EMI/EMC
LF Electromagnetics Overview

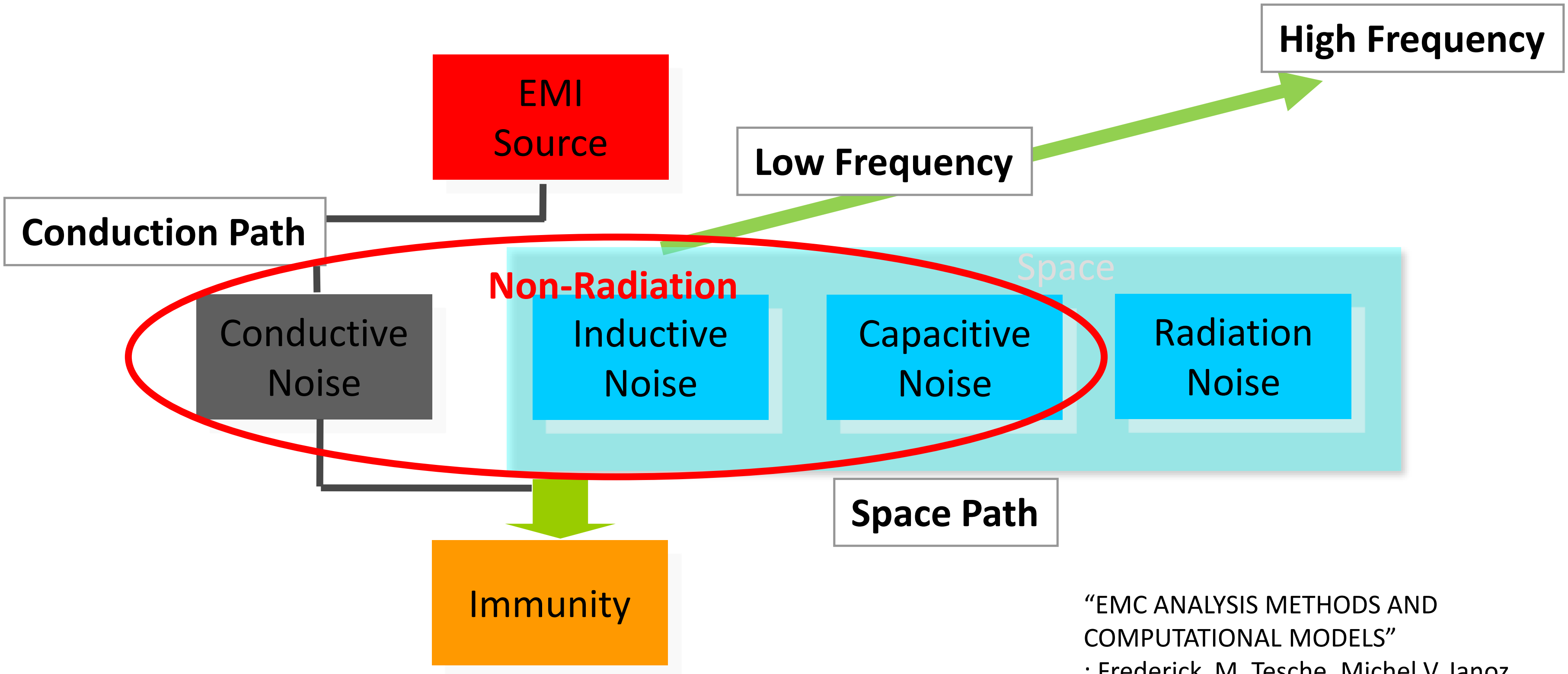
- Marius Rosu, PhD
- Lead Product Manager ANSYS Inc.

Agenda

- **EMI - Introduction**
- **Product Description**
- **Conductive Noise Simulation with Power Module and Cable**
- **Low Frequency Signal Integrity**

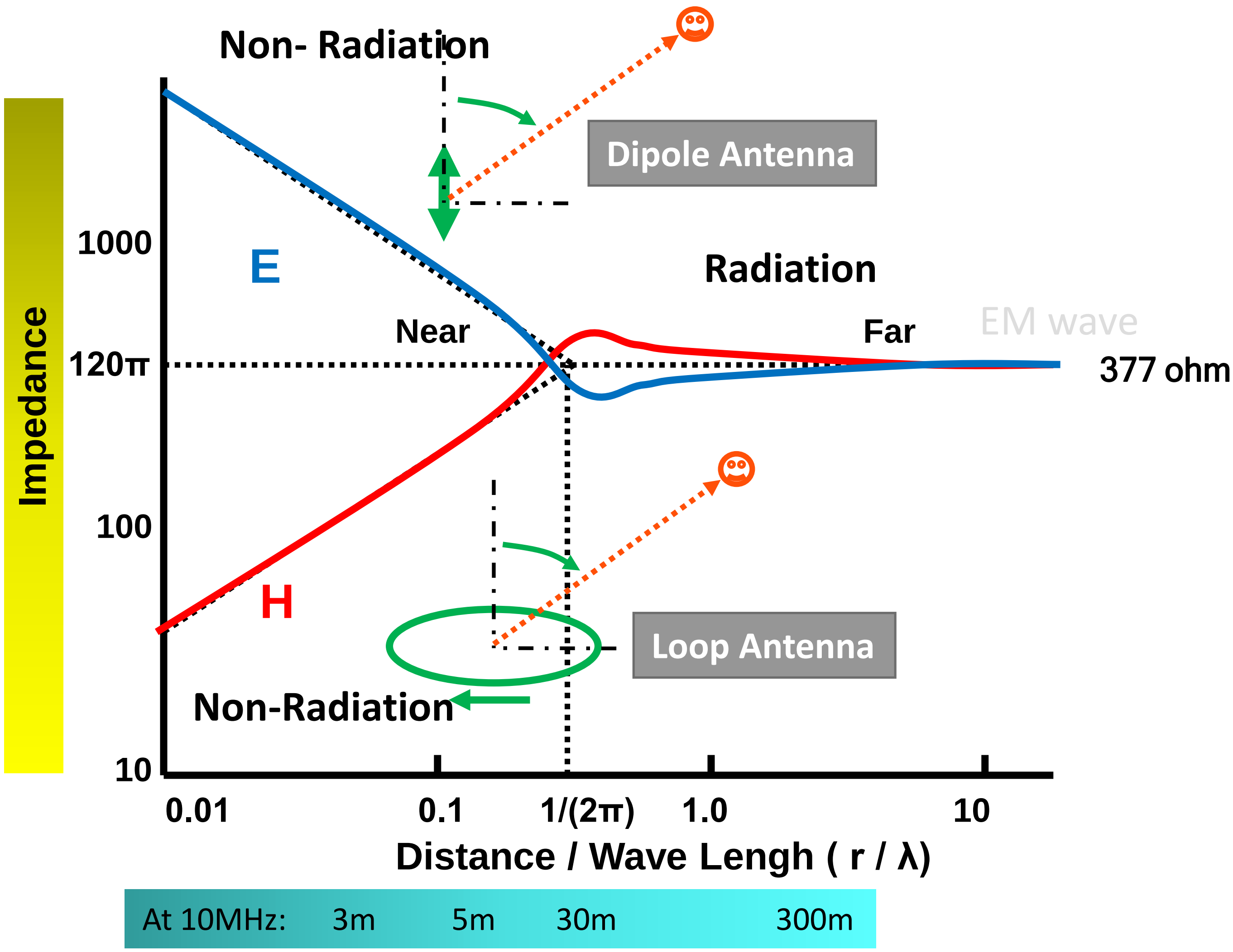
Three Factors – EM Noise Issue

1) Noise Source(EMI)
2) Load (Immunity)
3) Coupling Path



"EMC ANALYSIS METHODS AND COMPUTATIONAL MODELS"
: Frederick M. Tesche, Michel V. Ianoz
:John Wiley & Sons, Inc. 1997 p34-36

Noise Source / Electromagnetics Space Size

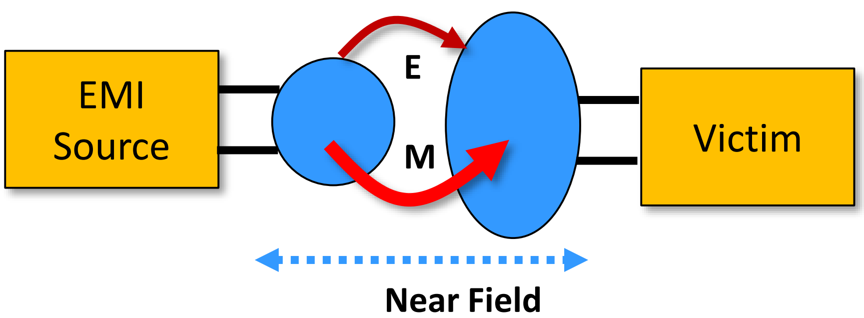


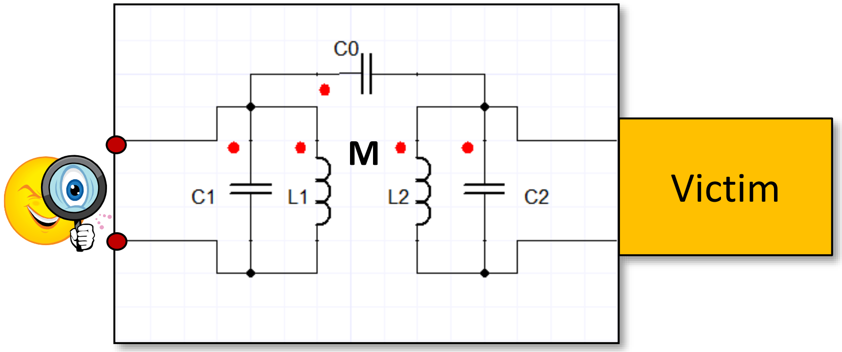
Tokyo Denki University Publication Bureau of the high frequency electromagnetic

Equivalent Circuit of Near Field Coupling

Inductive Noise

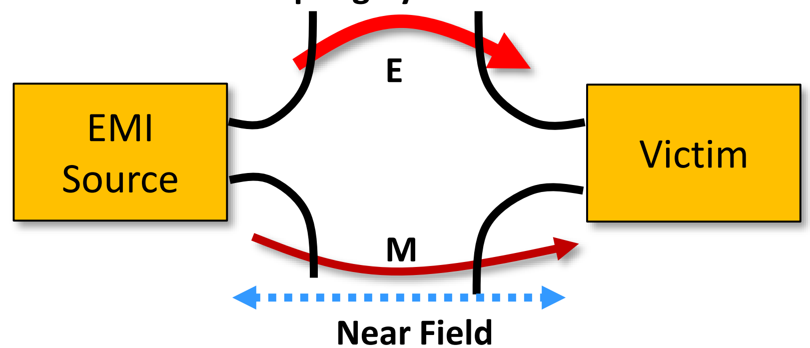
Source-Victim Coupling by Magnetic Field

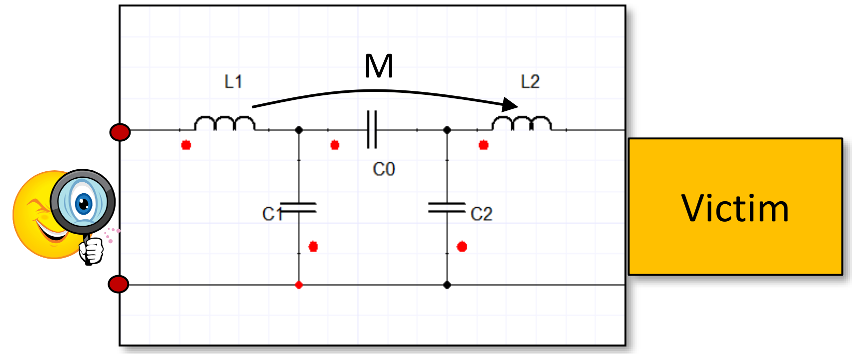




Capacitive Noise

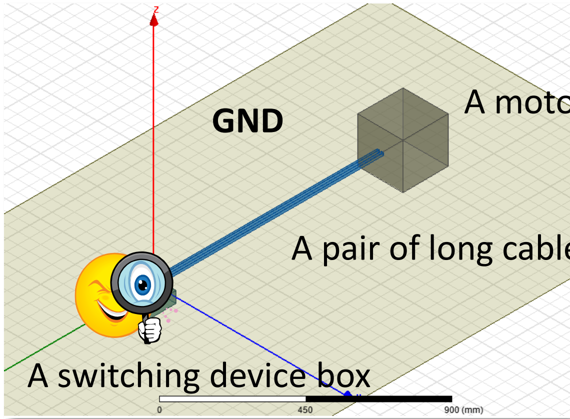
Source-Victim Coupling by E-Field



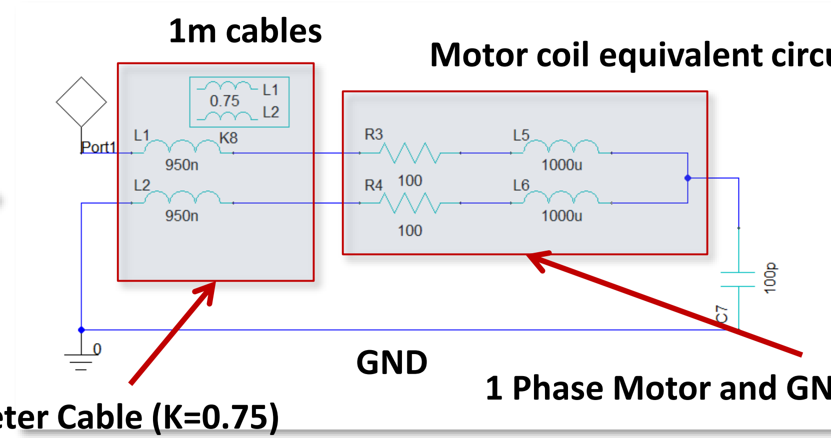


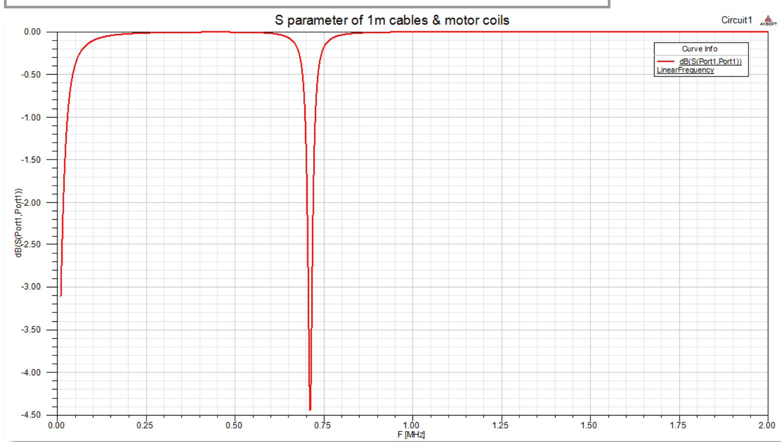
"EMC ANALYSIS METHODS AND COMPUTATIONAL MODELS"
: Frederick M. Tesche, Michel V. Ianoz: John Wiley & Sons, Inc.1997 p72-p86

Equivalent Circuit for Conductive Noise

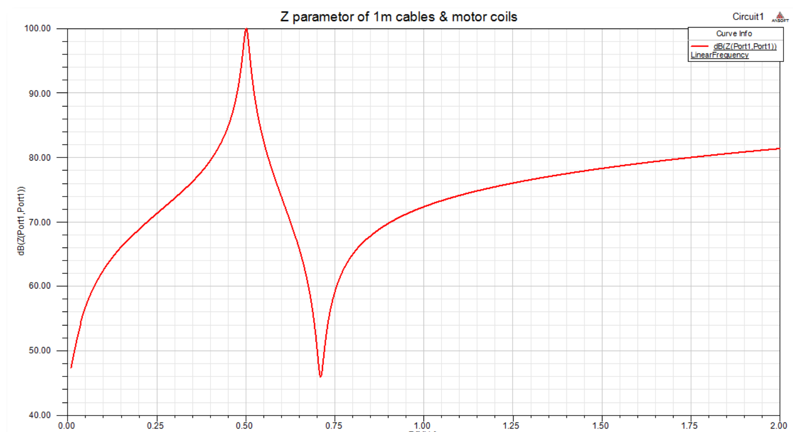


A model of motor and 1 meter cable





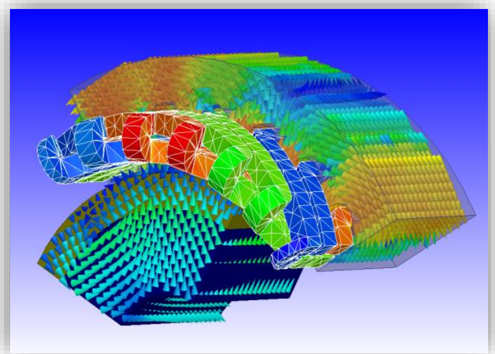
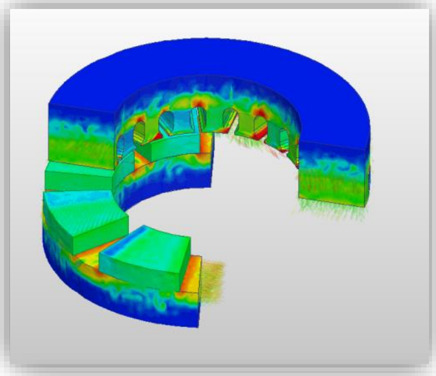
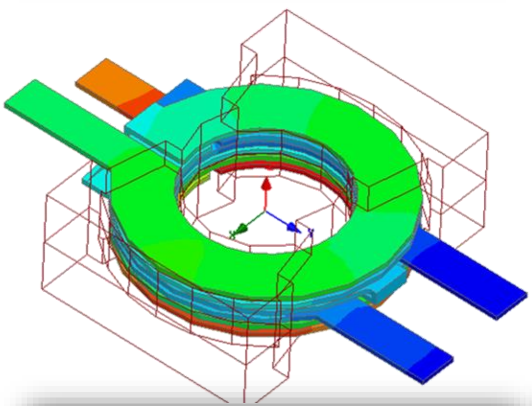
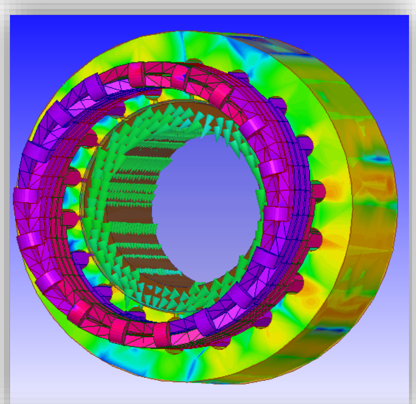
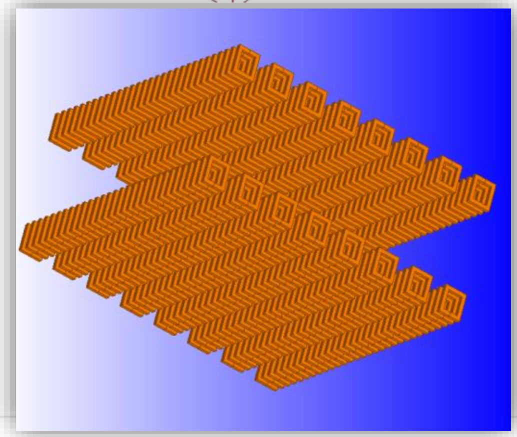
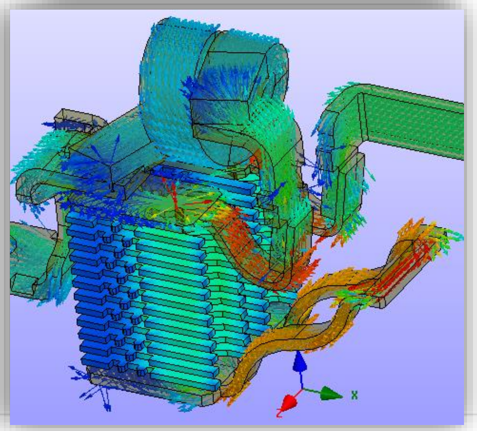
S-parameter (S11)



Z-parameter (Z11)

Traveling currents and voltages in a transmission line are affected when they meet a discontinuity caused by the insertion of a network into the transmission line. This is equivalent to the wave meeting an impedance differing from the line's characteristic impedance

ANSYS Maxwell

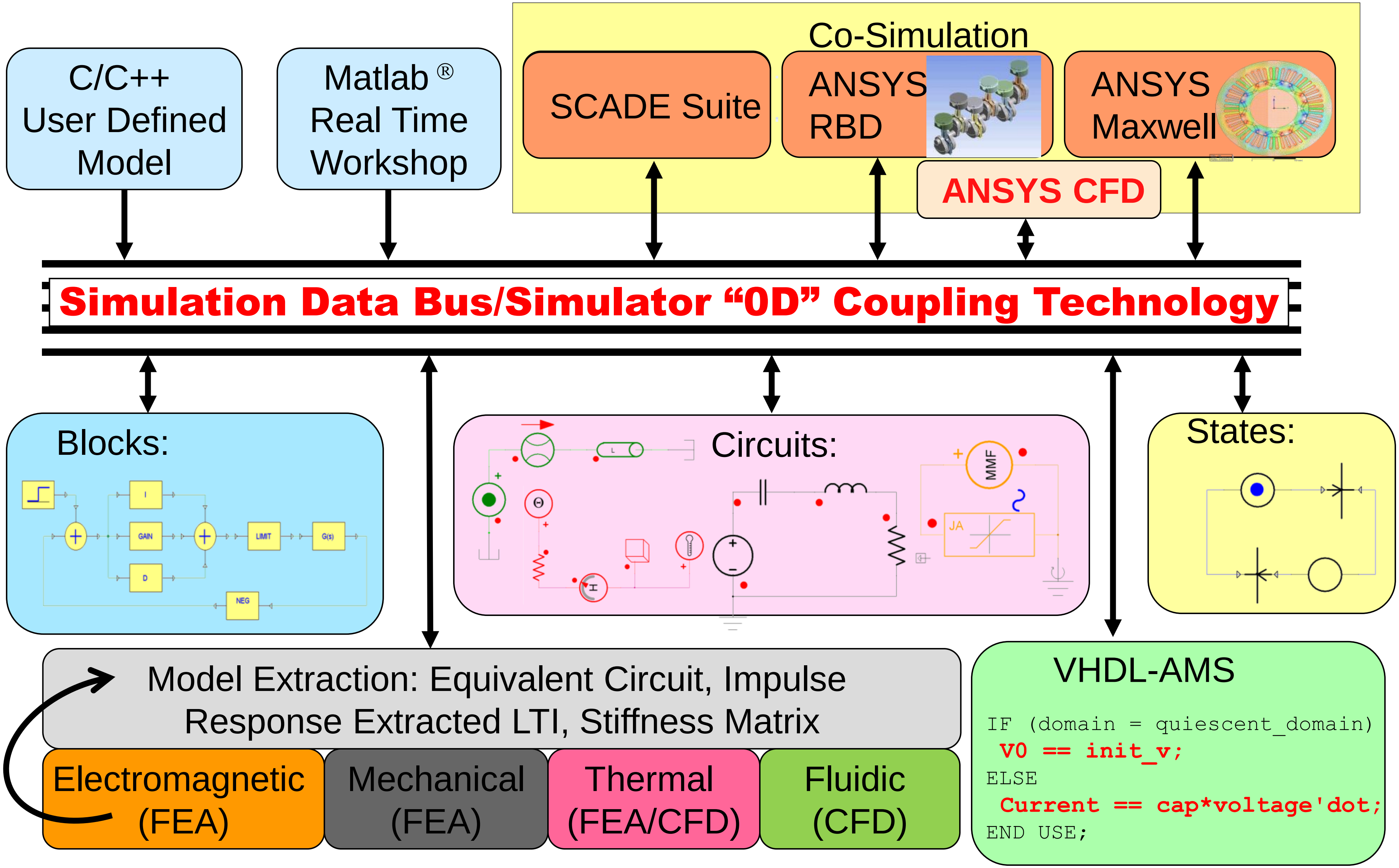
What it is

- 3D/2D LF electromagnetics physics-based solver

Applications

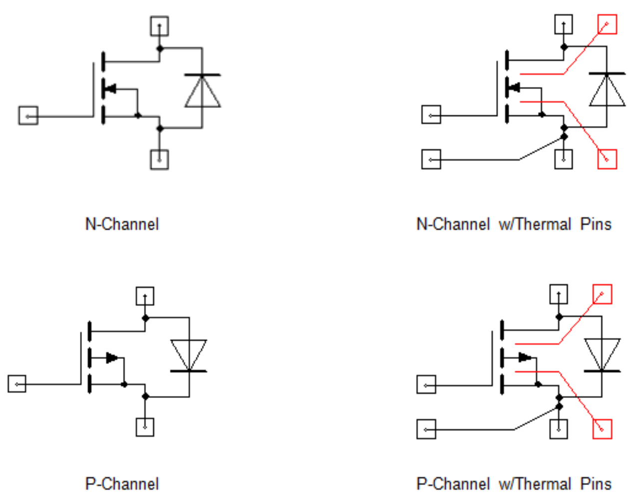
- Linear or rotational actuators
- Relays
- Magnetic recording heads
- Coils
- Permanent magnets
- Sensors
- Transformers
- Converters
- Bus bars
- Electrostatic discharge
- Electromagnetic shielding
- EMI/EMC
- Semiconductor
- Biomedical

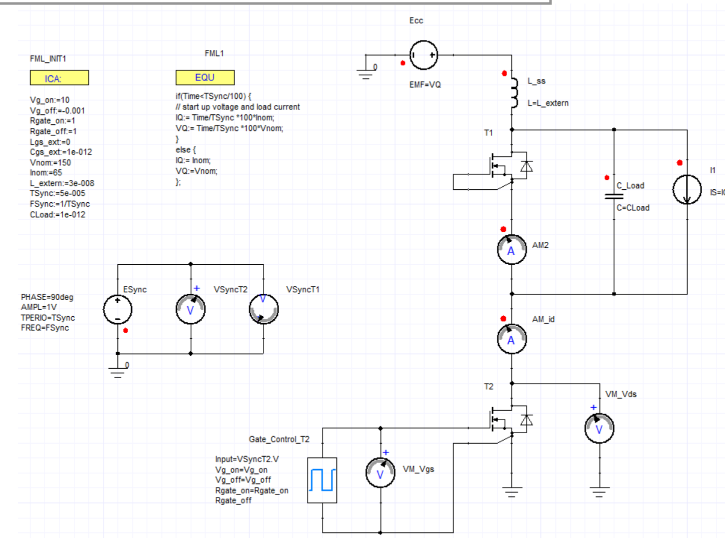
ANSYS Simplorer

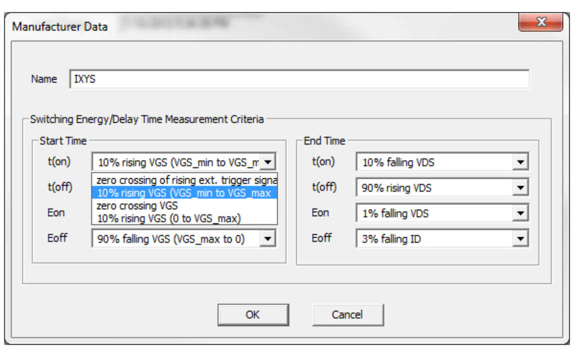


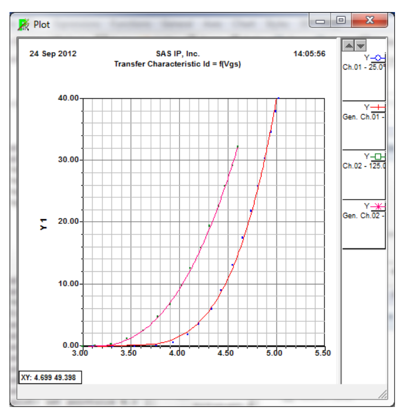
Characterization Device Capability

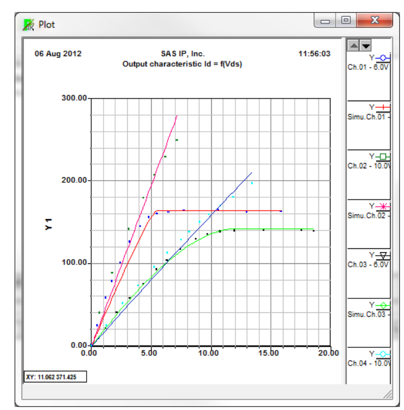
Allows creation of a Simplorer component from a datasheet for
- **IGBTs**
- **MOSFETs**



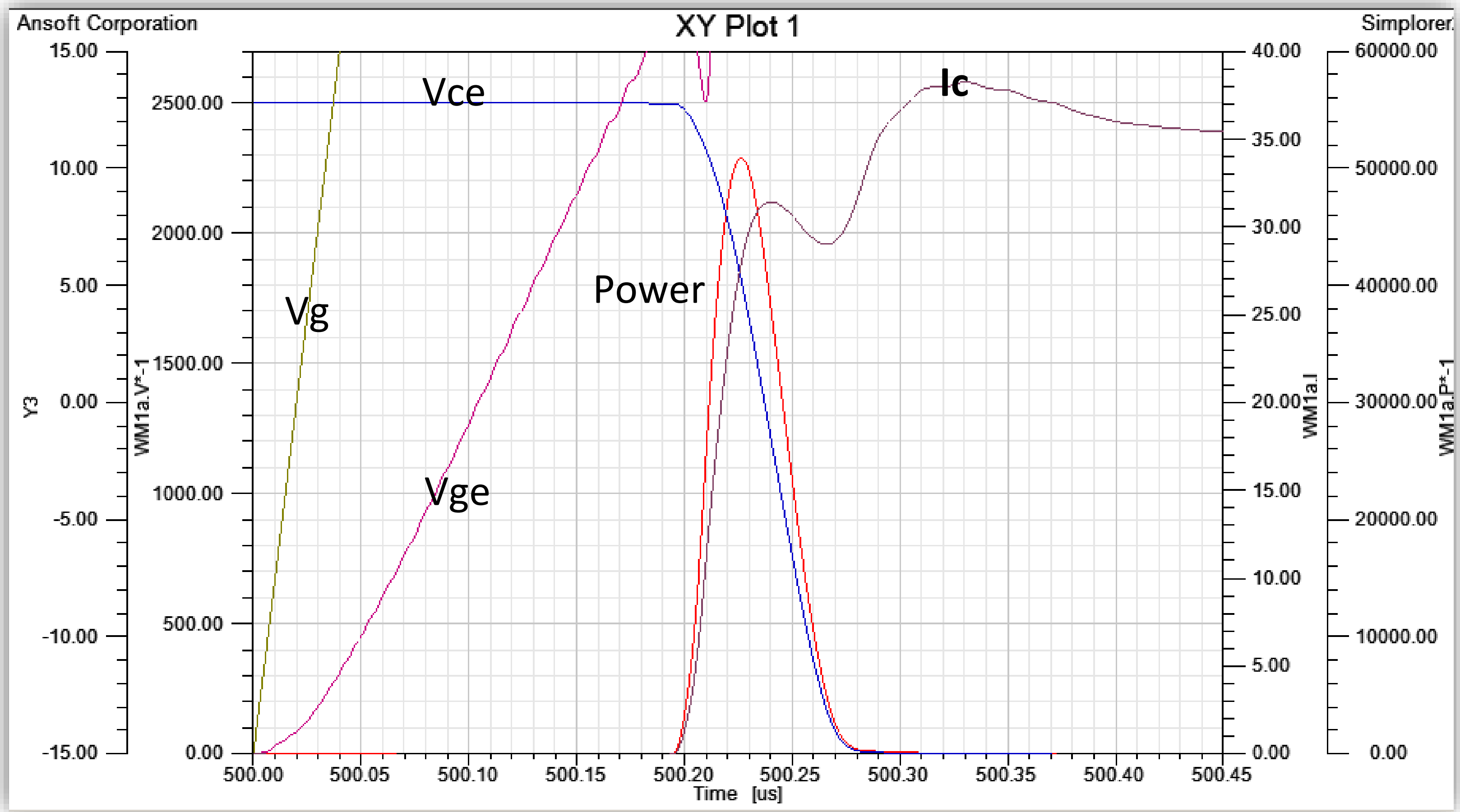






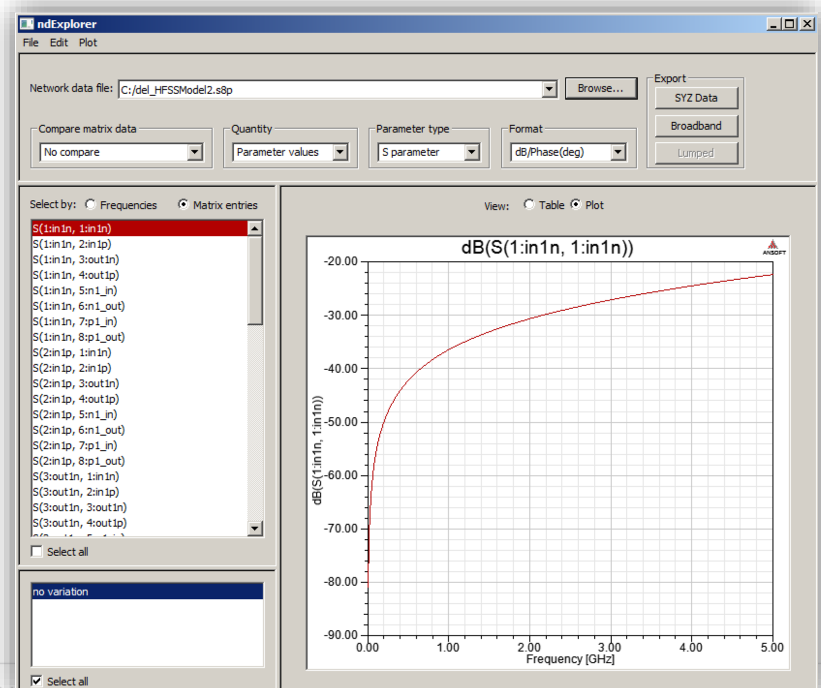


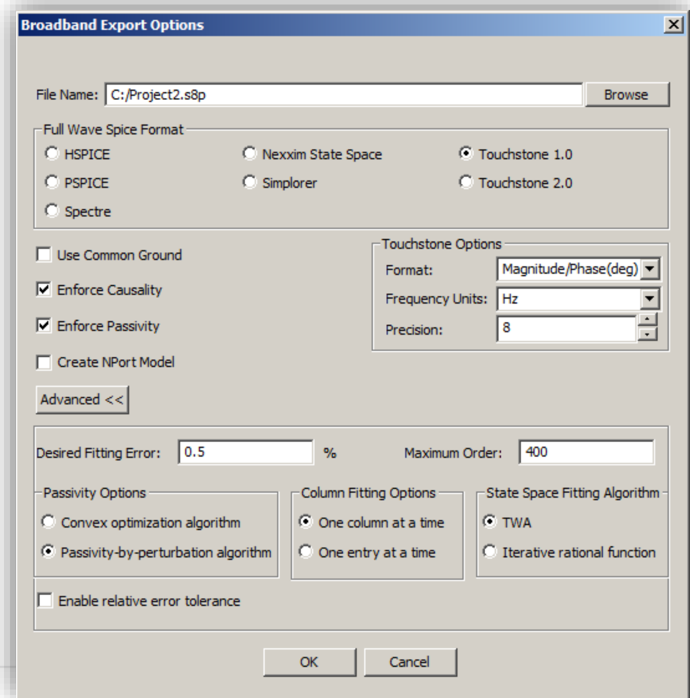
Characterization Device Capability



Simplorer Network Data (nD) Explorer

- Plots and data tables of S-parameter
  - Matrix entries and passivity information
  - Differential and Single ended S-parameters
  - A single model or a comparison between two models can be performed
  - Allows user to reduce order of S-parameter models by terminating selected ports and generating a new Touchstone file
  - Export fixed FWS file with enforced passivity and causality





ANSYS Q3D Extractor

Q3D Extractor Simulation Technology

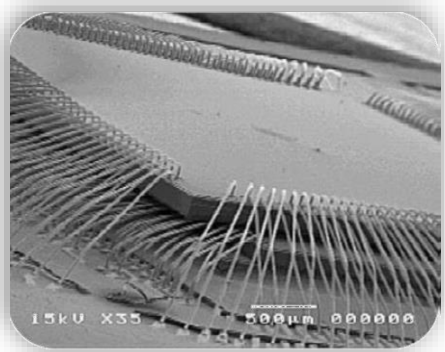
Quasi-Static Electromagnetics

Q3D Extractor Desktop

Boundary Element Method	Finite Element Method
Q3D Extractor	SI2D
Capacitance/Conductance DC Resistance/Inductance AC Resistance/Inductance	Admittance (C/G) Impedance (R/L)

Applications

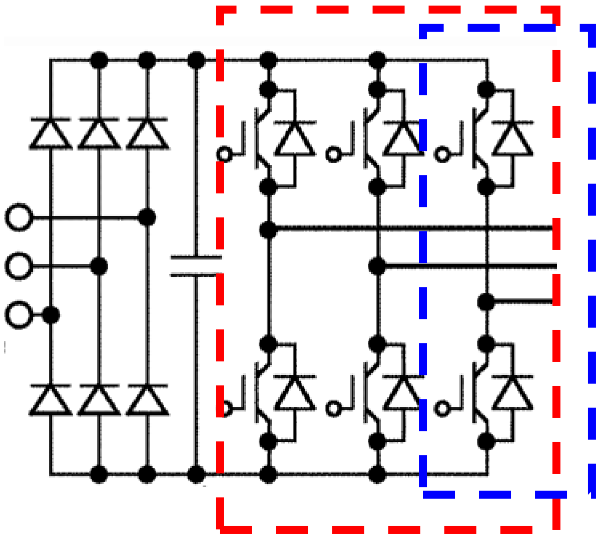
- **Packages**
  - BGAs, SiP and PoPs
- **IGBTs, FETs**
- **Touchscreen technologies**
  - Capacitive sensing
- **DDRx Memory Applications**
- **Flash memory**



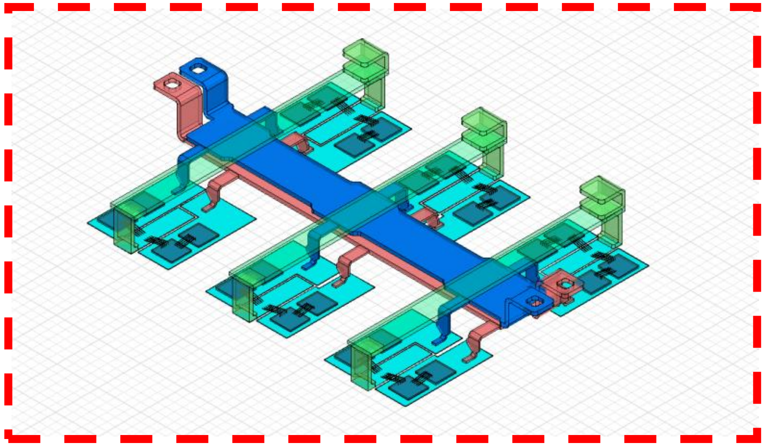
Conductive Noise Simulation with Power Module and Cable

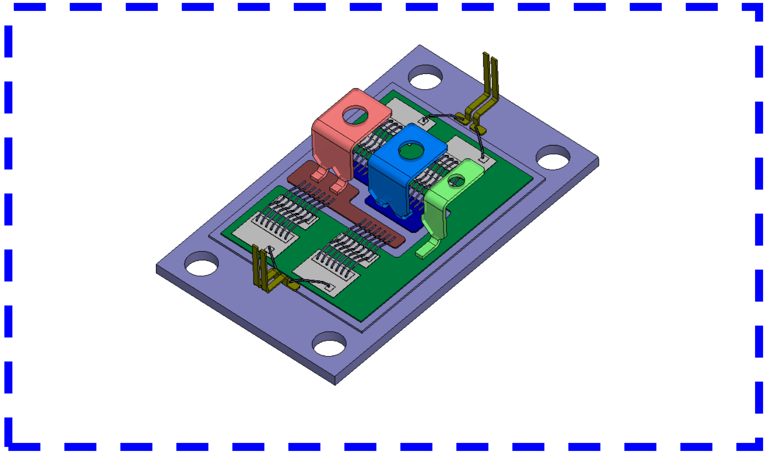
Inverter Package Model

- 3 Phase Model
- 1 Phase Model



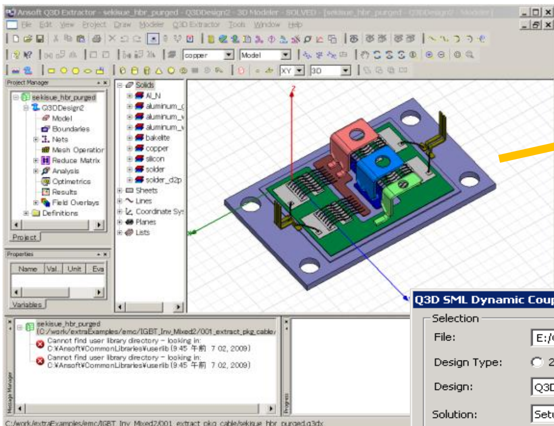
3 Phase Model



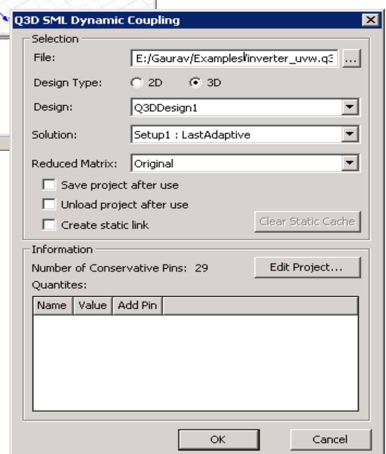


1 Phase Model

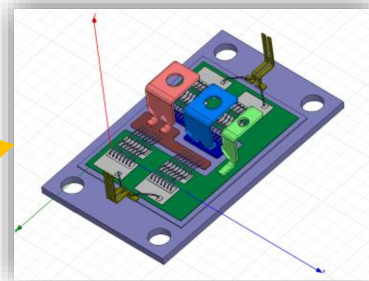
Q3D Extractor + Simplorer

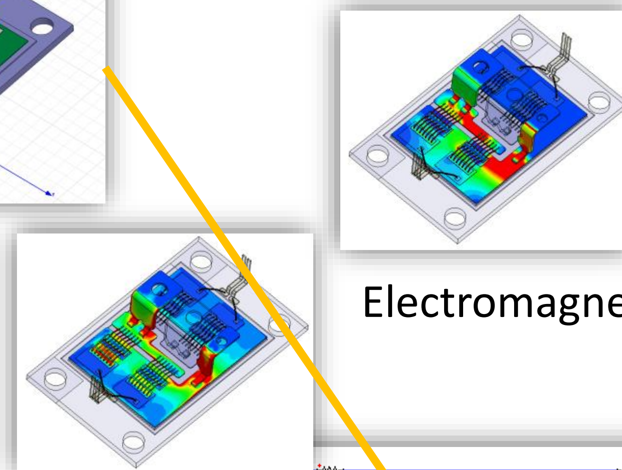


Q3D Extractor
(LCR extraction)
Export

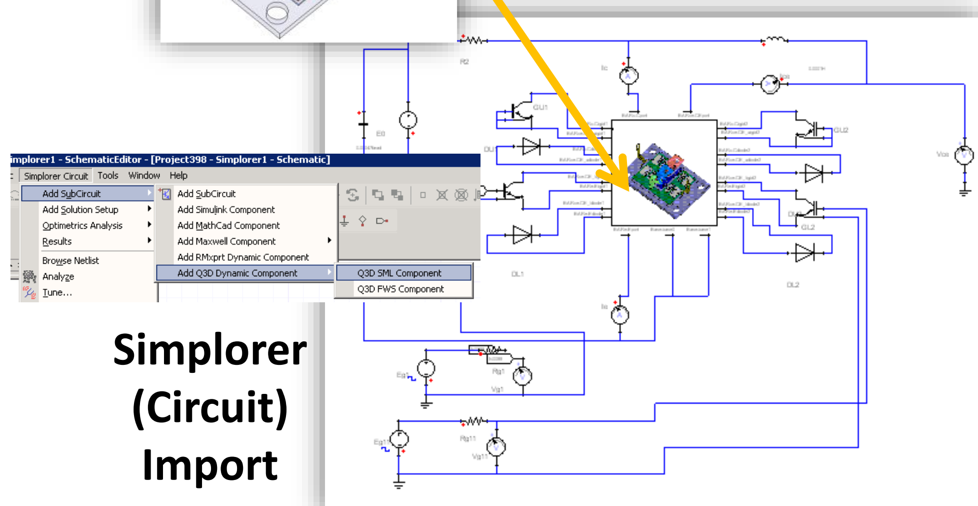


State Space Model



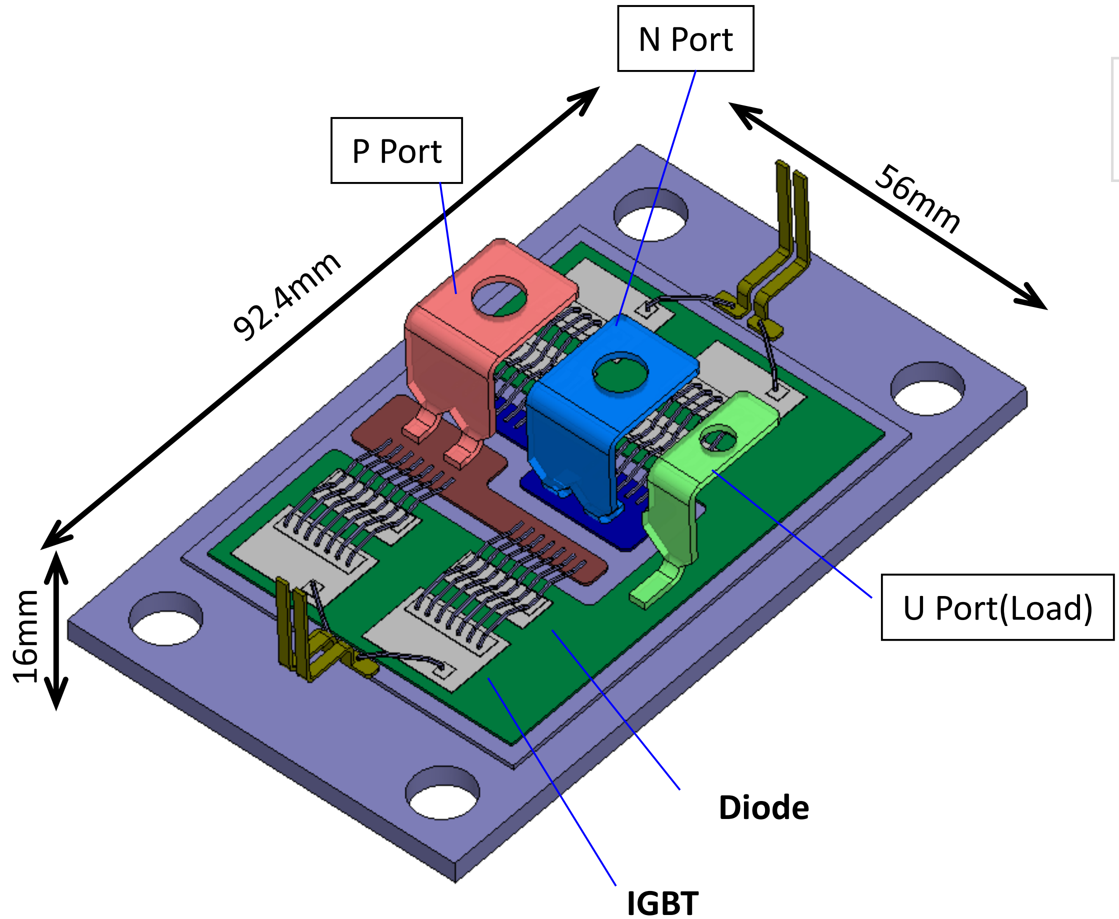


Electromagnetics

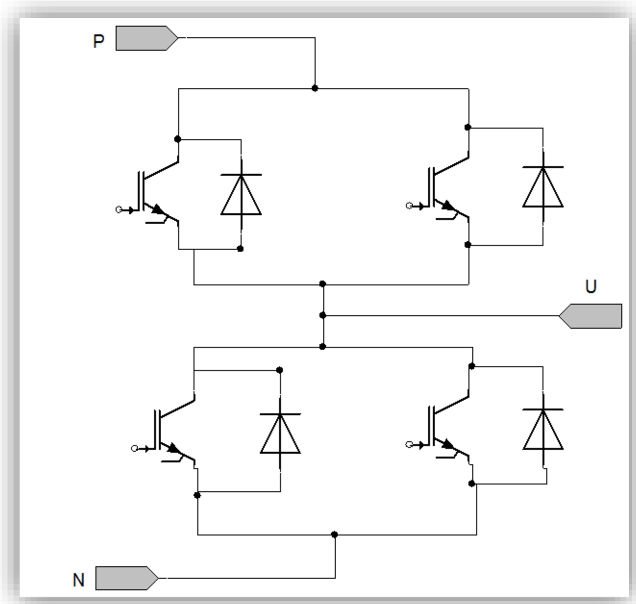


Simplorer
(Circuit)
Import

Parasitic Parameter Extraction Model 1-Phase



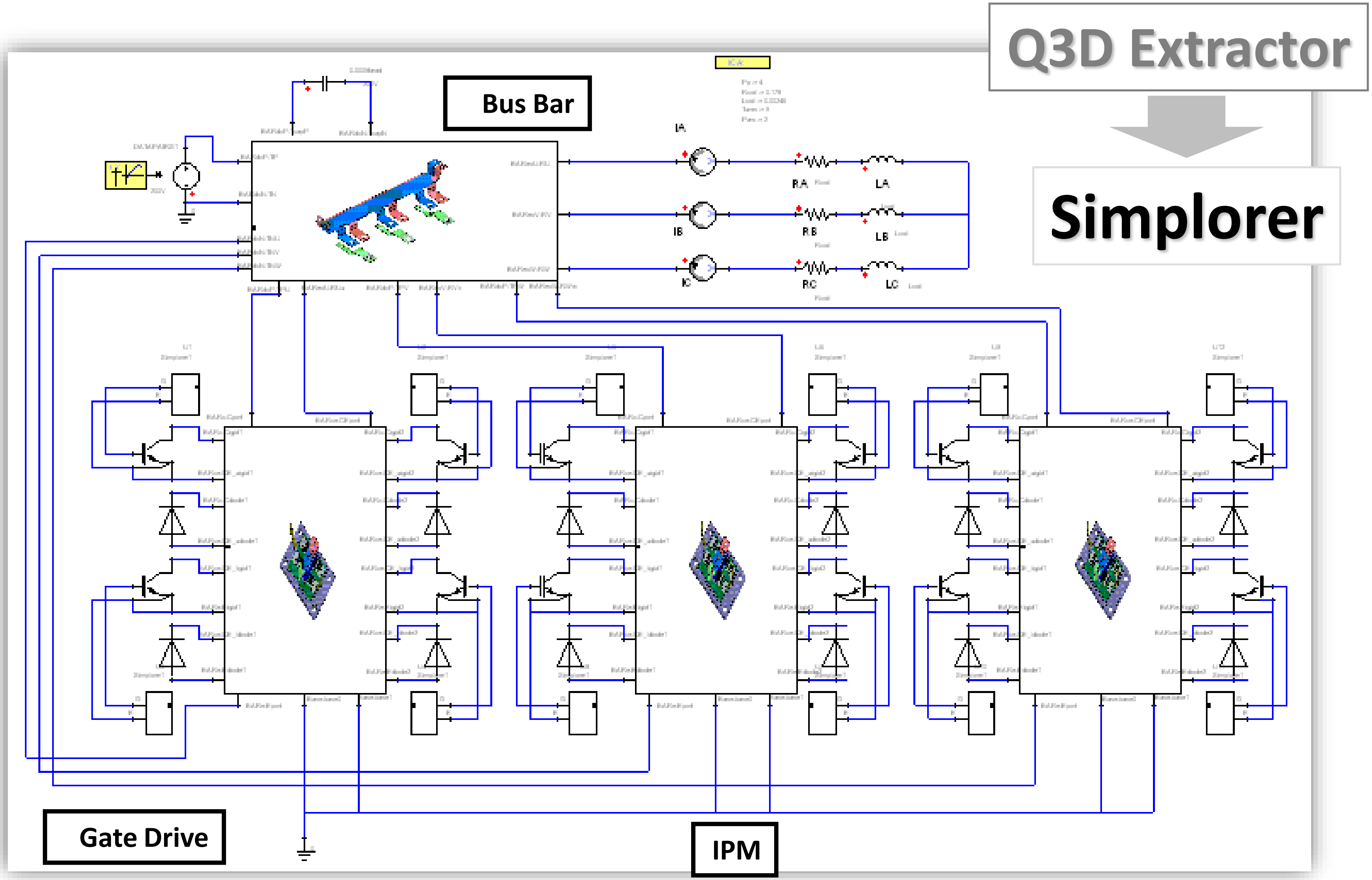
Q3D Extractor



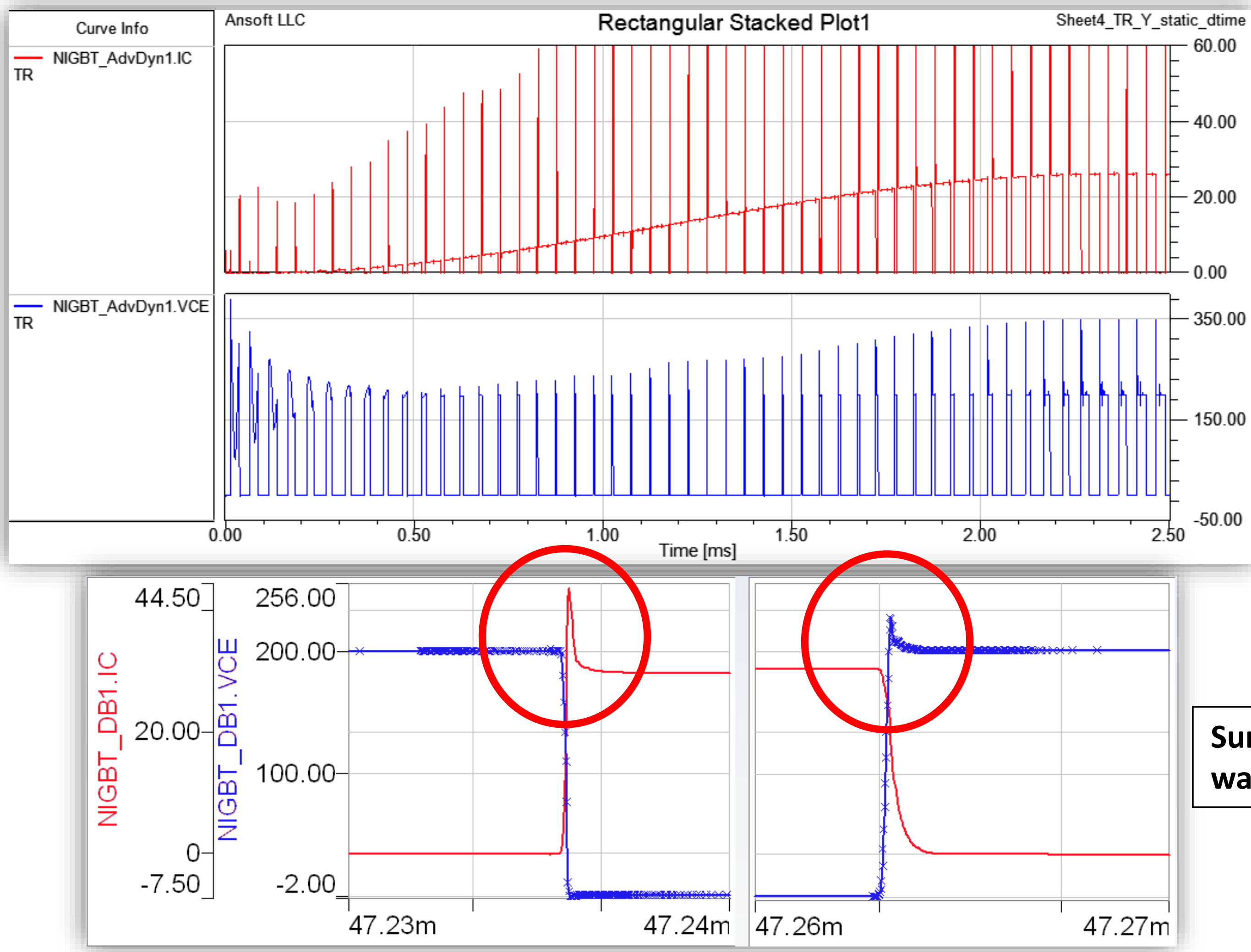
Equivalent Circuit

Bus bar, Base plate: Copper
Bonding wire: Aluminum

Definition of Inverter package circuit



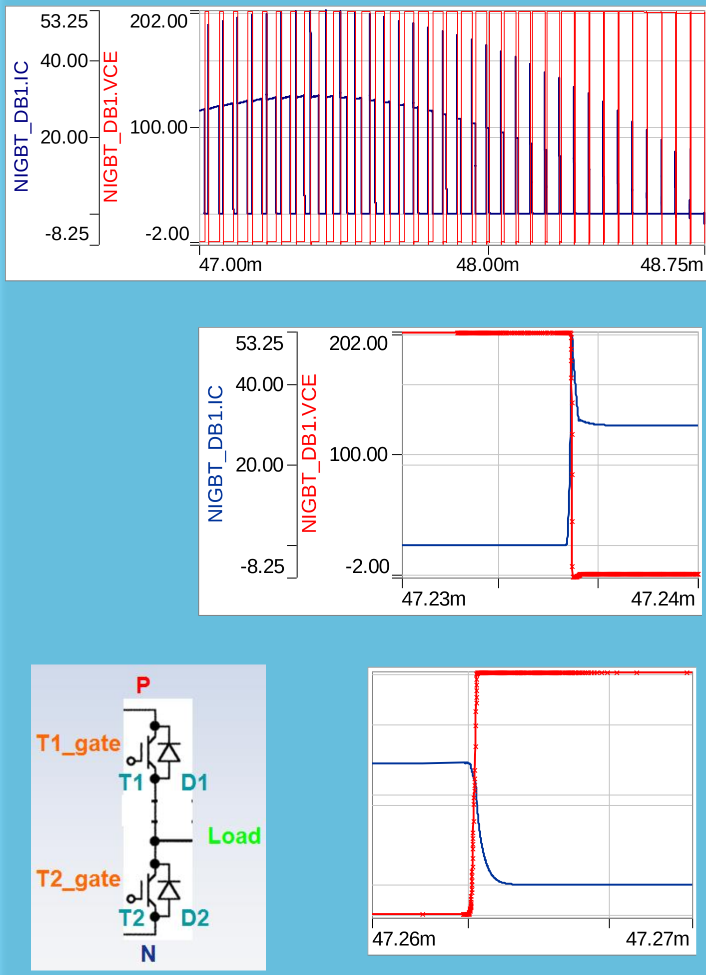
Output switching waveform with considered extracted parameter



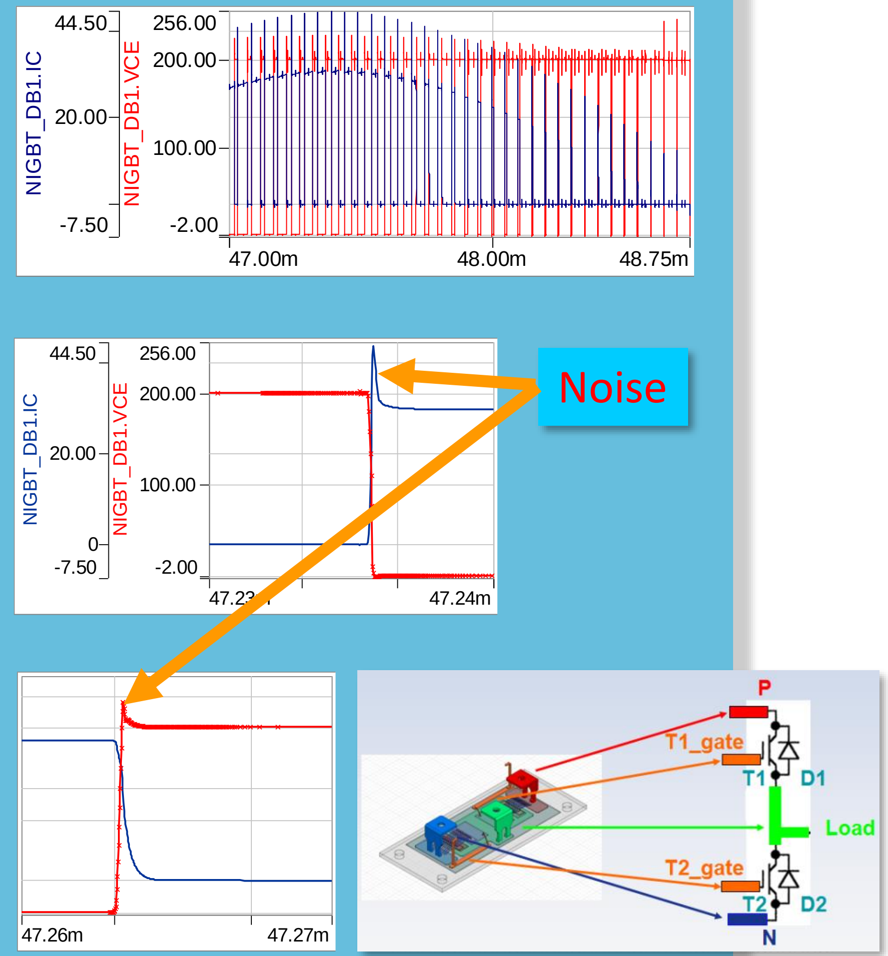
Surge and ringing waveform

Device Model + Parasitic parameter : Switching ON/OFF

Compared with/without parasitic parameter



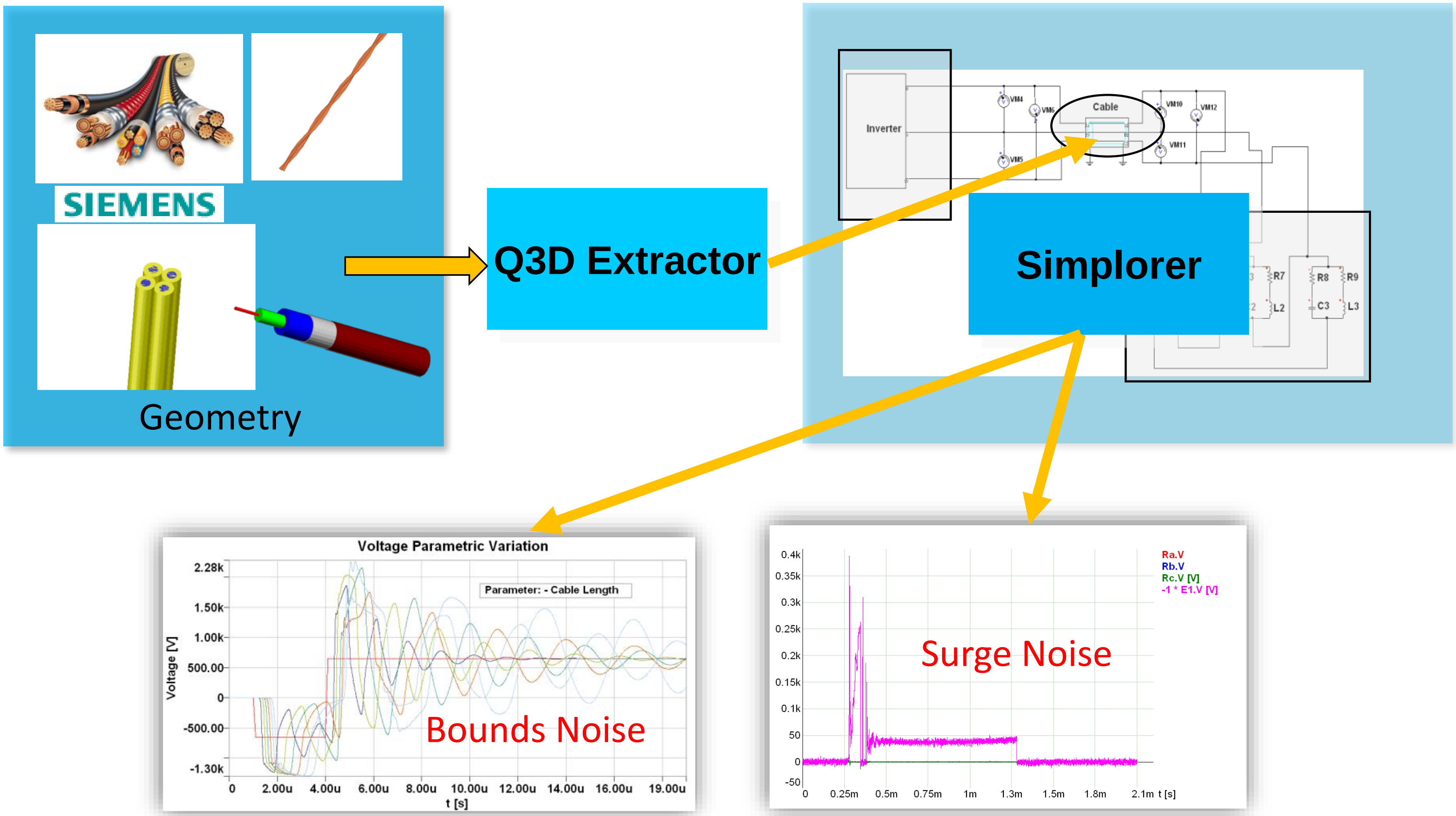
Without parasitic parameter



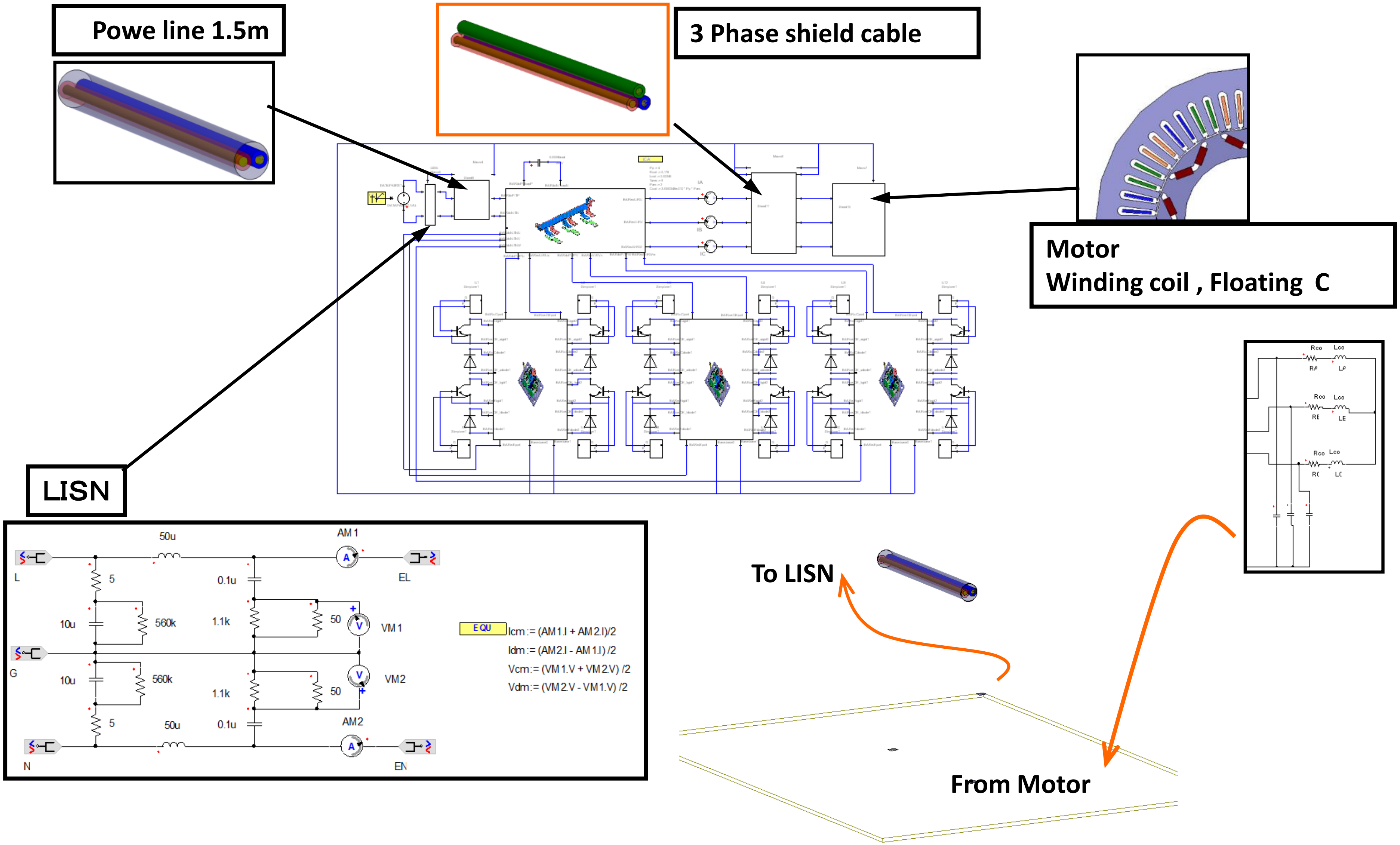
With parasitic parameter

Cable Modeling

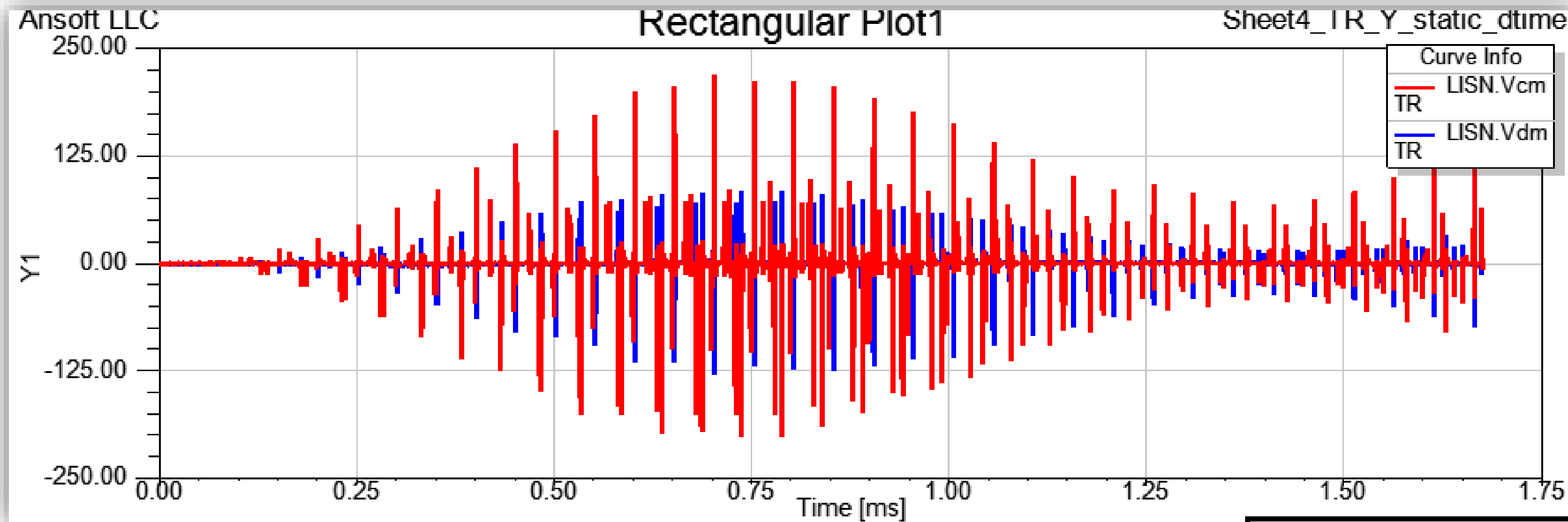
- Cable will be often called a noise main factor…



Adding Floating Capacitance, Ground Loop, and LISN



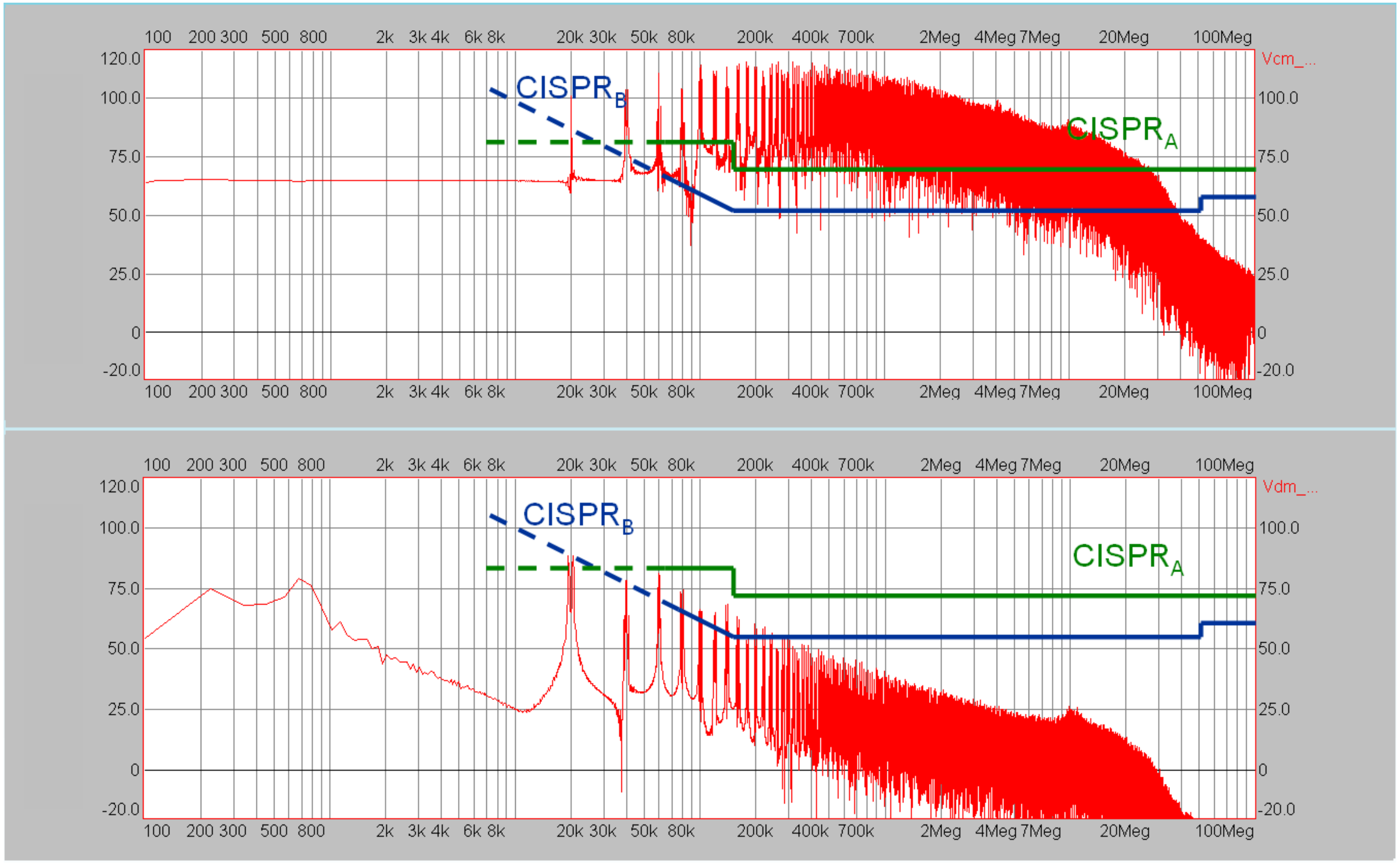
Separate CM/DM Voltage by LISN



Common Mode Voltage(Vcm) , Differential Mode Voltage(Vdm)

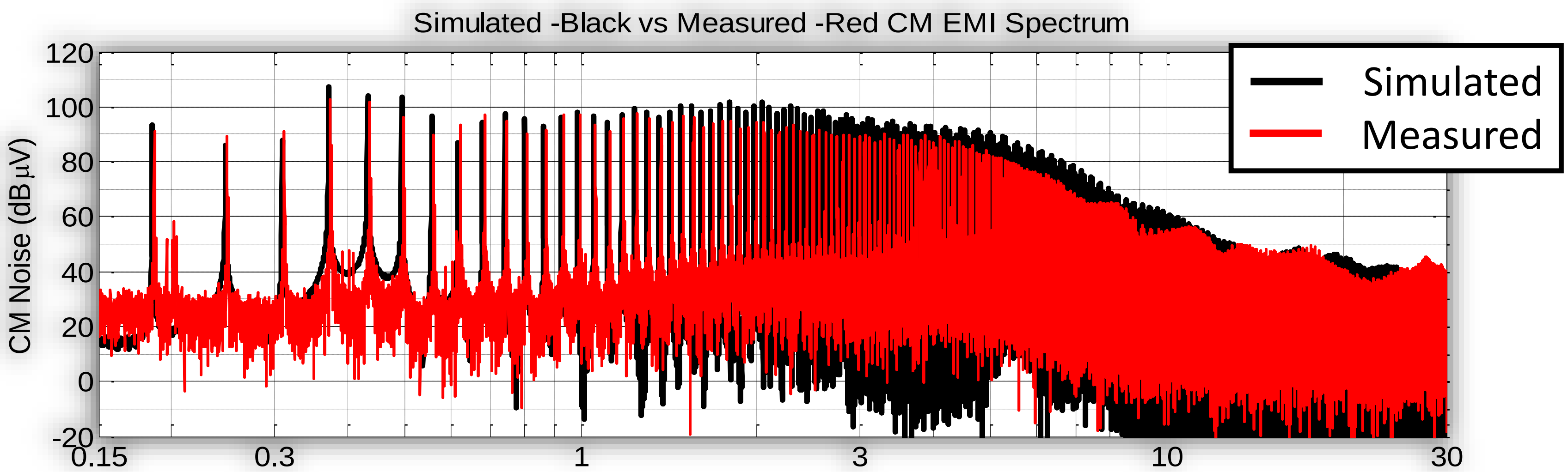
Waveform
- **CM Voltage: Vcm**
- **DM Voltage: Vdm**

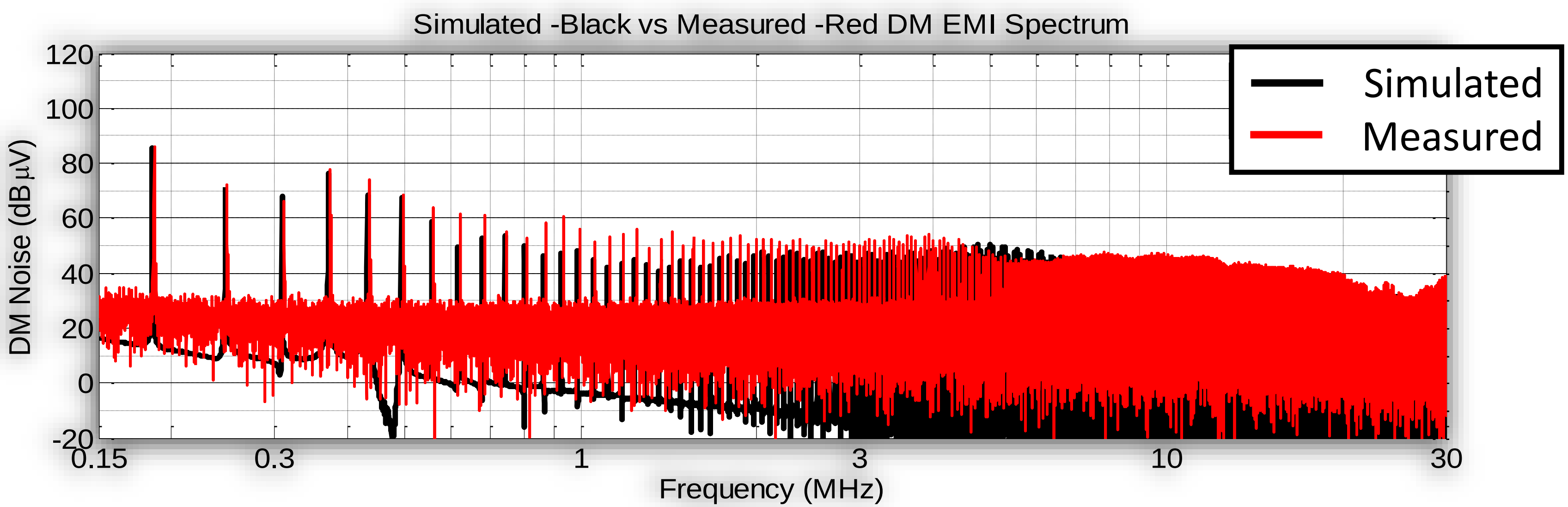
FFT: Waveform changes to Frequency domain



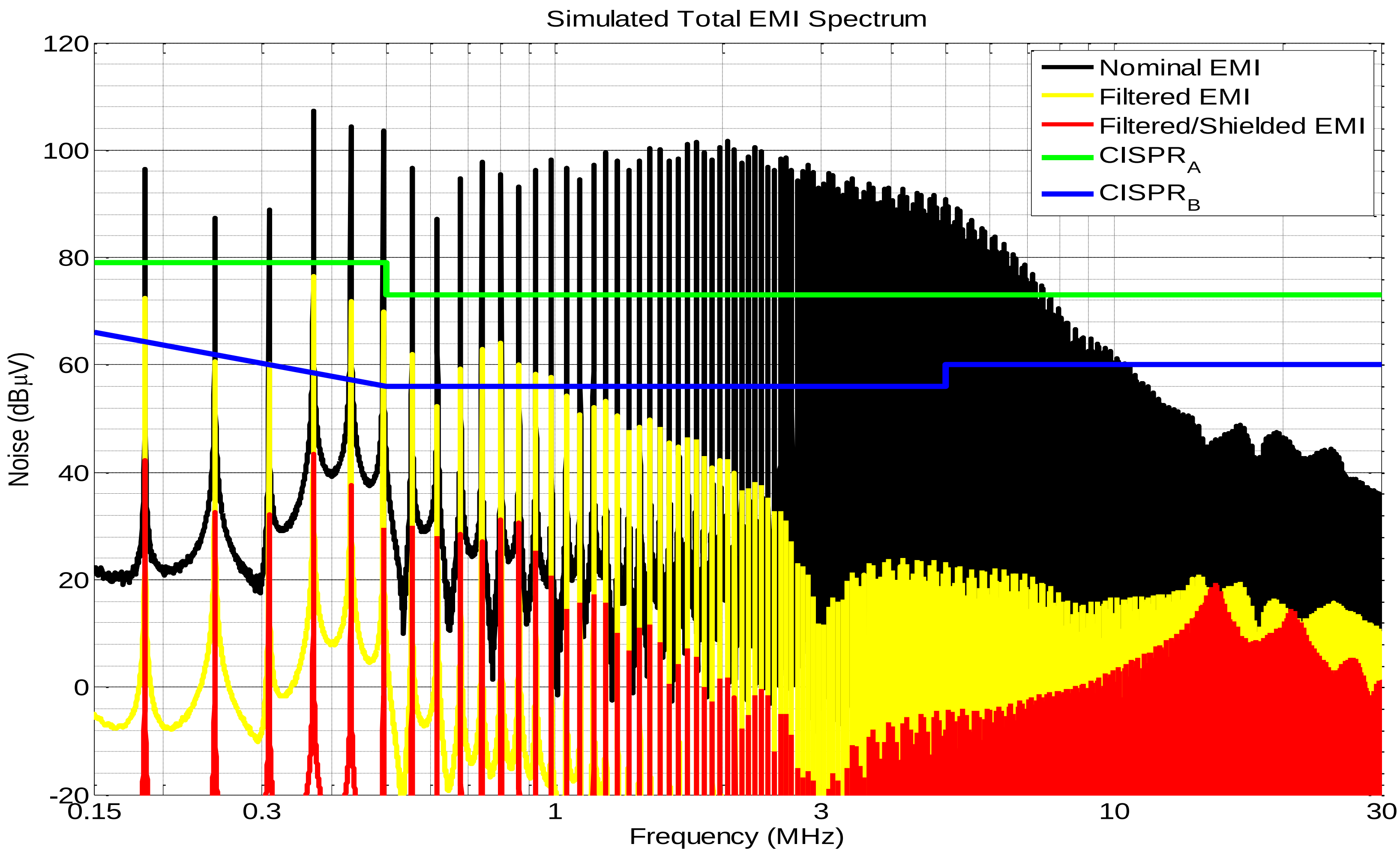
- **Common Mode Nose is over the CISPR regulations**

Compared with measurement results





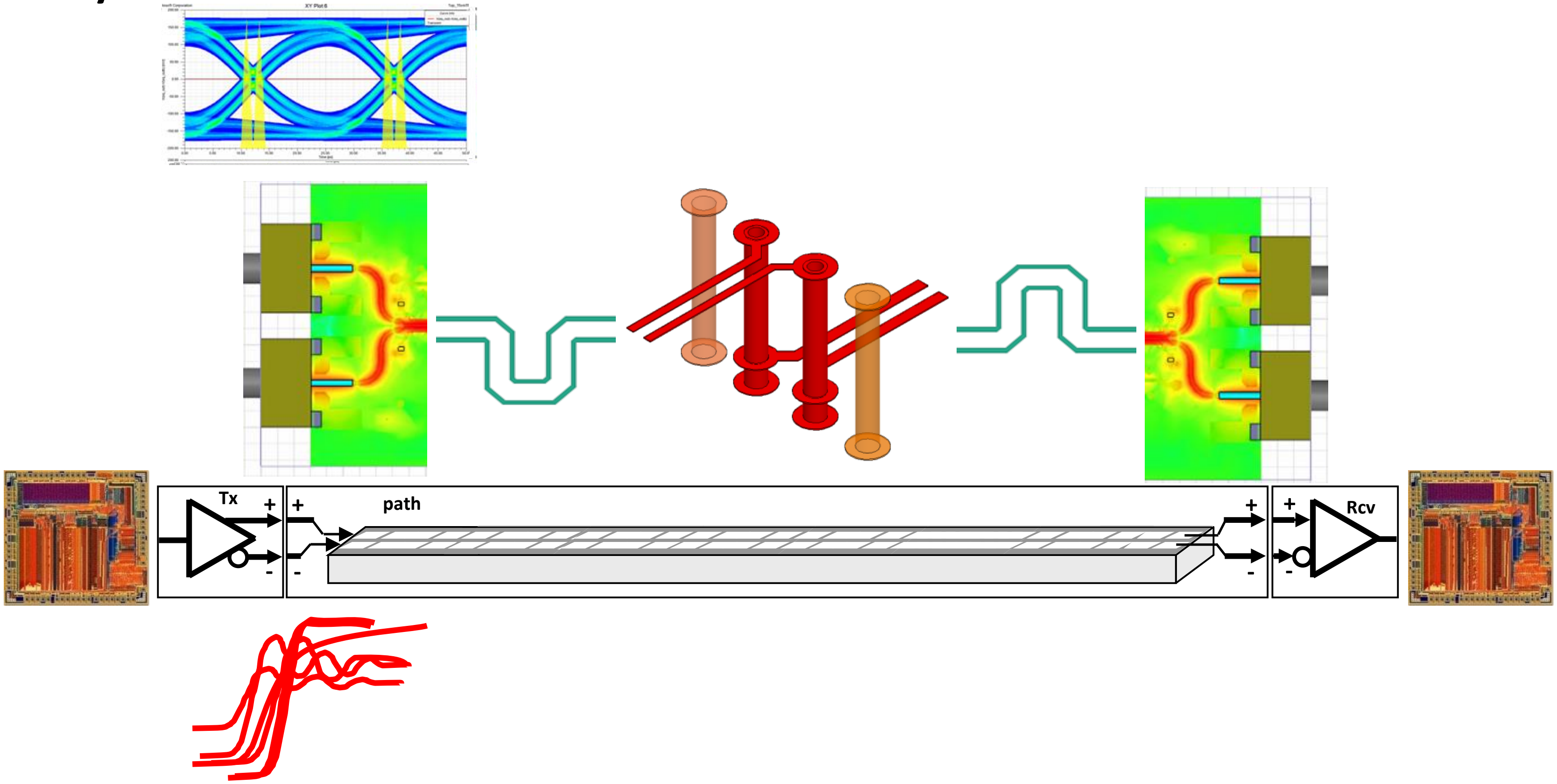
Virtual Prototype Design



Low Frequency Signal Integrity

Signal Integrity – Channel

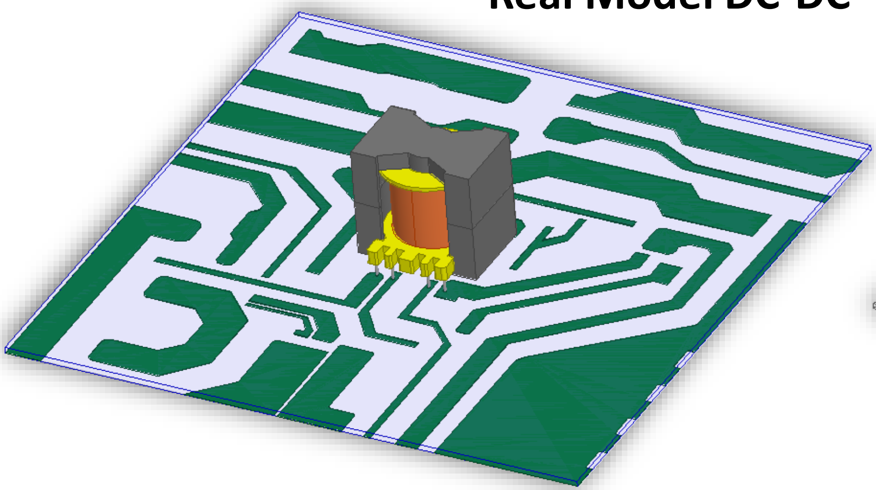
- Set of measures of the quality of an electrical signal (stream of binary values represented by voltage or current)
- Signal will see many discontinuities in its path
- Discontinuities will distort signal quality and reduce overall bandwidth of the system



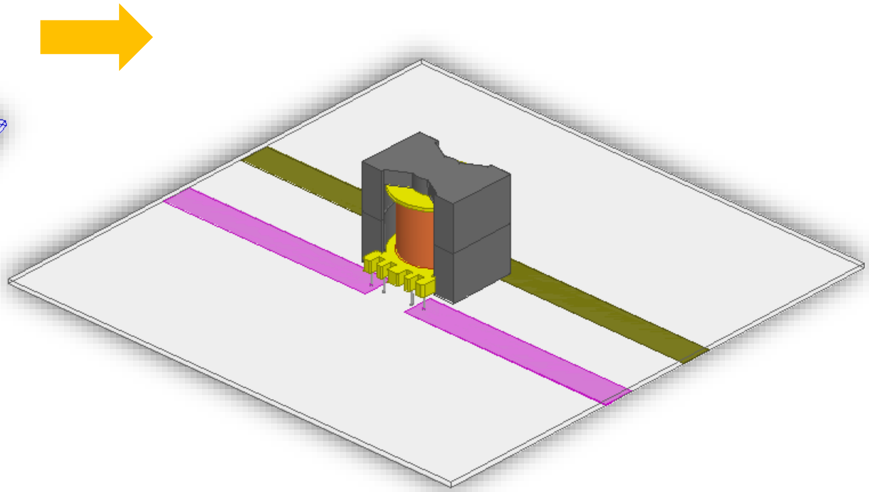
Low Frequency Signal Integrity

- What/How is the critical source of conducting noise on the
- power supply PCB?

Real Model DC-DC



Virtual Test Model



Inductor – Trace Coupling ?

Trace-Trace coupling ?

Step-by-Step Investigation

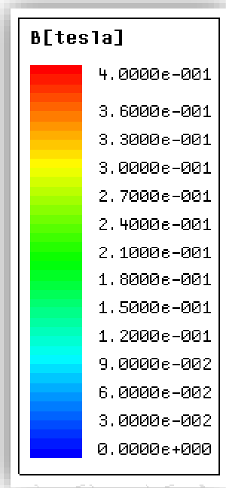
1. Electromagnetics
   1. Coil inductance (nonlinear) saturation (Maxwell)
   2. PCB Trace-to-Trace coupling (Q3D Extractor)
   3. Coil-to-Trace coupling (Maxwell)
2. Circuit
   1. Noise by Circuit + LRCK model (Simplorer)
   2. Noise by Circuit + EM (Q3D & Maxwell) model

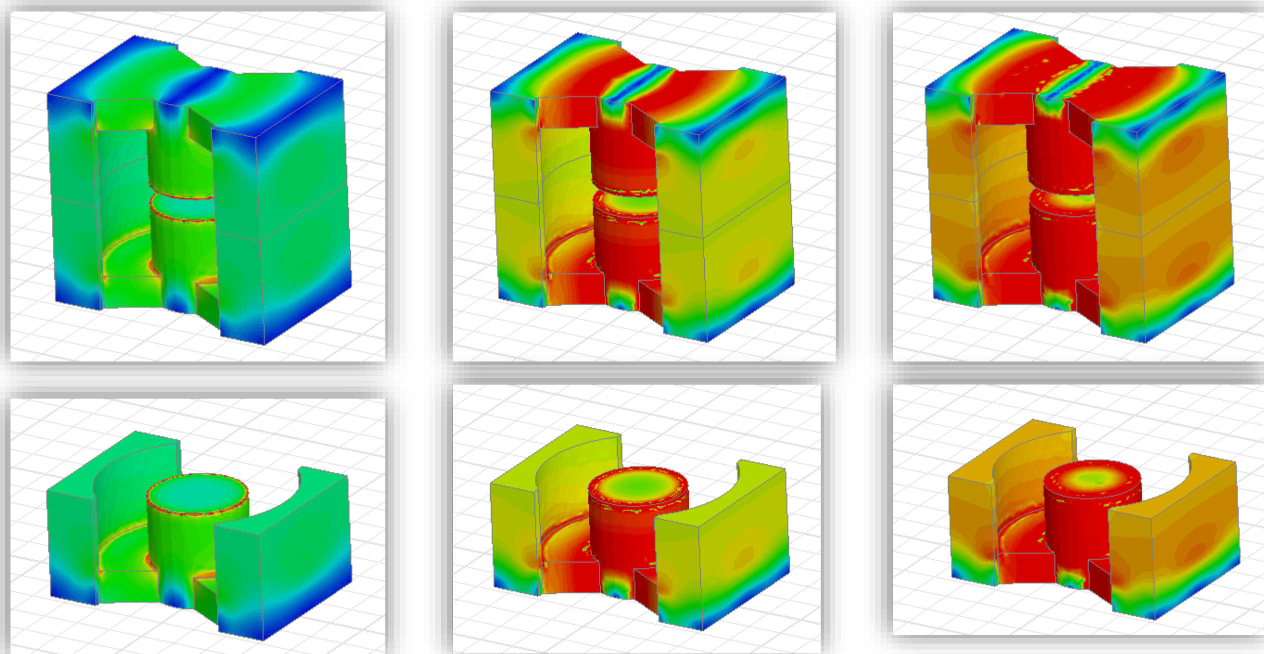
Analysis : EM 1-1 Saturation Characteristic

Maxwell

- B distribution around the core @10A
  - Start to saturate 0.4T～ over 20A

Max. 0.4[T]



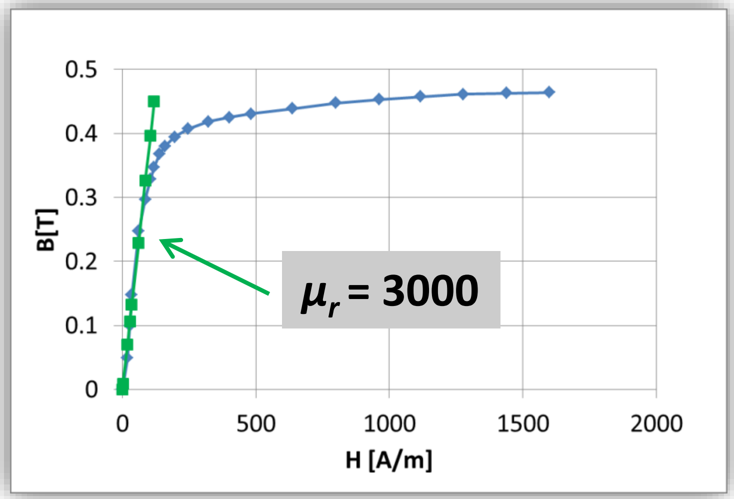


20A **40A** **50A**

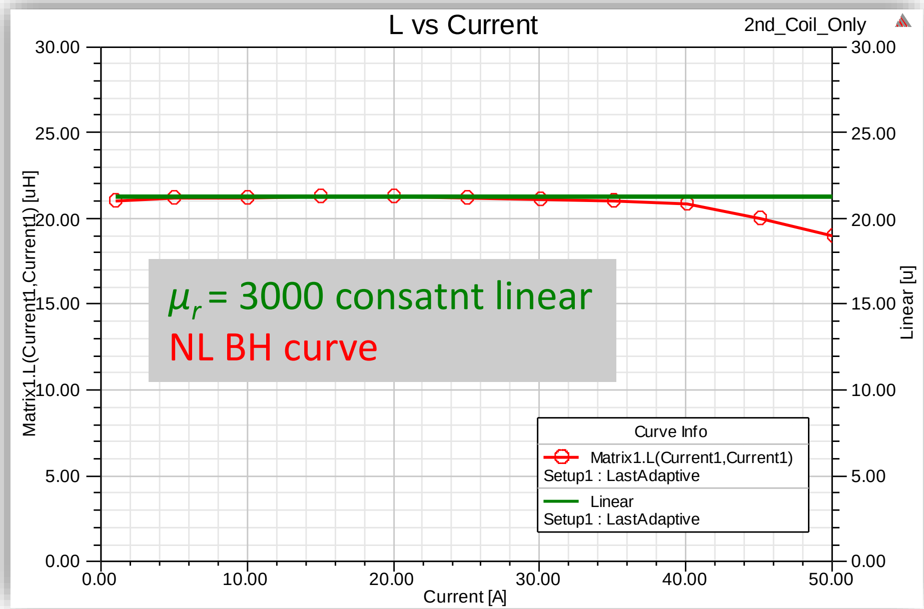
Analysis : EM 1-1 Saturation Characteristic

Maxwell

- Can be linear up to 10A ?
    - Yes, possible to be linear up to 30A for circuit simulation



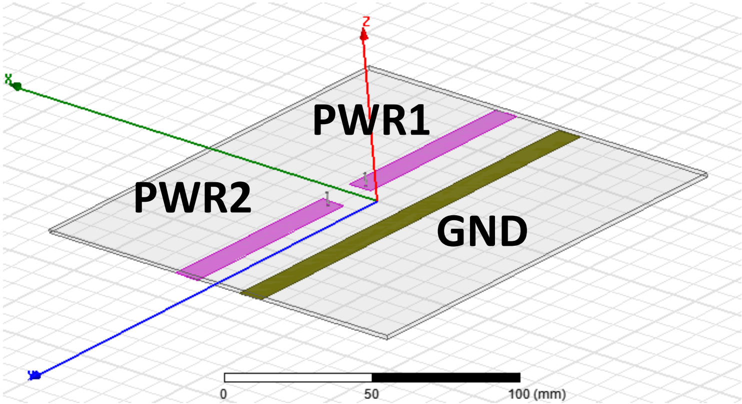
BH of core material

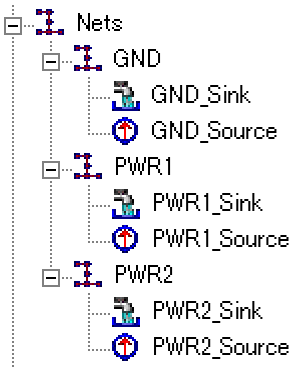


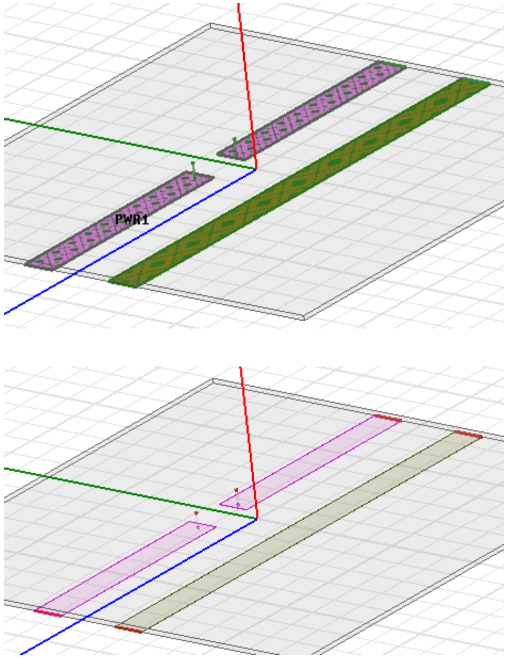
Simulated Inductance

Analysis：EM 1-2 Trace-Trace coupling

Q3D Extractor





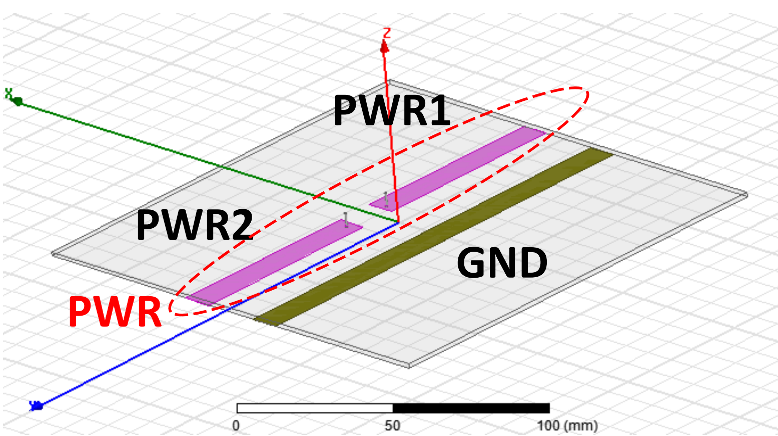


Source , Sink

Analysis：EM 1-2 Trace-Trace coupling

Q3D Extractor

- Matrix Reduction
- PWR1 and PWR2 are merged into one , then evaluate M, k with GND



☑ Inductance Units: nH Original ☐ All Freqs

Passivity Tolerance: .0001 Check Passivity Equivalent Circuit Expo

	GND:GND_Source	PWR1:PWR1_Source	PWR2:PWR2_Sourc
Freq: 0.1 (MHz)			
GND:GND_Source	143.86	21.983	21.982
PWR1:PWR1_Source	21.983	47.466	6.2798
PWR2:PWR2_Source	21.982	6.2798	47.472

☑ Inductance Units: nH RM1 ☐

Passivity Tolerance: .0001 Check Passivity

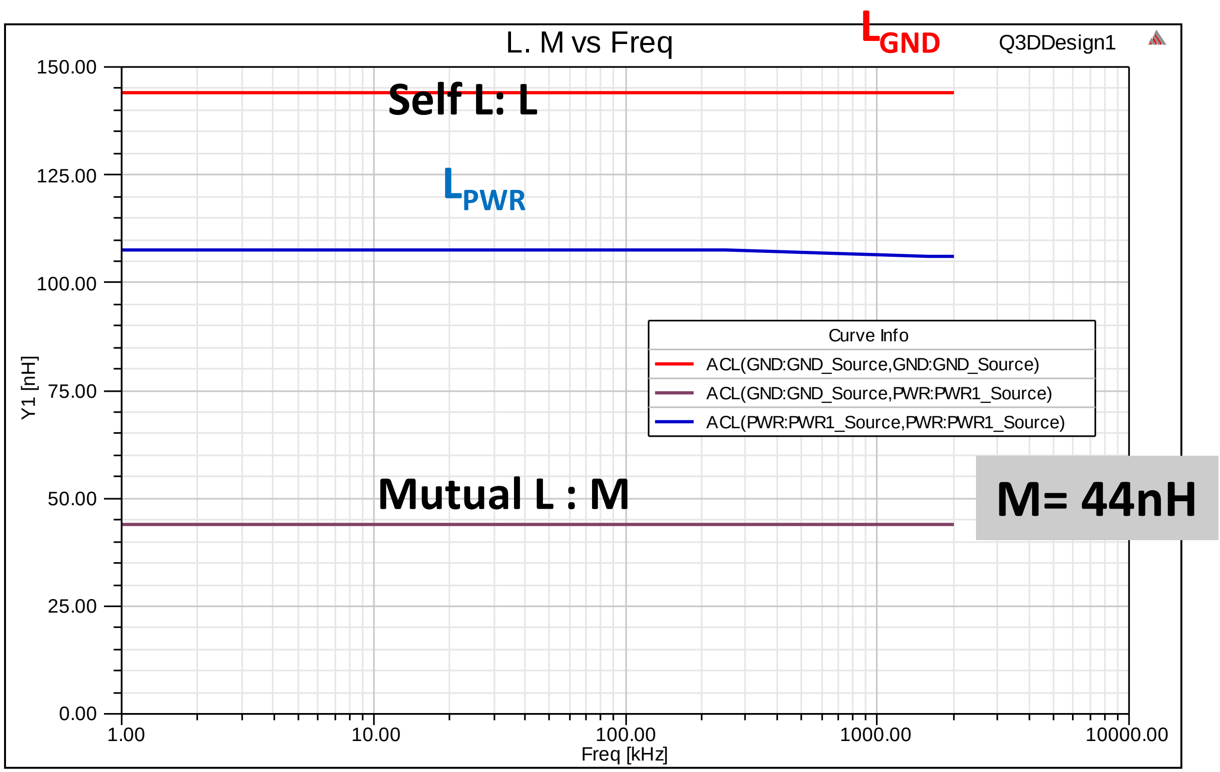
	GND:GND_Source	PWR:PWR1_Source
Freq: 0.1 (MHz)		
GND:GND_Source	143.86	43.966
PWR:PWR1_Source	43.966	107.5

L_{GND}	M
M	L_{PWR}

Analysis：EM 1-2 Trace-Trace coupling

Q3D Extractor

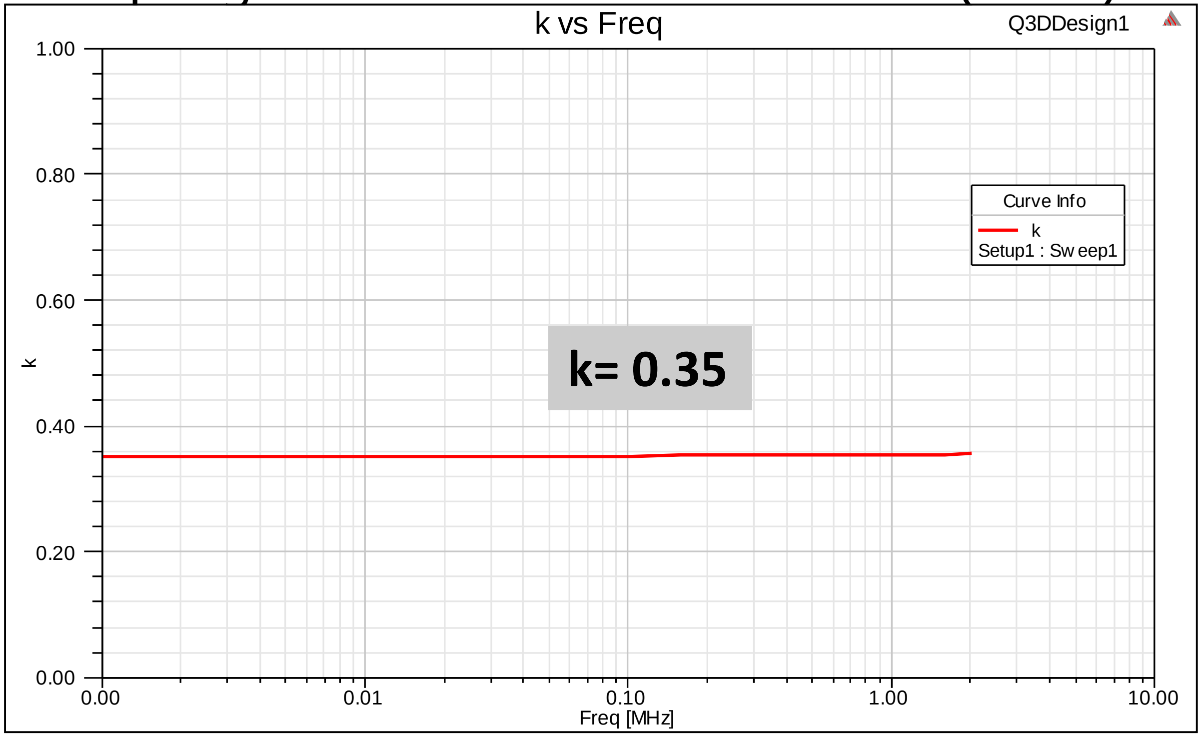
- Result : Self/Mutual inductance （AC)
  - Mutual Inductance M ： Constant (44nH)



Analysis：EM 1-2 Trace-Trace coupling

Q3D Extractor

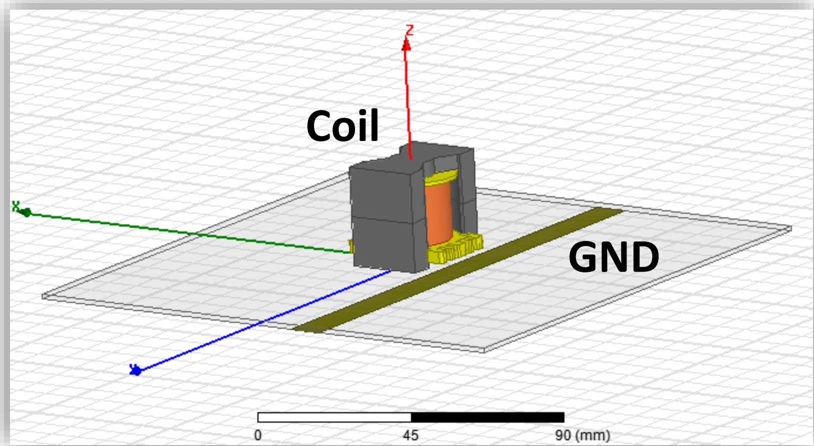
- Result : k（AC)
  - Coupling Co-efficient k： Constant (0.35)



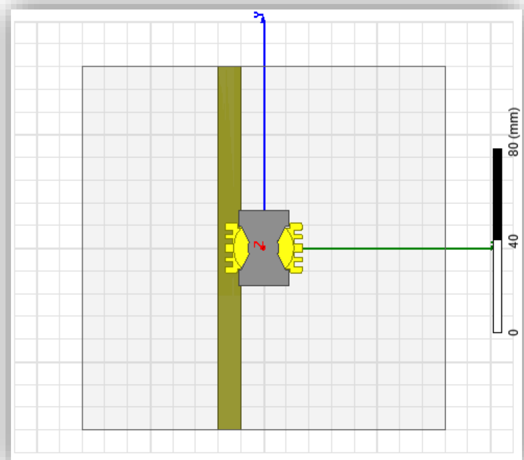
Analysis：EM 1-3 Coil -Trace coupling

Maxwell

- Mutual Inductance (M) and Coupling Co-efficient (k) between the coil and GND trace
- are evaluated
- Magnetostatic 1A～50A



Simulation model

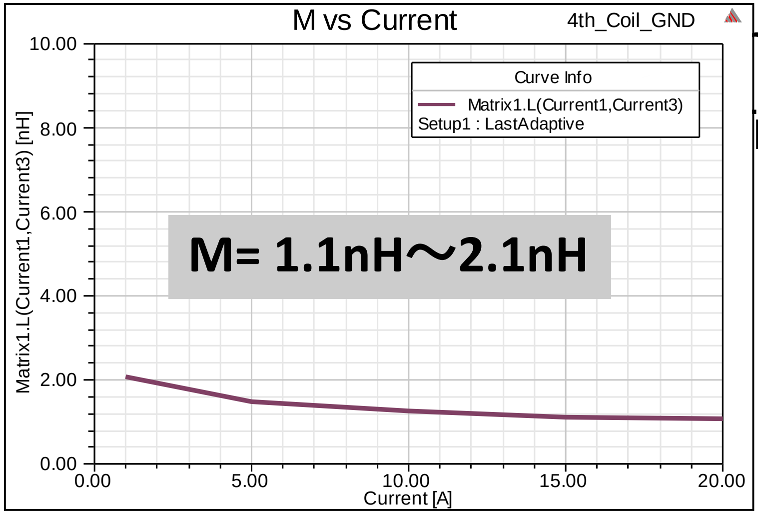


Top View

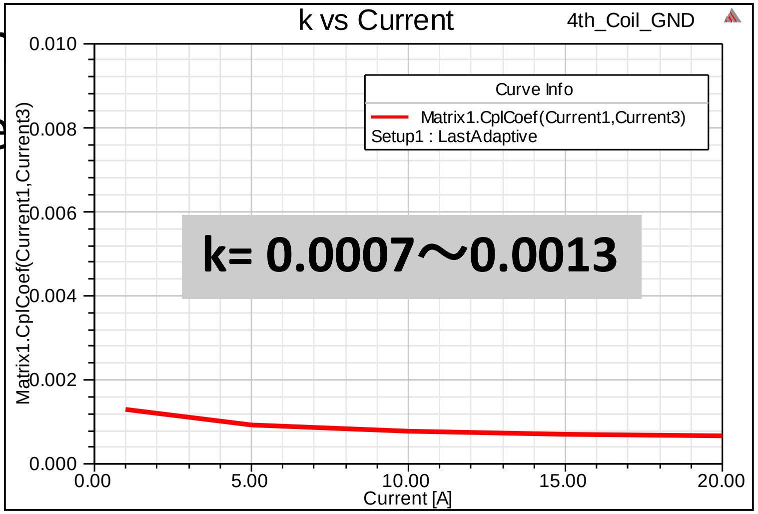
Analysis：EM 1-3 Coil -Trace coupling

Maxwell

- Result : Mutual Inductance (M)， Coupling Co-efficient (K) @1A ～20A
  - Mutual Inductance (M) : 1.1nH～2.1nH
  - Coupling Co-efficient : 0.0013～0.0007



Mutual Inductance (M)

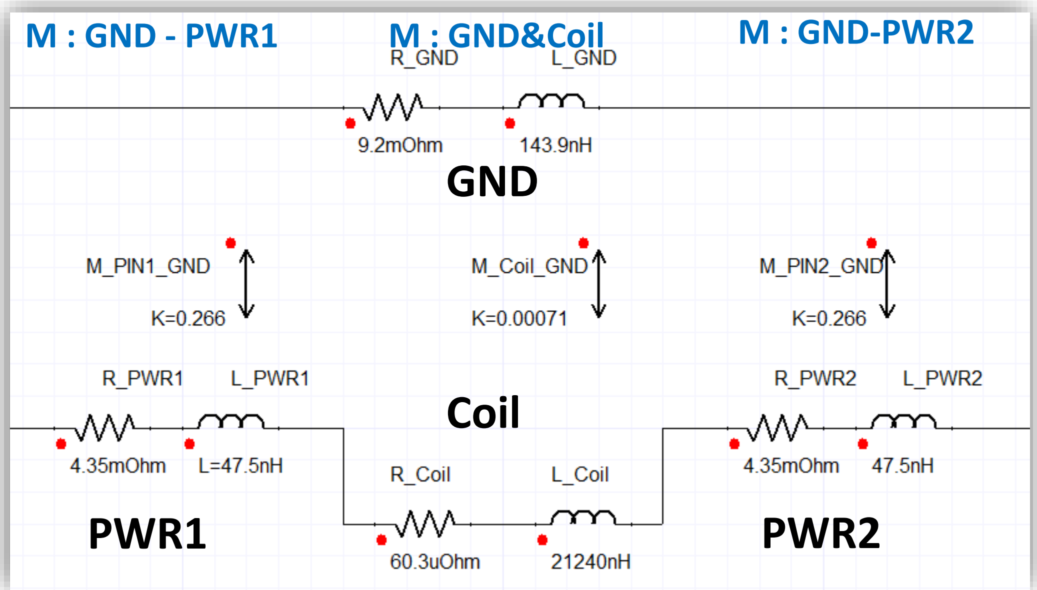


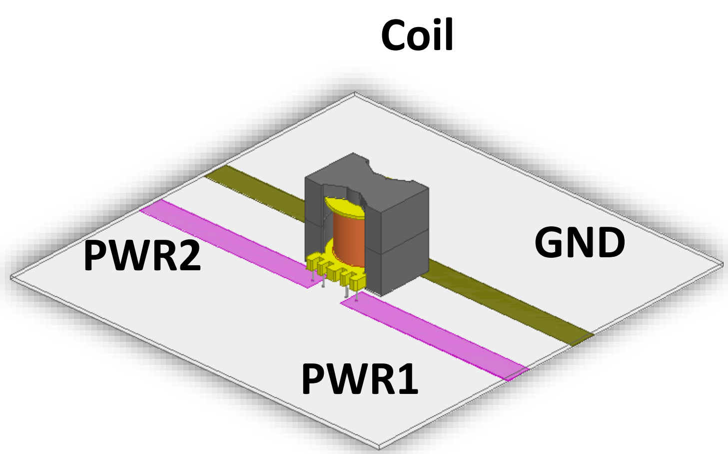
Coupling CO-effcient (k)

Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

- Simple Circuit ①
  - Equivalent Circuit with extracted R,L,M

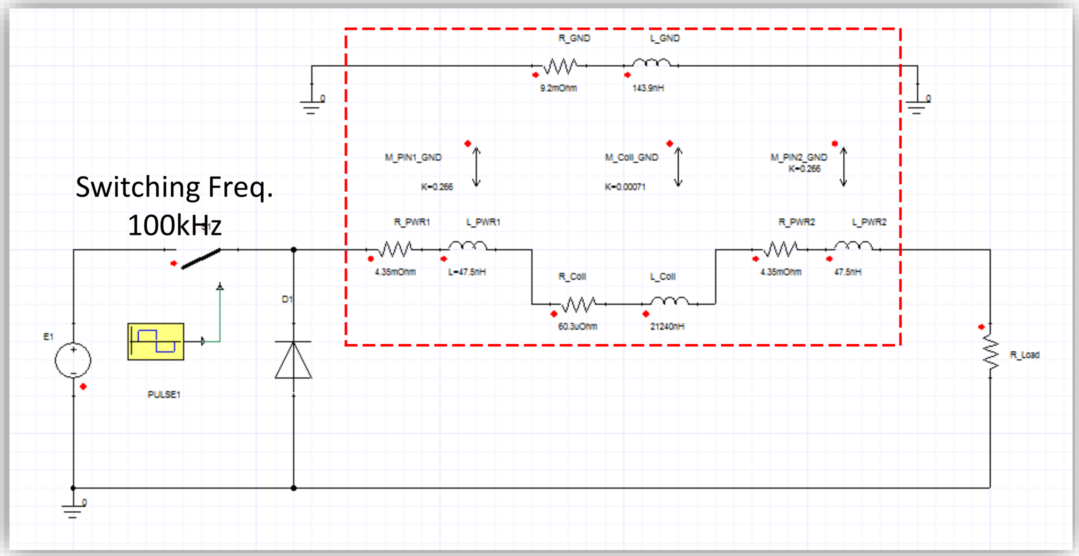


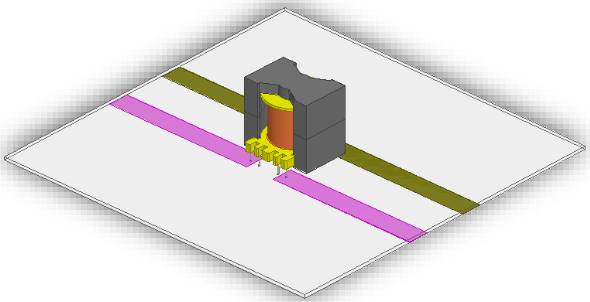


Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

- Switching Voltage Power is applied in the power line (Coil) and current in the GND Line is evaluated. (Induced Current ⇒ Induced Noise)
- **<u>Can easily identify the dominant inductance for Inductive Noise</u>**

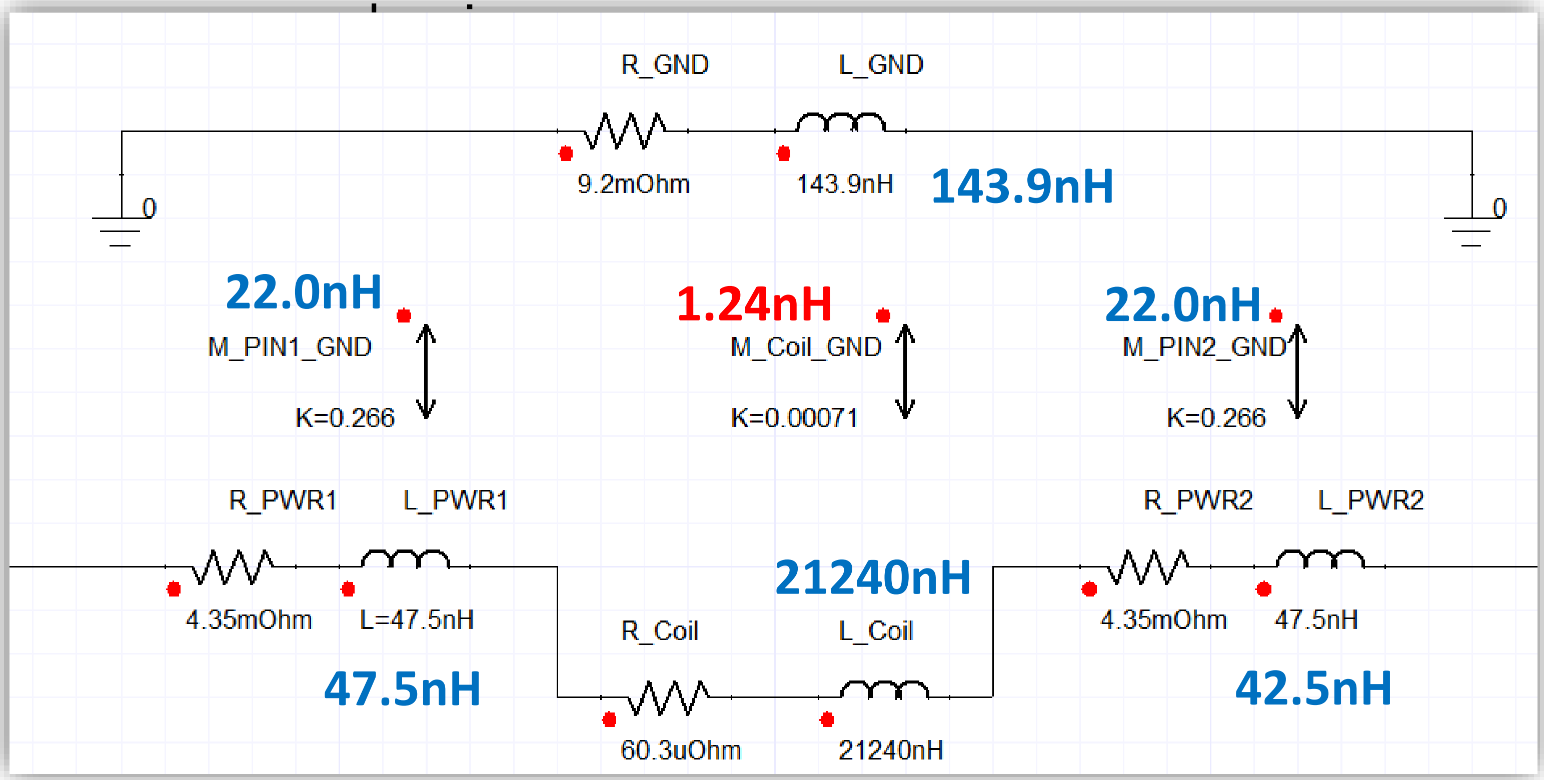




Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

- Simple Equivalent Circuit
  - Analyze / Identify the dominant factor of the induced

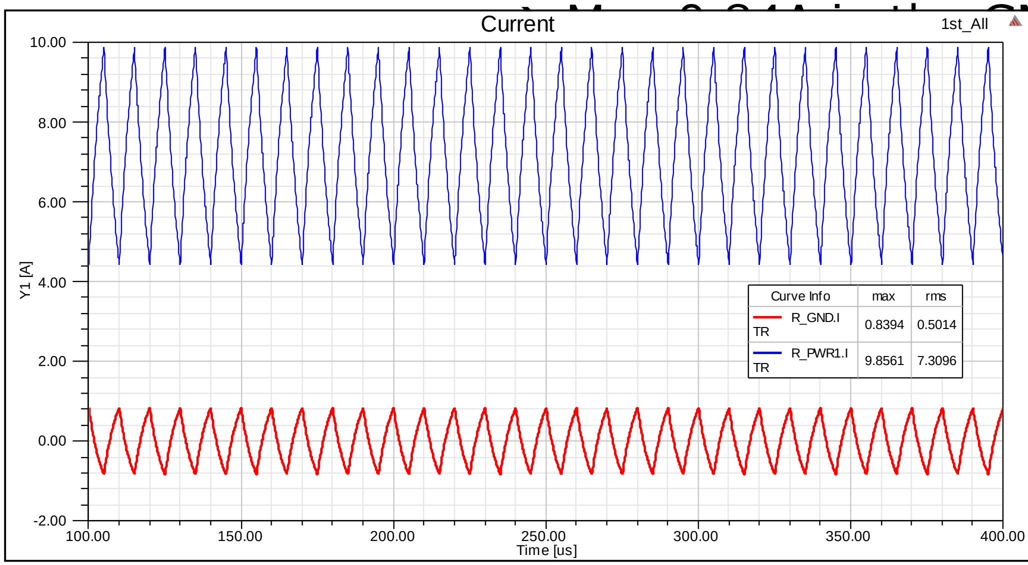


Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

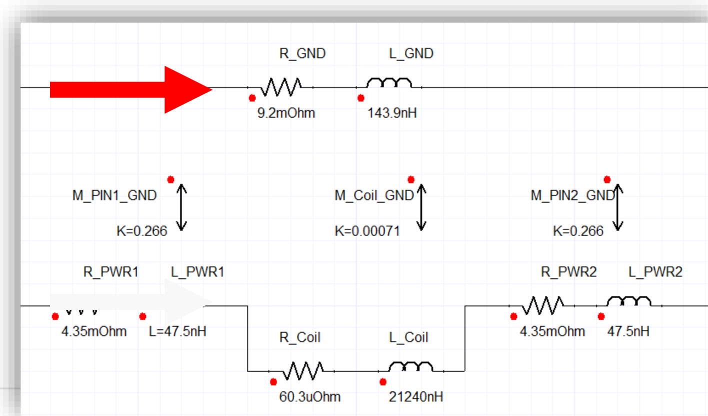
- Result ① : Current in the Power Line and Induced current in the GND Line

…ND Line @ Max. 10A in the



Coil, PWR Line Current

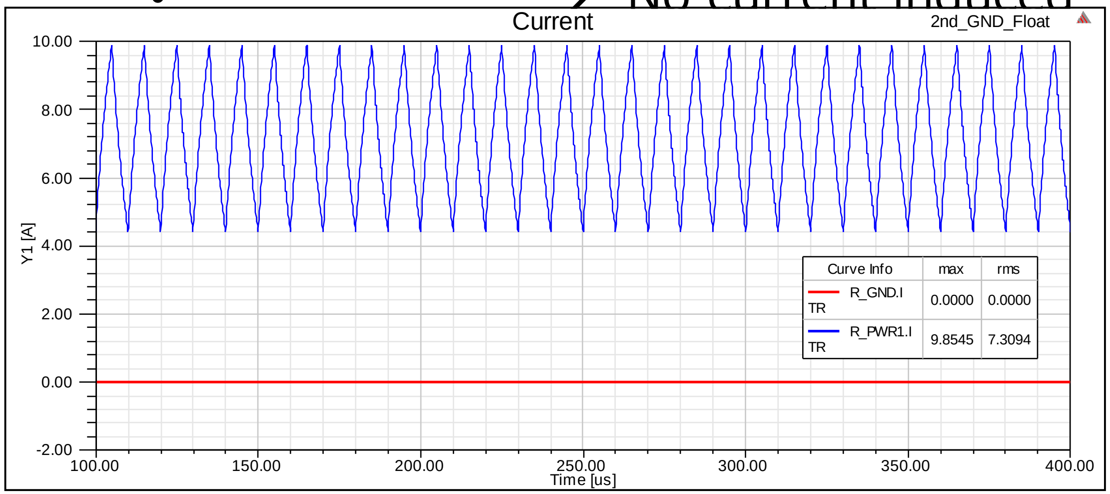
GND Line Current (Induced Noise)



Analysis : Circuit 2-1 Equivalent Circuit

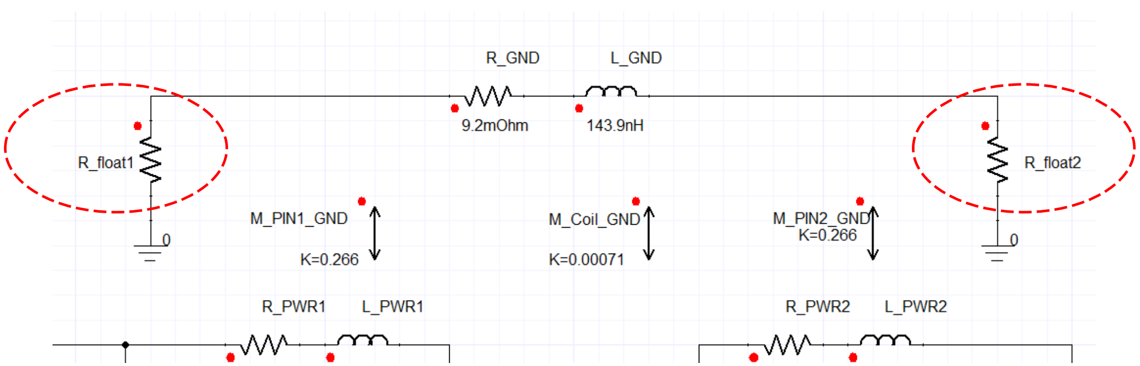
Simplorer

- Result ② : What happens if GND is floated
- → No current induced



Coil, PWR Line Current

GND Line Current
（Induced Noise）

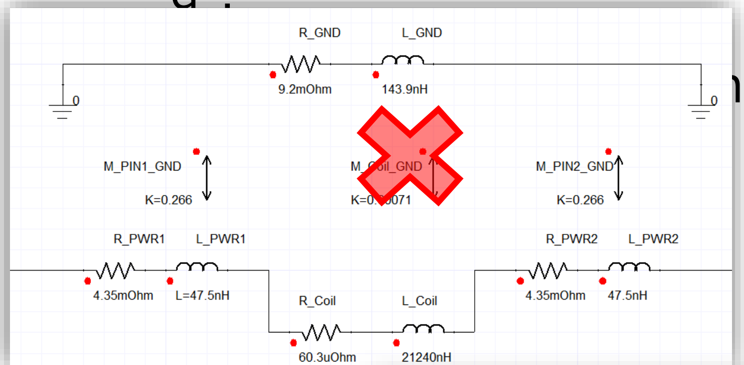


High Impedance
(1MHz) at GND Lines

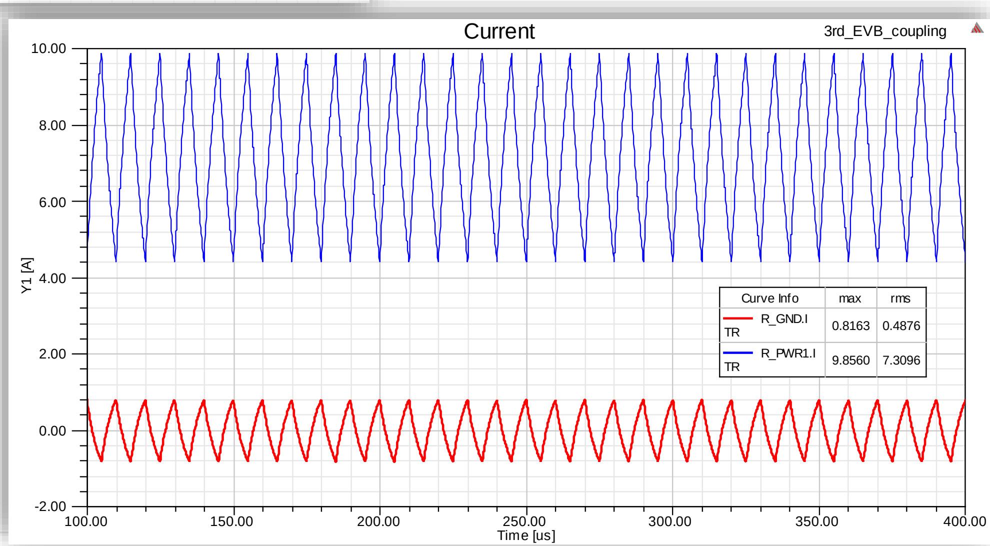
Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

- Result ③ : What happens if M between Coil and GND is neglected ?



ange in Inductive Noise



Coil, PWR Line Current

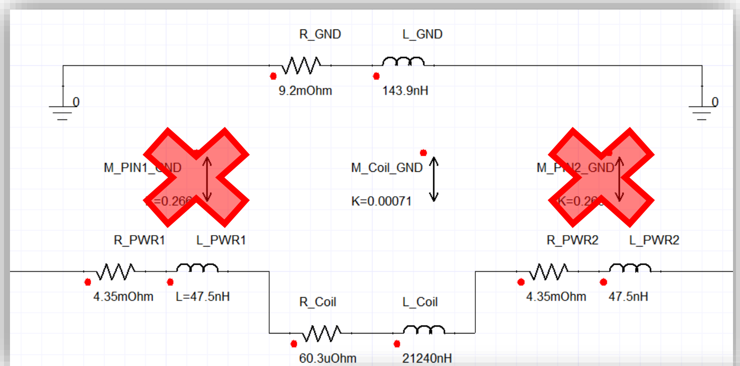
GND Line Current (Induced Noise)

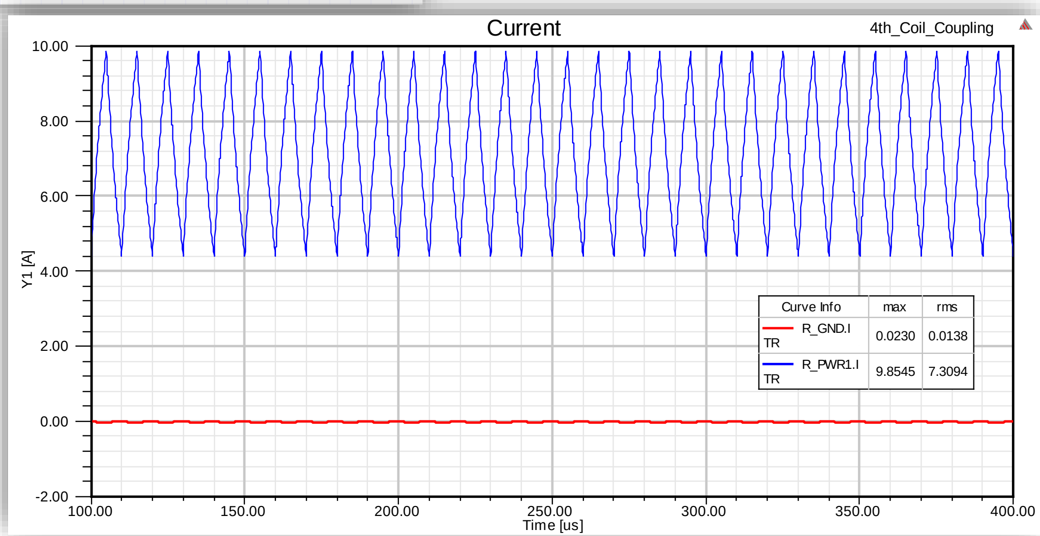
Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

Result ④ : What happens if M between (PIN_1, PIN_2) and GND is neglected ?

→ Inductive Noise significantly reduced





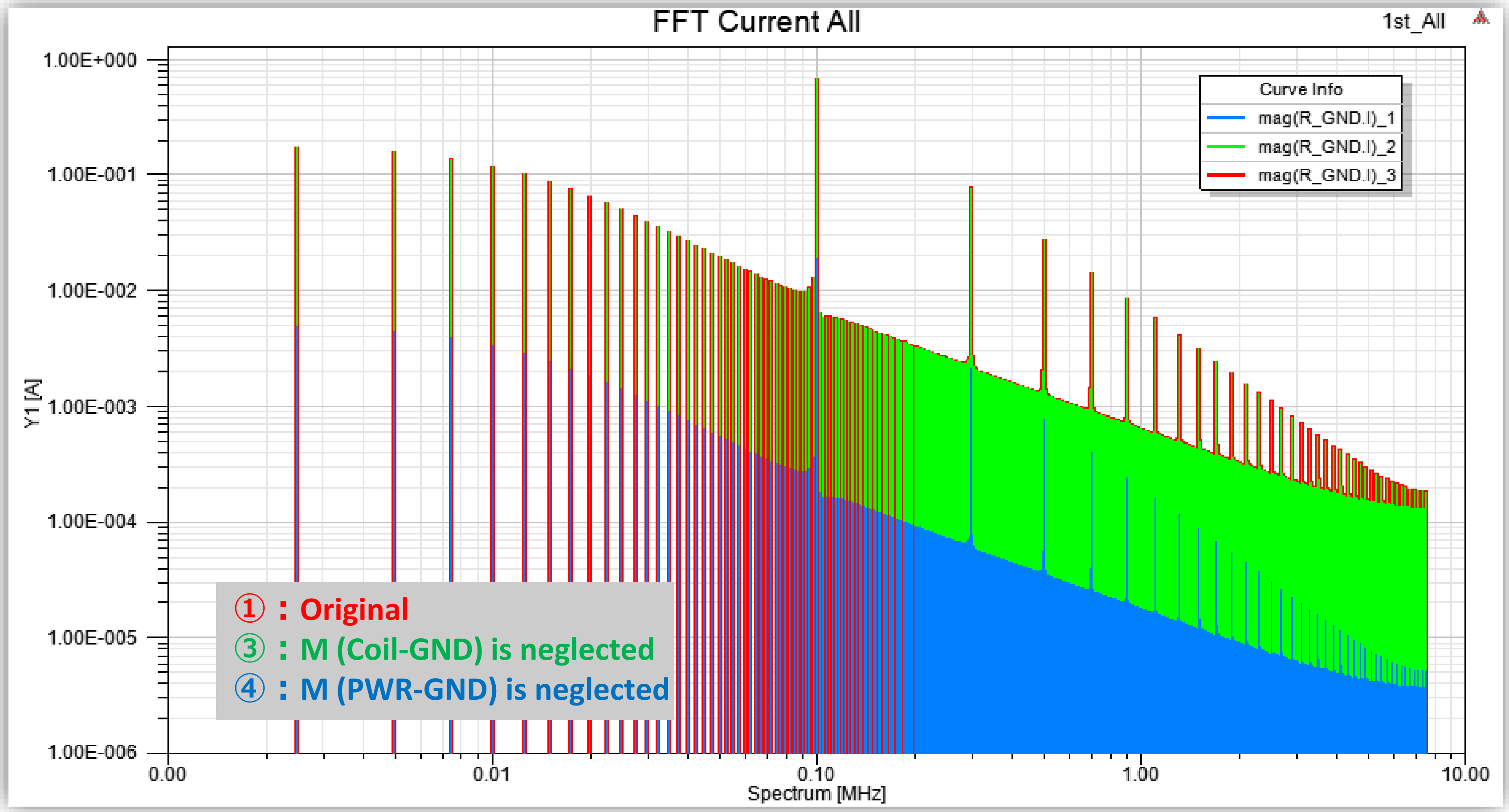
Coil, PWR Line Current

GND Line Current (Induced Noise)

Analysis : Circuit 2-1 Equivalent Circuit

Simplorer

- Result ①～④ : FFT on GND Line current



Remarks

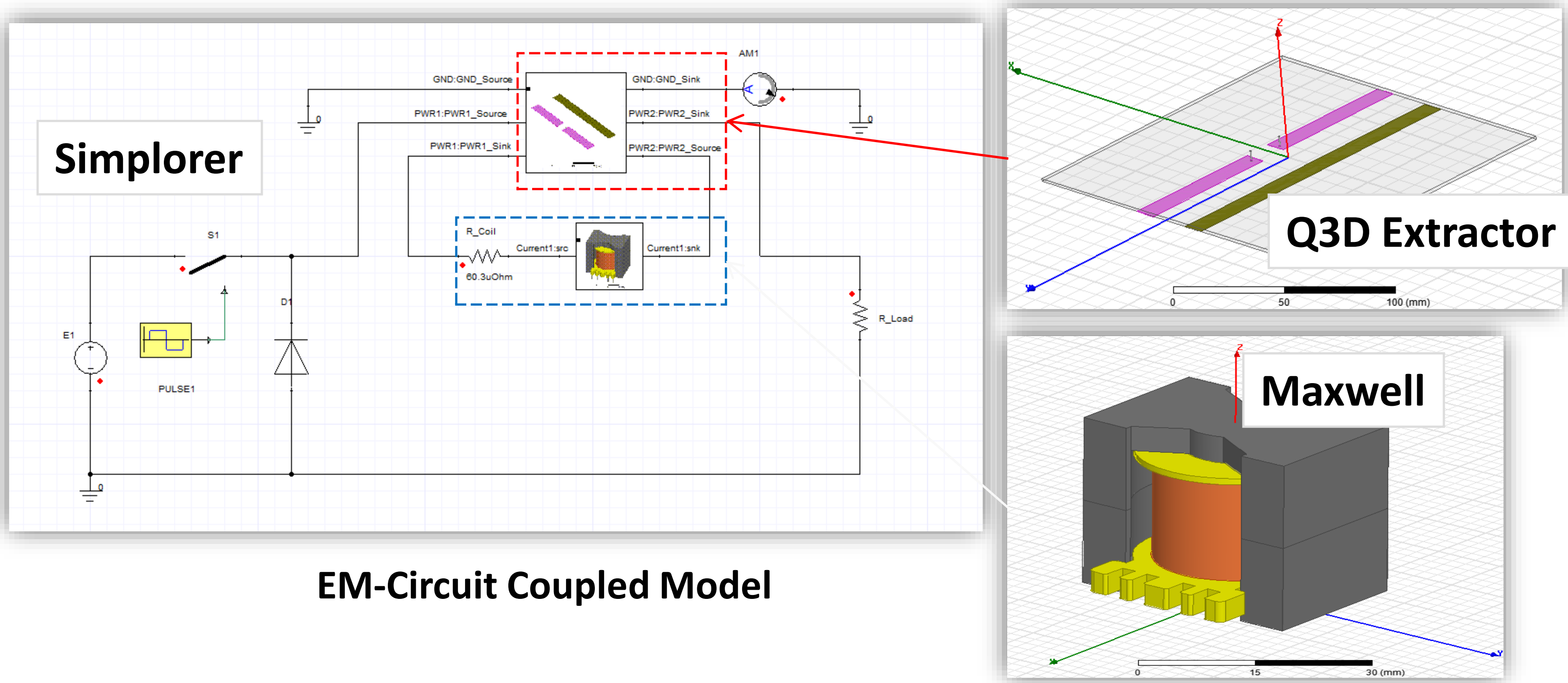
- * Simulation can identify the dominant factor of the GND noise
- * GND Line crosstalk noise is caused by the coupling between the tr aces.
- * Coupling between the coil and the traces is negligibly small.

•* Suppression of Trace-to-Trace crosstalk must be more important t han that of

- Trace-to-GND crosstalk.

Analysis：Circuit 2-2 EM-Circuit Coupling

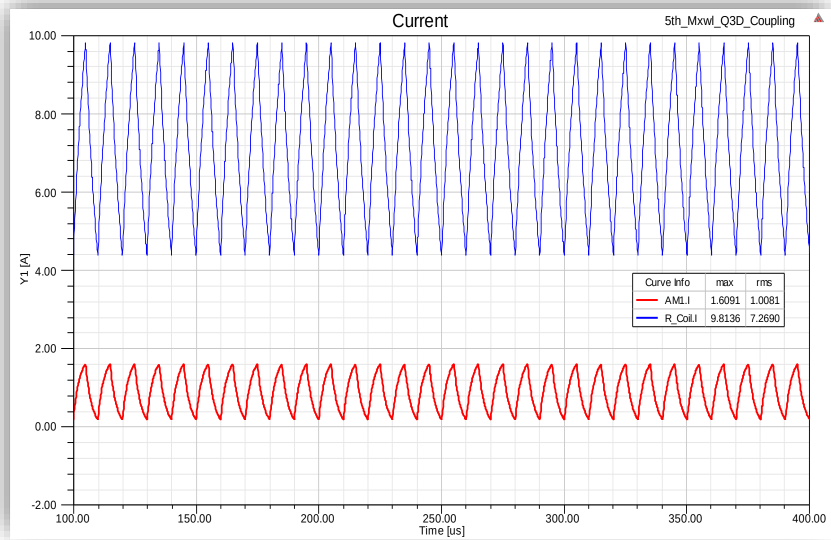
- Maxwell and Q3D models are imported into Simplorer
- Previous analysis confirmed the coupling between the Coil and the GND Li ne can be neglected



EM-Circuit Coupled Model

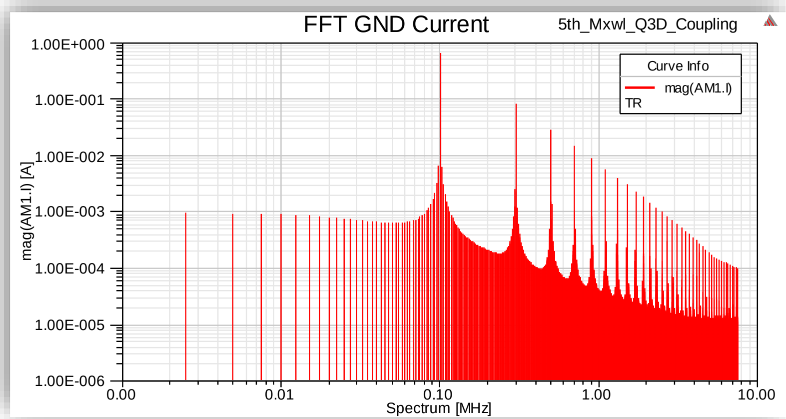
Analysis：Circuit 2-2 EM-Circuit Coupling

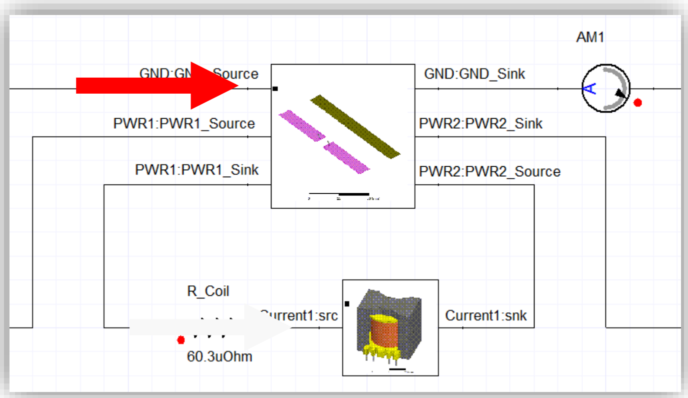
- Result ①: Current in the Power Line and Induced current in the GND Line



Coil, PWR Line Current

GND Line Current （Induced Noise）





Conclusions

- Effect of the leakage flux from the coil on the PCB traces is evaluated
- by simulation
- Possible three factors of the noise source are investigated
- Noise due to the crosstalk coupling among the traces on the PC B is dominant , while crosstalk between the coil and the traces i s negligible
- ANSYS can provide the effective noise evaluation solution by EM-Circuit coupled simulation

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