

Physics-Based Transformer Modeling for Power Converter Simulation

Introduction

Accurate transformer modeling is essential for reliable power converter simulation. In many traditional SPICE workflows, transformers are represented using linear inductors combined with ideal mutual coupling elements. While this approach is simple and computationally efficient, it assumes constant permeability and linear magnetic behavior. Ferrite cores used in power converters exhibit strongly nonlinear characteristics, including saturation, hysteresis, remanence, and bias-dependent permeability. These effects directly influence magnetizing current, core losses, waveform distortion, inrush behavior, and overall converter efficiency.

A linear SPICE inductor assumes a simple relationship between flux density and magnetic field strength, $B = \mu H$, where permeability μ is constant. However, real magnetic materials do not follow this linear relationship. Their B-H behavior forms hysteresis loops, and permeability varies with operating point, temperature, and DC bias. As switching frequencies increase and converters operate closer to material limits, these nonlinear effects become more pronounced and can no longer be neglected.

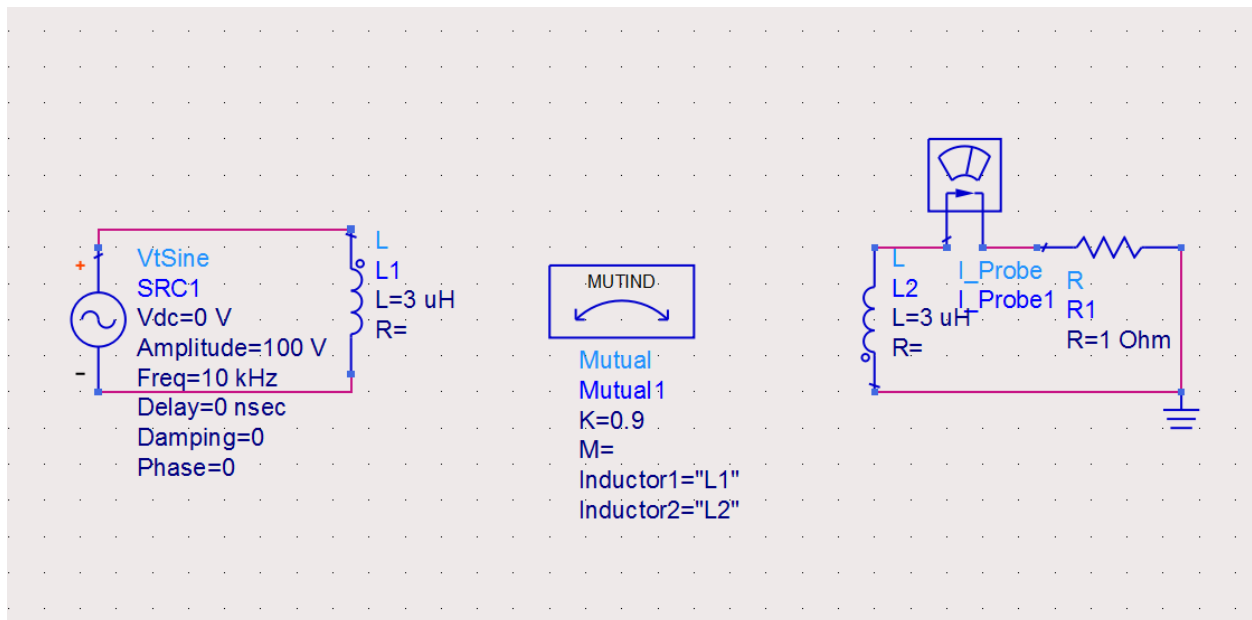


Figure 1. Linear transformer representation using traditional SPICE inductors and ideal mutual coupling

To address this limitation, Keysight's Advanced Design System (ADS) provides physics-based magnetic modeling through the Jiles-Atherton (J-A) model. The J-A model captures full hysteresis behavior, including saturation, coercivity, remanence, and differential permeability variation. By incorporating material physics directly into simulation, designers can more accurately predict magnetizing current, core losses, and nonlinear distortion effects within a power converter.

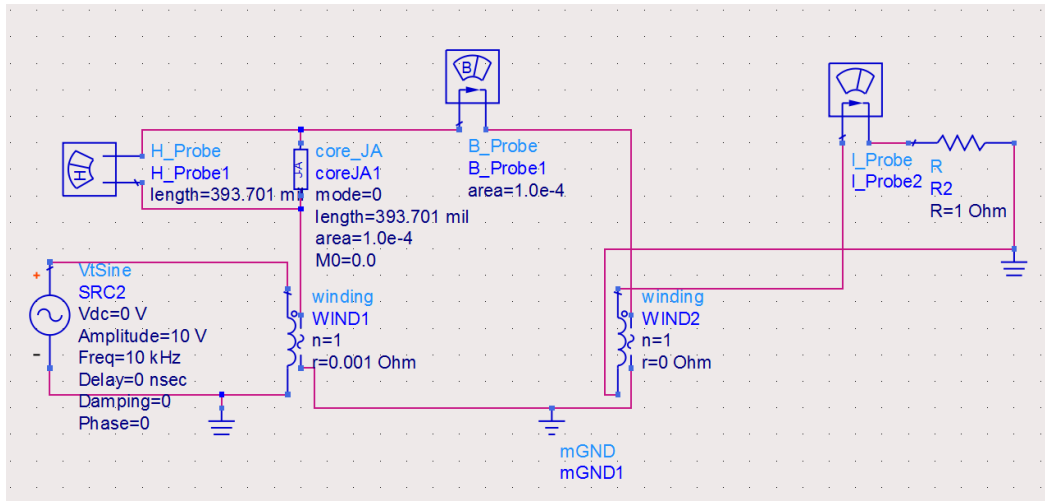


Figure 2. Transformer configuration using a physics-based Jiles-Atherton core and winding model in ADS

This application brief demonstrates how to use the Transformer Designer tool in ADS to create a transformer model based on real datasheet parameters. The example uses a U25/16/6 ferrite core with 3E27 magnetic material. The workflow shows how to extract geometric and magnetic parameters from datasheets, configure a nonlinear core model, generate the transformer cell, and simulate it in a testbench environment.

Accessing the Transformer Designer

The Transformer Designer is accessed from the ADS Schematic window.

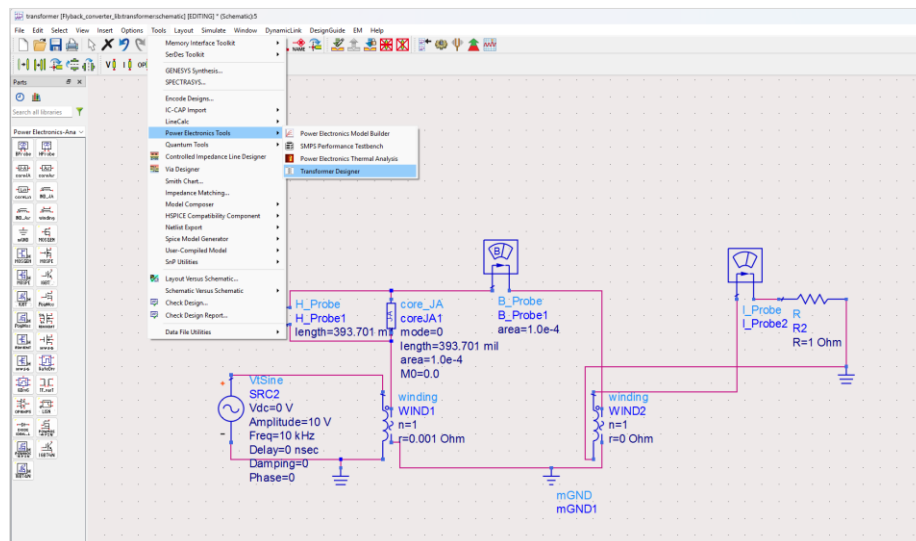


Figure 3. Accessing Transformer Designer from the ADS Schematic window

This opens the graphical interface used to define core geometry, magnetic material properties, winding configuration, and model type.

Example Overview

In this example, a transformer is constructed using a U25/16/6 ferrite core and 3E27 material. The design includes one primary winding and two secondary windings. The goal is to demonstrate how real manufacturer datasheets can be translated into a nonlinear simulation model suitable for power converter analysis.

The workflow begins with extracting effective magnetic path length and cross-sectional area from the core datasheet. Next, magnetic material behavior is defined either by selecting built-in library material or by adding a new material based on digitized B-H curve data. The transformer is then configured in the designer interface and automatically generated as an ADS cell that can be placed into a schematic for simulation.

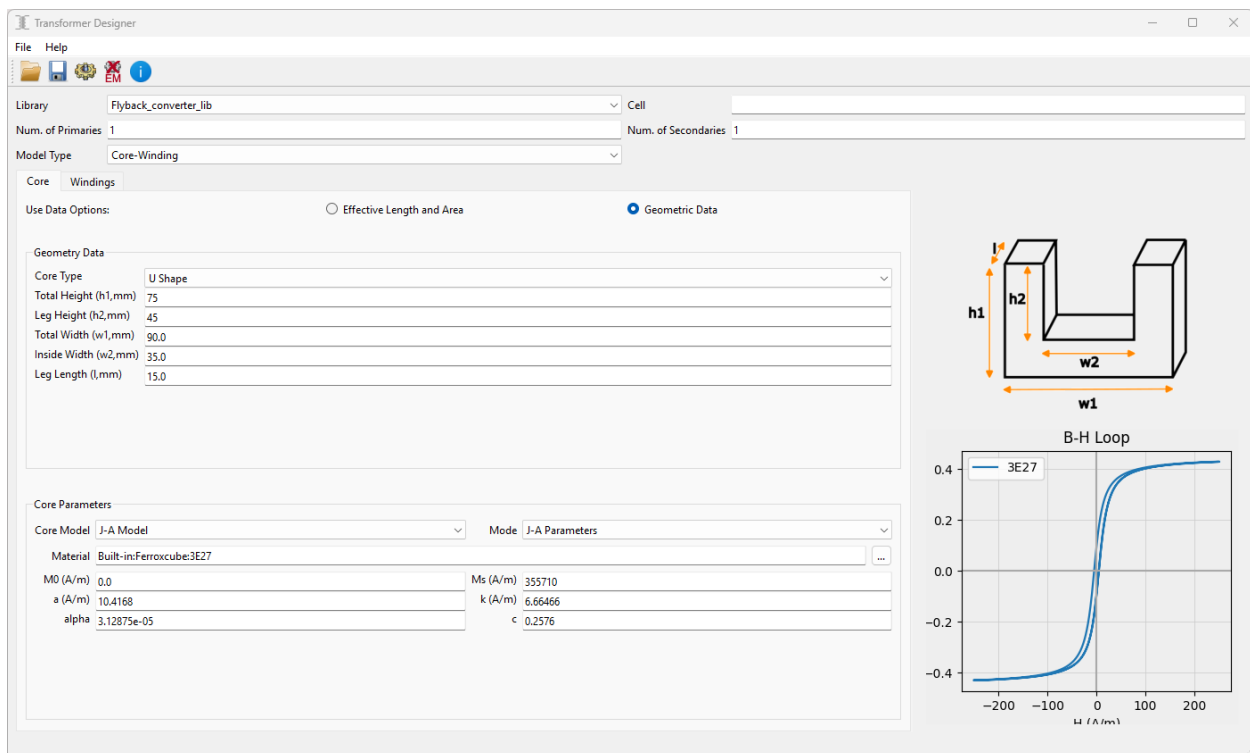


Figure 4. Transformer Designer Graphical User Interface (GUI)

Extracting Parameters from Datasheets

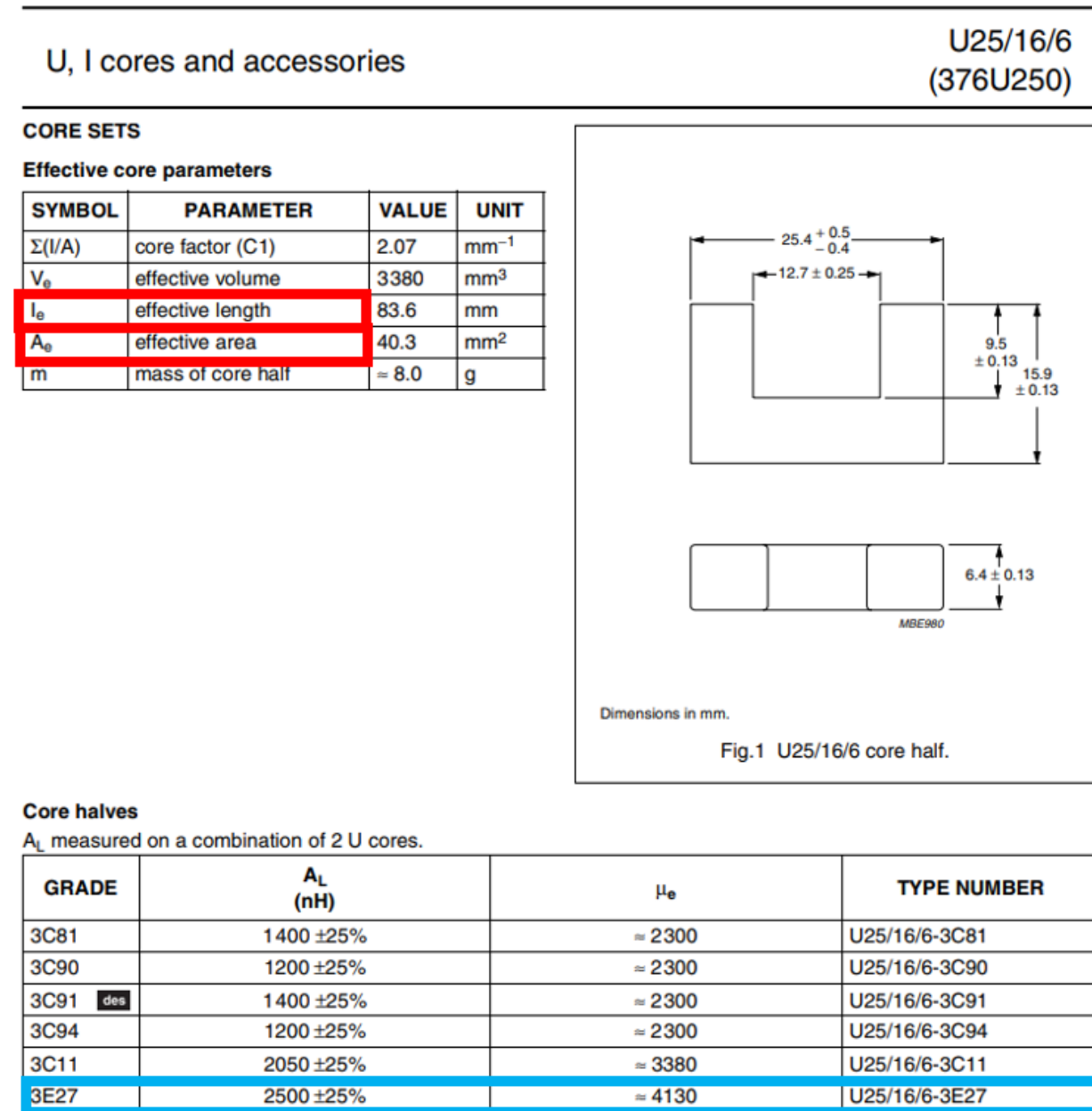


Figure 5. U25/16/6 ferrite core datasheet (Source: Ferroxcube ¹)

¹ <https://ferroxcube.home.pl/prod/assets/u25166.pdf>

The U25/16/6 datasheet provides the effective magnetic path length l_e and effective cross-sectional area A_e . These parameters are required when defining the core using the Effective Length and Area option in the Transformer Designer. For this example, the values are:

Effective length $l_e = 83.6 \text{ mm}$

Effective area $A_e = 40.3 \text{ mm}^2$

These quantities determine the magnetic flux density for a given magnetomotive force and are essential for accurate nonlinear modeling.

Magnetic Material: 3E27 Ferrite

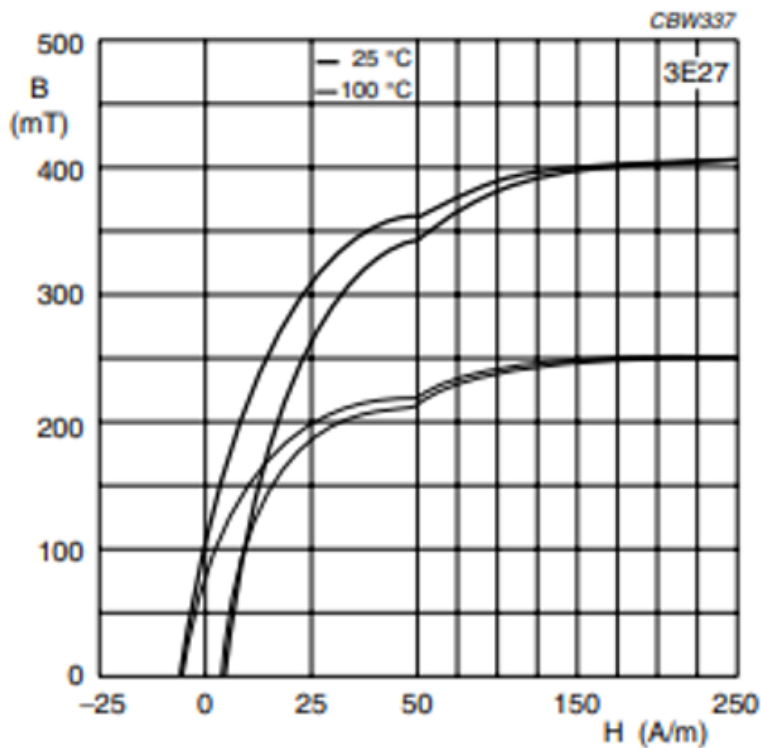


Figure 6. B-H hysteresis loop of 3E27 ferrite material (Source: Ferroxcube ²)

The magnetic behavior of the transformer is governed by the ferrite material. For 3E27, the datasheet provides B-H loop data, initial permeability, coercive field strength, and saturation flux density. These characteristics define how the material responds to excitation and determine whether the core remains in the linear region or enters saturation during operation.

If the material is available in the built-in library, it can be selected directly in the Core Parameters section. The corresponding Jiles-Atherton parameters and B-H loop are automatically loaded into the model.

² <https://ferroxcube.home.pl/prod/assets/3e27.pdf>

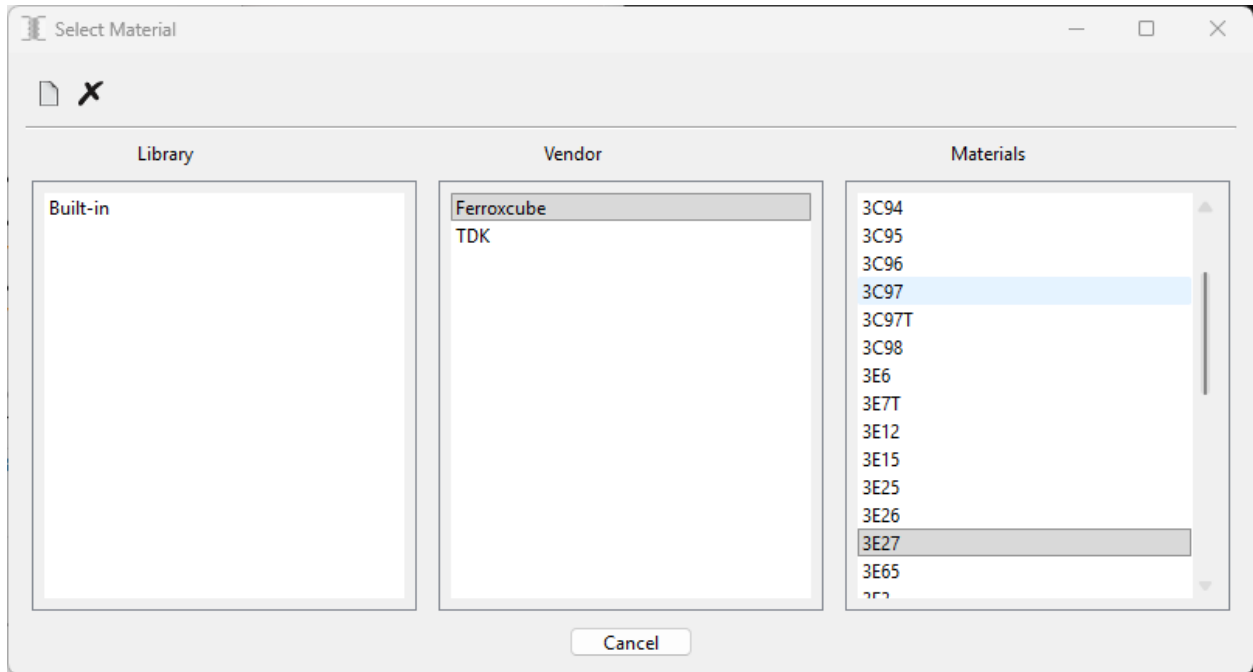


Figure 7. Built-in core material library in ADS Transformer Designer

If the material is not available, it can be added using digitized B-H loop data. The data file must contain two comma-separated columns representing H (A/m) and B (T or mT), with ascending and descending curves separated by a blank line. Once loaded, ADS extracts the J-A parameters that define the nonlinear hysteresis behavior. The extracted material can then be stored in the workspace library for future reuse.

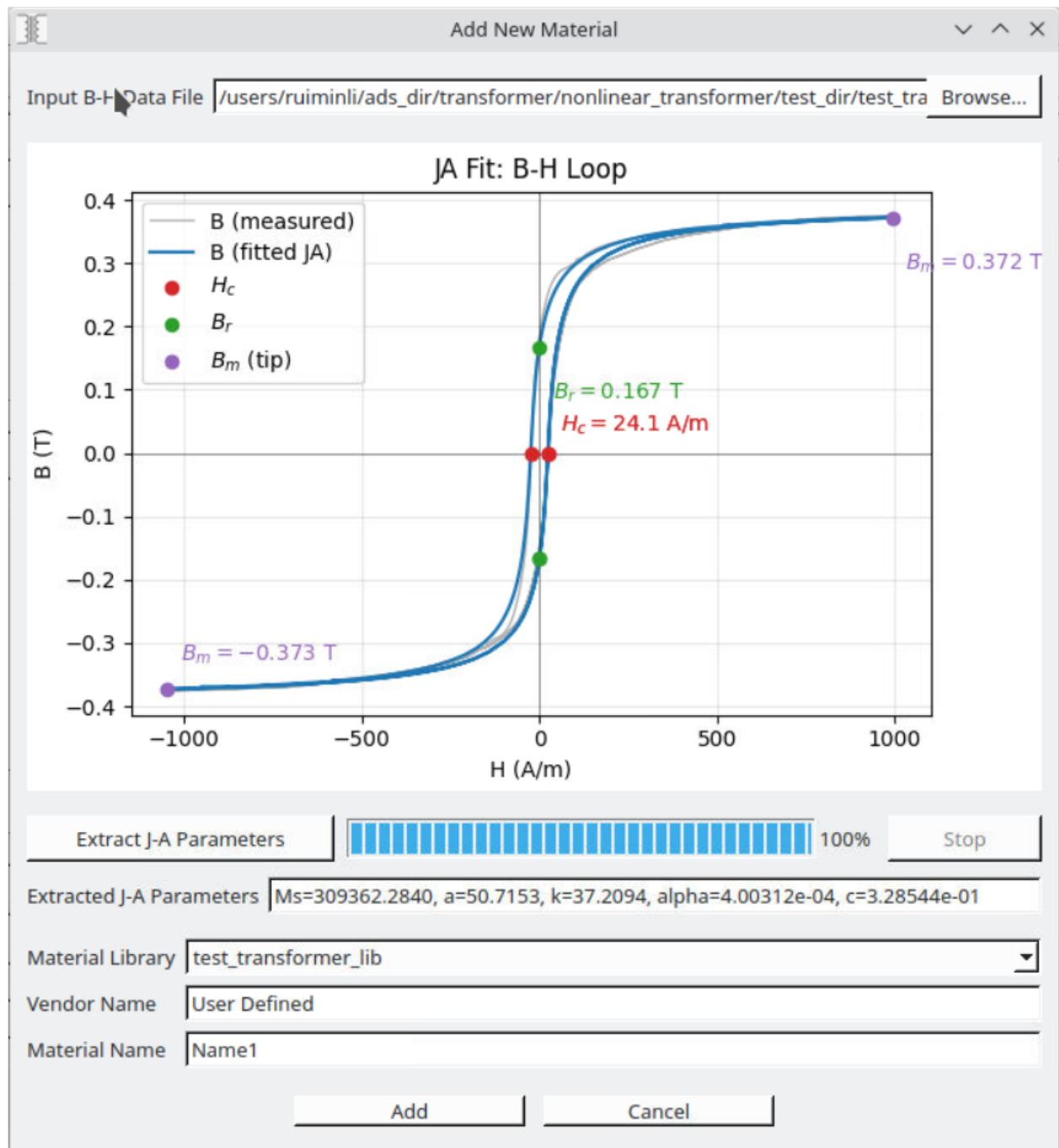


Figure 8. Automatic extraction of Jiles–Atherton (J-A) parameters from B-H loop data

Computing B-H Model Parameters

When using the Two-Curve B-H loop mode, the nonlinear parameters are derived directly from the digitized curve. The magnetization M used in the model is related to flux density B and magnetic field H by:

$$M = \frac{B}{\mu_0} - H$$

where μ_0 is the permeability of free space. The differential permeability is obtained from the slope of the B-H curve, and the relative differential susceptibility is derived accordingly. By identifying key points on the loop such as remanence, coercive field, and maximum operating point, the required model parameters (K_{in} , H_m , M_m , K_m , M_r , H_c , etc.) can be calculated.

This approach ensures that the simulated core reproduces the actual hysteresis behavior observed in measurement, including saturation and bias-dependent inductance.

Configuring the Transformer in ADS

Within the Transformer Designer interface, the user defines the target library and cell name, specifies the number of windings, and selects the modeling approach. Three modeling options are available: a simple mutual inductance model, a core-winding model, and a core-winding model with layout parasitics.

The mutual inductance model uses linear inductors with ideal coupling and is suitable for conceptual studies where nonlinear magnetic effects are not critical. The core-winding model incorporates either a linear or Jiles-Atherton core description, allowing accurate modeling of hysteresis and saturation. The layout-parasitic option further integrates EM-extracted parasitics to capture high-frequency effects associated with winding geometry and substrate interactions.

For this example, the core-winding model with nonlinear J-A material behavior is selected. The effective length and area are entered in the Core tab, and the 3E27 material is applied. In the Windings tab, one primary and two secondary windings are defined, including number of turns and resistance per turn. The winding direction is specified to ensure correct polarity between dotted terminals.

Generating the Transformer Cell

After all parameters are defined, clicking the Run button generates the transformer cell. ADS creates both a schematic representation of the internal magnetic structure and a reusable symbol for placement in system-level schematics. The generated cell encapsulates the nonlinear core model, winding resistances, coupling, and optional leakage elements.

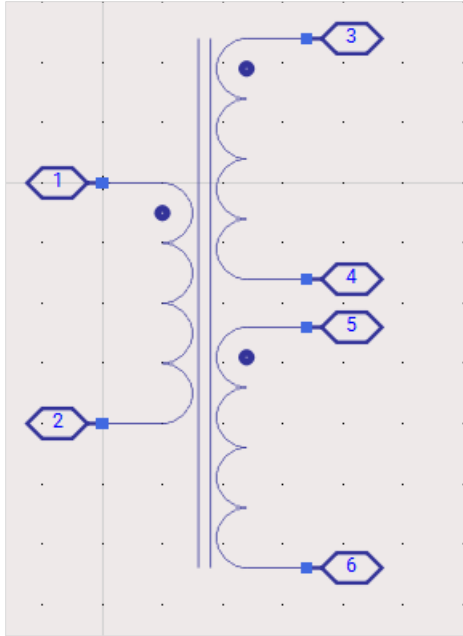


Figure 9. Nonlinear Core Model Output Symbol

Building and Simulating a Testbench

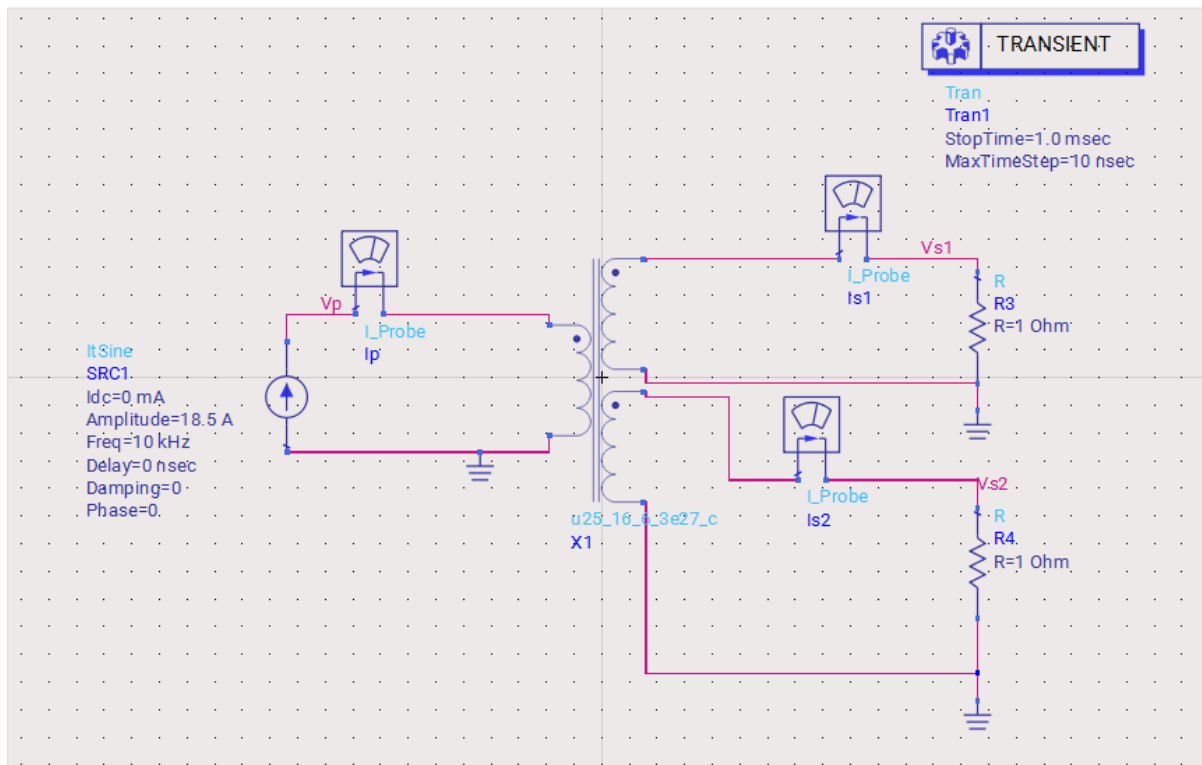


Figure 10. Test Bench for Nonlinear Core Model Validation

To evaluate performance, the generated transformer symbol is placed in a new schematic. A voltage source excites the primary winding, and a resistive load is connected to the secondary. Voltage and current probes are used to observe magnetizing current and output behavior.

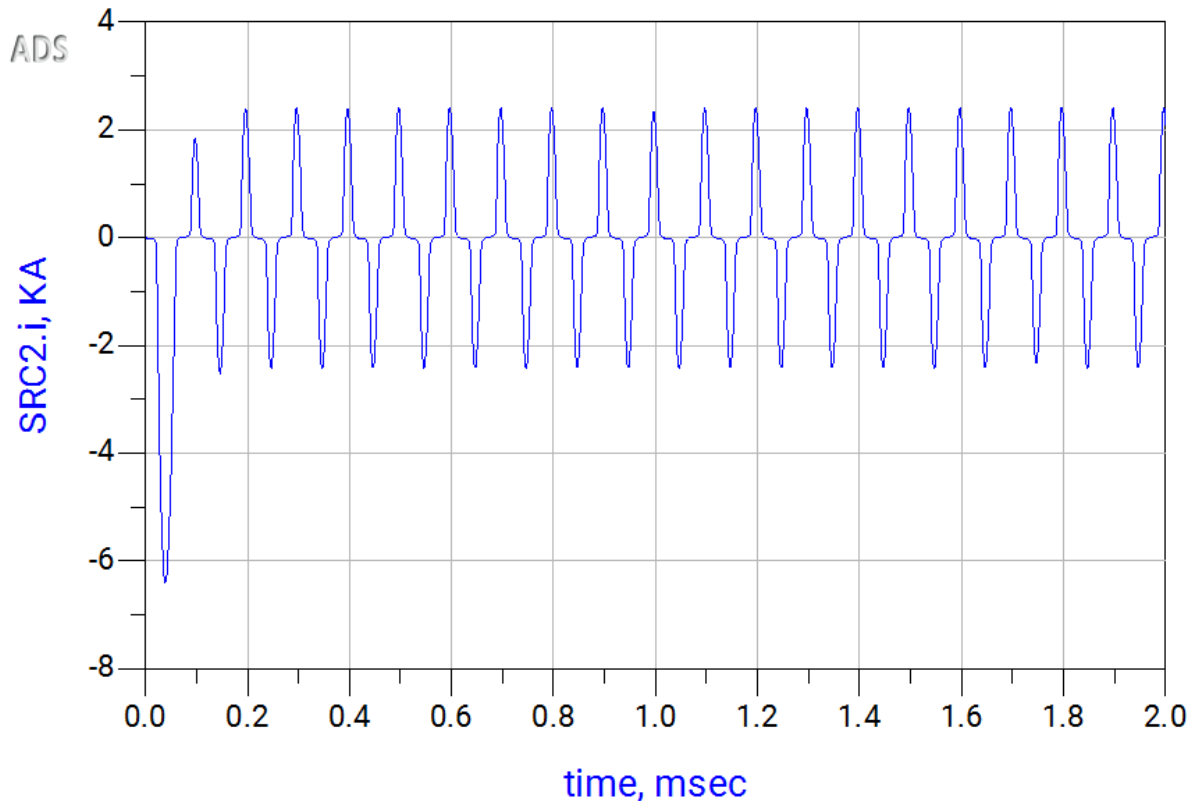


Figure 11. Saturation Effect Under Large-Signal Excitation

A transient simulation verifies the turns ratio and reveals nonlinear effects. Unlike a linear SPICE model, the J-A based transformer exhibits realistic magnetizing current distortion as the core approaches saturation. The waveform shape reflects hysteresis behavior and bias-dependent permeability, providing more predictive insight into real converter performance.

Core-Winding Model with Layout Parasitics

The Core-Winding with Layout Parasitics mode is the highest-fidelity Magnetics Designer workflow because it combines two effects that are often modeled separately: the nonlinear magnetic behavior of the transformer core and the frequency-dependent electrical behavior created by the physical winding layout. The result is a physically consistent transformer model that can be used directly in the surrounding power-converter schematic rather than approximating the transformer with ideal coupling and manually added lumped parasitics.

One Workflow from Physical Definition to a Simulation-Ready Model

Magnetics Designer links the core definition, planar winding geometry, PCB substrate, full-wave electromagnetic analysis, and circuit-model generation. The nonlinear core is represented with the Jiles–Atherton formulation so the circuit simulation can reproduce hysteresis, saturation, remanence, and operating-point-dependent permeability. In parallel, the PCB winding structure is generated in 3D and analyzed electromagnetically to characterize the layout-dependent behavior across frequency.

Magnetics Designer in ADS 2027

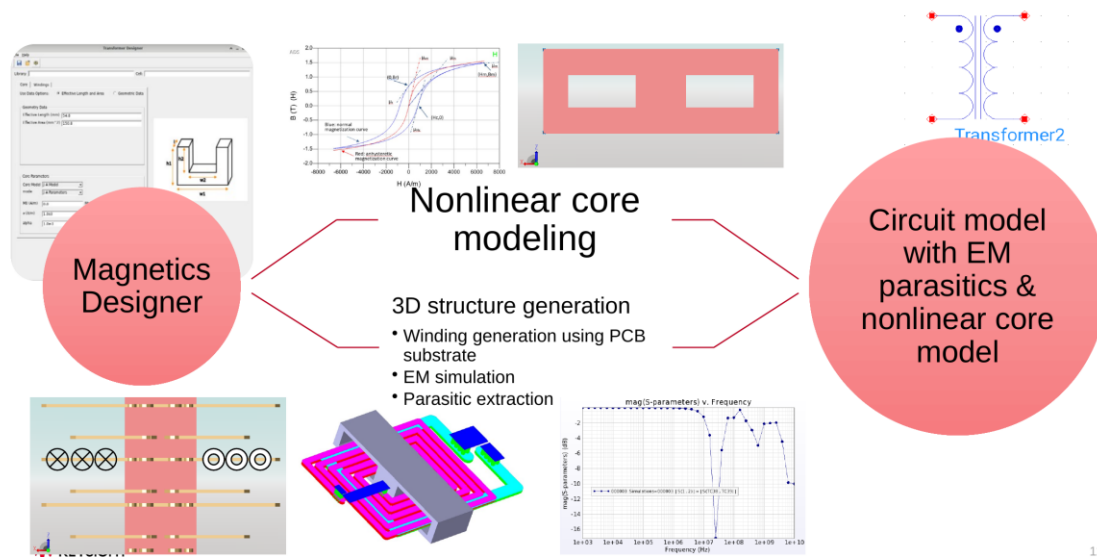


Figure 12. Magnetics Designer combines nonlinear core modeling, 3D winding generation, EM simulation, and parasitic extraction.

Layout-Aware Planar Transformer Definition

The designer can begin with a predefined transformer structure and then define the core dimensions, substrate stack-up, conductor material and thickness, winding shape, number of turns, layer assignment, winding stack, and terminal locations. A 3D preview provides a direct check of the physical configuration before extraction. This is particularly valuable for planar magnetics, where layer placement, spacing, conductor dimensions, and primary-to-secondary arrangement determine leakage paths, coupling, AC resistance, and capacitive interaction.

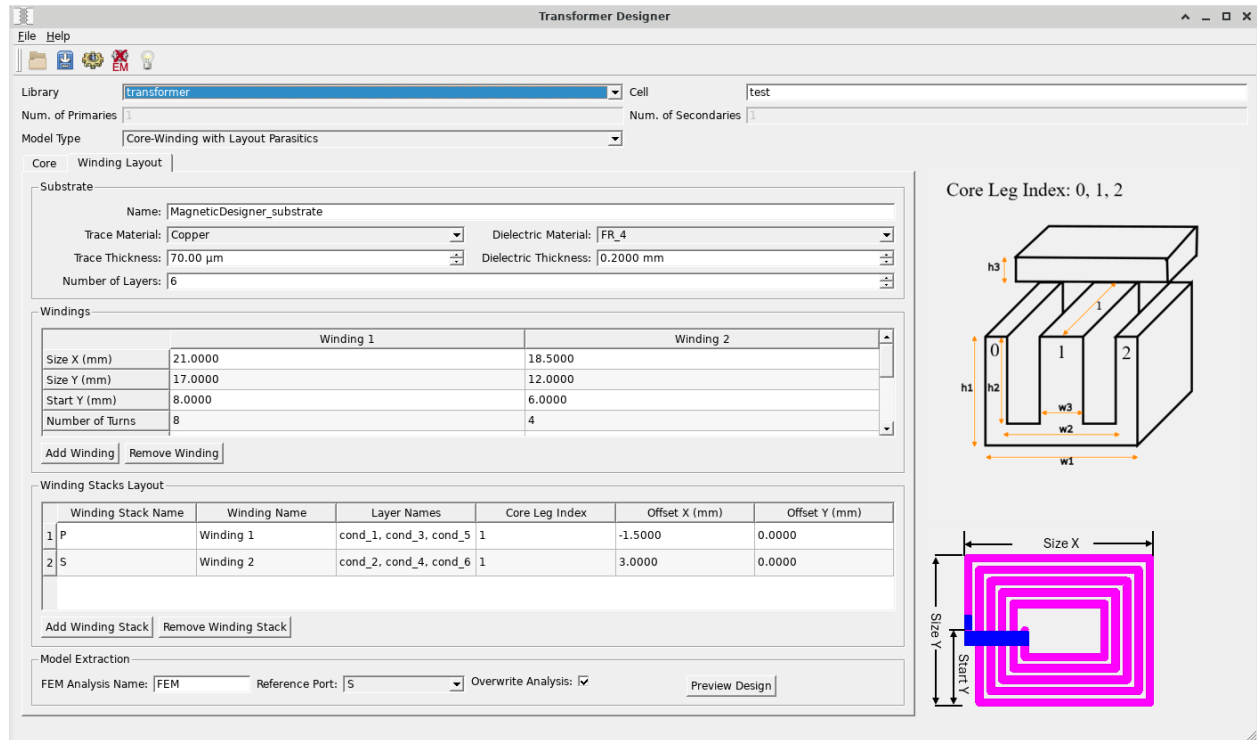


Figure 13. Core, substrate, winding geometry, stack-up, and terminal definitions used to generate the 3D planar transformer.

Automatic Combination of Core Physics and EM-Extracted Parasitics

After the structure is analyzed, Transformer Designer automatically creates a reusable schematic symbol and circuit netlist. The generated model combines the nonlinear core and winding representation with the broadband parasitic network extracted from the 3D layout. This preserves the schematic-level usability of a transformer component while embedding the physical effects of the implemented structure, including leakage and coupling behavior, frequency-dependent winding loss, and inter-winding interaction. The model can therefore replace an ideal or simplified transformer in an existing converter testbench without requiring the designer to manually assemble separate magnetic and parasitic submodels.

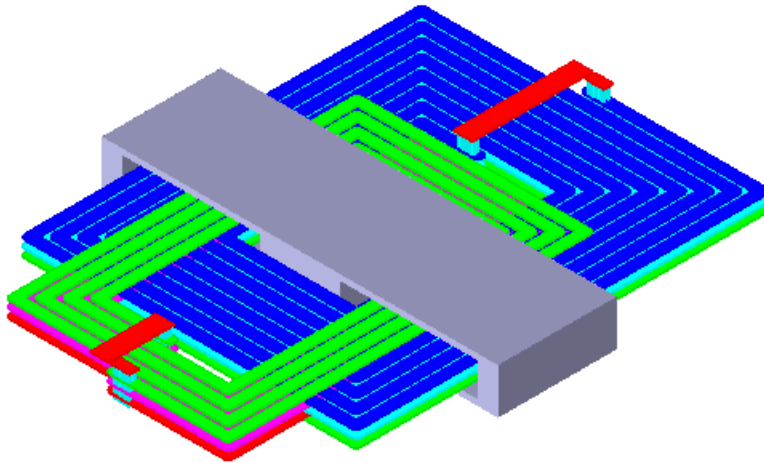


Figure 14. Automatically generated transformer symbol and netlist combining the nonlinear core model with the EM parasitic network.

Design Insight Delivered Earlier

By bringing the physical transformer implementation into the same ADS testbench as the switching devices and control network, engineers can evaluate magnetizing-current stress, saturation margin, waveform distortion, winding loss, switching ringing, and output regulation before hardware is built. This supports earlier comparison of core material, core size, turns count, PCB stack-up, conductor geometry, and winding arrangement, helping reduce late-stage model tuning and hardware rework while improving correlation between circuit simulation and the realized planar transformer.

Conclusion

This application note demonstrated how to construct a physics-based transformer model in ADS using real datasheet information. By replacing simplified linear inductors with a nonlinear Jiles-Atherton core model, designers can capture saturation, hysteresis, and DC bias effects that significantly impact power converter operation.

For modern power electronics design (particularly in flyback, forward, and resonant converters) accurate magnetic modeling is essential. Physics-based transformer models improve confidence in simulation results, reduce design iterations, and enable higher-fidelity prediction of efficiency and waveform integrity.

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