电源系统传导干扰仿真

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ANSYS CHINA

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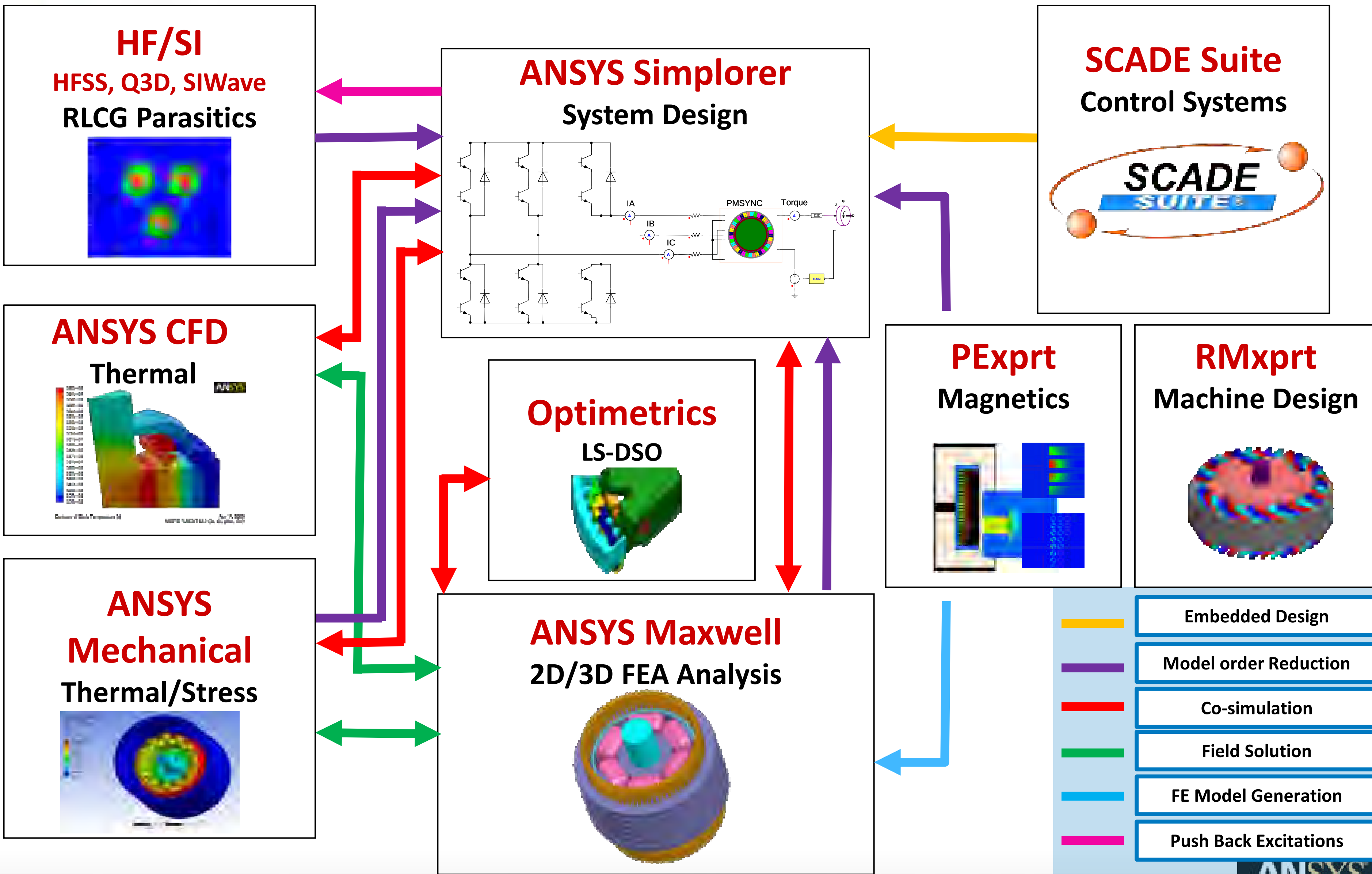
D. 用于噪声计算的动态耦合方法

A. 用于传导干扰EMI的工具介绍

传导干扰EMI需要考虑的问题

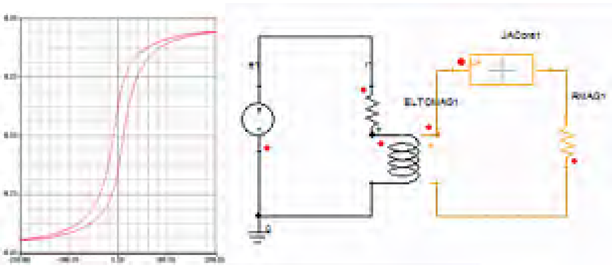
- 传导干扰受到很多因素的干扰，把考虑这些因素的模型链接到电路仿真工具中，就可以对传导干扰进行仿真分析；
- 为了考虑EMI的多种物理影响，ANSYS有丰富的工具和模型用于电力电子仿真；
- 仿真应用包含中低频率的开关电源SMPS，PWM功率变换器，逆变器，整流器，传感器，做动器，电机和电机驱动器等

ANSYS 机电系统解决方案

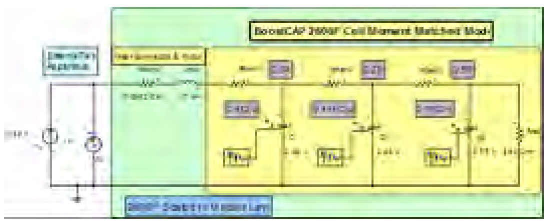


非线性器件

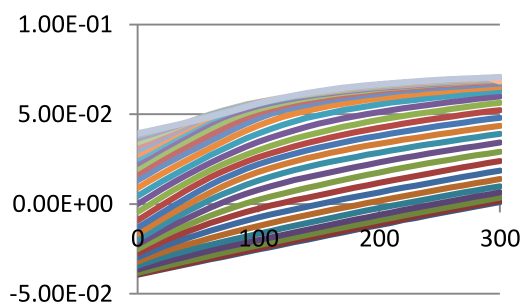
Simplorer



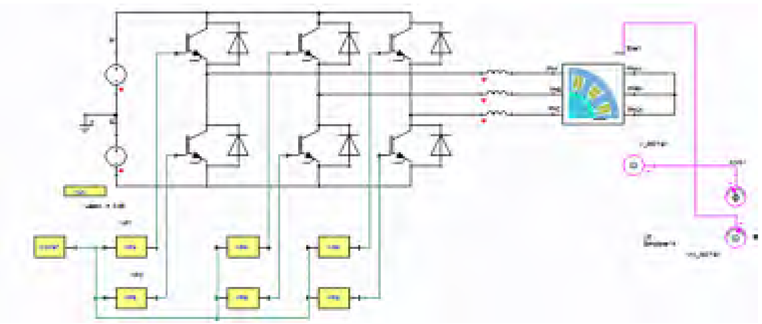
- NL Magnetic Core Model.

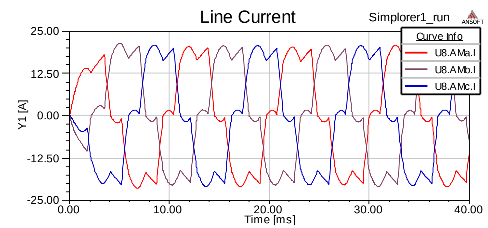


- NL Capacitor Model. C(θ, V)

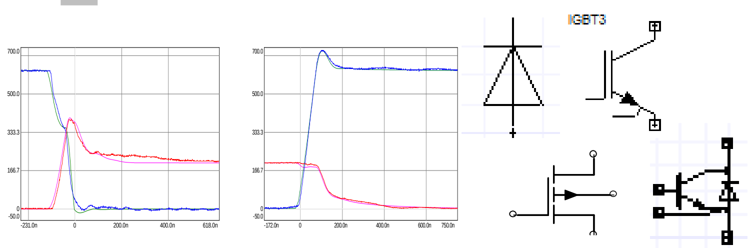


- Extraction Magnetic Char. via Maxwell



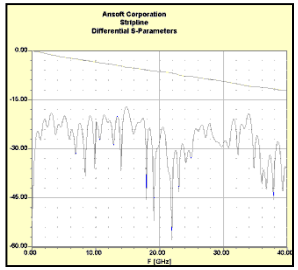


Motor current

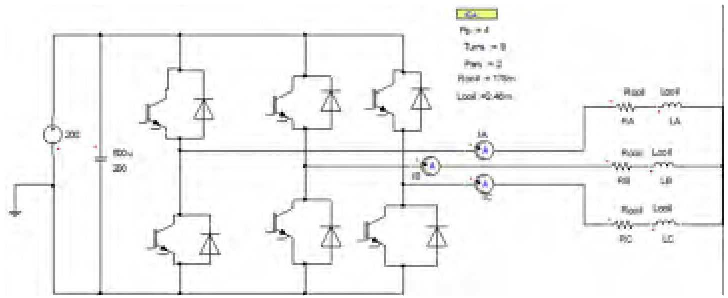


- Semiconductor Device Model

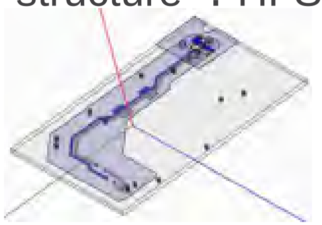
无源器件、线性器件耦合(Parasitics)

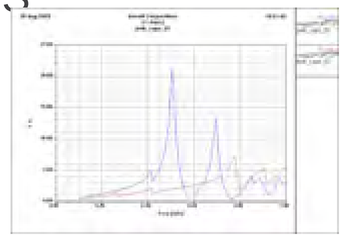


Simplorer

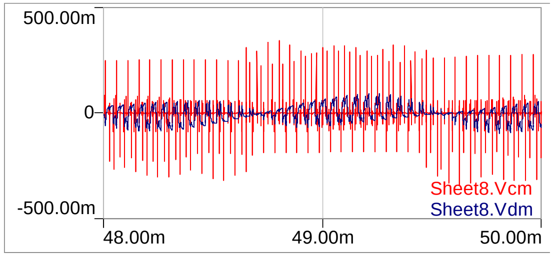


- transmission characteristic of 3D
- structure ：HFSS

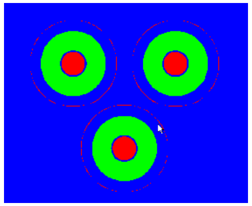


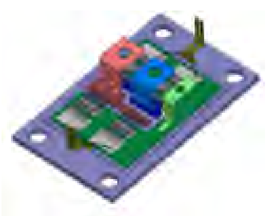


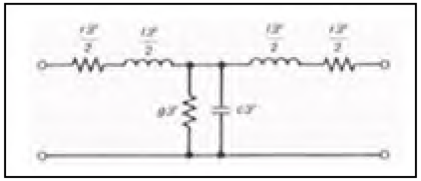
- Impedance of a 2.5D board ：SIWave



Common mode Voltage (Vcm)
Normal mode Voltage (Vdm)





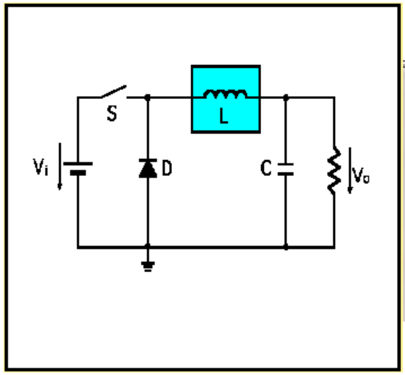


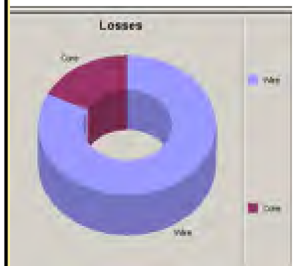
- The parasitism ingredient of a cable /3D structure ：Q3D Extractor

Coupling with various ANSYS electromagnetic-field analysis tools is possible.

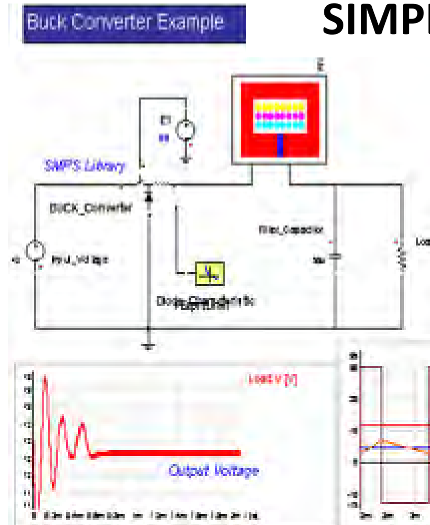
磁性器件设计- Inductors/Transformers

PExprt

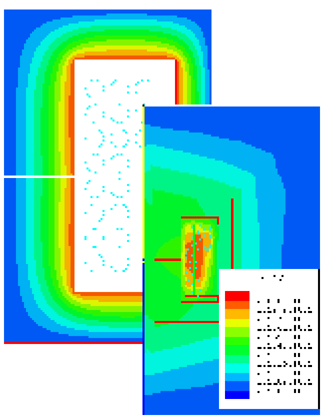


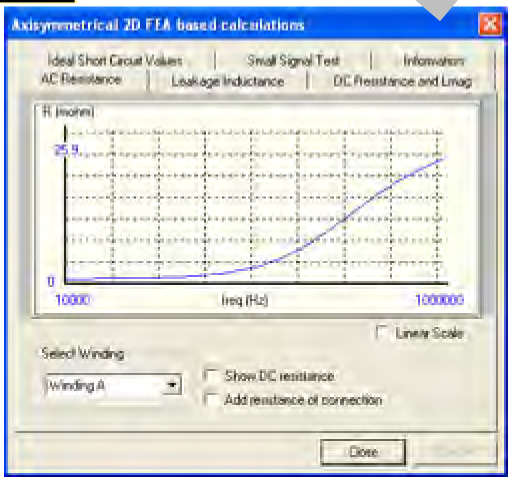


SIMPLORER

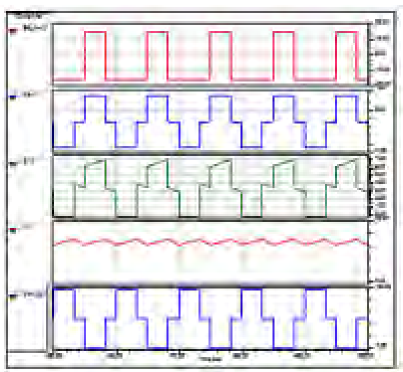


Maxwell

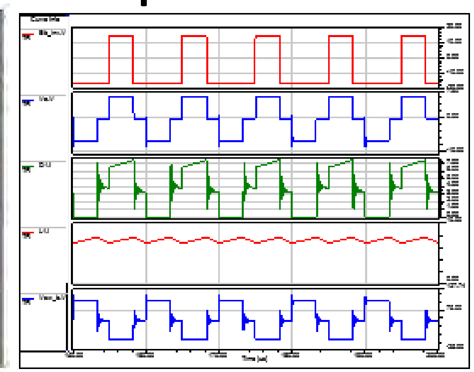




Ideal Transformer

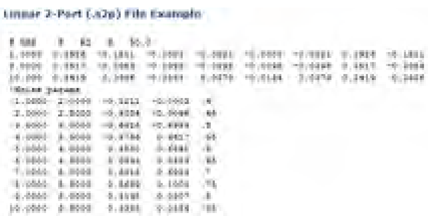


PExprt Transformer



ANSYS

测试器件的频率响应



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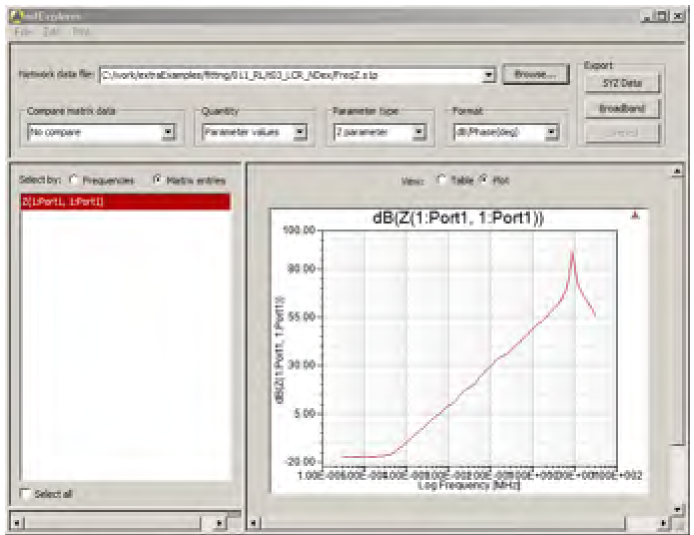
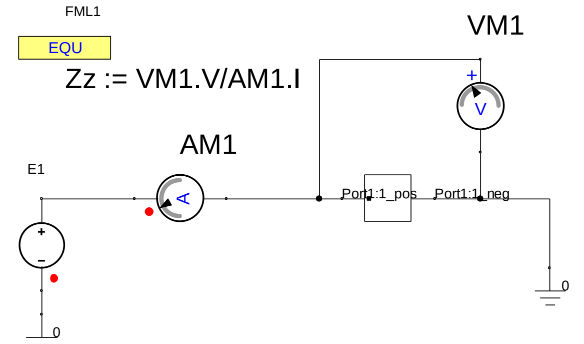
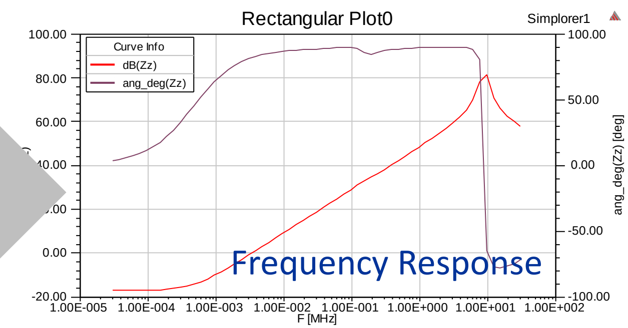
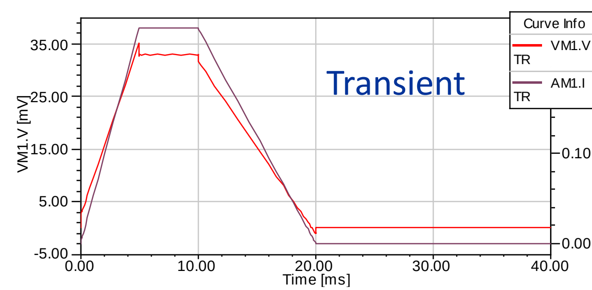
TouchStone



Network Data Explorer



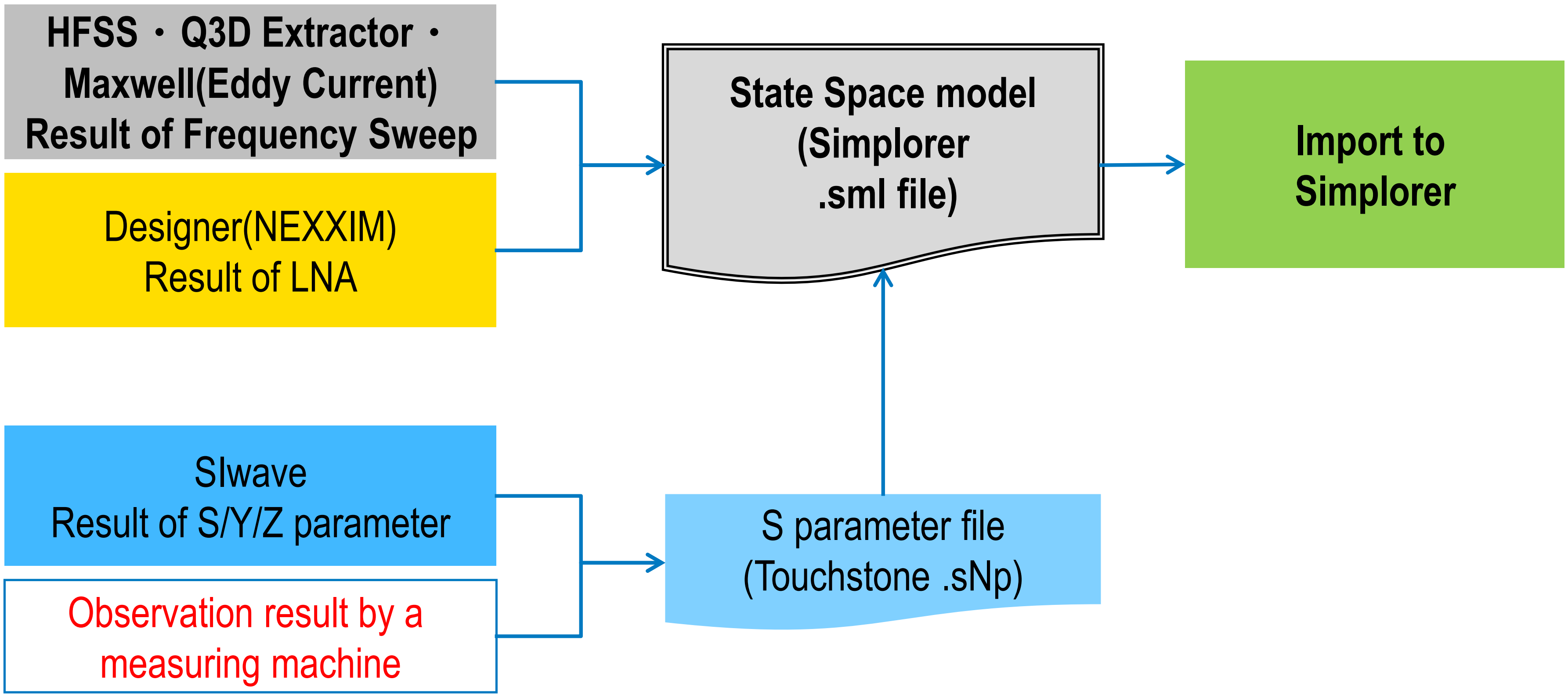




Import as State Space Model.

Using the Network Data Explorer, the TouchStone format file is importable into Simplorer, for both AC and Transient simulations./同时进行交流和瞬态分析

从电磁场到电路的频率响应耦合流程

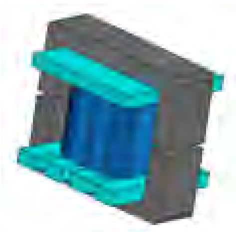


Everything uses fitting method of frequency response to generate a "state space model".

用ANSYS EM 工具提取部件或结构参数

Maxwell

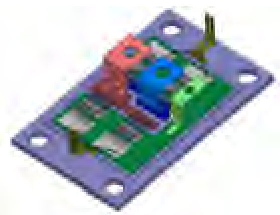
ElectroMagnetic Components
- **Non-Linear Cores**
- **Coils**



Winding impedance.
Capacitance between windings.
(Loop inductance is solved = Looped conductor are needed.)

Q3D Extractor

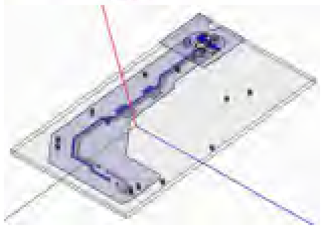
Electrical Components
- **3D branch conductors**
- **2D Cables**



Branched conductor impedance.
(Partial inductance is solved = any geometry is possible, but detailed L(F) are ignored.)

SIwave

Multi layered circuit board (PCB)
- **Large # of terminals**



Well grounded PCB.
(Perpendicular electric field is assumed. = Thin layered conductors are needed.)

HFSS

High Frequency Electrical components
- **Connectors**
- **3D Cables**

High frequency transmission.
(Transmission-mode matching is performed on a port. = Ground connections are needed.)

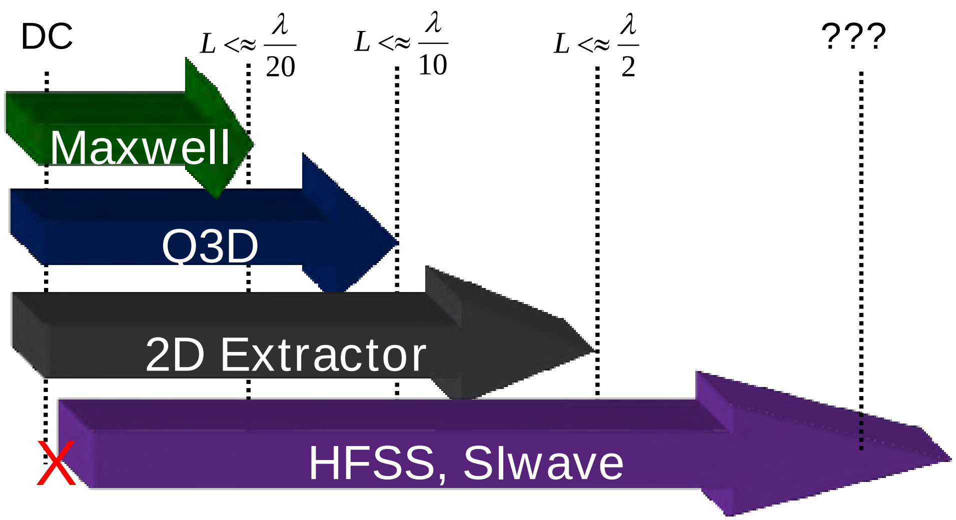
不同的应用场合采用不同的仿真工具

- Q3D is a tool streamlined for quickly characterizing electrical parasitics of interconnects, busbars, and cables across frequency.
  - Q3D Extractor: 3-D quasi-static lumped RLC parameter extractor. Linear permeability = 1.
  - 2D Extractor: 2-D T-line RLGC parameter extractor. Linear permeability.

- SIwave is meant specifically for multi-layer PCBs with a good ground-plane. It can handle many ports.

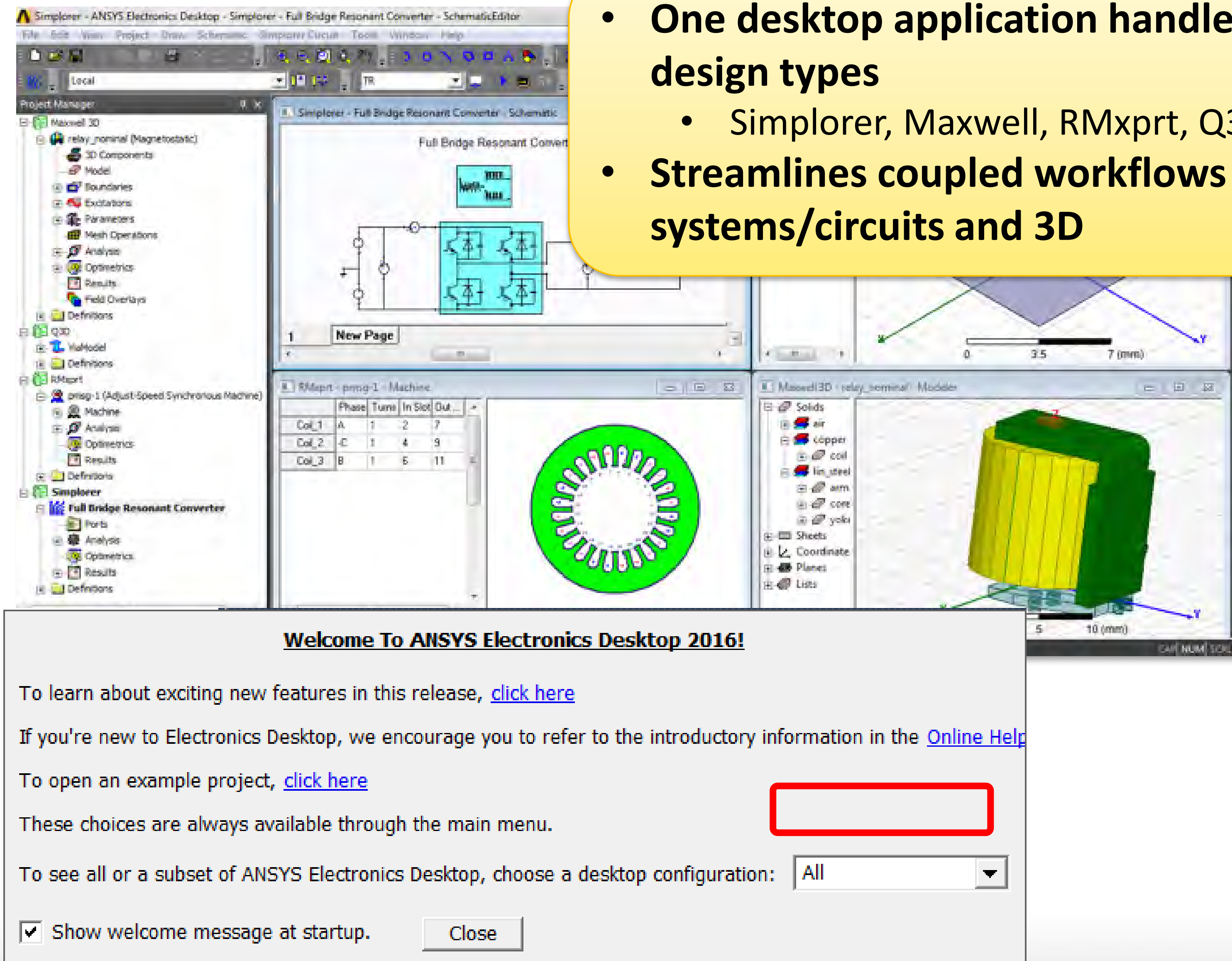
- HFSS is meant for microwave solution, when the wavelength is close to the geometry size (when electrically large).

- Maxwell is meant for coils and magnetics.



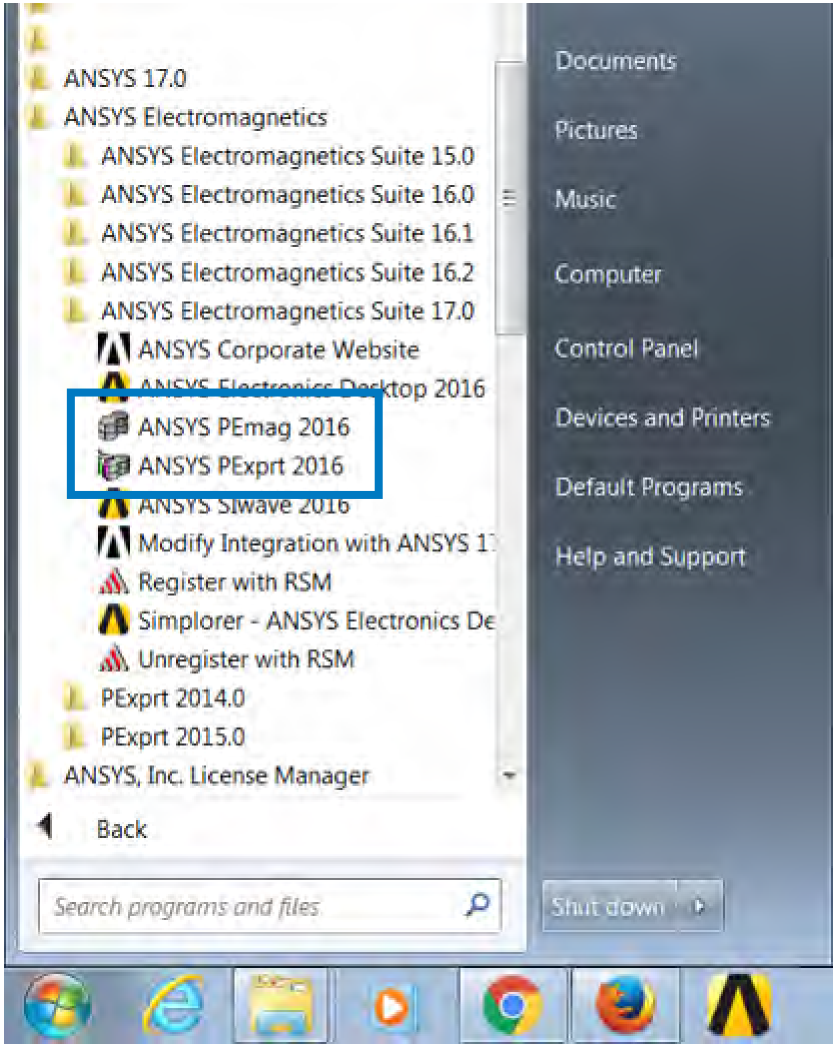
ANSYS集成设计平台

- **One desktop application handles multiple design types**
  - Simplorer, Maxwell, RMxprt, Q3D, HFSS
- **Streamlines coupled workflows between systems/circuits and 3D**



访问 PExprt/PEmag

- **PExprt/PEmag are opened from the Windows > Start menu**
- **Or, open PEmag from within the Electronics Desktop (in the Tools menu, find PEmag)**



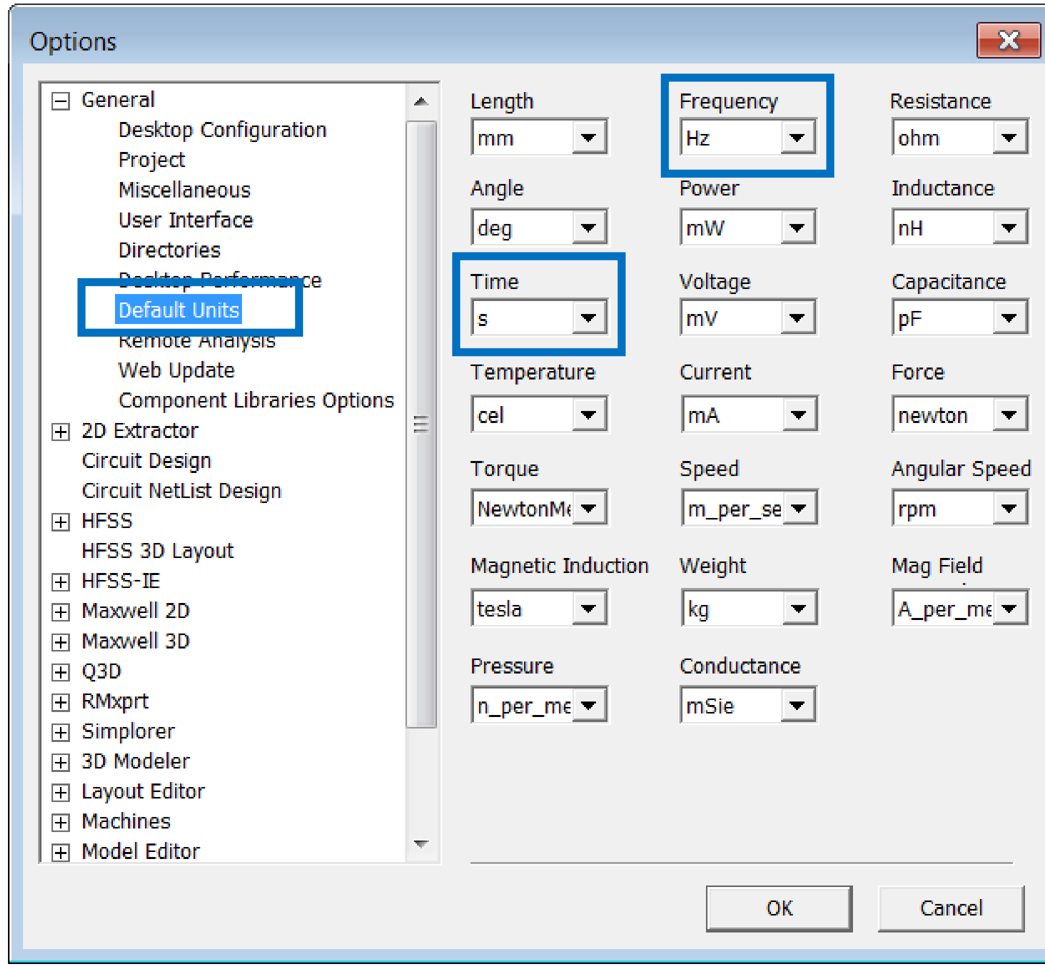
设置和选项

- **In the General Options window, you can find the Default Units.**

- **For Low-Frequency applications, change:**

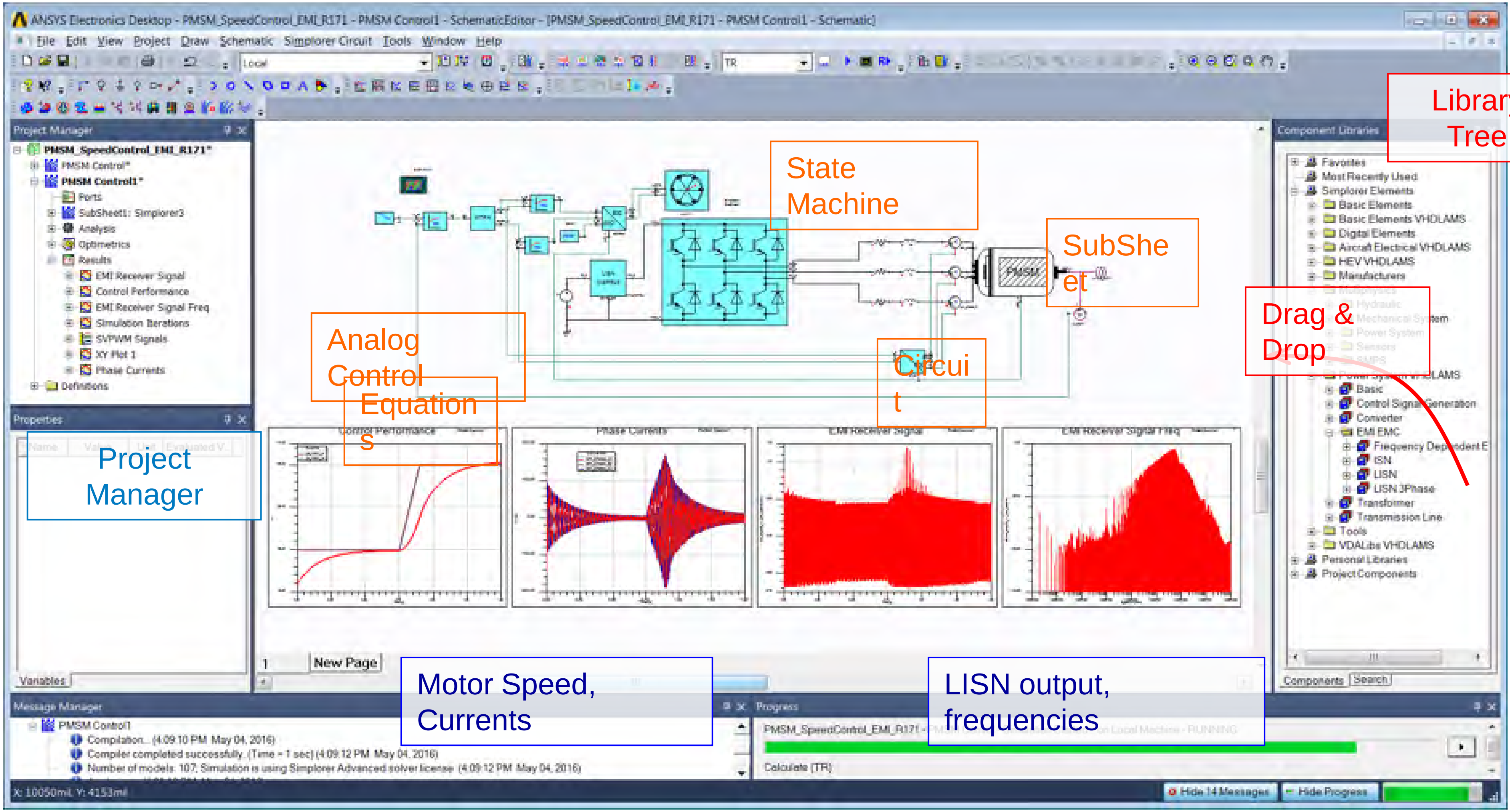
  Time: [s]

  Frequency: [Hz]



B. Simplorer 用于电力电子设计

Simplorer用户接口



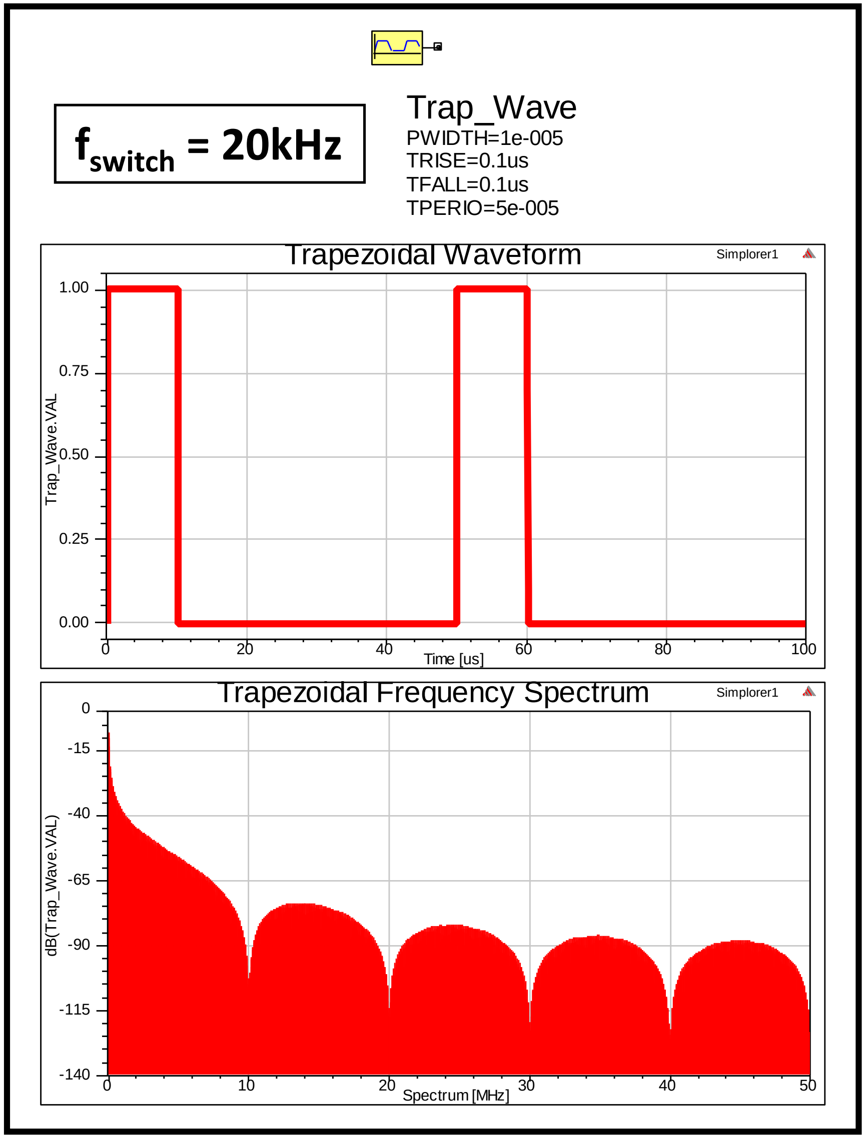
Simplorer 传导噪声仿真应用

This is a "low-frequency" EMI solution from DC to ~100MHz.

The switching frequency may be from 10Hz to ~100kHz.

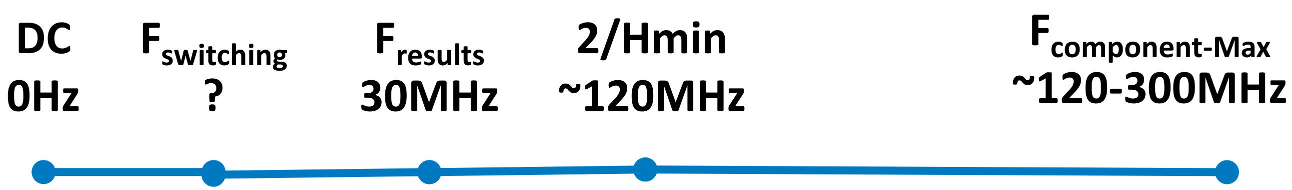
Sometimes we may need several time-steps per rise/fall, and the transient simulation requires higher-frequency data (from measurement or simulation).

If all components are characterized across the frequency, then the results will also be valid across freq.



仿真步长设置Time-steps <= 1/2F_{max}

- The time-step used in the transient circuit simulation is dictated by the dynamics of the circuit/system.
- For results up to 30MHz (CISPR upper limit), then you will want time-step at <=15ns.
- Whatever time-step (Hmin) is used, you should provide frequency-dependent component data above 2/(Hmin).

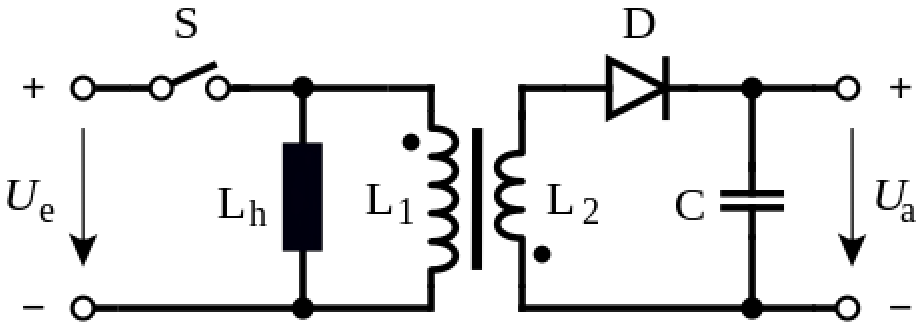


用于瞬态仿真的频域模型

- 在Simplorer中进行电力电子仿真时，有非常多的开关动作，所以是非线性的
- 能体现频域特性的模型和数据决定系统的动态响应
- 有多种方法建立和使用这些能体现频域特性的模型和数据

Simplorer里的参考地

- Simplorer中即使是隔离的变换器，也需要参考地



- 可以建立有别于大地的信号地和系统地
- 大地和其它地之间可以用实际的阻抗隔离

仿真设置和流程

- **定义系统中的关键部件**
  - ✓ Characterize these well across operating points
  - ✓ Model all passive components from impedance analyzer
  - ✓ Model active components from datasheet if not measurement
- **对所有电流路径-特别是地电流路径建模**
- **Q3D抽取寄生参数**
- **Simplorer中求解瞬态模型**
- **与各种标准比较**
- **优化设计-同时包含电路和PCB Layout**

C. Q3D 用于电力电子设计

Introduction to Q3D for Power Electronics

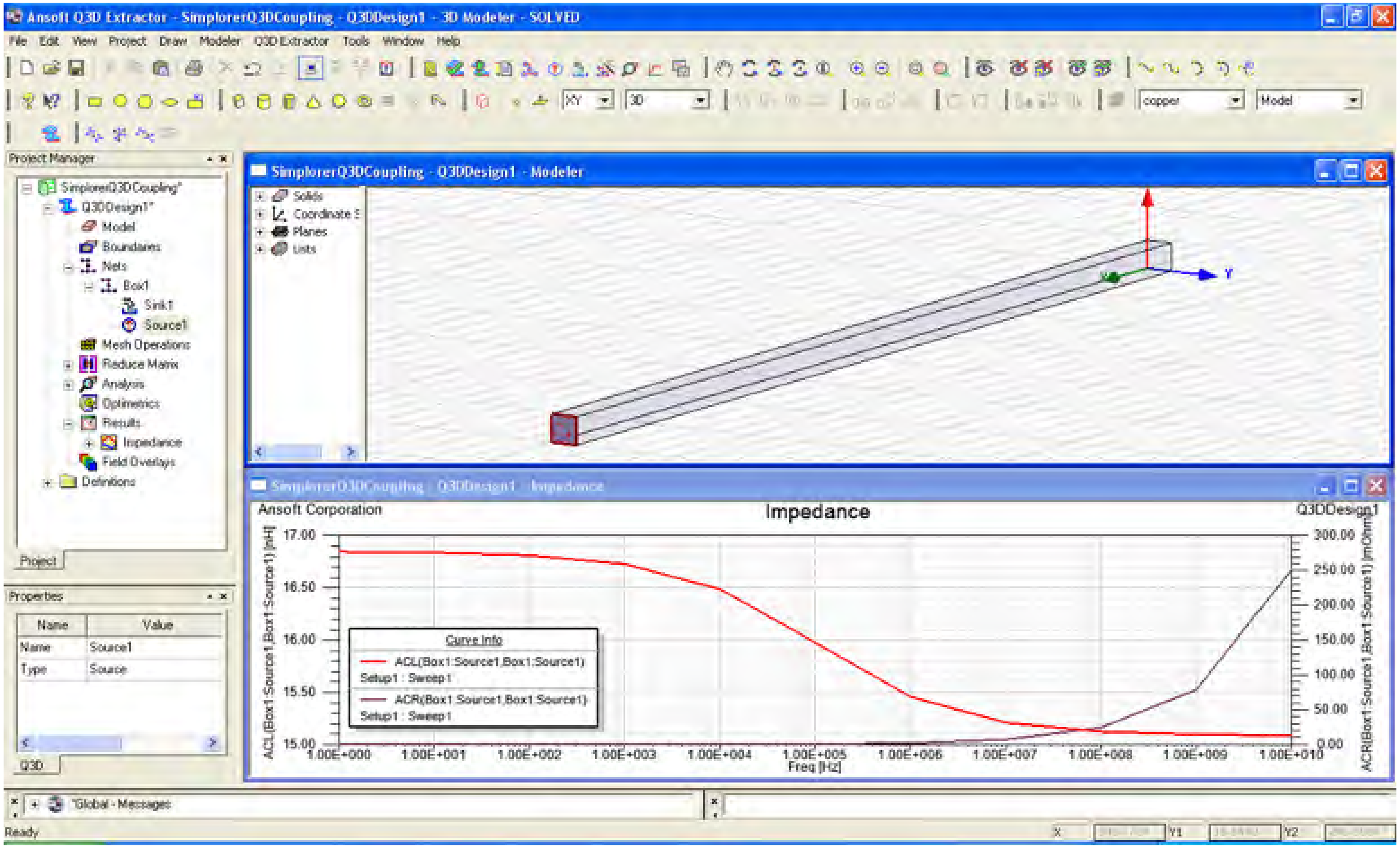
- Main LF applications are:
- Bus bar systems
- Power modules (coming from a MCAD package)
- Power boards (coming from an ECAD package)
- Assembly (board + housing + busbar for instance)

•We specifically cover the following issues:

- Solver setup/求解设置
- State Space model generation to Simplorer/生成状态空间模型到Simplorer

Q3D Extractor Graphical Interface

- Please refer to the Q3D User's Guide for detailed descriptions



Import Geometry – ECAD and/or MCAD

ECAD

- Cadence Allegro/APD/SiP
- Mentor Graphics Board Station
- Mentor Graphics Expedition
- Mentor Graphics PADS Layout
- Zuken CR5000
- ODB++
- DXF
- GDSII

↓

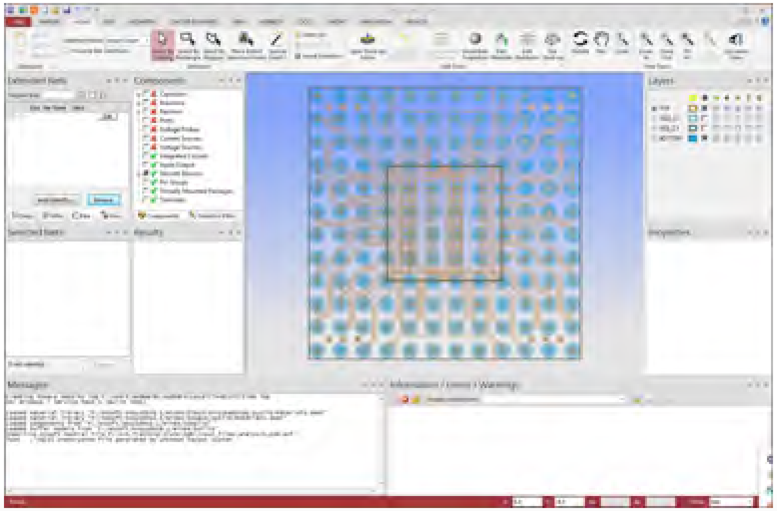
SIwave → **HFSS** / **Q3D Extractor** / **3D CAD Model**

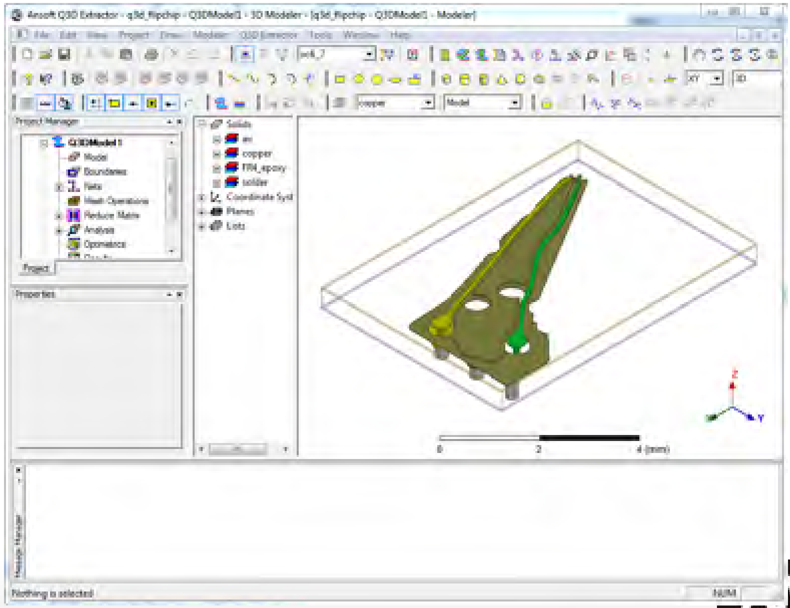
MCAD

- IGES
- STEP
- ACIS
- Parasolid
- Pro-ENGINEER
- AutoCAD
- CATIA
- Siemens PLM NX

↓

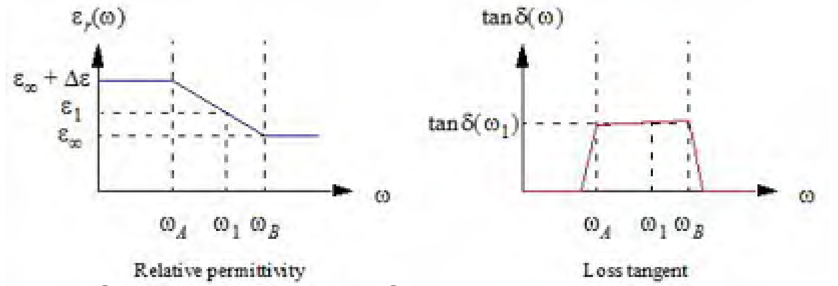
Q3D





材料特性

- Conductors / Dielectrics have distinct behavior./导体和电介质有不同的行为特性
- Materials are Passive, Causal, and Linear, but frequency-dependent./频变材料
- Conductors determine capacitance surfaces ("nets"), and solid current paths where you can assign source/sink terminals.
- Dielectrics affect capacitance (frequency dependence) as well as dielectric loss (conductance).
- To maintain causality, the frequency-dependence of the dielectric material needs to satisfy criteria, and are automatically adjusted in some cases.
- To simplify geometry, the Background material can be set as dielectric so that dielectric objects can be excluded from geometry.



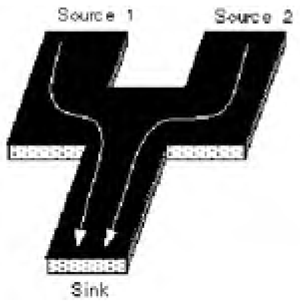
In LF power-electronic applications, G is very small, and it is suggested to ignore G by setting Loss Tangent = 0.

导电网络

- A net is a collection of touching conductor objects.
- Use Auto-Identify Nets to generate conductor nets for all separate conduction paths.

- A net must have source & sink terminals for RL analysis
- A net does not need either terminal for CG analysis

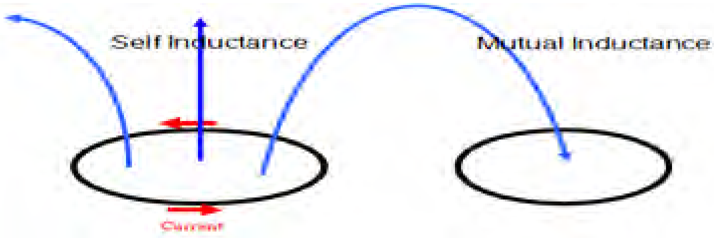
- A net cannot have more than one sink terminal
- You can have multiple sources



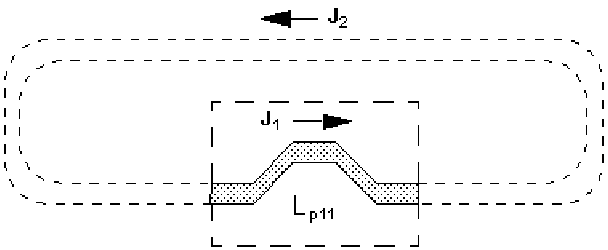
Source and Sink (Terminals)

- Source/Sink can be assigned to faces of 3D objects or 2D sheet objects touching a 3D conductor.
- [Source]: The face which becomes an inflow source of an electric current.
- [Sink]: The face which becomes an outflow source of an electric current.
- It's possible to set only 1 sink per conduction net. You can switch around the direction of Source/Sinks in the Matrix Reduction, but it is not necessary for use in Circuit simulations.
- Do not select multiple faces and assign them to one source or one sink. Assign each face separately and combine in Matrix Reduction if necessary.

Partial vs. Loop Inductance – Overview



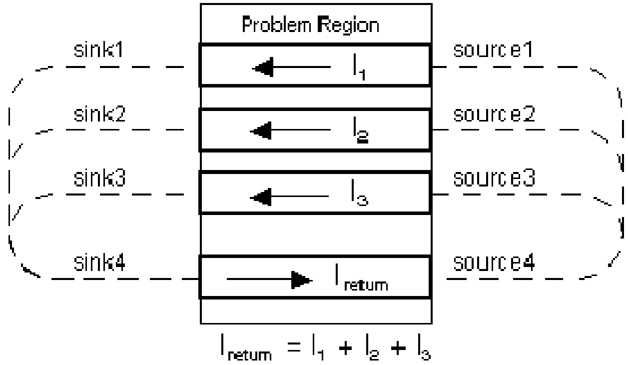
- Inductance can be defined as:
  - ✓ Partial Inductance, or Loop Inductance
  - ✓ Each of these inductances have self and mutual (in a multi-conductor system) components



- **Q3D Extractor** calculates **Partial inductance**
- Loop inductance is measured in the lab
  - ✓ Typically an inductance measurement requires a complete circuit path (i.e. loop) and the location of the return path has an effect on this Inductance value. We can also specify the self inductance and mutual inductance.
- Sometimes the return path may be difficult or impossible to specify but it is possible to integrate over a known current path only and call this partial inductance. Partial inductance represents the component of inductance that results only from the part of the current loop that is explicitly being modeled.

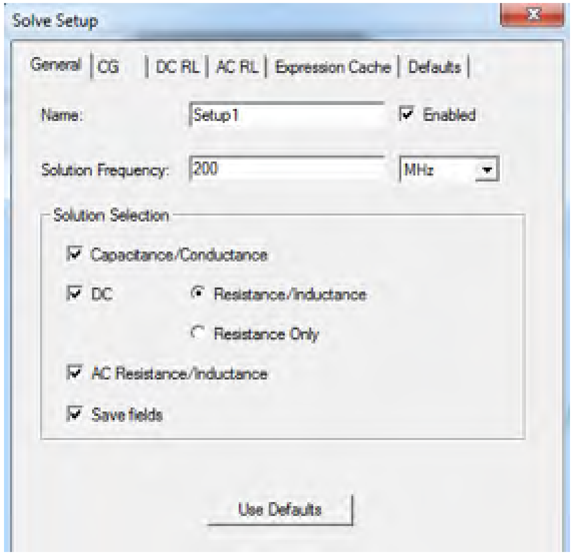
Partial vs. Loop Inductance (Continued)

- The total loop inductance is the sum of the partial self and mutual inductances for each section of the loop. $L_{loop} = L_{11} + L_{12} + L_{21} + L_{22}$
- In order to correlate the Q3D Extractor results with measurement results, a return path matrix reduction operation can be performed. This reduction allows us to specify a net to serve as a return path for current. We can then approximate the loop inductance of a closed conduction path. Specifying a return path does not simulate the effect of the full current loop because parts of the loop may not be explicitly modeled.



Simulation Setup

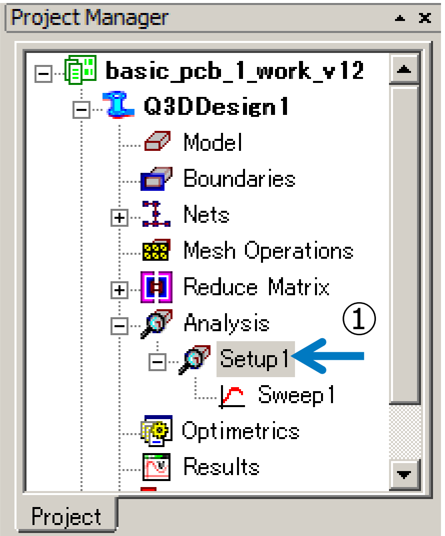
- **Solution Frequency is at the frequency where you only have surface currents due to skin-effect. In LF applications, a frequency ~100-500MHz is usually sufficient.**

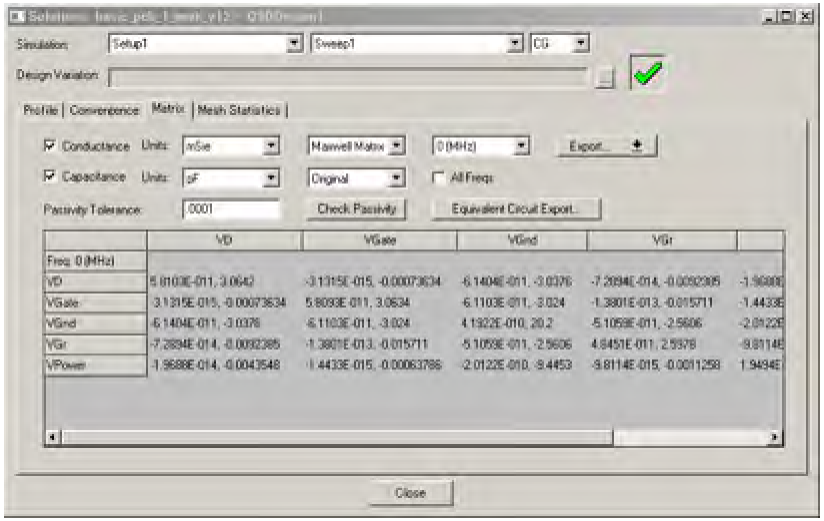


- **This solution frequency should only correspond to where skin-effect is dominant, and not to any intermediate frequencies. Intermediate frequencies are extracted in RLC results only.**

LCR matrix calculation

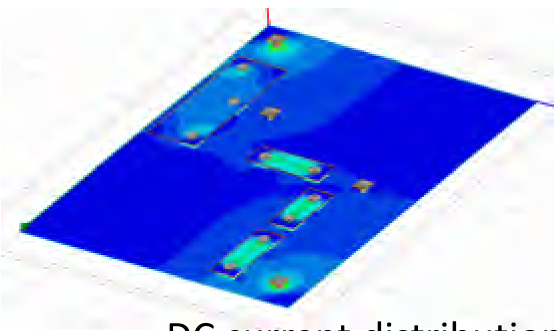
- <u>LCR matrix</u>
  Right-click on Analysis>Setup and the C, R, L is displayed in the *Matrix* tab.



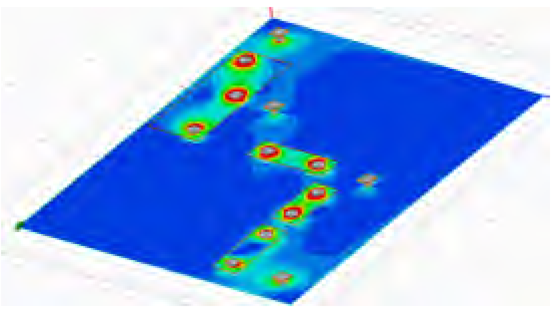


The resistance value in DC, inductance value and the capacitance are displayed.

The resistance value at AC solution frequency and inductance value are also available as a calculation result of ACR/ACL.



DC current distribution.



AC current distribution on surfaces.

Matrix Reduction (optional)

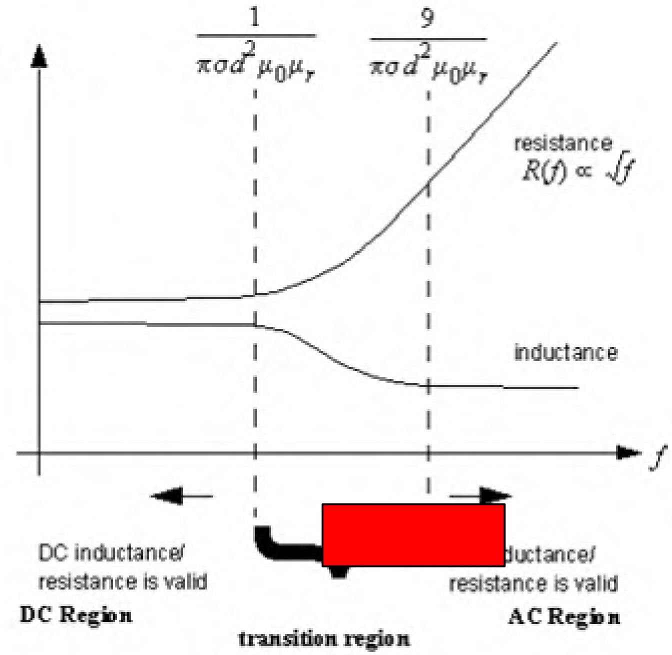
- **Matrix Reduction is not necessary for circuit simulation, as the terminals can be connected in a circuit simulation.**
- **Reduction allows (reduces/adjusts pins):**
- **Move/Add Sink (changes Source/Sink locations)**
- **Join in Series/Parallel (combines R/L for separate paths)**
- **Float/Ground Net (adjusts C/G)**
- **Float Terminal (no R/L contribution)**
- **Float at Infinity (no infinite contribution to C/G)**
- **Return Path (a specific Join in Series)**
- **Change Frequency (used automatically in Frequency Sweep)**

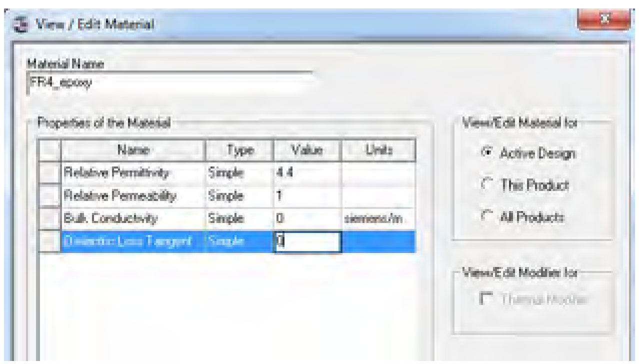
Frequency Solution and Effects

- **RL solution does not solve in transition region**
- **One RL Solve at DC**
- **One RL Solve at AC**
  - ✓ Surface current (skin depth) is well developed
- **Intermediate frequencies are interpolated in the transition region.**

CG solves across frequency sweep only if dielectric permittivity, and loss-tangent produce frequency-dependent effects.

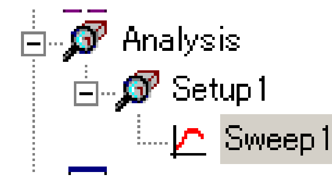
In LF power-electronic applications, G is very small, and it is suggested to ignore G by setting Loss Tangent = 0.





Frequency Sweep

- **To generate an accurate State Space Model, it is important to get enough frequency values.**



- **For that, create an Interpolating Sweep using a log scale with at least 5 samples per decade. Start at 1Hz (DC).**

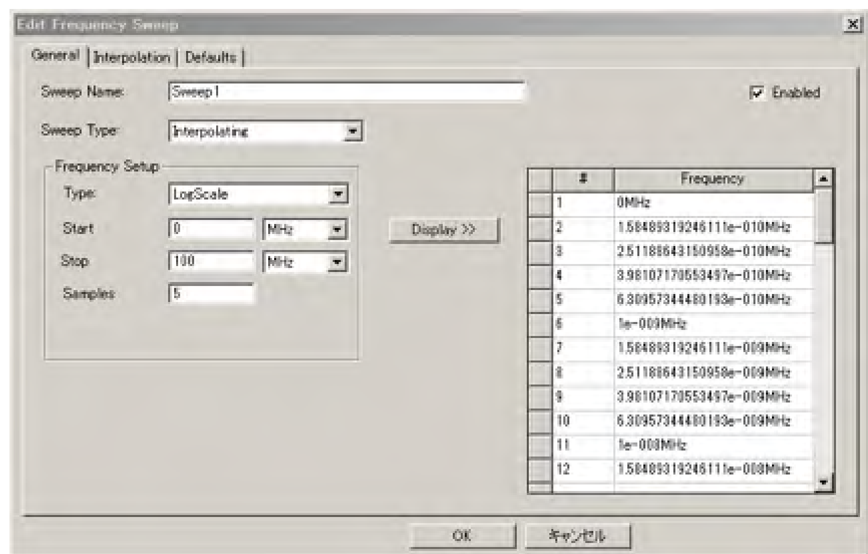
The max frequency is the highest frequency involved in the upcoming Simplorer simulation.

$2 * f_{max\_Simpl\_result} < f_{max\_Q3D\_sweep}$

$1/(5 * \text{rise-time}) < f_{max\_Q3D\_sweep}$

$2/H_{min} < f_{max\_Q3D\_sweep}$

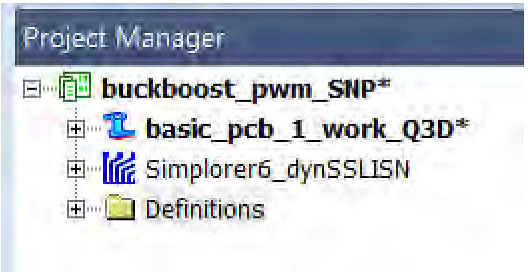
Hmin = Simplorer minimum time-step

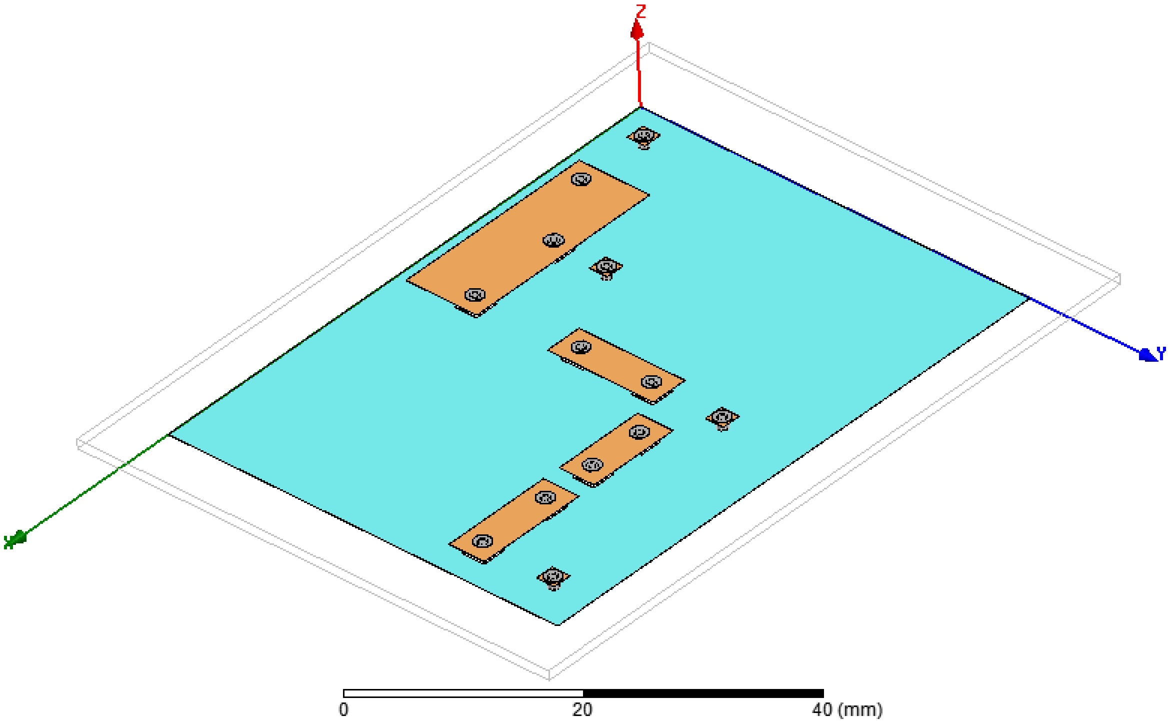


D. 用于噪声计算的动态耦合

Start Electronics Desktop

- Open the ANSYS Electronics Desktop
  ① Open example file “buckboost_pwm_SNP.aedt”
  ② Show design “basic_pcb_1_work_Q3D”
  (Start solving if desired.)

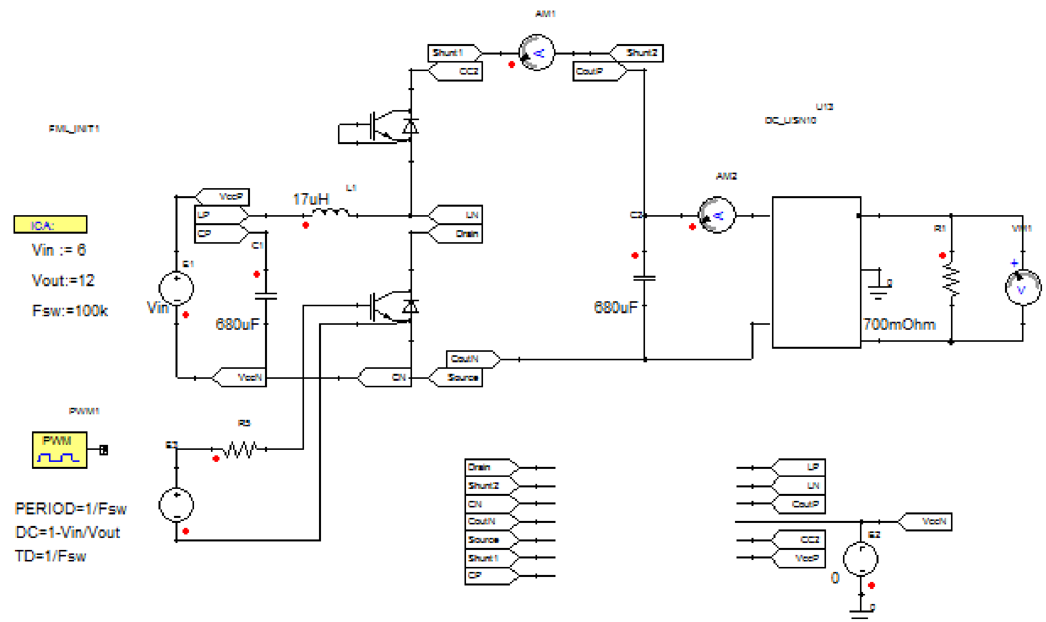




ANSYS

Switch to Simplorer Design

- Switch to Simplorer Design
  ① open design "Simplorer6_dynSS_LISN"

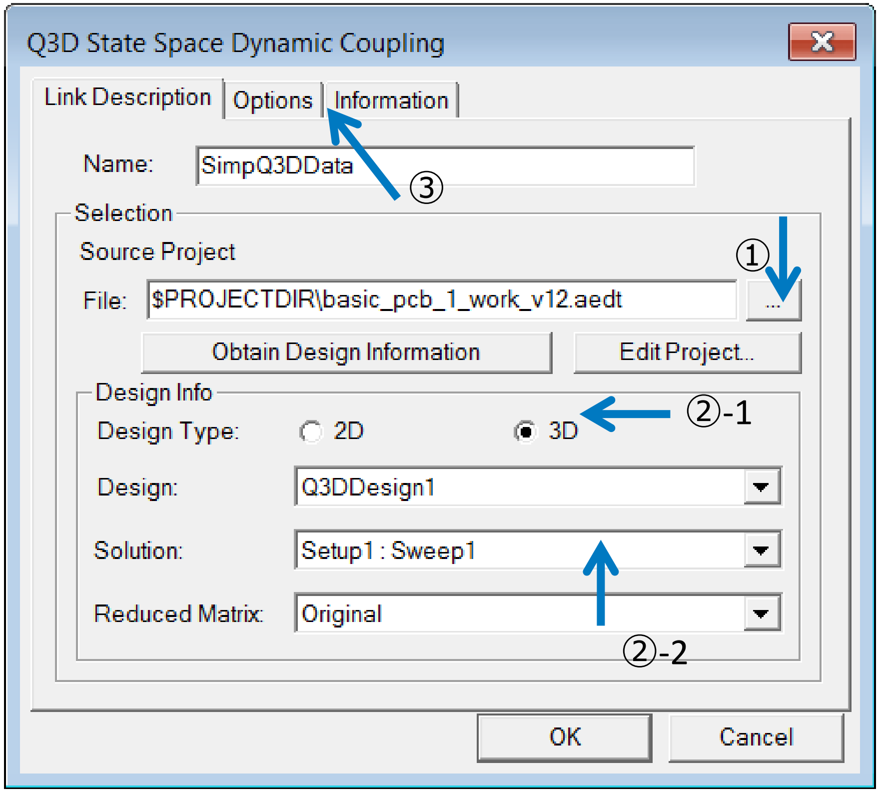


Import state space model

- Importing state space model

  ① menu [SimplorerCircuit] / [SubCircuit] / [Q3D Dynamic Component] / [Add State Space]

  Select Q3D/Desktop file. Select own project filename. Could be another file.

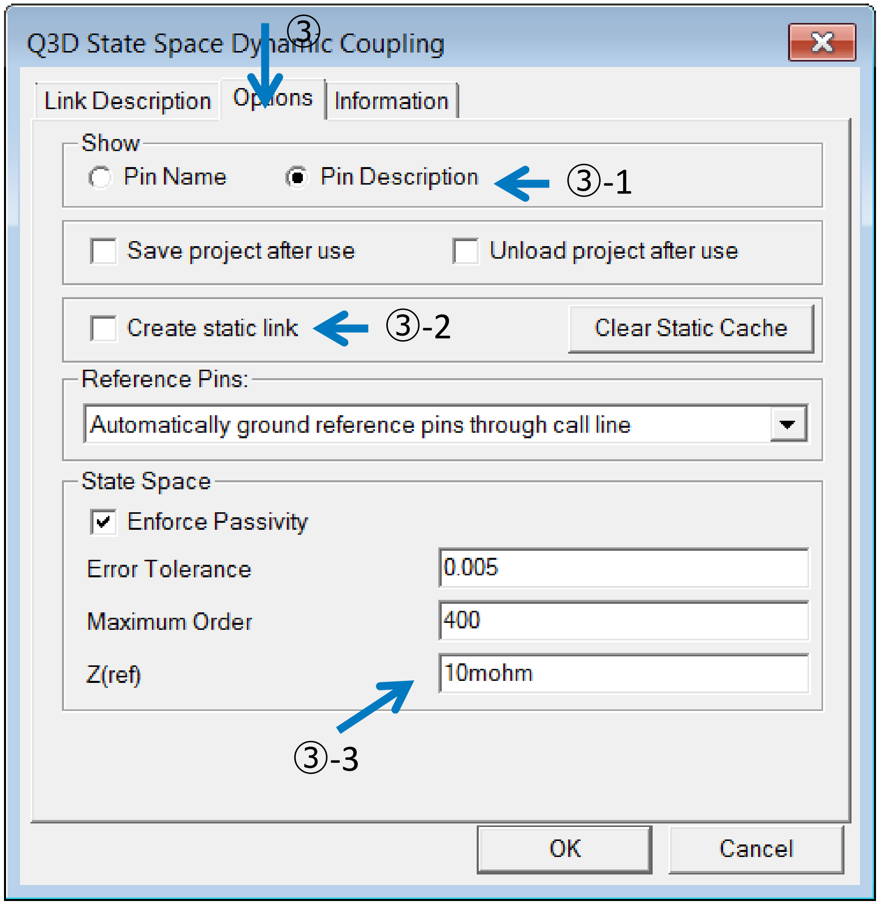


② Select Q3D design data.
First, select 3D, for 3D geometry.
A frequency sweep setting name is specified for the model data.

③ Next, we go to the Options tab.

Import state space model(2)

③ Check the Options tab settings.



③-1 [Pin Description]

The multi-terminal model used in Simplorer can make use of the source/sink names by selecting Pin Description. Interaction with the component is much easier, so this setting is recommended.

③-2 [Static link]

OFF (default): Every time a simulation is begun, Q3D is started so that the data is update.

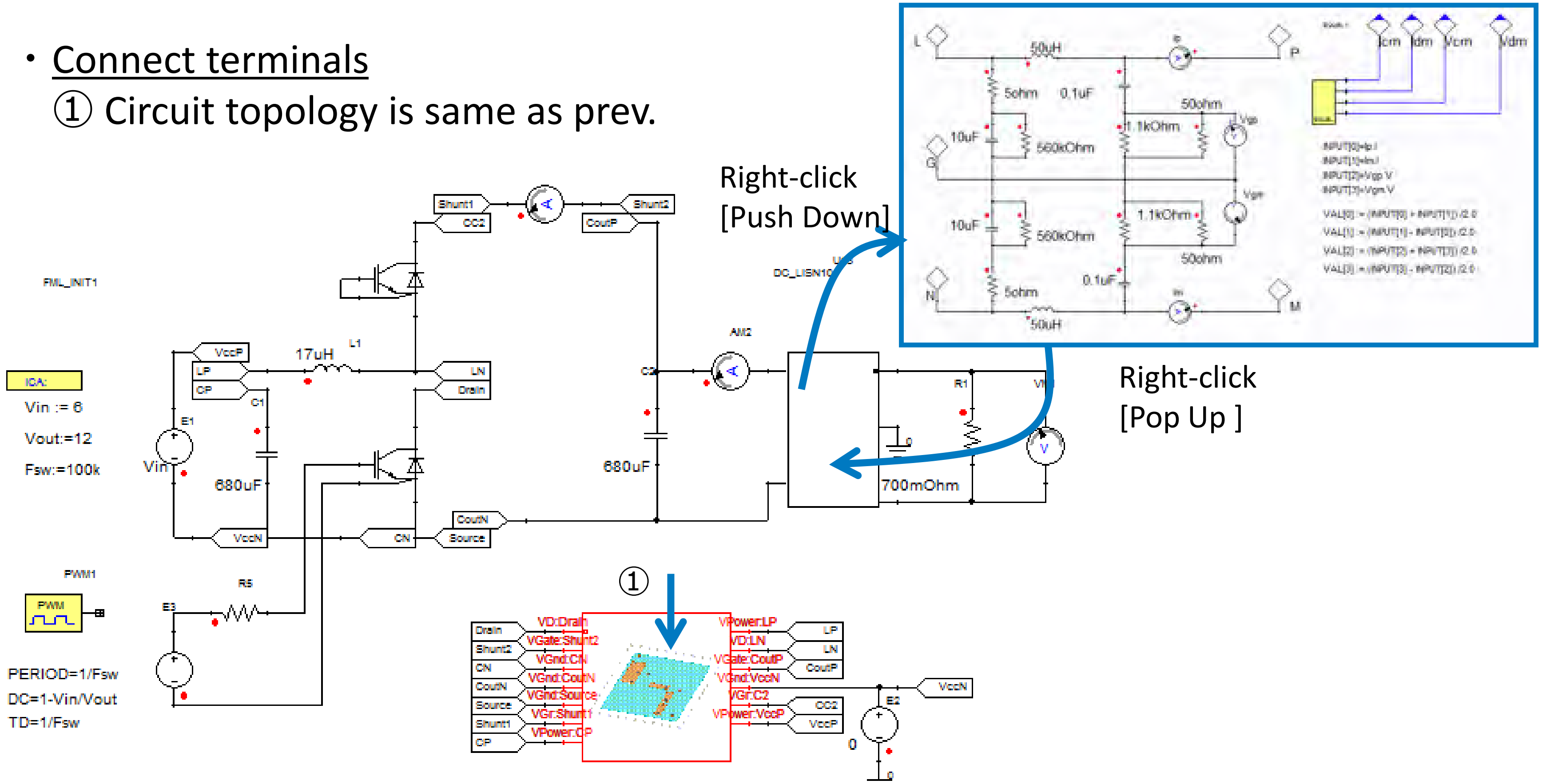
ON: The model data is embedded in Simplorer after first created. The Simplorer file can be moved to other computers on its own, and it's possible to simulate Simplorer without a Q3D license. If there is a parameter variation/change, then Q3D will be called to extract the data for the new variation.

③-3 [Z(ref)]

This is a reference impedance for the state-space model data. It is suggested that this value match the impedance in your system, possibly 1mOhm-1Ohm.

Place parts

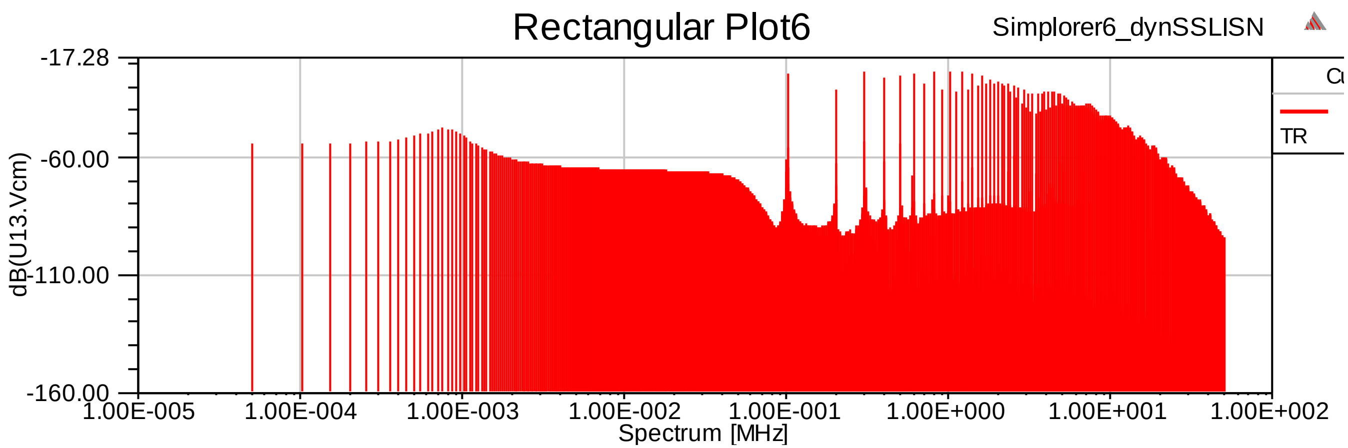
- <u>Connect terminals</u>
  ① Circuit topology is same as prev.



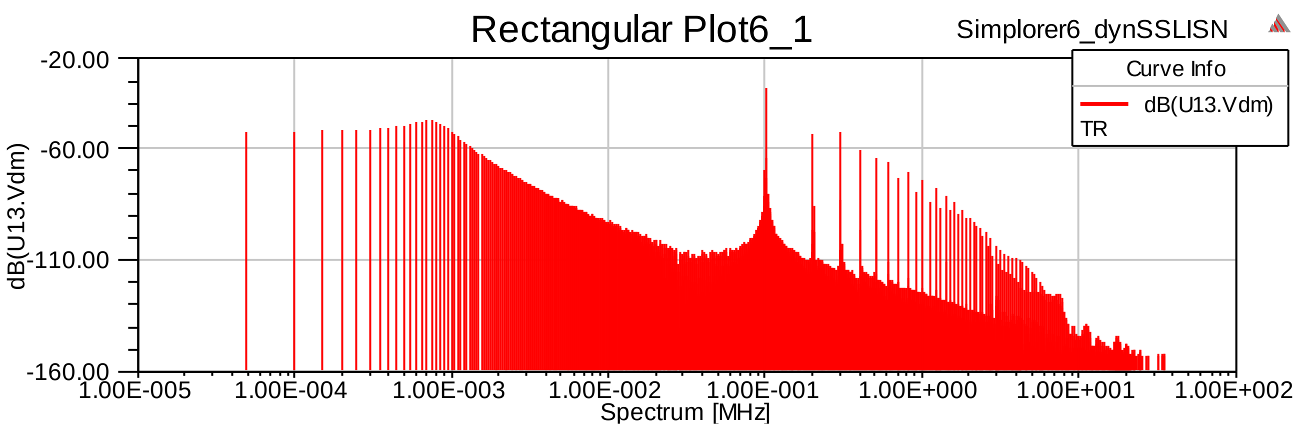
Right click menu [Push Down] to show LISN sub circuit. Go back to upper level, [Push down] in right click menu on free space of sheet.

[Tips] [Add at unconnected pins]/[Page connectors] right-clicks a part, and is convenient.

Simulation result

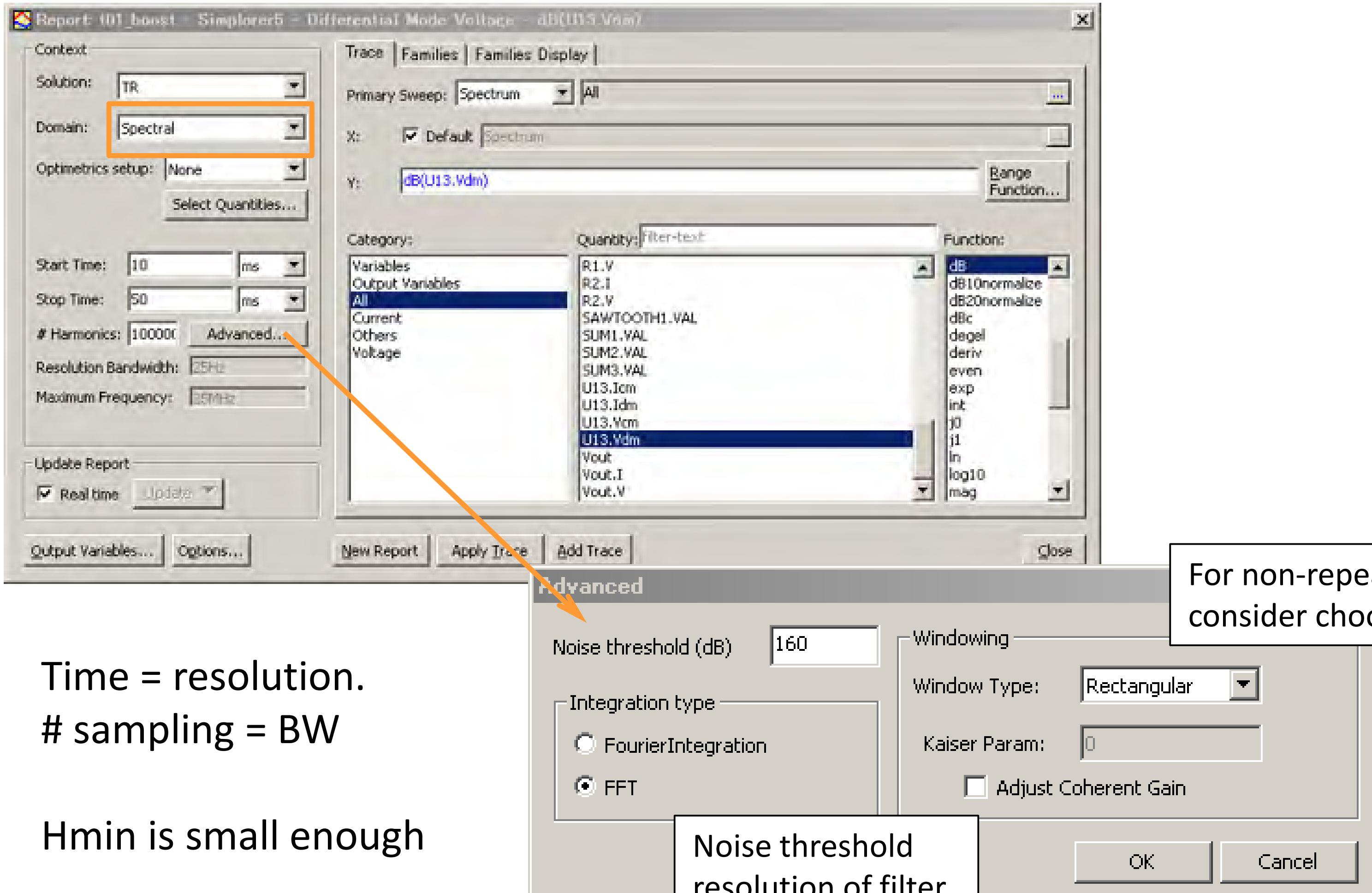


Common mode voltage Vcm [dB]



Normal mode voltage Vdm [dB]

FFT: Trace setting



For non-repeating waveforms, consider choosing a window.

Noise threshold resolution of filter. default = 40[dB]

Time = resolution.
# sampling = BW

Hmin is small enough

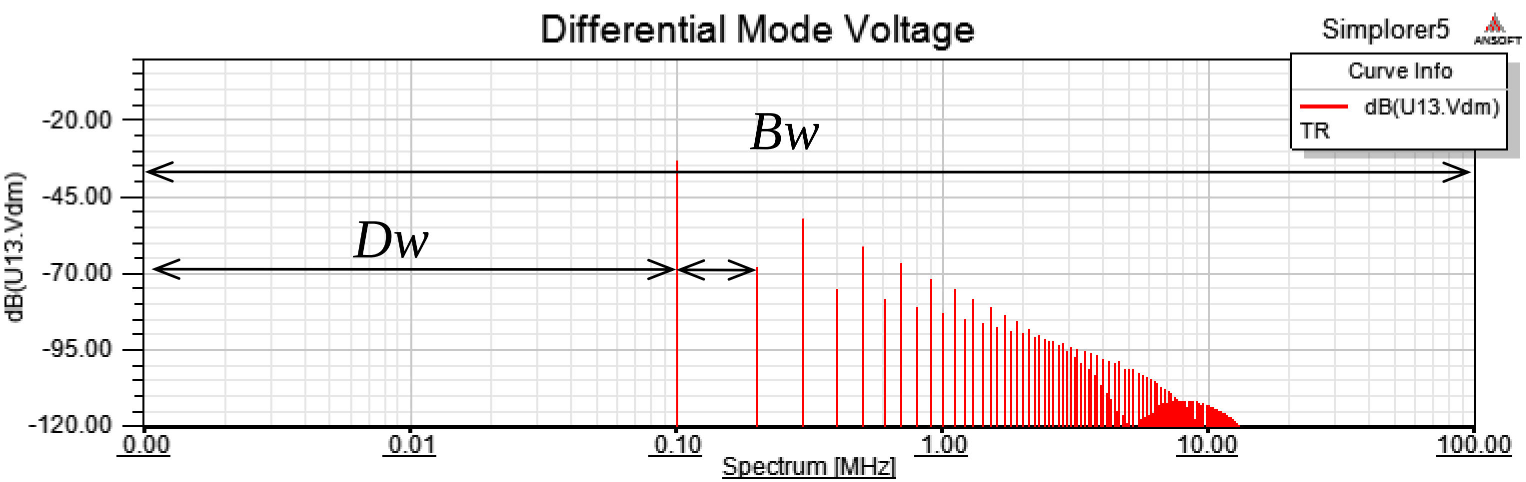
FFT Resolution

Don't alias your post-processing FFT's. If there are higher frequencies, make sure you use enough FFT points.

- **time T = StopTime-StartTime**
- **Sampling N = #Harmonics**

resolution $$Dw = \frac{1}{T}[Hz]$$

Band width $$Bw = \frac{1}{T/N}[Hz]$$



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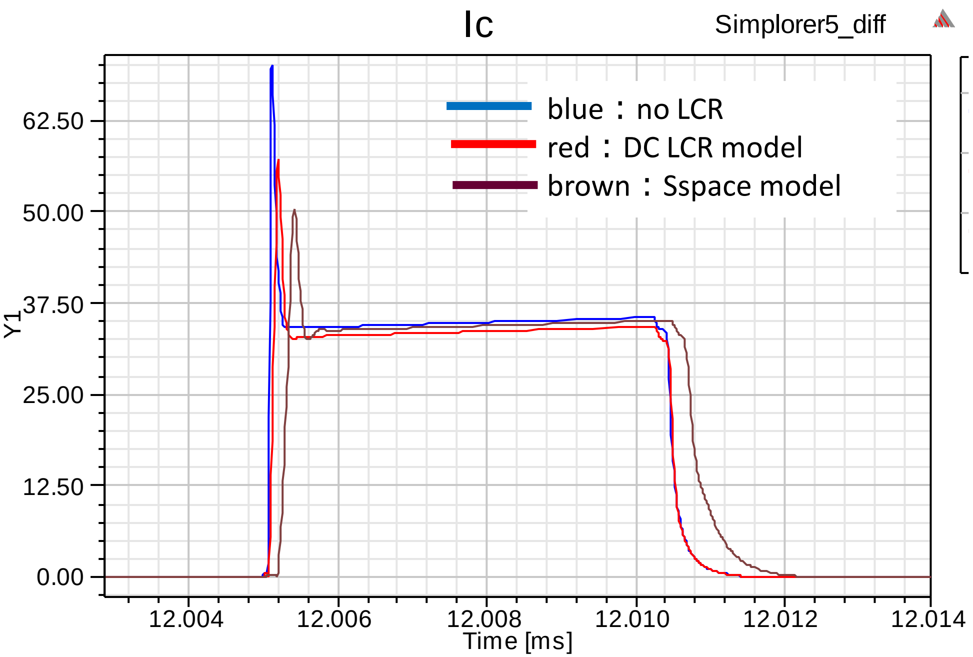
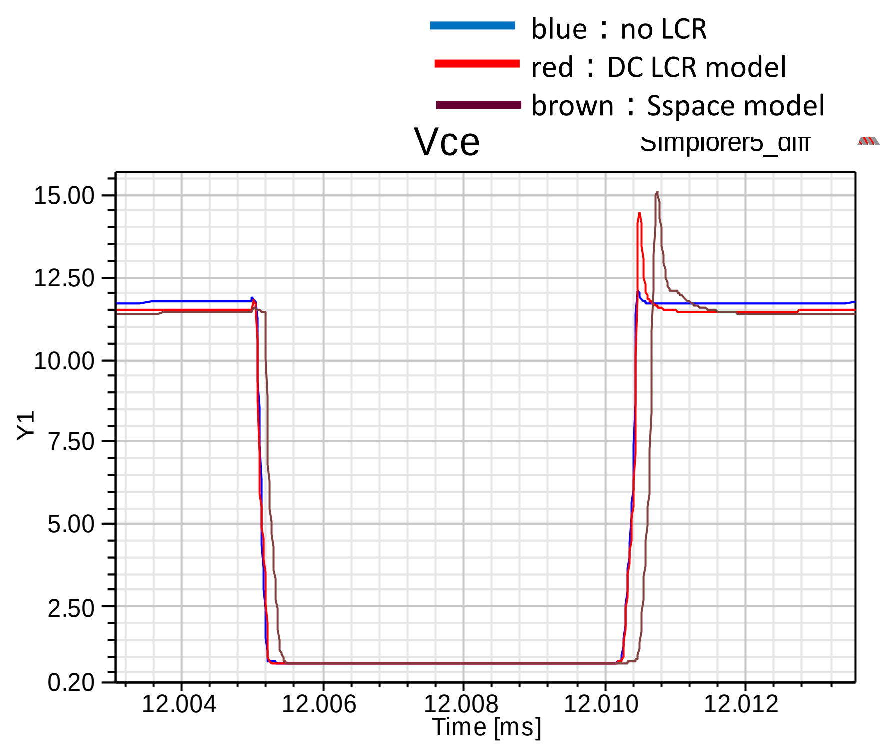
Switching waveform



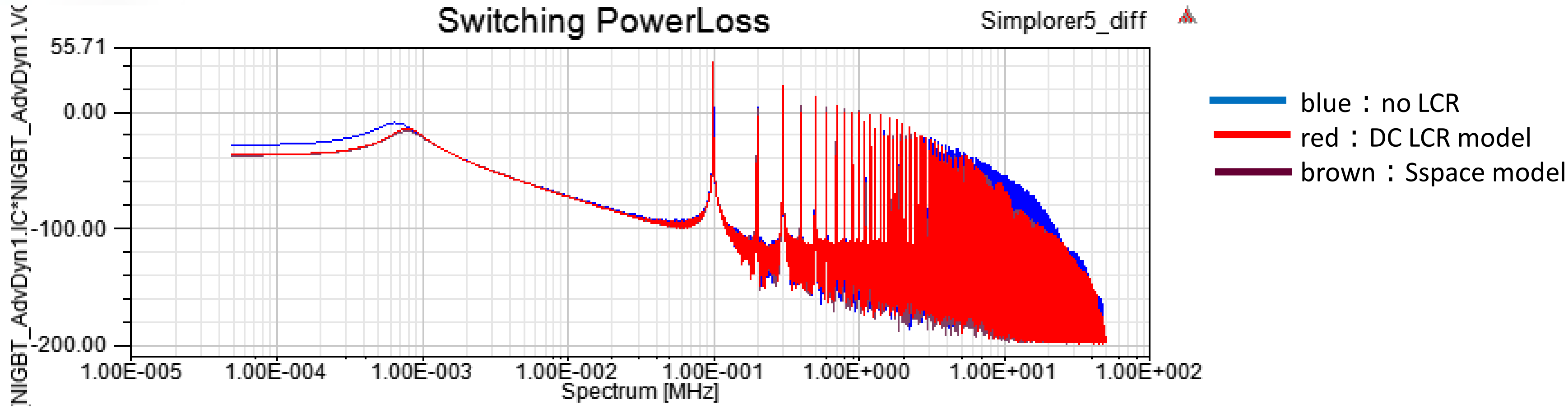
Turn on/off current Ic



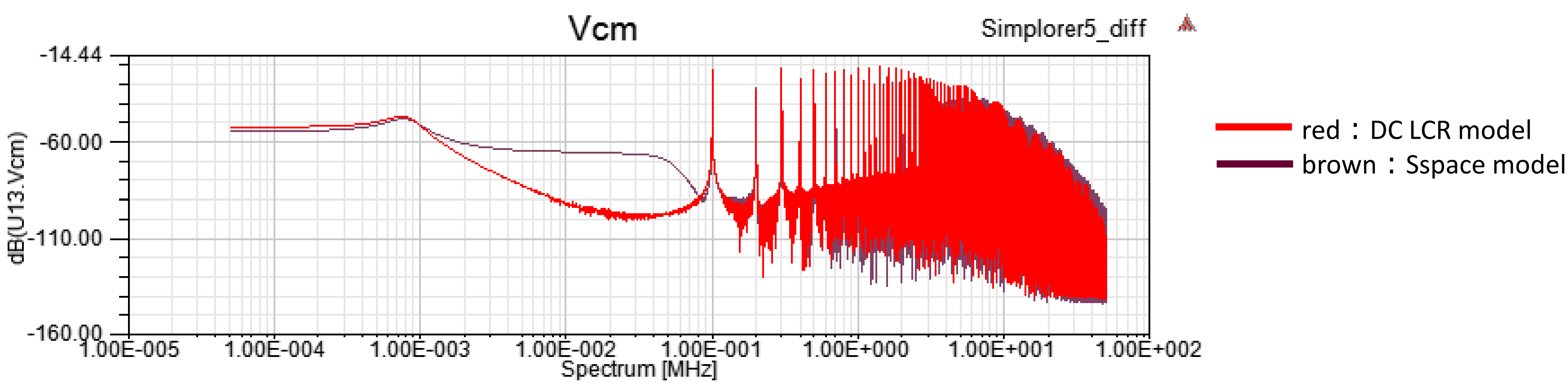
Turn on/off voltage Vce

A surge corrugation and the inclination are also affected.
⇒ The influence to noise will be confirmed.

Confirmation of a noise ingredient



Switching loss (Ic × Vce) [dB] frequency component

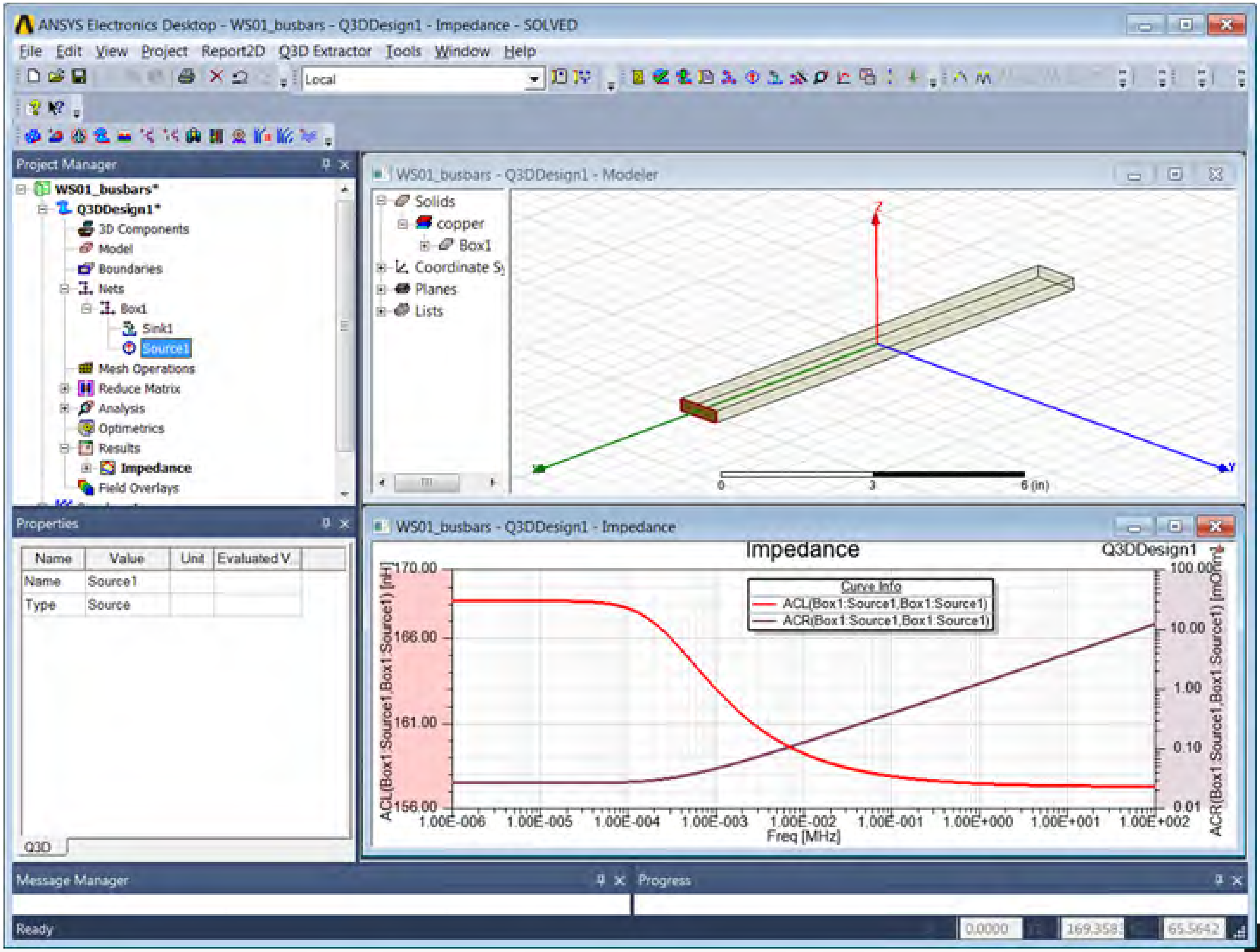


Common mode voltage Vcm[dB] frequency component

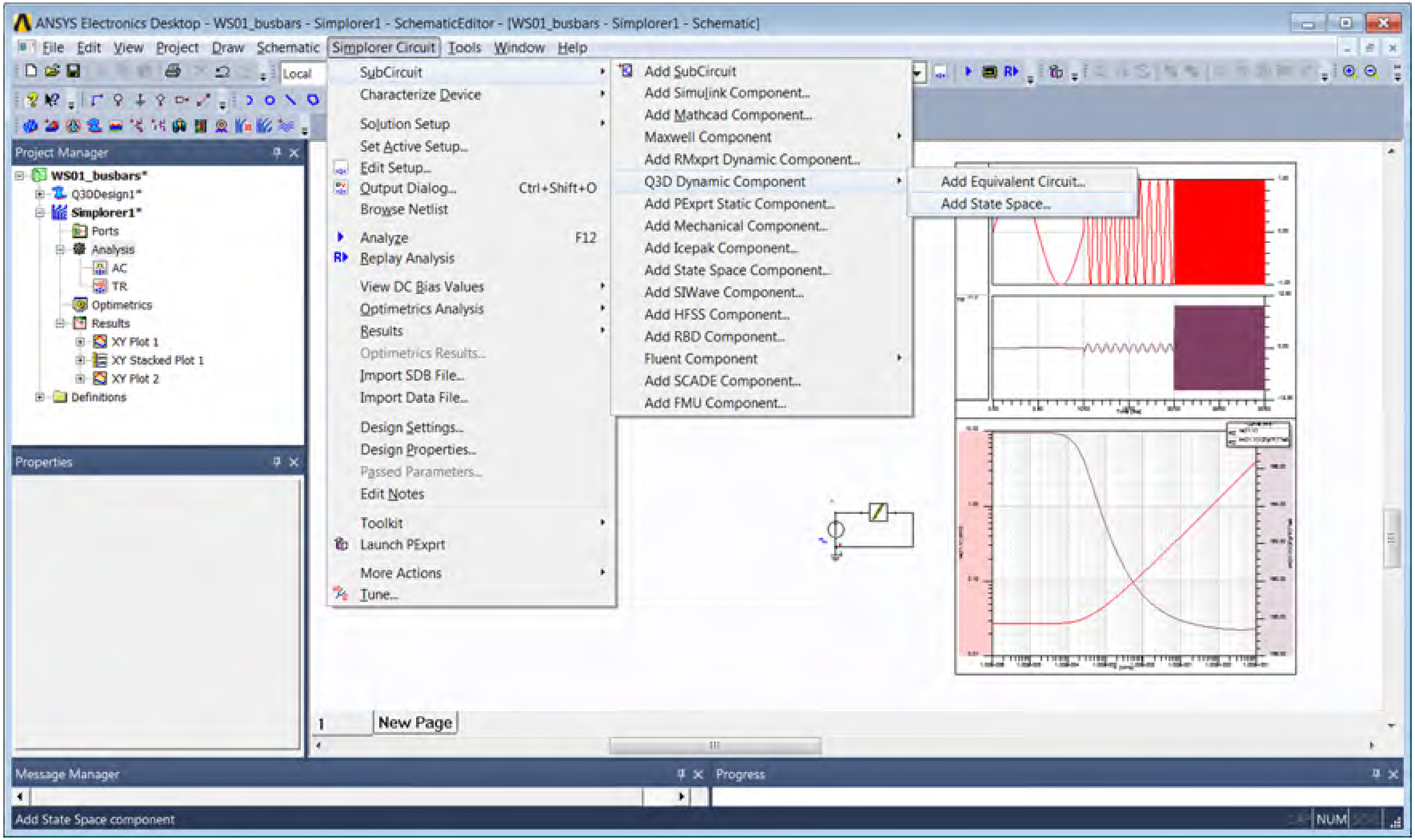
Behavior in the 10kHz where the inductance changes showed conspicuously.

It's also necessary to expand a sweep area to see the difference in the high frequency component

Frequency Dependent Busbar Model Example



Frequency Dependent Busbar Model Example



感谢聆听

ANSYS-China