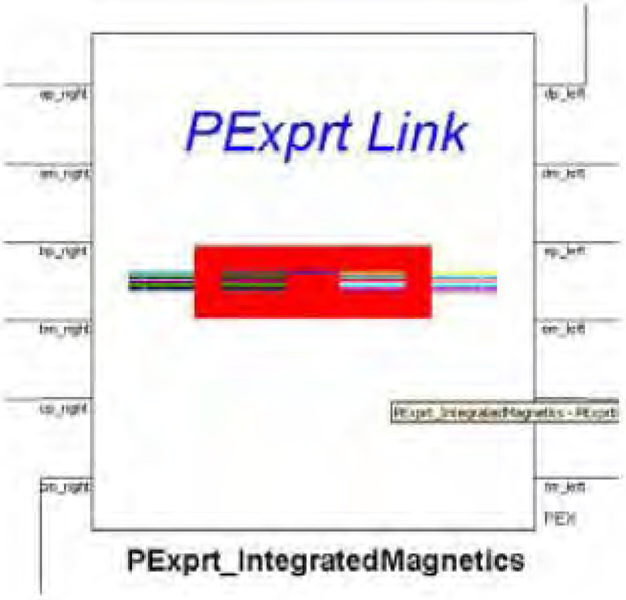


Figure 11. PExprt generates the Simplorer symbol.

Validation Of Results

As evident in Figures 12 and 13, the model created by PExprt closely matches the measured results of the device.

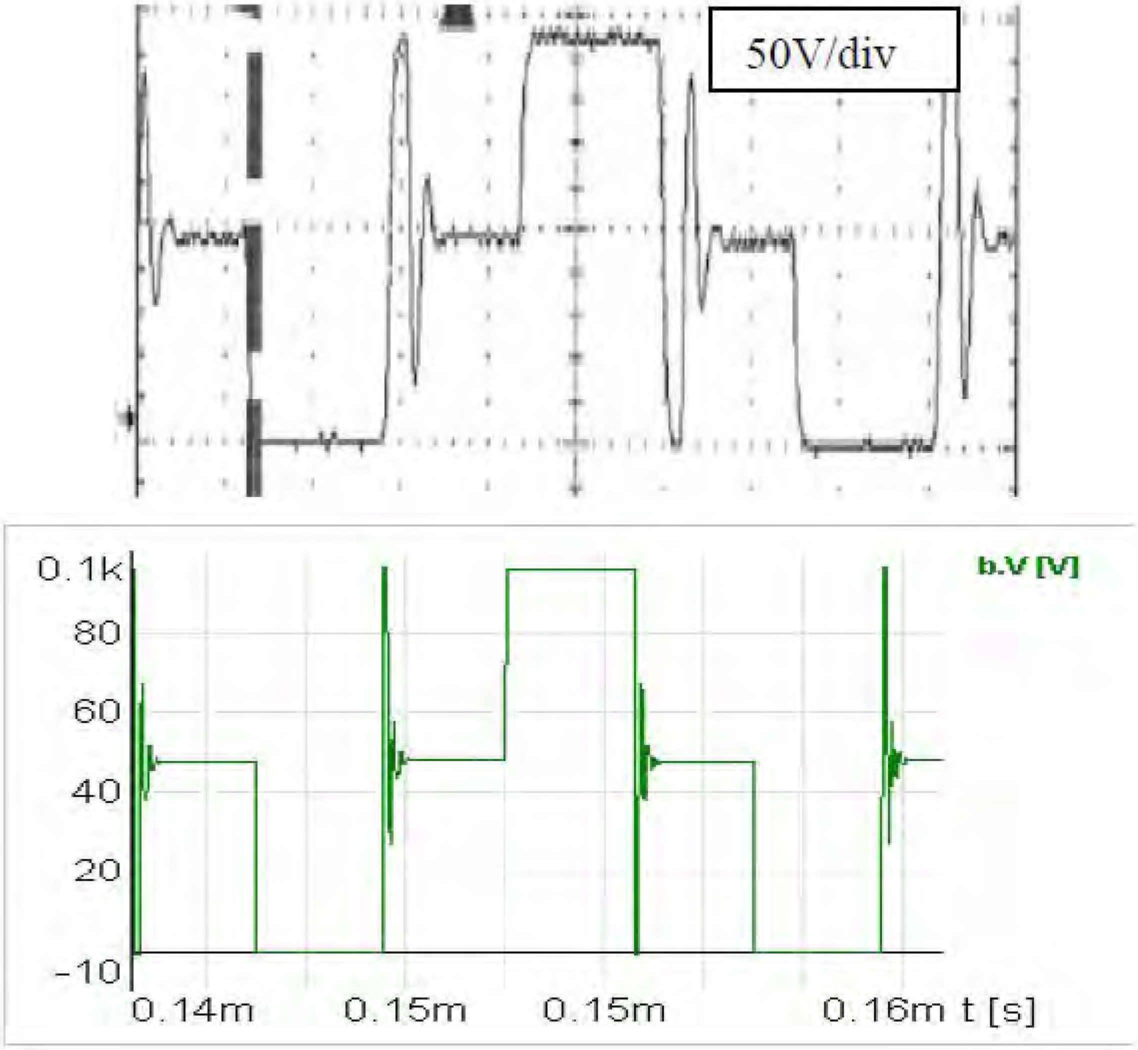


Figure 12. Vds in primary MOSFETs: Measurements (top) vs simulated results (bottom).

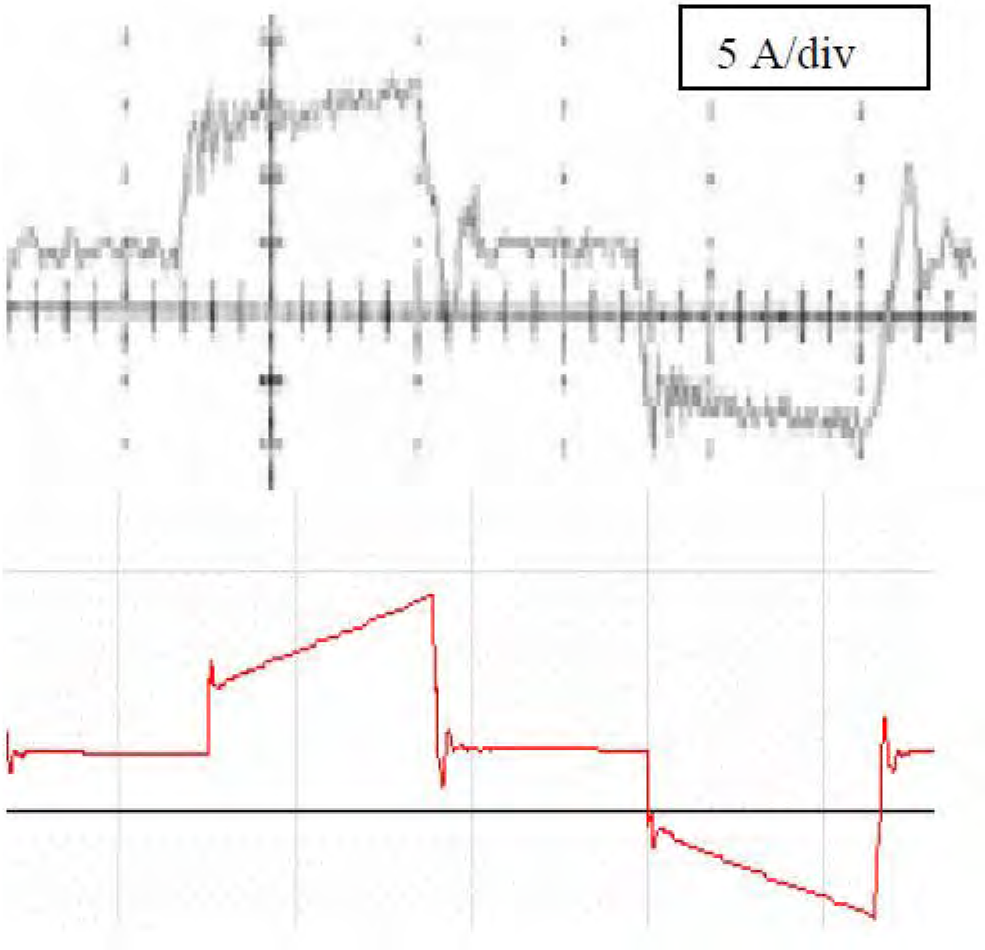


Figure 13. Primary current. Measurements (top) vs simulated results (bottom).

Conclusions

Using PExprt it is possible to quickly generate an accurate frequency-dependent model of integrated magnetics. The primary advantages of PExprt can be summarized as follows:

- PExprt's FEA calculations are accurate, achieving an error below 10% for most of the application range. The effects of geometry and frequency-like fringing flux effect around the air gap area are considered.
- The frequency-dependent model is valid for nonsinusoidal waveforms.
- The couplings between each pair of windings are accurately calculated.
- The solution time is quite fast (average time for common components is below 15 minutes).

**This paper was originally presented at the 2009 Electrical Manufacturing & Coil Winding Expo, held September 29-October 1, 2009 in Nashville, Tenn. For more information, see http://www.emcwa.org/.*

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About The Authors

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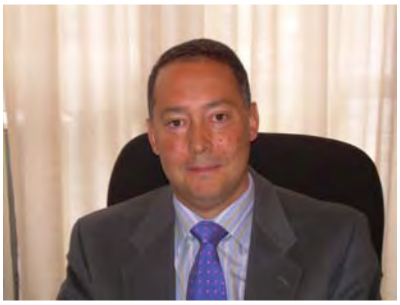

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For further reading on integrated magnetics, see the How2Power Design Guide and search the Design Area category and select the Magnetics subcategory.