

SMPS Design from Systems to Component: shortening the cycle with simulation

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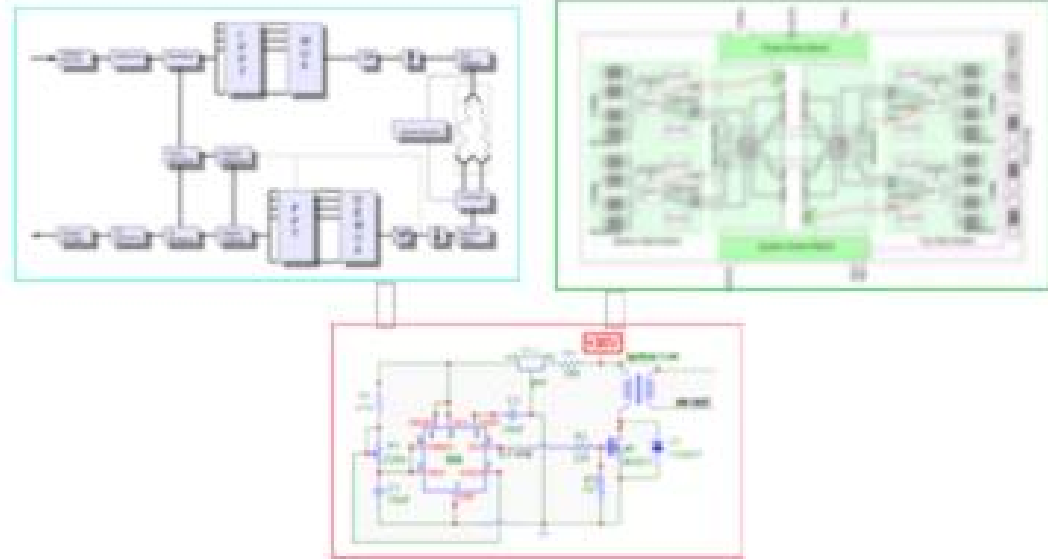


LeadingInsight

Application Workshops for High-Performance Design

Simulation of the complete system

- Multiple domains
 - Mechanical
 - Hydraulic
 - Electrical
 - Thermal
- Different levels of abstraction
 - Conceptual
 - Behavioral
 - Component level

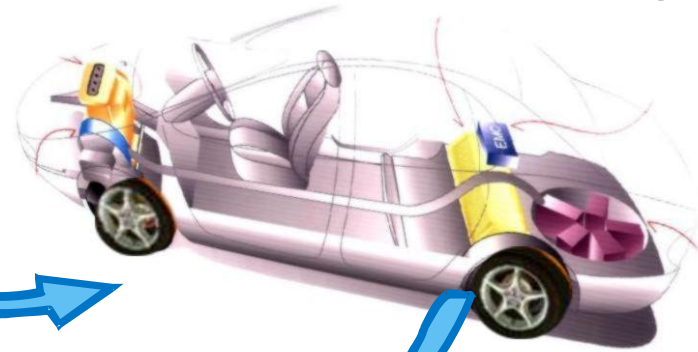


From the system level to the subsystem level

Complete system

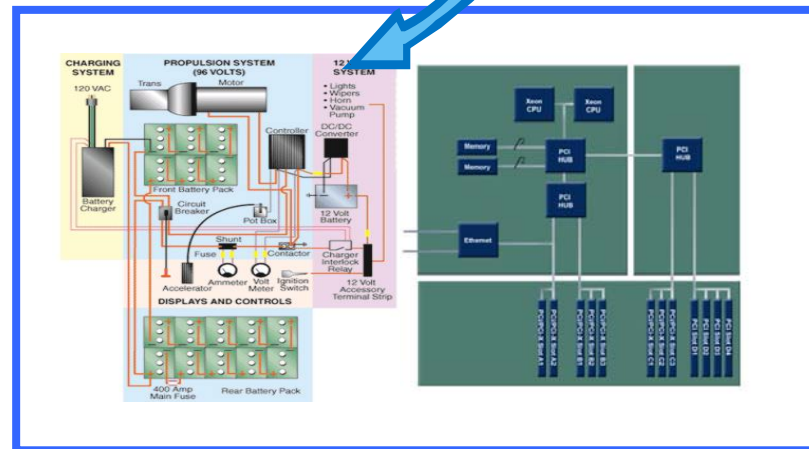


Power system



The power system can not be modeled as an ideal system

- The power system involves:
 - Losses
 - Dynamic limitations
 - Temperature issues
 - Failures



System and subsystem design

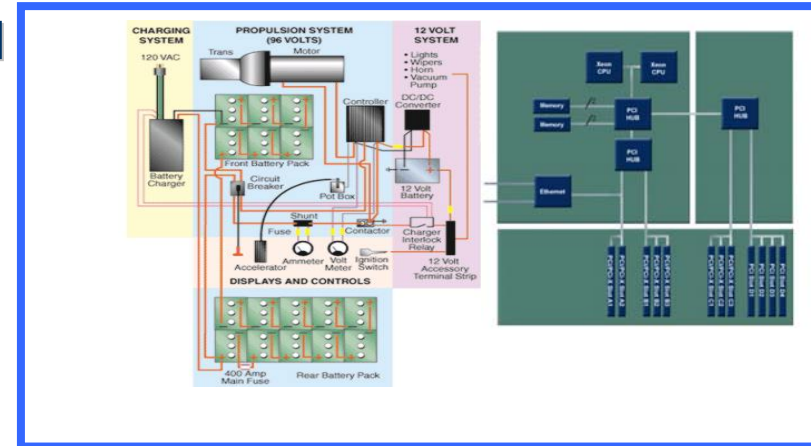
The power system architecture is defined based on the system requirements

The architecture can be implemented with:



Commercial modules

There is a wide list and are already tested



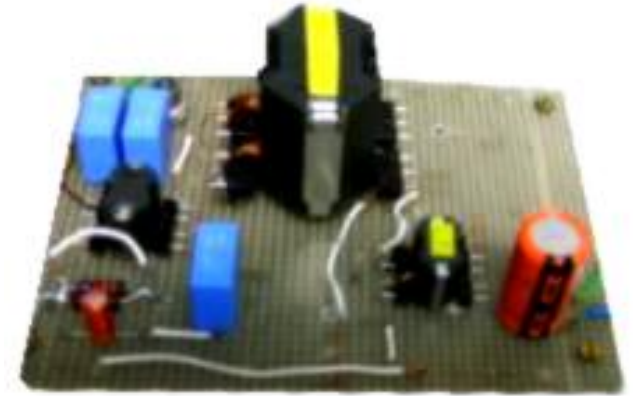
Custom made modules

Are developed to meet specific requirements

DC/DC converters: device level

Custom made modules implementation steps:

- 1 Design
- 2 Model development (Component level)
- 3 Module simulation
- 4 Physical implementation
- 5 Verification



Component level model used in the complete system simulation

Advantages

- Accurate
- Provides detailed information

Disadvantages

- Slow
- Provides unnecessary information

DC/DC converters: system level

Commercial modules implementation steps:

- 1 Select based in the datasheet information
- 2 Physical verification



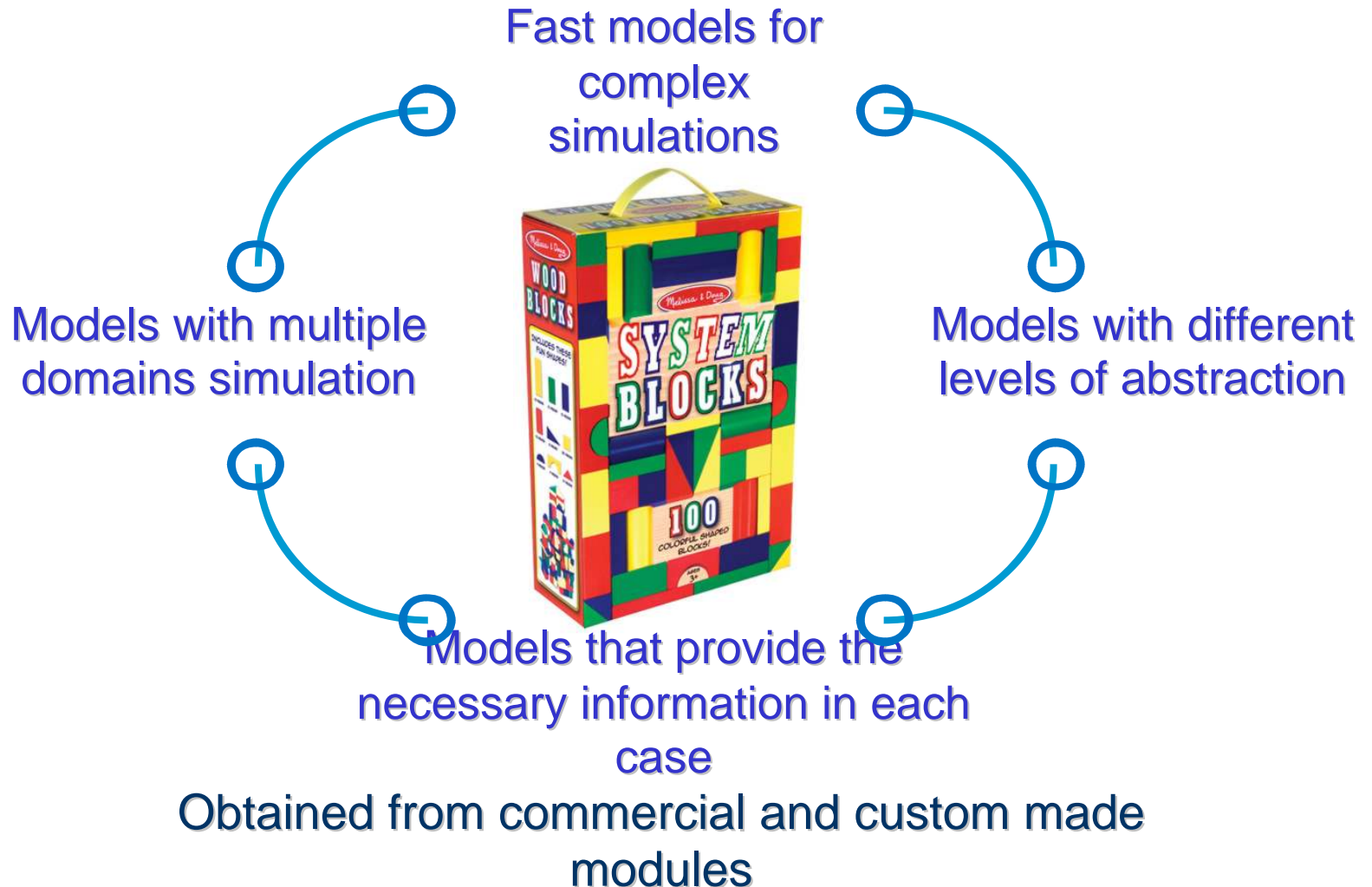
Commercial converters

Disadvantages

- In most cases component or average level model can not be obtained

System level simulation

Power systems simulation require



Example: Airbus A400M



Dimensions

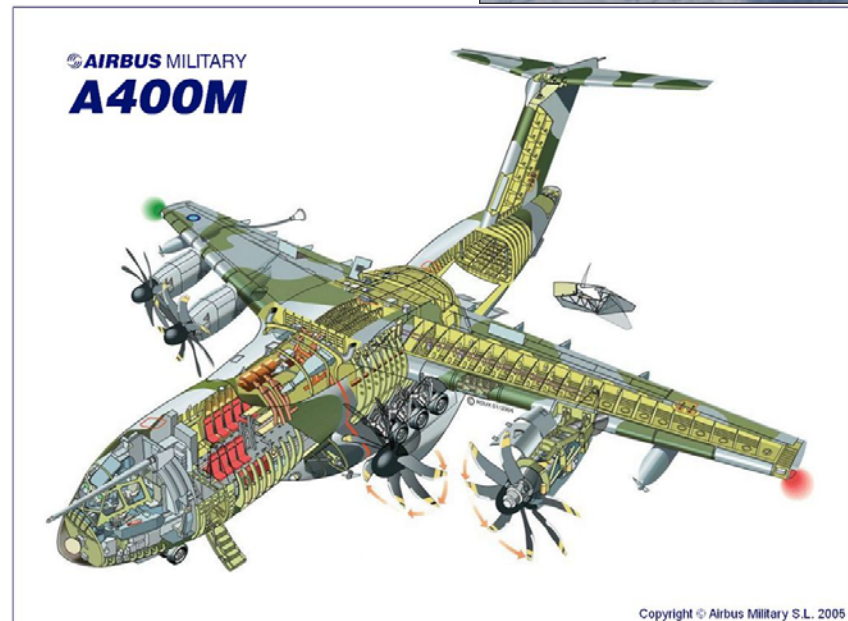
| | |
|----------------|--------|
| Overall Length | 45.1 m |
| Wing Span | 42.4 m |
| Overall Height | 14.7 m |

Cargo Box Dimensions

| | |
|-------------------------|---------|
| Length (excluding ramp) | 17.71 m |
| Ramp Length | 5.40 m |
| Width | 4.00 m |
| Height | 3.85 m |
| Height (aft of wing) | 4.00 m |

Weights (2.25g)

| | |
|----------------------|---------|
| Max. Take-off Weight | 136.5 t |
| Max. Landing Weight | 120 t |
| Max. Payload | 37 t |
| Total Internal Fuel | 47.7 t |



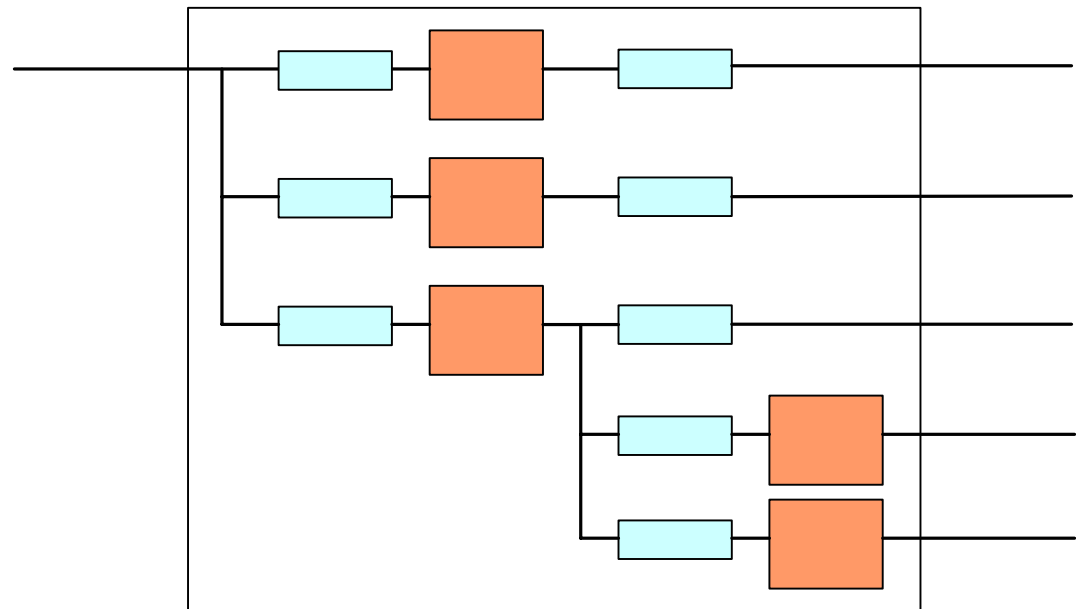
Subsystem design (Airbus A400M)

Converters

- +28V to +48V
- +28V to +15V
- +28V to +5V
- +5V to +3.3V
- +5V to -5V

Filters

- Eight filters

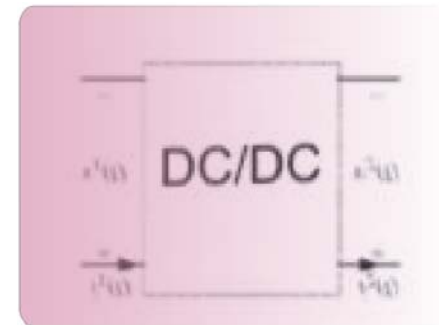
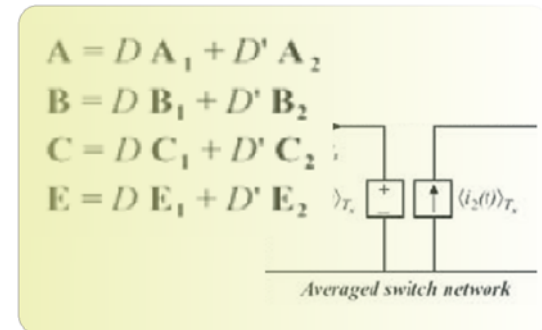
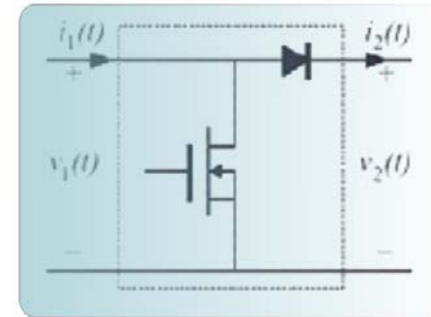


Power sub-system example

Modeling approaches

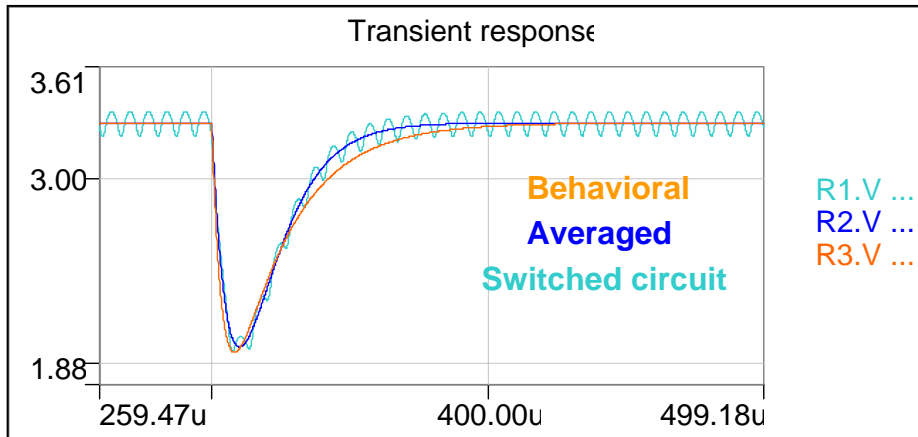
DETAIL

- Switch level models
 - Are based directly on the structure
 - Provide information for each component in every switching cycle
- Averaged models
 - Switching information is lost but structure is kept
 - There are several techniques like:
 - State space averaging
 - Averaged switch modeling
- Behavioral models
 - Based on the input-output behavior
 - The model is a black box, the real structure is lost



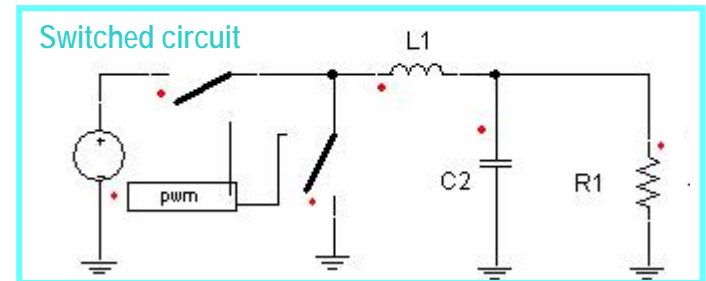
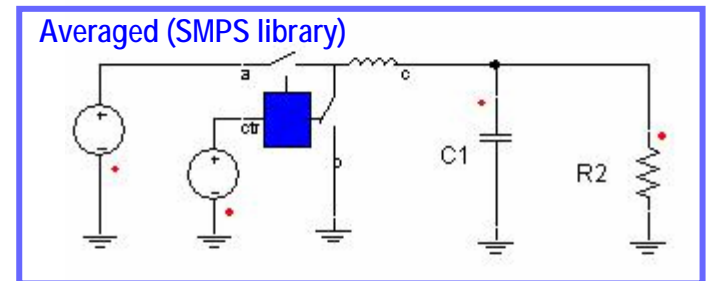
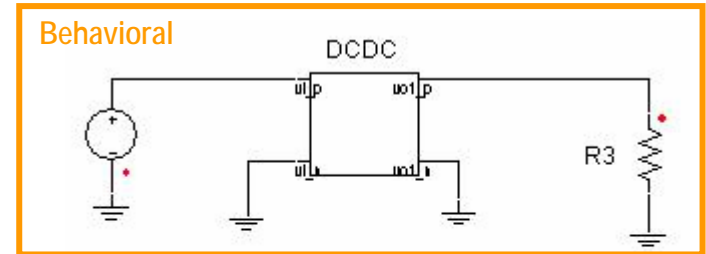
SPEED

Modeling approaches



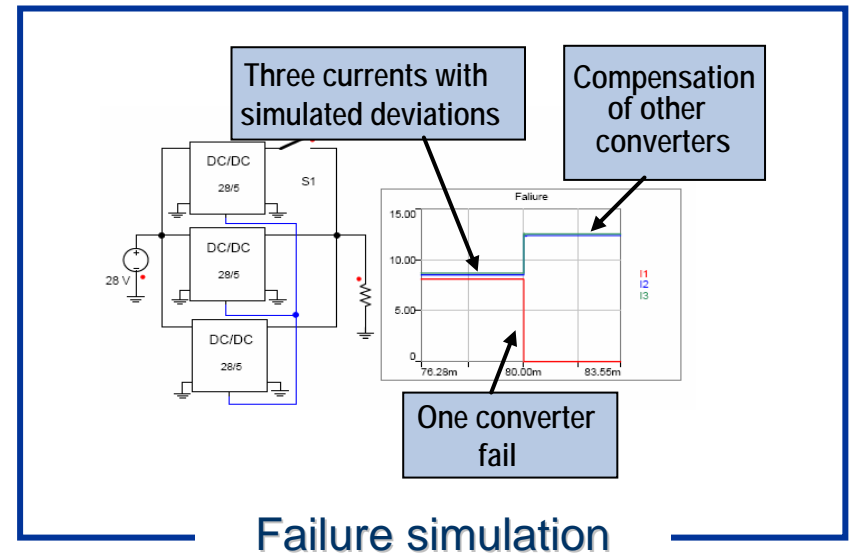
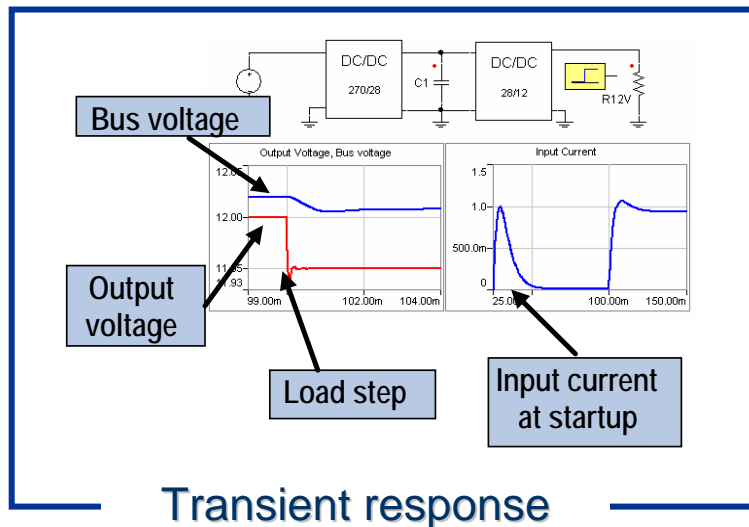
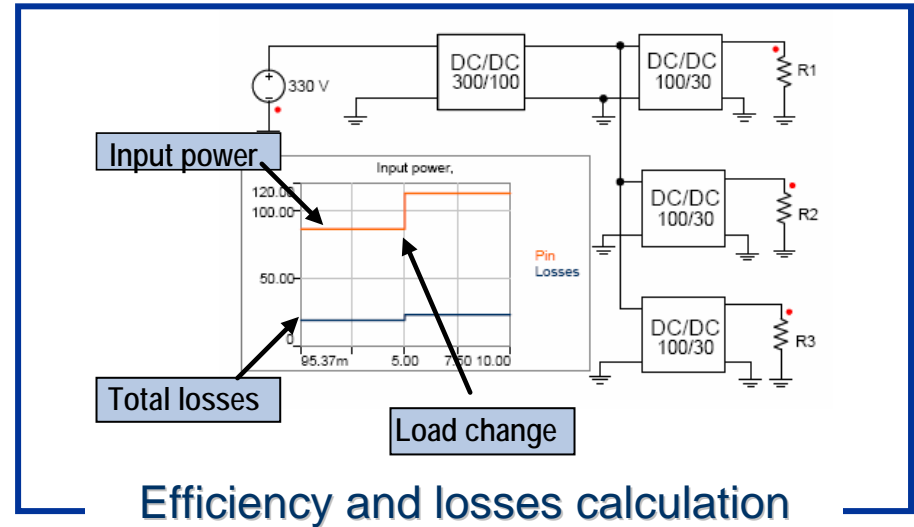
Comparison of a switch level circuit, an averaged model and a behavioral approximation

SIMPLORER®



Behavioral models capabilities

- Behavioral models common uses
 - Efficiency calculation
 - Transient responses
 - Temperature calculation
 - Stability
 - Failures simulation

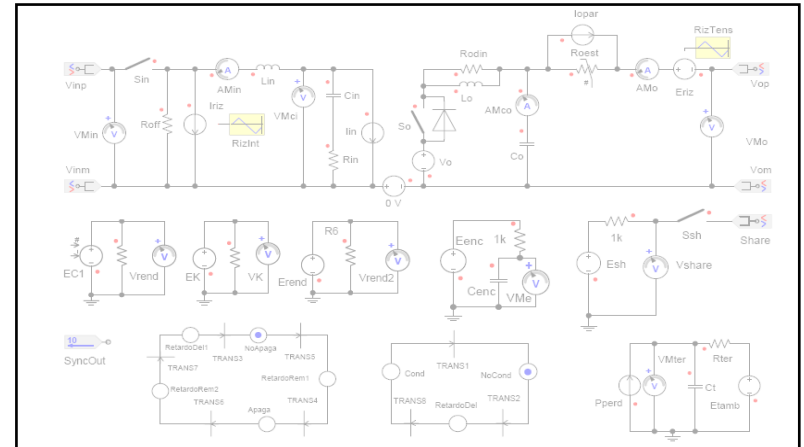


Behavioral model advantages

Is not necessary to know the real structure

Models can be obtained from commercial and custom made converters

The model can be adapted to the get required information for each test.



Circuit implementation

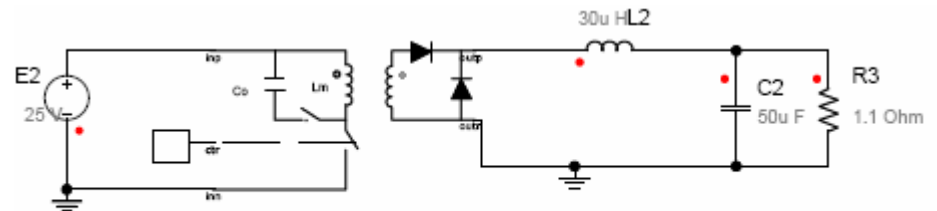
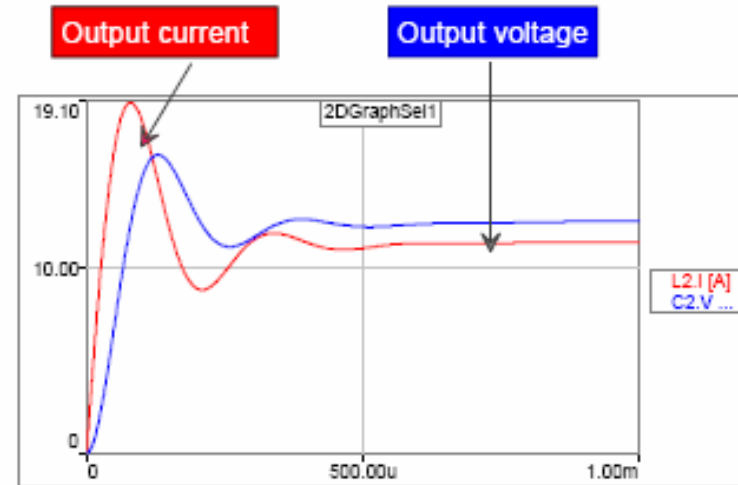
```
begin
sec:=Rest1Sec;
while (Io1>Rest1Points(sec+1) and sec<Rest1Points'right-1)or(Io1<Rest1Points(
if Io1>Rest1Points(sec+1) and sec<Rest1Points'right-1 then
sec:=sec+1;
end if;
if Io1<Rest1Points(sec) and sec>Rest1Points'left then
sec:=sec-1;
end if;
end loop;
Rest1Sec<=sec;
end process;
break on Rest1Sec;
TempEfficiency==(EfficiencyM(EfficiencySec) *Io1+EfficiencyC(EfficiencySec));
if TempEfficiency>1.0 use
Efficiency==1.0;
elseif TempEfficiency<0.0 use
Efficiency==0.0;
else
Efficiency==TempEfficiency;
end use;
```

VHDL-AMS implementation



Averaged model advantages

- 🔧 The effect of each component in the design can be analyzed
- 🔧 Provide a more accurate dynamic behavior
- 🔧 Plus all information of behavioral models



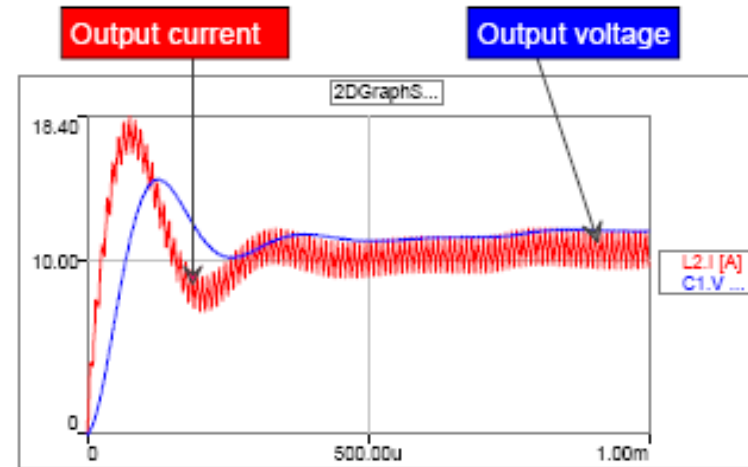
SMPS Library

SIM  **plorer**®

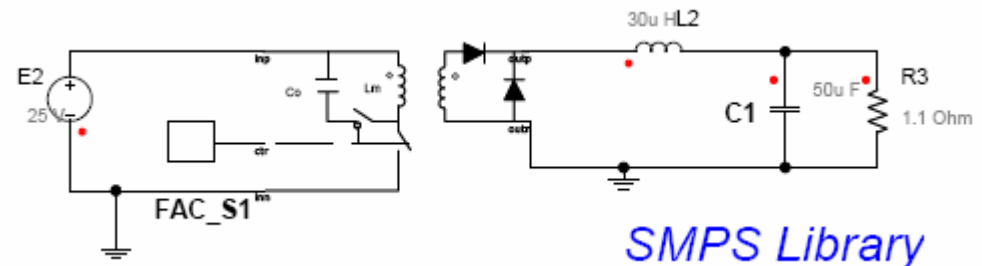
Averaged Forward with active clamp
from SMPS library

Switched model advantages

- Provides information about the instantaneous stresses for each component



- EMI effects can be analyzed



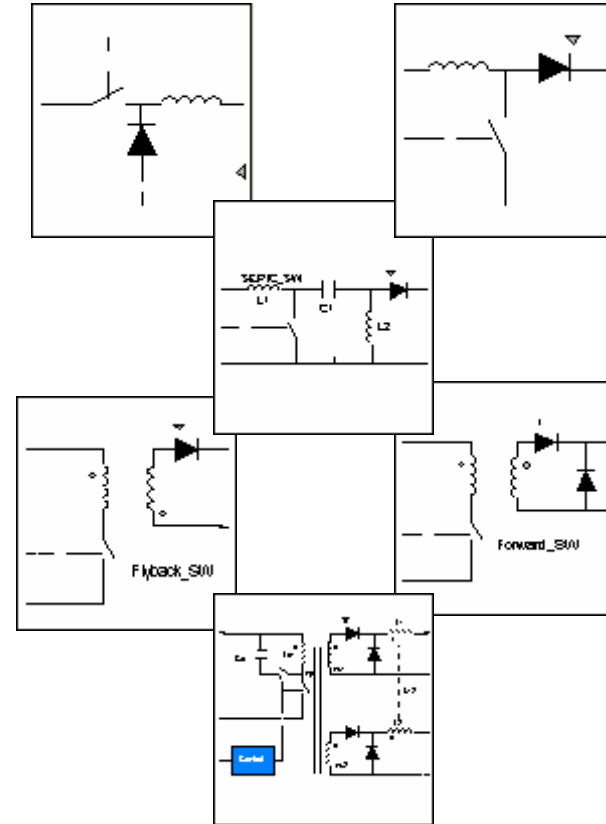
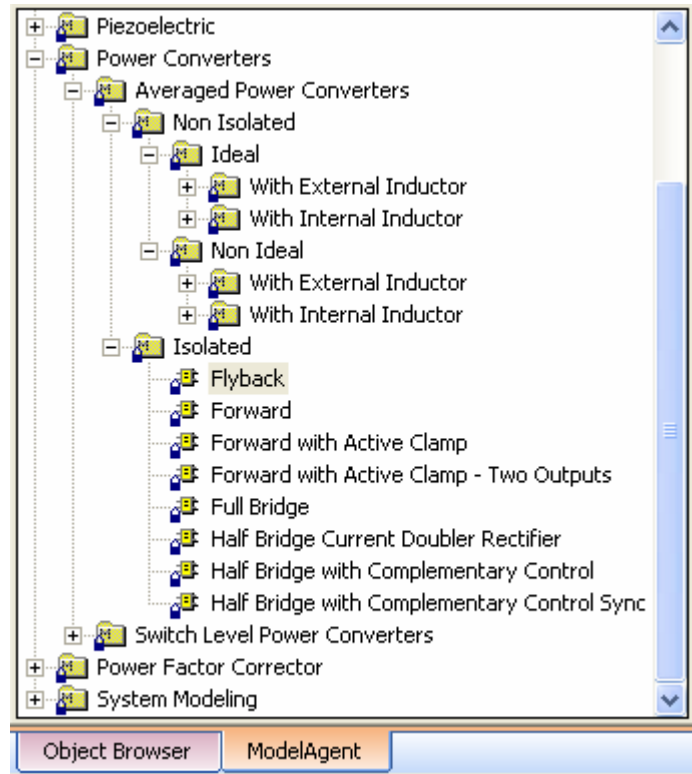
Switch level Forward with active clamp from SMPS library

- Plus all information in behavioral and averaged models

SIMPLORER

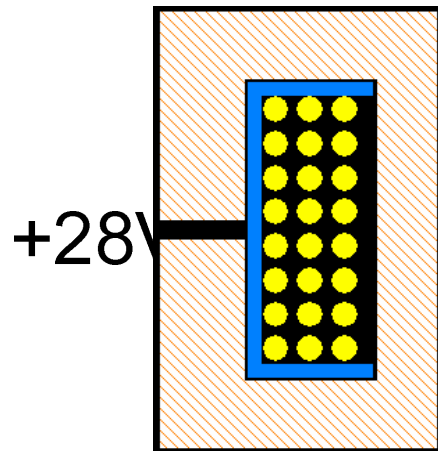
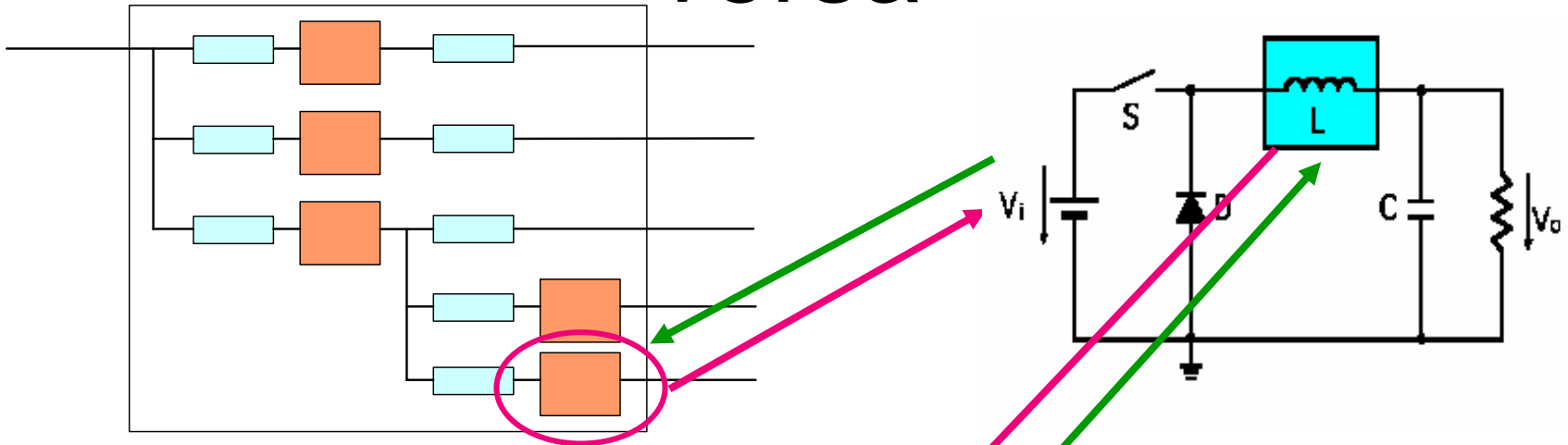
Simplorer SMPS library

SMPS library contains a wide list of averaged and switch level models



SIMPLORER

From System to Device and vice-versa



Filter

DC/DC

Filter

DC/DC

Device Level with PExprt. Step 1: Design

Waveforms | Design Inputs | Modeling Options

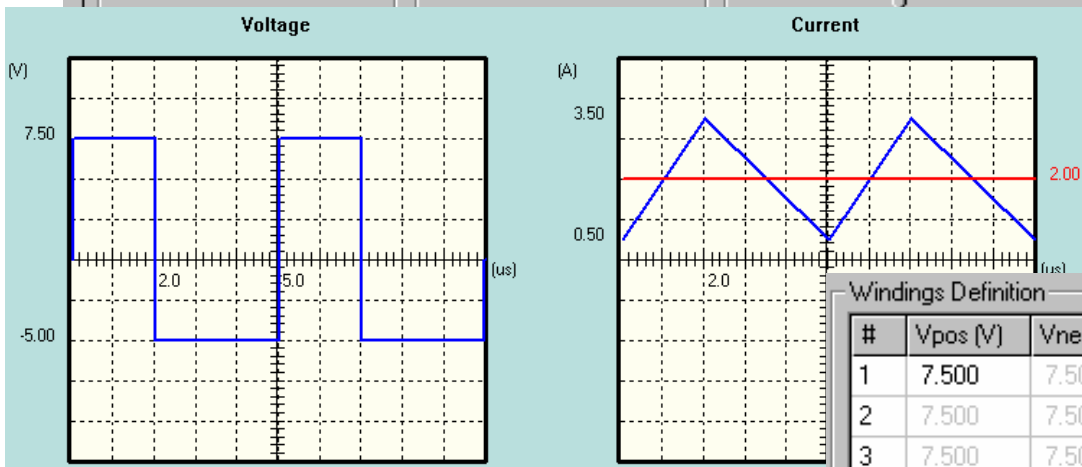
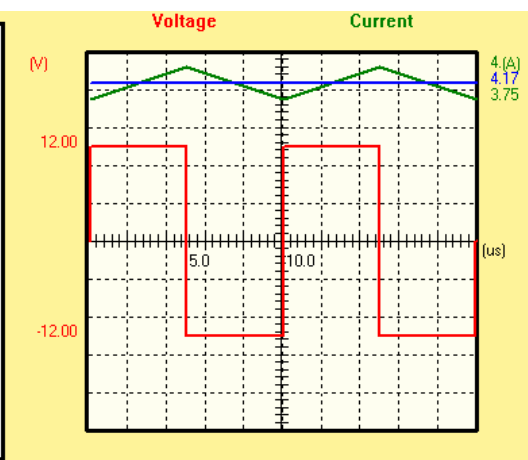
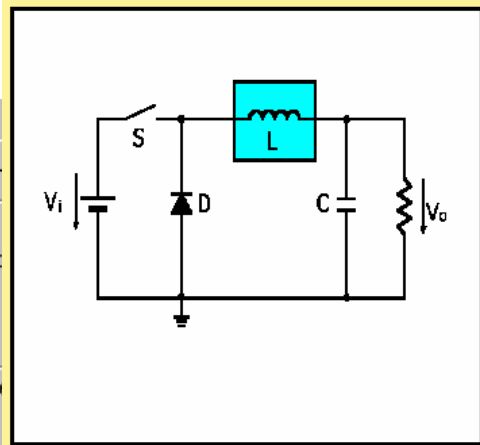
Voltage Waveform: Square Sinusoidal

Voltage value: Vpositive: 7.5 V, Vnegative: 5 V

Frequency: 200 kHz

Inductance: 5 uH

Current: Iaverage: , Ripple: , Duty Cycle:



Windings Definition

| # | Vpos (V) | Vneg (V) | Turns ratio | Power (W) | CT |
|---|----------|----------|-------------|-----------|--------------------------|
| 1 | 7.500 | 7.500 | 1 | 50.000 | <input type="checkbox"/> |
| 2 | 7.500 | 7.500 | 1 | 25.000 | <input type="checkbox"/> |
| 3 | 7.500 | 7.500 | 1 | 25.000 | <input type="checkbox"/> |

Add Winding | Remove Winding

Frequency: 200 kHz

Voltage Waveform: Square Sinusoidal

Voltage Shape: Symmetrical Asymmetrical User defined Vneg

Duty Cycle (tpos/T): 0.25

Dead Time Duty (tdead/T): 0.5

PExprt. Step 2: Select & Compare

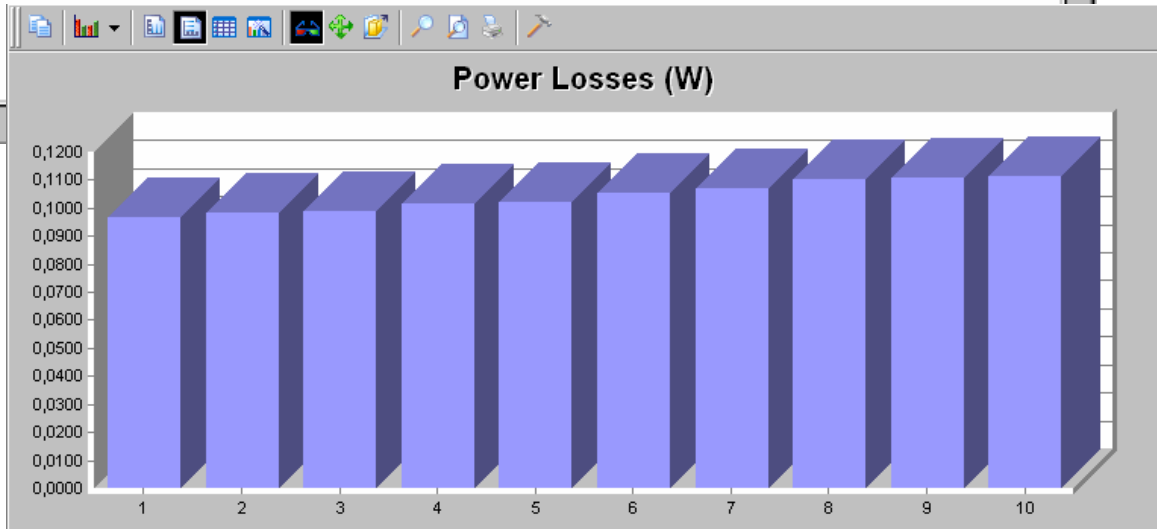
| Core [Name] | Wire [Name] | Volume [mm ³] | Turns | Temperature [°C] | Parallel Turns [n] | Power Losses [W] | Window Filling [%] |
|-------------|-------------|---------------------------|-------|------------------|--------------------|------------------|--------------------|
| RM10 | AWG10 | 3469.44 | 2 | 26.91 | 1 | 0.0967 | 43.59 |
| RM10/I | AWG15 | 4308.36 | 2 | 26.95 | 2 | 0.0983 | 29.70 |
| RM8/I | AWG15 | 2419.20 | 2 | 27.96 | 2 | 0.0988 | 42.24 |
| RM10 | AWG15 | 3469.44 | 2 | 27.02 | 2 | 0.1017 | 28.70 |
| RM10/I | AWG15 | 4308.36 | 2 | 27.07 | 2 | 0.1018 | 35.98 |
| RM10 | AWG15 | 3469.44 | 2 | 27.14 | 2 | 0.1053 | 34.76 |
| RM8 | AWG15 | 1846.00 | 2 | 28.22 | 2 | 0.1072 | 39.92 |
| RM10/I | AWG15 | 4308.36 | 2 | 27.19 | 2 | 0.1100 | 29.70 |
| | | | 2 | 27.20 | 1 | 0.1107 | 43.59 |
| | | | 2 | 27.27 | 3 | 0.1111 | 26.77 |

Customize List of Results

| | Maximum | Minimum |
|---|---------|---------|
| <input checked="" type="checkbox"/> Core [name] | | |
| <input type="checkbox"/> Bobbin [name] | | |
| <input checked="" type="checkbox"/> Wire [name] | | |
| <input type="checkbox"/> Material [name] | | |
| <input checked="" type="checkbox"/> Volume [mm ³] | 4308.36 | 1846.00 |
| <input type="checkbox"/> Height [mm] | | |
| <input type="checkbox"/> Footprint [mm ²] | | |
| <input checked="" type="checkbox"/> Turns [#] | 2.00 | 2.00 |
| <input checked="" type="checkbox"/> Power Losses [W] | 0.1111 | 0.0967 |
| <input checked="" type="checkbox"/> Temperature [°C] | 28.22 | 26.91 |
| <input type="checkbox"/> Leakage Ind. [nH] | | |
| <input checked="" type="checkbox"/> Parallel Turns [#] | 3.00 | 1.00 |
| <input checked="" type="checkbox"/> Window Filling [%] | 43.59 | 26.77 |
| <input type="checkbox"/> Winding Rate [%] | | |
| <input type="checkbox"/> ID # [#] | | |

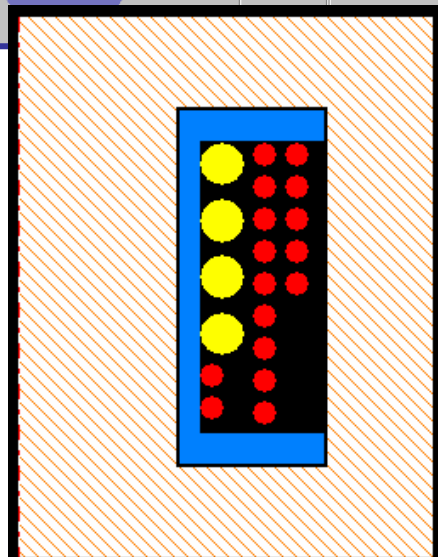
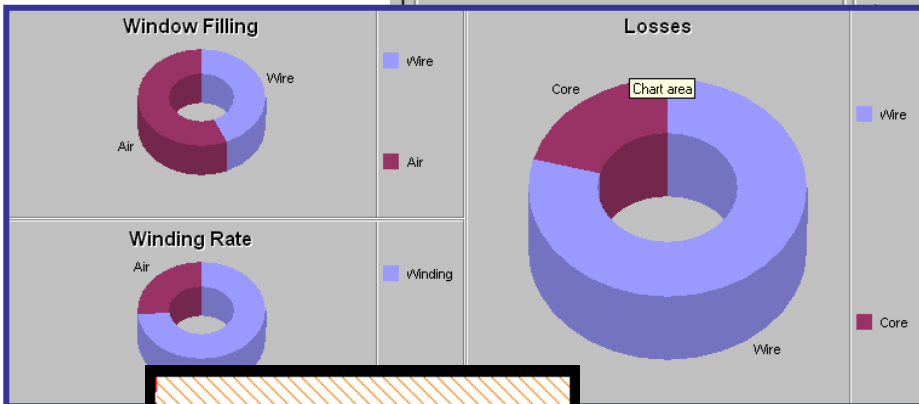
Show Only 1D Solutions

OK Cancel



PExprt. Step 2: Select & Compare

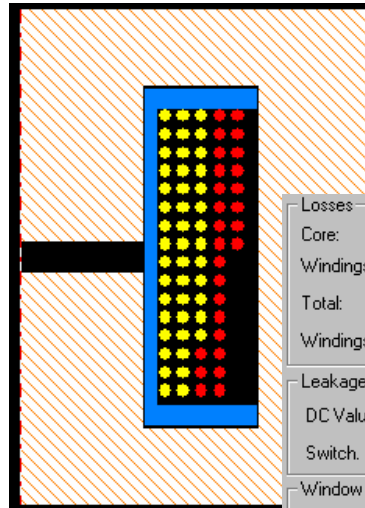
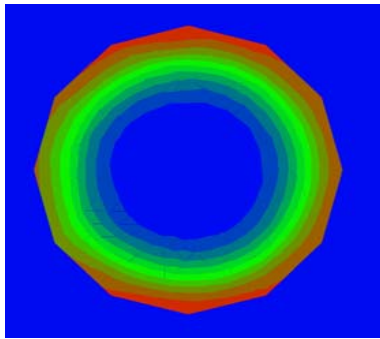
| | | | | | |
|---|--|---|--|---|--|
| Losses Core: <input type="text" value="20.241 mW"/> Windings: <input type="text" value="76.444 mW"/> Total: <input type="text" value="96.685 mW"/> Windings (with Rdc): <input type="text" value="26.717 mW"/> Leakage Inductance: <input type="text"/> | | Windings Winding 1 <input type="text" value="Winding 1"/> Current Density: <input type="text" value="805.54 mA/mm<sup>2</sup>"/> Magnetizing Inductance: <input type="text" value="18.08 uH"/> Voltage (V): <input type="text" value="7.500"/> Losses (selected model): <input type="text" value="44.650 mW"/> Losses (with Rdc): <input type="text" value="8.925 mW"/> DC Resistance: <input type="text" value="401.405 uohm"/> Current: <input type="text" value="4.715 A"/> | | Window Occupancy Window Filling (%): <input type="text" value="43.59"/> Winding Rate (%): <input type="text" value="73.40"/> Flux Density Variation of B (mT): <input type="text" value="56.34"/> Maximum B (mT): <input type="text" value="28.17"/> Temperature Max. Temperature (°C): <input type="text" value="26.91"/> Core Temperature (°C): <input type="text" value="26.82"/> | |
|---|--|---|--|---|--|



| | | | |
|--|--|--|--|
| Component Core Size: <input type="text" value="RM10/I"/> Bobbin: <input type="text" value="RM10/I"/> Core Material: <input type="text" value="3C94"/> Library: <input type="text" value="Ferroxcube_Design"/> | | Windings Winding 1 <input type="text" value="Winding 1"/> Wire: <input type="text" value="AWG15"/> Number of Turns: <input type="text" value="2"/> Parallel Turns: <input type="text" value="2"/> | |
|--|--|--|--|

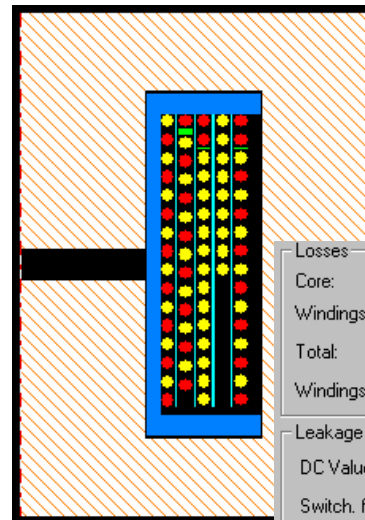
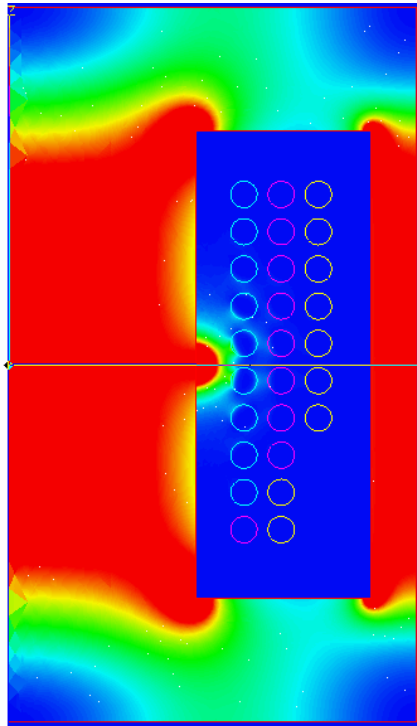
PExprt. Step 3: Optimize

Non-Interleaved Solution



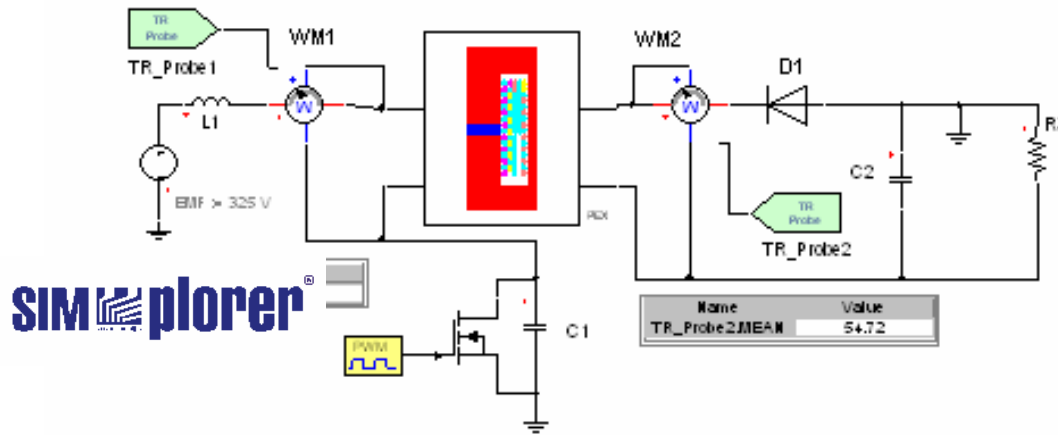
| Losses | | Windings | | Flux Density | |
|----------------------|------------|--------------------------|------------------------|--------------------------|---------|
| Core: | 340.258 mW | Winding 1 | | Variation of B (mT) | 99.76 |
| Windings: | 8.908 W | Current Density: | 1.26 A/mm ² | Maximum B (mT) | 99.76 |
| Total: | 8.908 W | Magnetizing Inductance: | 332.04 uH | Incremental permeability | |
| Windings (with Rdc): | 339.295 mW | Voltage (V): | 325.000 | Havg (A/m): | 5.60 |
| Leakage Inductance | | Losses (selected model): | NA | Permeability Value | |
| DC Value: | NA | Losses (with Rdc): | 73.752 mW | Initial: | 2700.00 |
| Switch. freq. value: | 13.795 uH | Rdc (DC Resistance): | 119.847 mohm | Actual: | 2700.00 |
| Window Occupancy | | Irms: | 784.465 mA | Temperature | |
| Window Filling (%): | 41.47 | | | Max. Temperature (°C) | 109.11 |
| Winding Rate (%): | 82.51 | | | Core Temperature (°C) | NA |

Interleaving Application

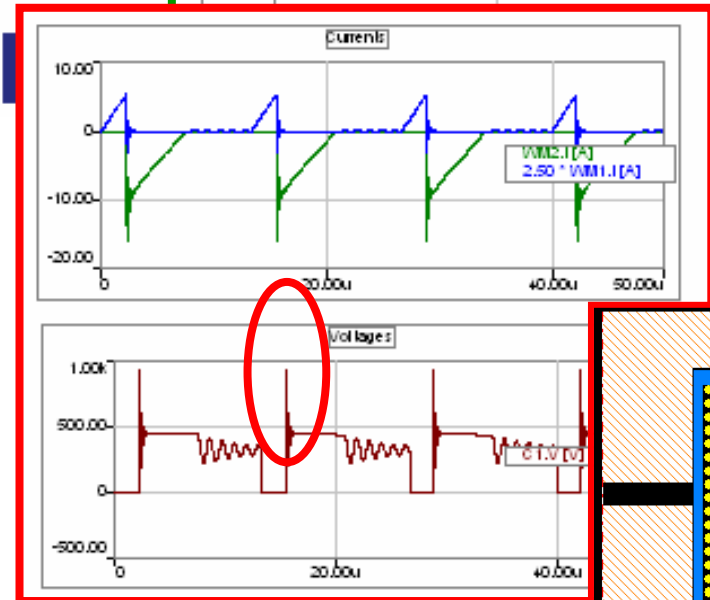
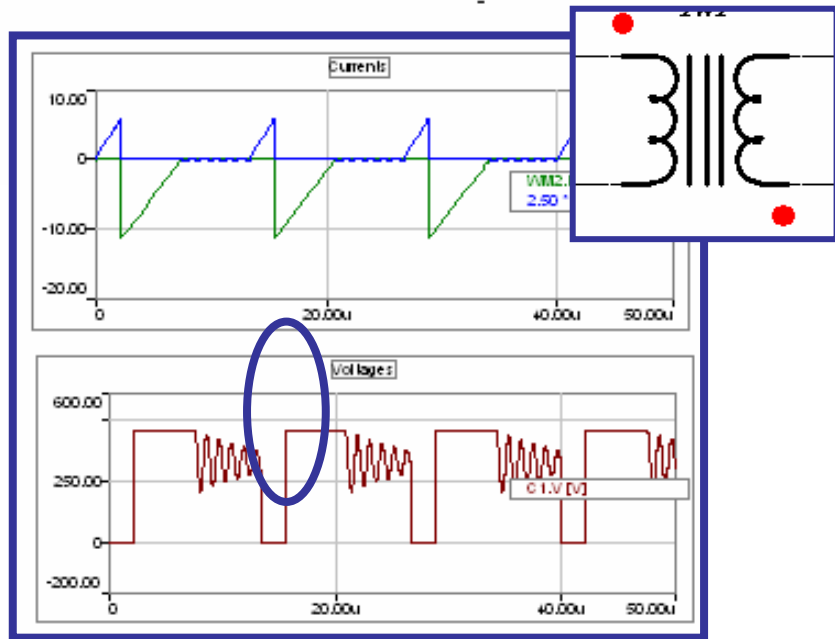
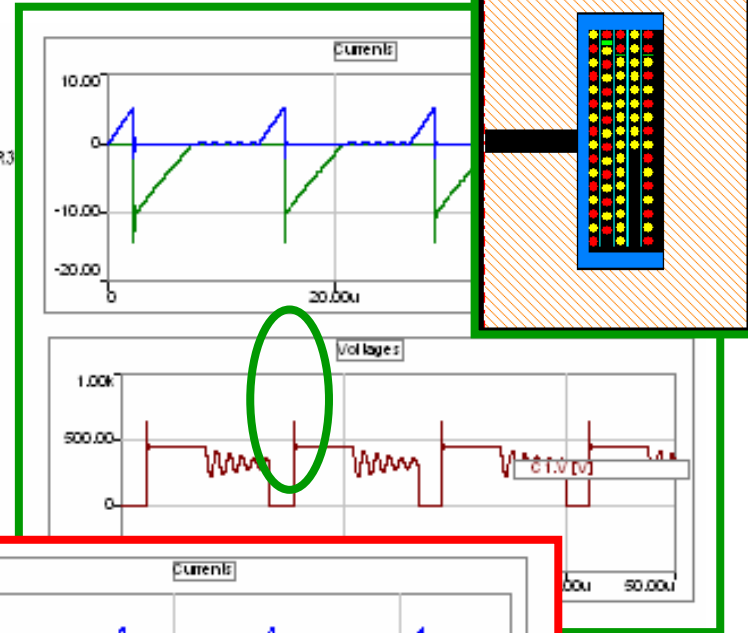


| Losses | | Windings | | Flux Density | |
|----------------------|------------|--------------------------|------------------------|--------------------------|---------|
| Core: | 340.258 mW | Winding 1 | | Variation of B (mT) | 99.76 |
| Windings: | 6.674 W | Current Density: | 1.26 A/mm ² | Maximum B (mT) | 99.76 |
| Total: | 6.674 W | Magnetizing Inductance: | 339.41 uH | Incremental permeability | |
| Windings (with Rdc): | 327.982 mW | Voltage (V): | 325.000 | Havg (A/m): | 5.60 |
| Leakage Inductance | | Losses (selected model): | NA | Permeability Value | |
| DC Value: | NA | Losses (with Rdc): | 82.607 mW | Initial: | 2700.00 |
| Switch. freq. value: | 3.316 uH | Rdc (DC Resistance): | 134.237 mohm | Actual: | 2700.00 |
| Window Occupancy | | Irms: | 784.465 mA | Temperature | |
| Window Filling (%): | 41.47 | | | Max. Temperature (°C) | 89.53 |
| Winding Rate (%): | 82.51 | | | Core Temperature (°C) | NA |

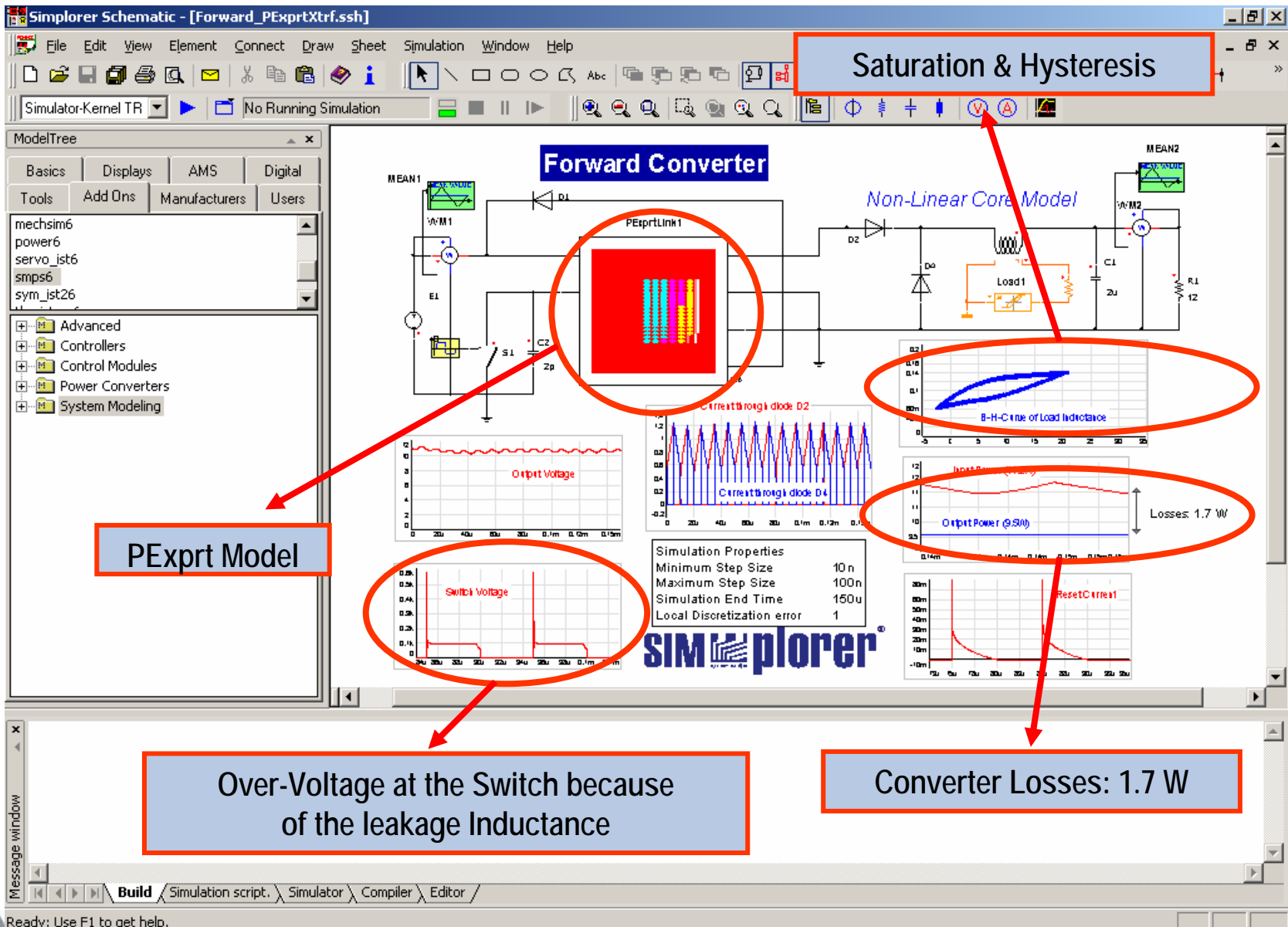
PExprt. Step 4: Simulate



simplorer

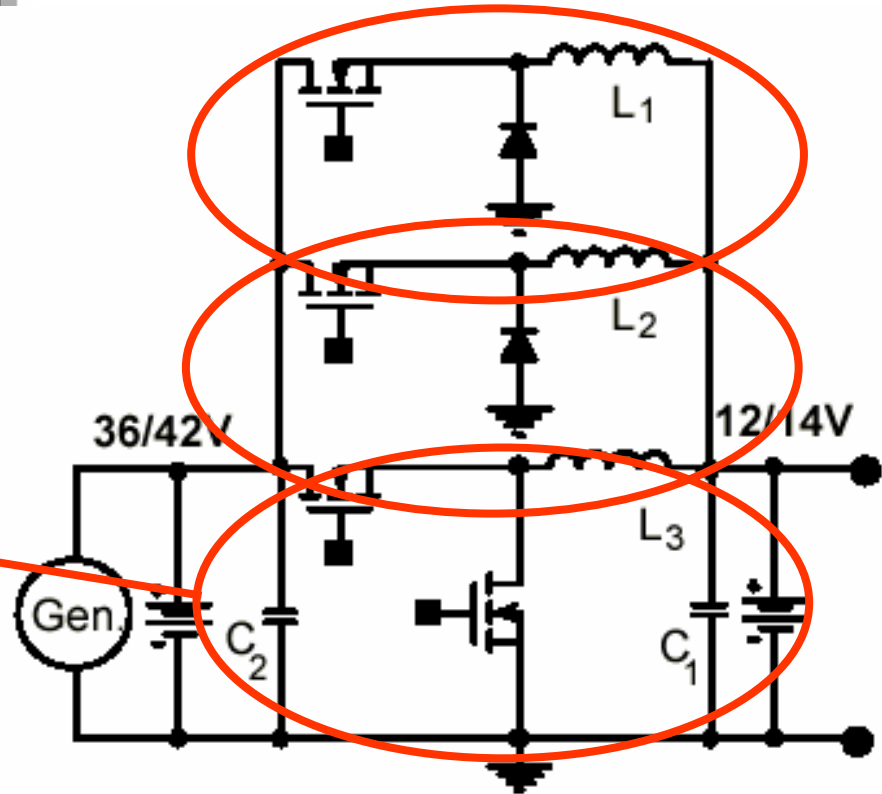
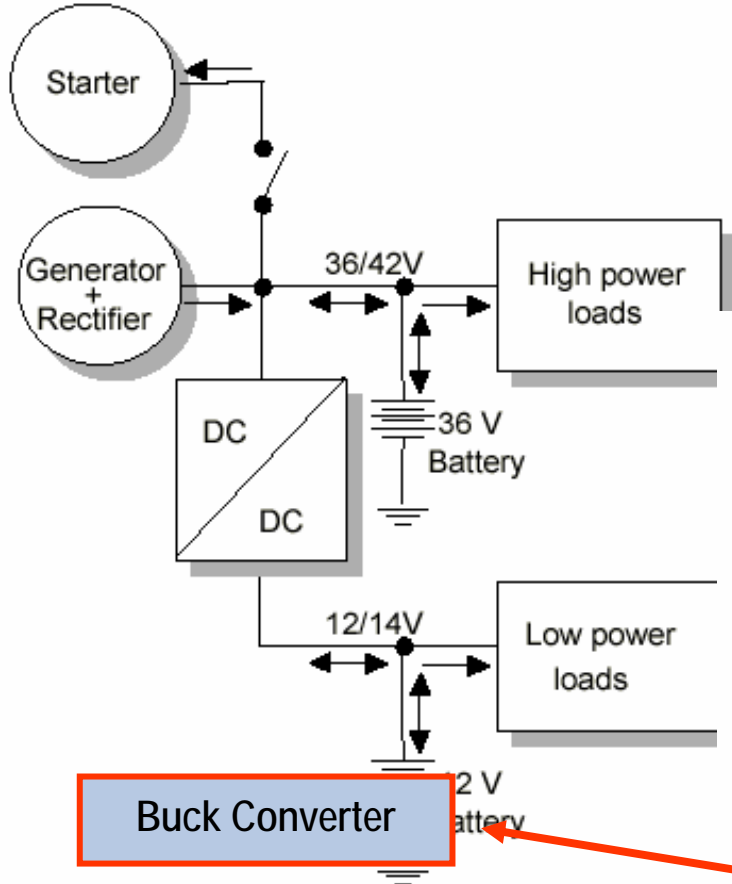


PExprt. Results: Simplorer Model



PExprt Example 1: Buck Converter

Step 1: Select the topology



Buck Converter

Decide to use either average or switch level Buck Converter

Step 2: Simulate in Simplorer with SMPS library

Use switch level Buck Converter from SMPS library

Change duty cycle and inductor value to achieve desired output voltage

Simulation properties:
Step width max: 50n
Step width min: 10n
Simulation end time: 2m

```
Build / Simulation script. / Simulator / Compiler / Editor
```

Ready; Use F1 to get help.

Step 3: Design Inductor with PExprt



Easy transition from Simplorer to PExprt

Build a waveform based inductor or buck converter in PExprt

Step 3: Design Inductor with PExprt

Run the PExprt model and select the design you prefer

| Core (Name) | Wire (Name) | Volume (mm ³) | Turns | Temperature ... | Gap (mm) | Parallel Turns (n) | Power Losses ... |
|-------------|-------------|---------------------------|-------|-----------------|----------|--------------------|------------------|
| P26/16 | AwG19 | 3530.64 | 8 | 4.19 | 0.7465 | 3 | 0.1571 |
| P30/19 | AwG19 | 6192.40 | 9 | 3.15 | 1.4851 | 3 | 0.1641 |
| P36/22 | AwG19 | 10746.40 | 10 | 2.76 | 2.9784 | 3 | 0.1994 |
| P26/16 | AwG19 | 3530.64 | 8 | 5.46 | 0.7465 | 2 | 0.2114 |
| P30/19 | AwG19 | 6192.40 | 9 | 4.30 | 1.4851 | 2 | 0.2338 |
| P42/29 | AwG19 | 18179.00 | 13 | 2.48 | 7.1013 | 3 | 0.2690 |
| P36/22 | AwG19 | 10746.40 | 10 | 3.85 | 2.9784 | 2 | 0.2928 |
| P26/16 | AwG19 | 3530.64 | 8 | 9.40 | 0.7465 | 1 | 0.3743 |
| P42/29 | AwG19 | 18179.00 | 13 | 3.50 | 7.1013 | 2 | 0.4007 |
| P30/19 | AwG19 | 6192.40 | 9 | 7.87 | 1.4851 | 1 | 0.4430 |

Power Losses (W)

PExprt Version 5.0.16. Copyright: 1992-2003. Universidad Politécnica de Madrid (UPM) and Ansoft Corporation

PExprt design results, including constructive data

Step 4: Generate Model

Property Value

| | |
|---------------------|----------|
| Name | 3F3 |
| Rel. Permittivity | 100000.0 |
| Init. Permeability | 2000.00 |
| Saturation B [T] | 0.34 |
| Resistivity [ohm*m] | 2.00 |

Winding Setup Current Design Design Status

Define properties of the model

Model Settings Model Language

Capacitances Core Model Curve Fitting Settings

Core Model

Linear

Non Linear (*)

PEmag Tip

Linear core model accounts for Eddy Currents losses, but not for hysteresis. Non linear models accounts for non linearities, Eddy current losses and hysteresis.

(*) Non linear core model cannot be used with Maxwell Spice language models.

Cancel Aplicar

PEExprt Modeler [PEmag] version 5.0.16. Copyright 1992-2003

NUM

Generate a 1D Analytical or a 2D FEA based model

Can include core non-linear effects using Jiles-Atherton model if the core is operating in the nonlinear range (usually this is a bad design)

Step 5: Import PExprt Model into Simplorer

The screenshot displays the Simplorer Schematic environment for a Buck Converter. The ModelTree on the left shows the 'PExprt' link selected under the 'interfaces6' folder. A red circle highlights the 'PExprt - LINK' component in the circuit diagram, with an arrow pointing to the ModelTree. A text box on the right states: "Use Simplorer PExprt link to substitute ideal inductor with PExprt model". The simulation results show the Output Voltage (Load.V [V]) and the inductor current (Load.I [A], L1.V [V], L1.I [A]). The Message window at the bottom shows the successful creation of the model script.

ModelTree

- Basics
- Displays
- AMS
- Digital
- Tools
- Add Ons
- Manufacturers
- Users

automotive6
bjt6
dc_ist26
diodes6
interfaces6

- ECE Link
- EMC Link
- PExprt**
- Full-Wave SPICE Link
- Simulink Interface
- MathCAD Interface

Buck Converter Example

PExprt - LINK

Use Simplorer PExprt link to substitute ideal inductor with PExprt model

Simulation properties

- Step width max: 50n
- Step width min: 10n
- Simulation end time: 2m

Message window

```
Create model script (C:\Rober\Departamento\Ansoft\Simplorer_PExprt\BuckConverter_OpenLoop_SimpleInductor.sml) ...  
Sorting blocks automatically.  
... Creation of model script (C:\Rober\Departamento\Ansoft\Simplorer_PExprt\BuckConverter_OpenLoop_SimpleInductor.sml) succ
```

Step 6: Simplorer Simulation With PExprt Model

The screenshot displays the SIMPLORER interface for a "Buck Converter Example". The main workspace shows a schematic diagram of a buck converter circuit. A red circle highlights the PExprt model symbol, which is a square with a grid of colored dots. The circuit includes an input voltage source (42V), a switch, an inductor (E1), a diode, a filter capacitor, and a load resistor. The simulation results are shown in three plots:

- Top Right Plot:** Shows the output voltage (blue) and current (green) over time. The voltage is a square wave between approximately 10V and 20V, and the current is a triangular wave.
- Bottom Left Plot:** Shows the output voltage (red) over time, labeled "Output Voltage". It shows a transient response followed by a steady-state value around 12V.
- Bottom Right Plot:** Shows the output voltage (red), load current (blue), and PExprt model voltage (orange) over time. The voltage is a square wave, and the current is a triangular wave.

Simulation properties are listed at the bottom left:

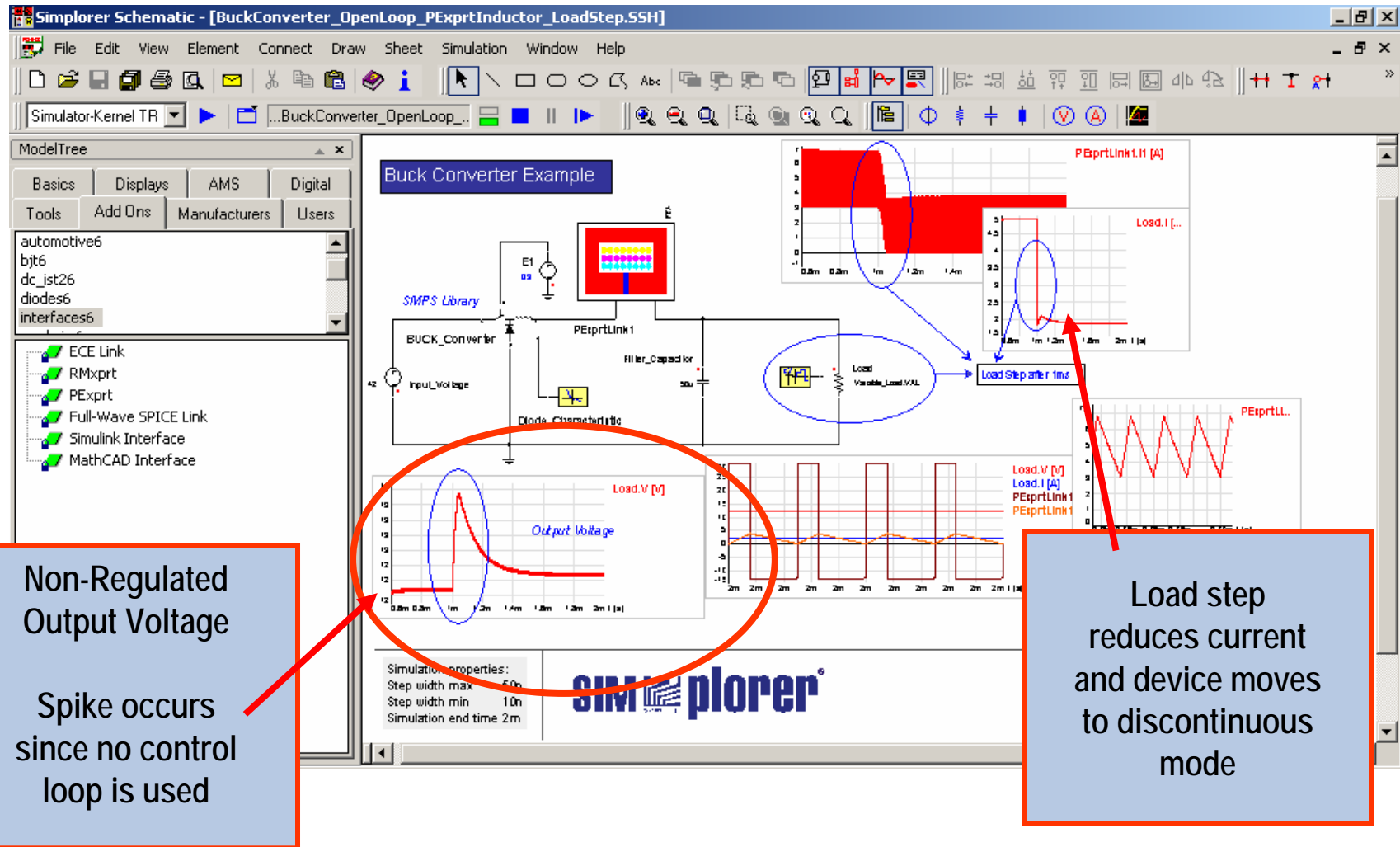
- Simulation properties
- Step width max: 50n
- Step width min: 10n
- Simulation end time: 2m

The SIMPLORER logo is visible at the bottom center.

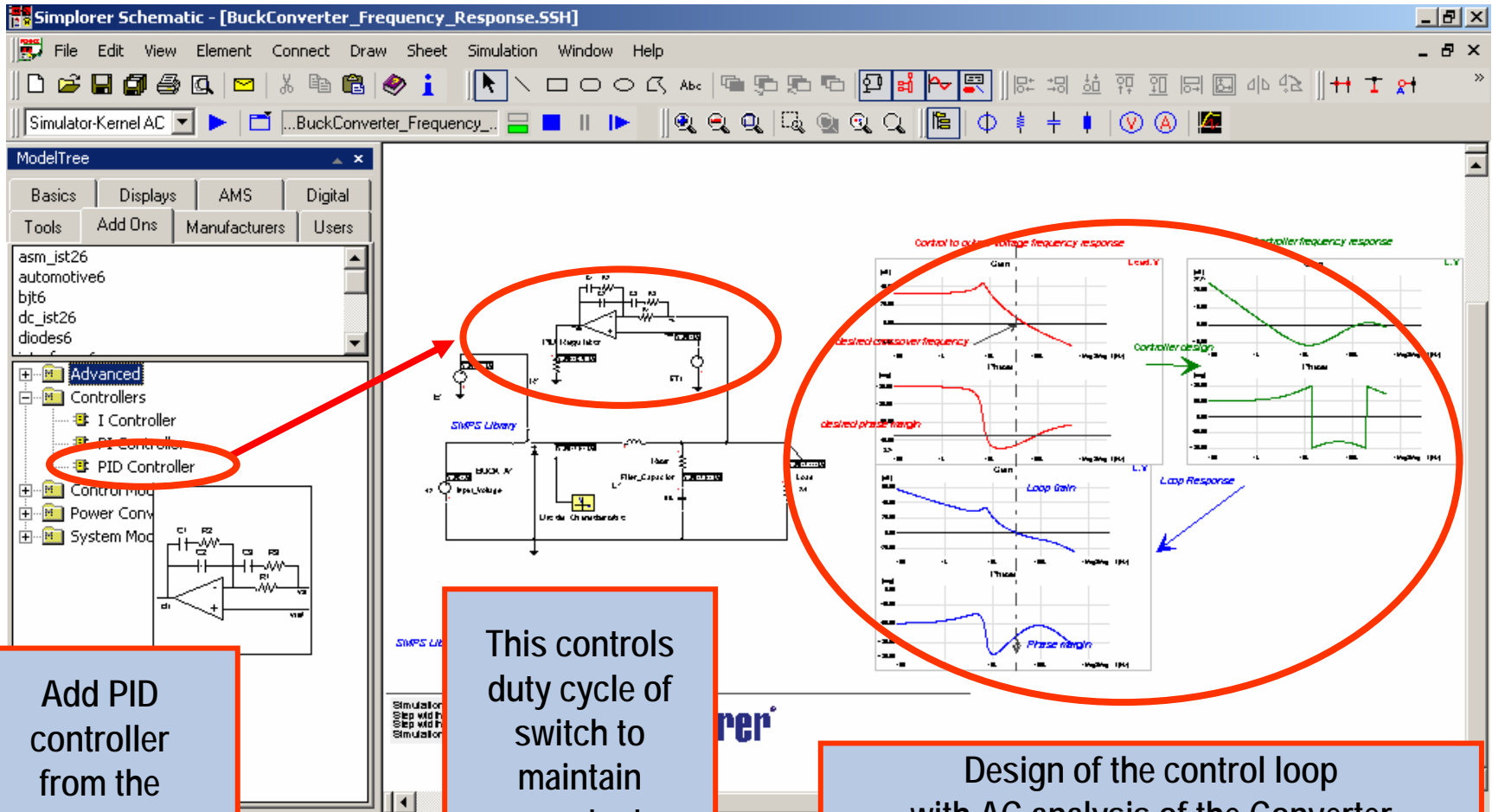
PExprt Model and Symbol

Simulate the PExprt model in Simplorer

Step 7: Load Step Test: Feedback loop is needed



Step 8: Design Feedback Loop in frequency domain



Add PID controller from the SMPS library

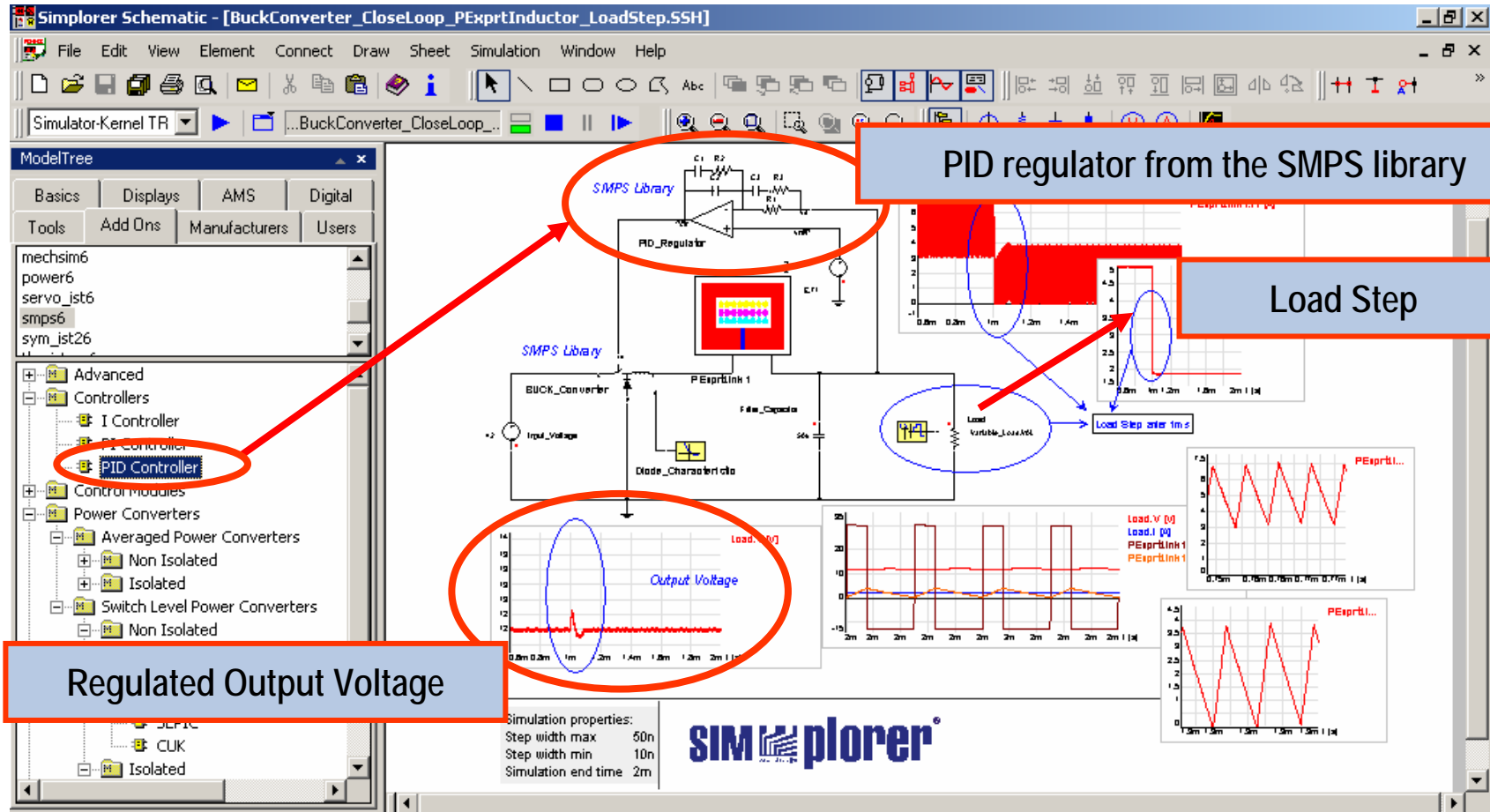
This controls duty cycle of switch to maintain constant output voltage

Design of the control loop with AC analysis of the Converter

Specifically, select R and C in the PID controller

Step 9: Feedback Loop Test: Time Domain

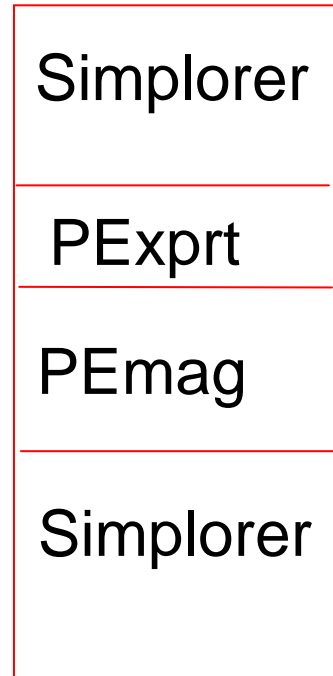
Finally, return to the time domain analysis to see how the buck converter performs



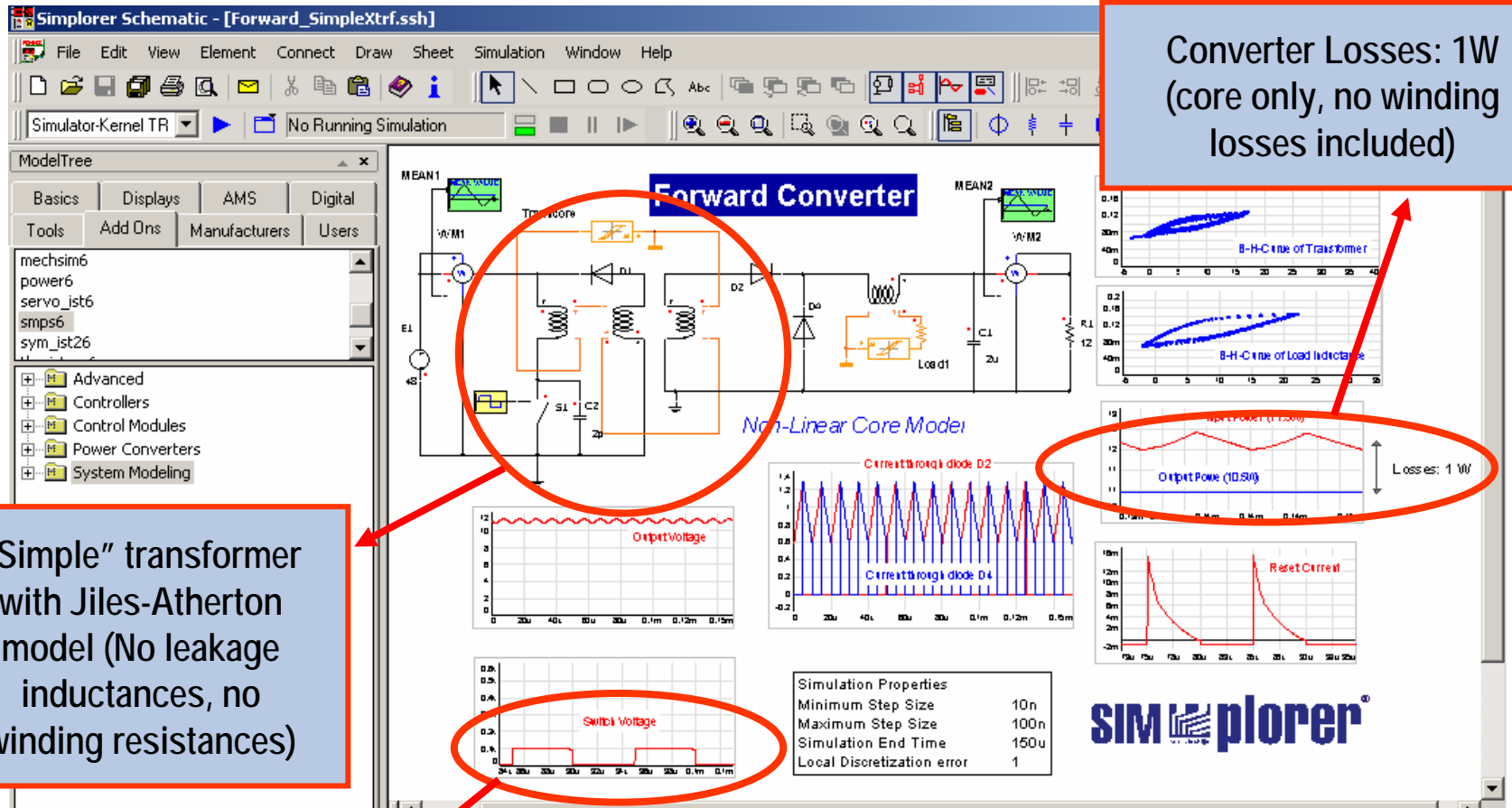
PExprt Example 2: Forward Converter

Summary of Design Process

- 1 Basic design using Simplorer
- 2 Study saturation effects using JA Model
- 3 Detailed design using PExprt
- 4 Model Generation with PExprt Modeler [PEmag]
- 5 Use Simplorer to simulate the detailed PExprt model



Step 1: Basic topology design in Simplorer



Converter Losses: 1W
(core only, no winding losses included)

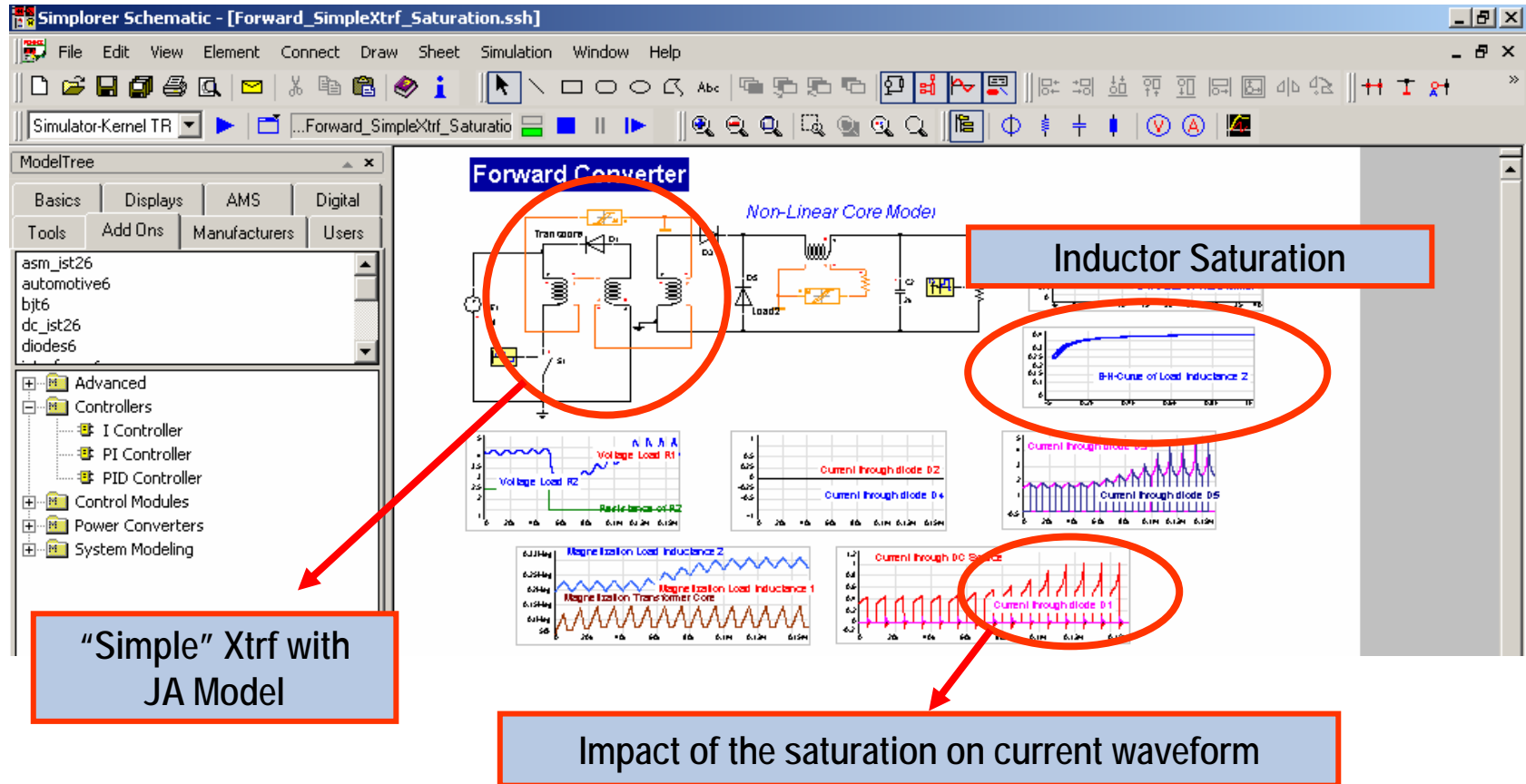
“Simple” transformer with Jiles-Atherton model (No leakage inductances, no winding resistances)

Since no leakage inductance, no over-voltage at the switch (and MOSFET cannot be selected)

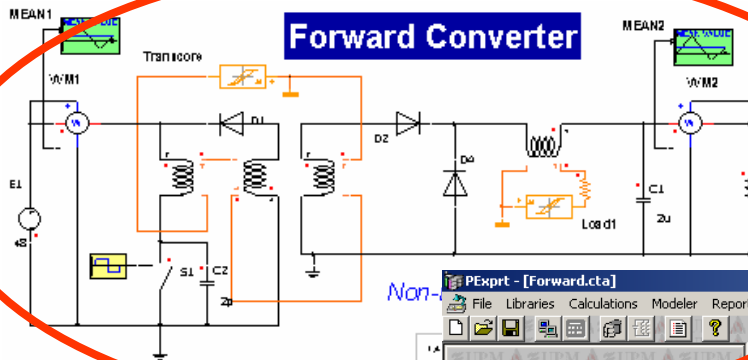
Converter output voltage can be checked based on duty cycle chosen

Step 2: Study saturation effects using JA Model

As load is increased the Jiles-Atherton core model shows saturation



Step 3: Detailed design using PExprt



Easy transition from Simplorer to PExprt

Use PExprt to include leakage inductance and AC winding resistance for MOSFET selection and for efficiency

PExprt Version 5.0.16. Copyright 1992-2003. Universidad Politécnica de Madrid (UPM) and Ansoft Corporation

Step 3 (cont): Detailed design using PExprt

The screenshot displays the PExprt software interface for a transformer design. The main window shows design parameters for a component, including Core Size (RM6S), Bobbin (RM6S), Core Material (3C81), and Library (Ferroxcube_Design). The Winding section shows Winding 1 with Wire (AWG30), Number of Turns (50), and Parallel Turns (1).

The Performance Results window provides detailed data:

| Category | Parameter | Value | |
|-------------------------|------------------------|------------------------|-------|
| Losses | Core | 98.798 mW | |
| | Windings | 157.788 mW | |
| | Total | 256.586 mW | |
| | Windings (DC) | 157.890 mW | |
| Leakage Inductance | DC Value | NA | |
| | Switch. freq. value | NA | |
| Windings | Current Density | 5.00 A/mm ² | |
| | Magnetizing Inductance | 6.44 mH | |
| | Voltage (V) | 48.000 | |
| Losses (selected model) | Losses (DC) | 73.410 mW | |
| | DC Resistance | 586.269 mohm | |
| | Irms | 353.635 mA | |
| Window Occupancy | Window Filling (%) | 50.61 | |
| | Winding Rate (%) | 78.12 | |
| Flux Density | Variation of B (mT) | 154.84 | |
| | Maximum B (mT) | 77.42 | |
| | | Temperature Rise (°C) | 17.35 |

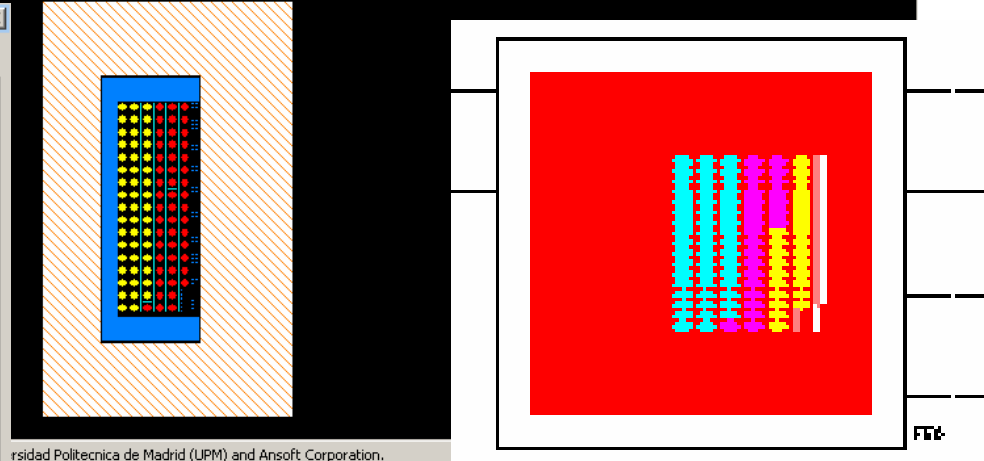
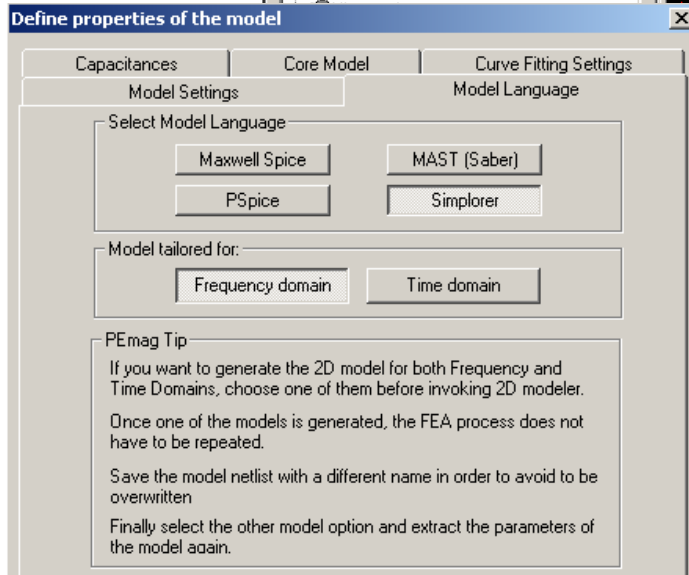
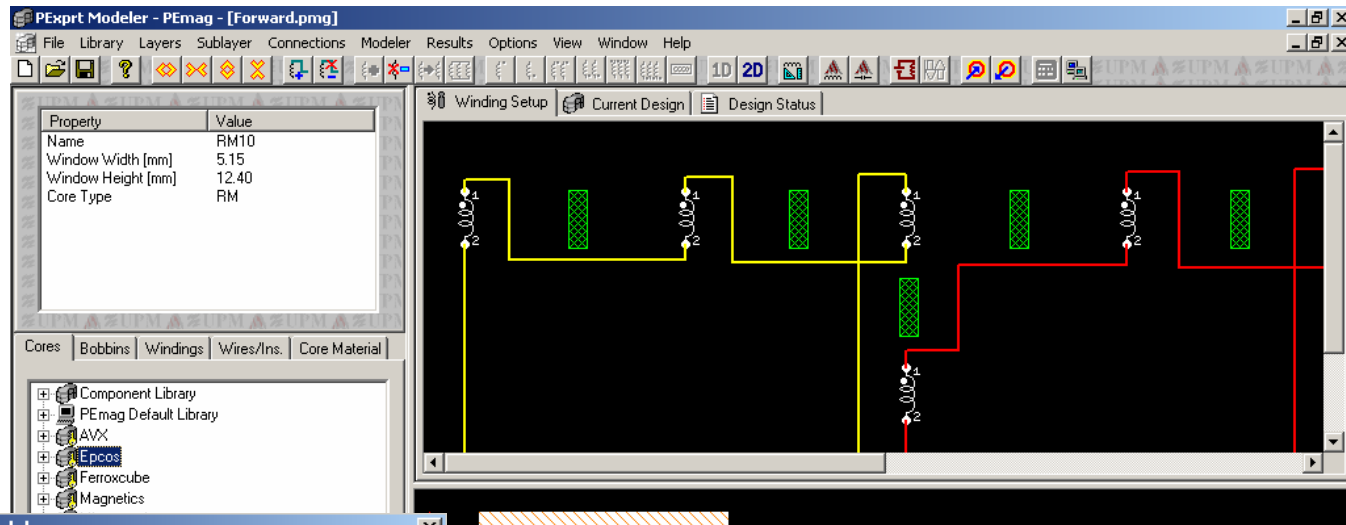
The Constructive Results window shows a 3D visualization of the transformer core and windings. The Pie Charts section displays Magnetizing Current distribution:

- Window Filling:** 49.39% (Wire), 50.61% (Air)
- Winding Rate:** 3.12% (Wire), 21.88% (Winding), 75.00% (Air)
- Losses:** 38.50% (Wire), 61.50% (Core)

PEXprt Version 5.0.16. Copyright 1992-2003. Universidad Politecnica de Madrid (UPM) and Ansoft Corporation

PEXprt design results, including performance results and constructive data

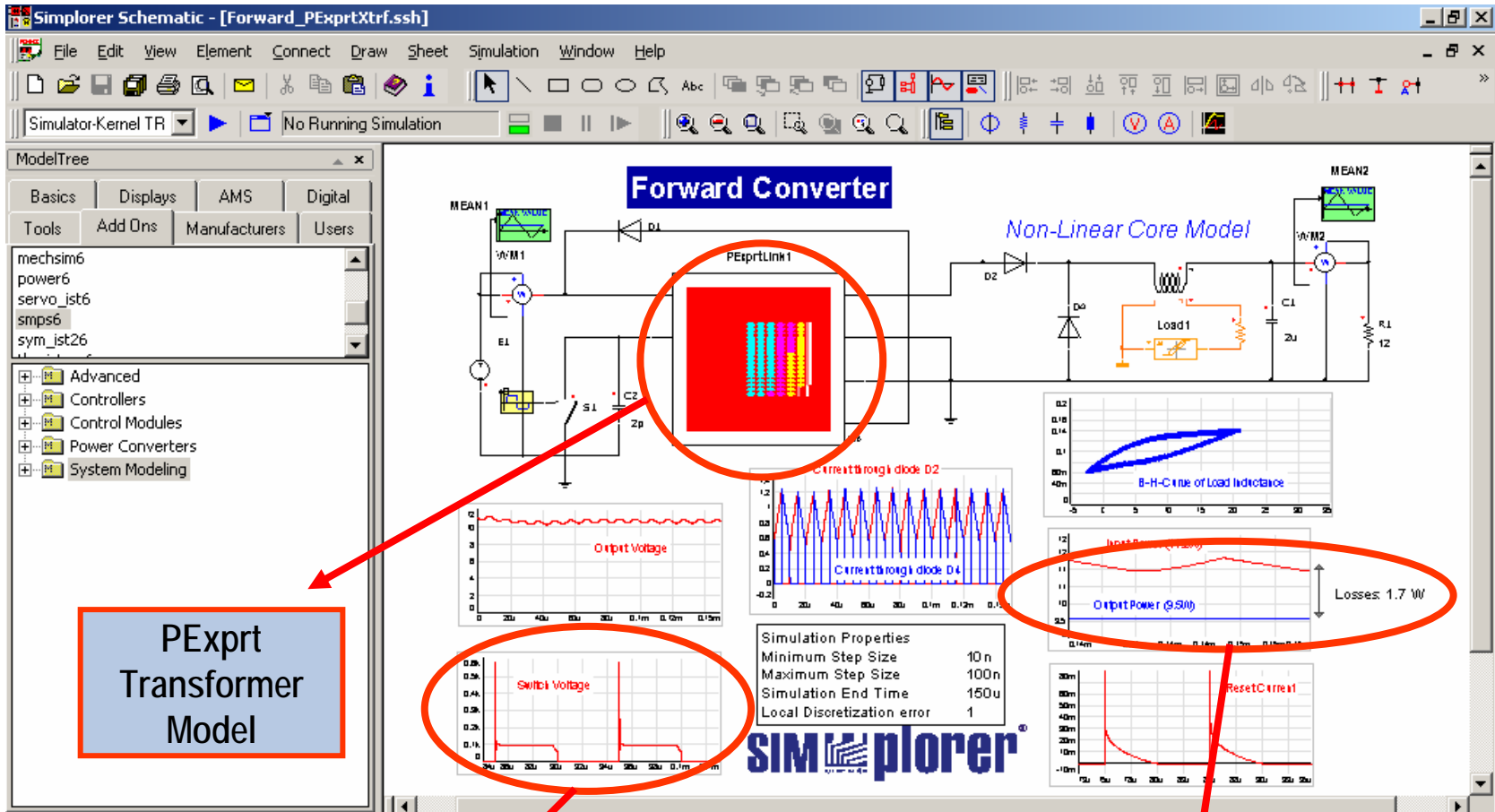
Step 4: Model Generation with PExprt Modeler



rsidad Politecnica de Madrid (UPM) and Ansoft Corporation.

Very easy procedure to generate Simplorer model, including the symbol

Step 5: Simplorer analysis using PExprt model



Over-Voltage at the Switch because of the leakage Inductance

Converter Losses: 1.7 W