Emissions Simulation for Power Electronics Printed Circuit Boards

Patrick DeRoy
Application Engineer

Patrick DeRoy completed his B.S. and M.S. degrees in Electrical and Computer Engineering from the University of Massachusetts Amherst in 2012. His coursework focused primarily on microwave and RF engineering, but he now specializes in the field of Electromagnetic Compatibility (EMC). He completed his Master's work with investigations on cable shielding and transfer impedance modeling using CST STUDIO SUITE and validating simulation results with measurements. He is an Application Engineer at CST of America, Framingham, MA, supporting customers modeling EMC problems including ESD, conducted and radiated emissions and BCI, among others. He is also interested in the simulation of PCBs for Signal and Power Integrity and mitigation of EMI at the board level.

Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

- Effect of EMI filter

Radiated Emission of a DC-DC Buck Converter

- RE as a near field coupling and the effect of shielding

Summary and Q&A

Agenda

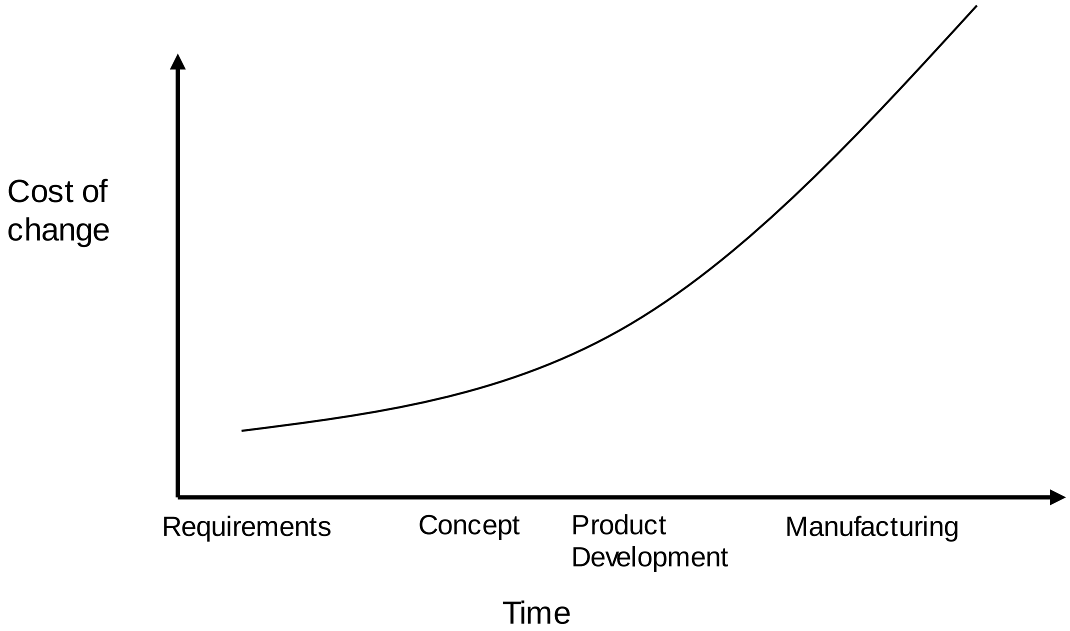
- Introduction and Motivation
- Coupled 3D Field and Circuit Simulation
- Conducted Emission of a Motor Control
  - Variable frequency drive, the effect of PCB layout
- Conducted Emission of a DC-DC Buck Converter
  - Effect of EMI filter
- Radiated Emission of a DC-DC Buck Converter
  - RE as a near field coupling and the effect of shielding
- Summary and Q&A

EMC at Different Stages of the Design Process

Multiple troubleshooting iterations

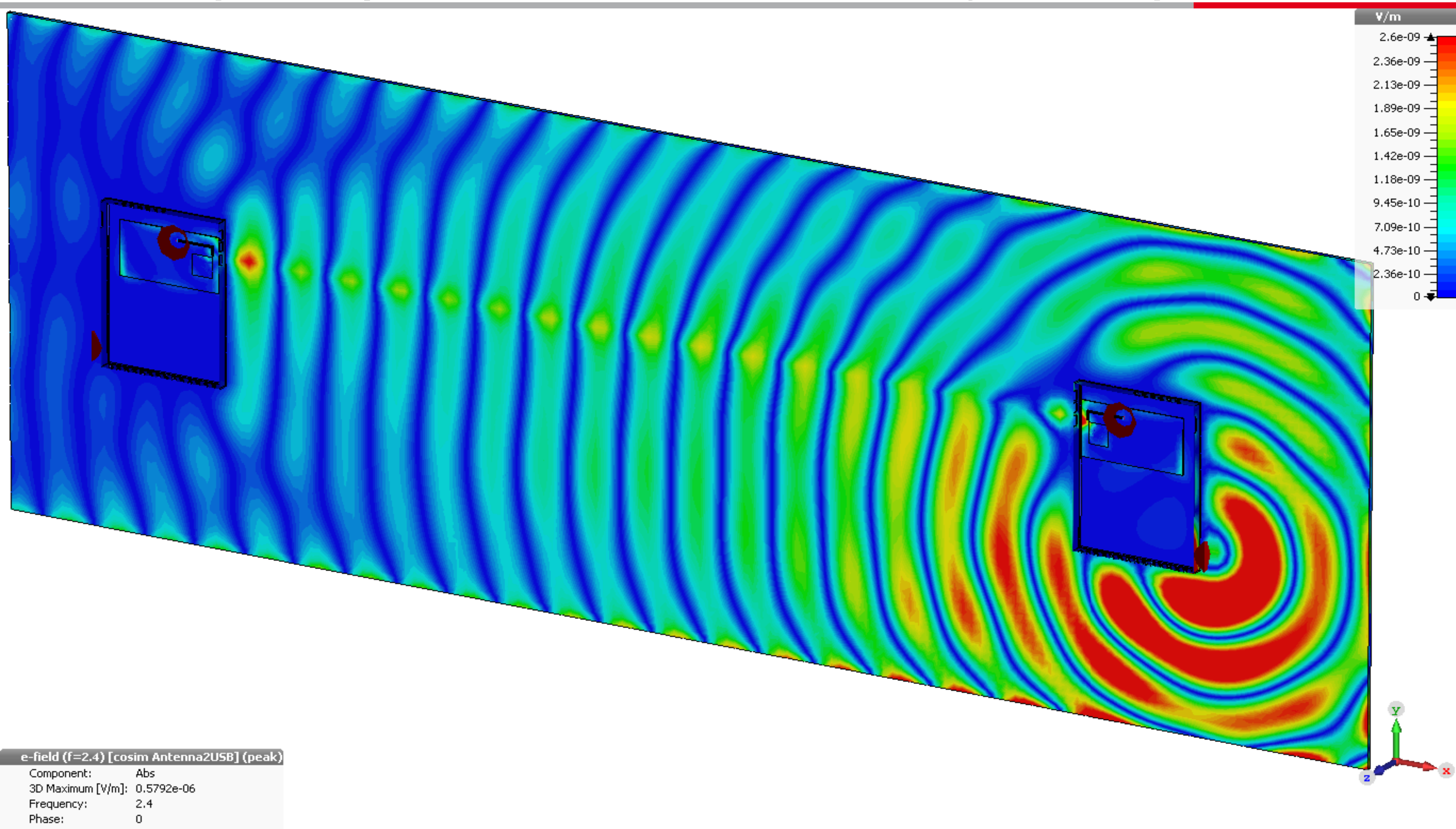
High effort and costs to correct

Delayed time to market

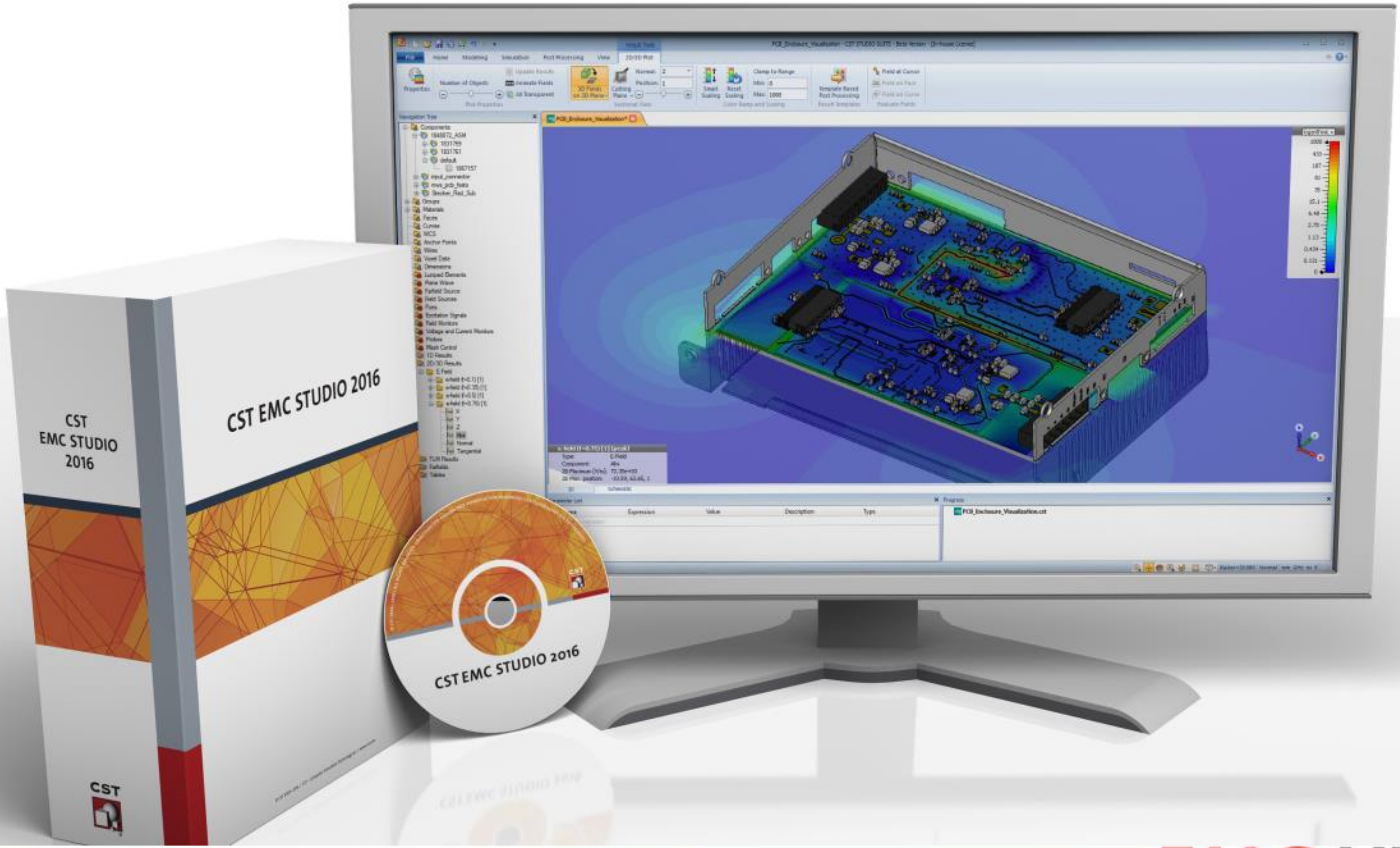


CEM (Computational Electromagnetics) for EMC

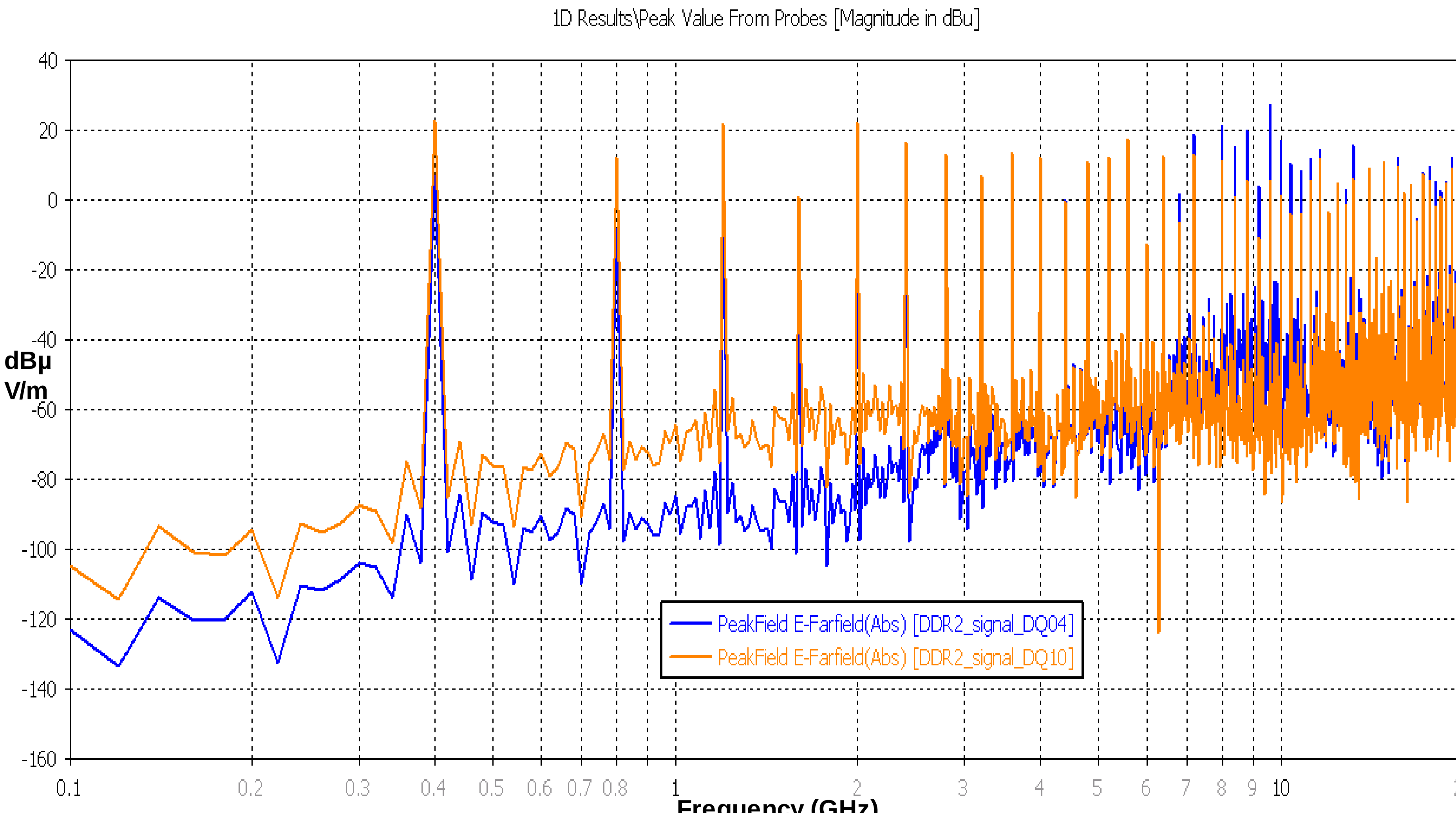
CEM (Computational Electromagnetics) for EMC



CEM (Computational Electromagnetics) for EMC



CEM (Computational Electromagnetics) for EMC



EMC Simulation in the Design Process

Design Stage

- Should be employed as early as possible in order to minimize the need for troubleshooting
- Can be performed without a prototype
- Can give answers to fundamental “what if” questions
- Can deliver outputs not accessible by measurements

Troubleshooting

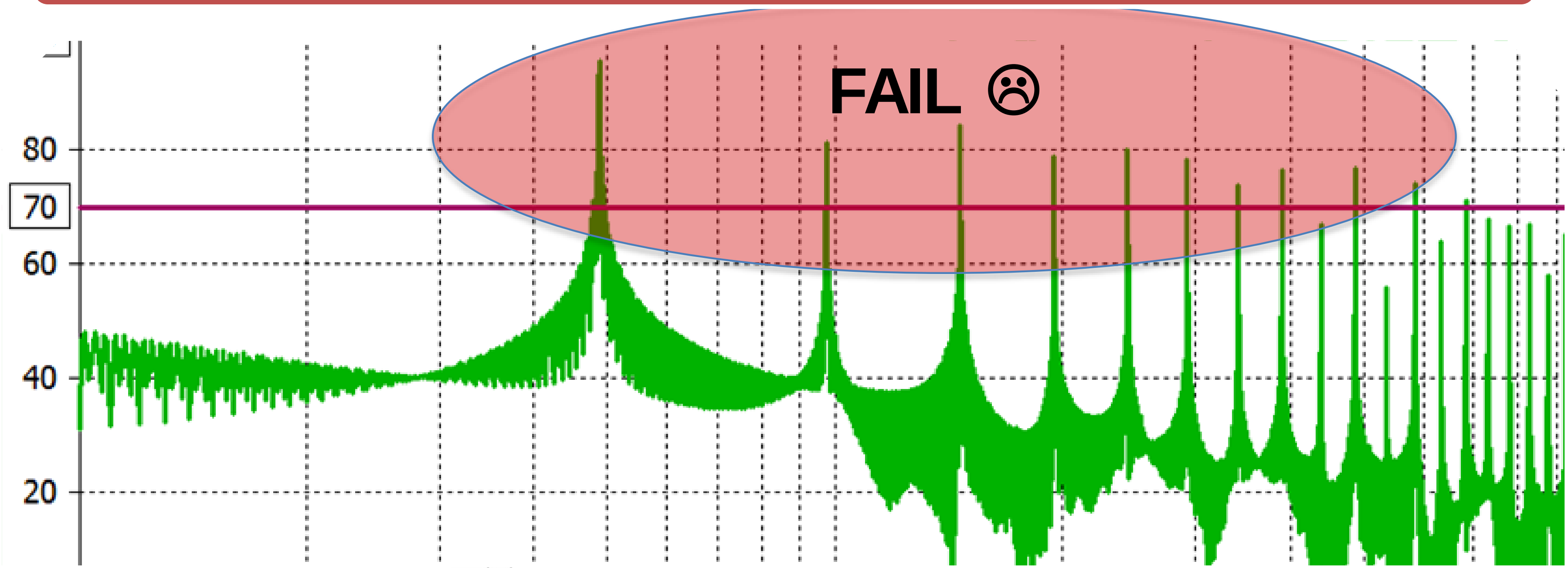
- Can help to understand behavior of the device
- Not a competitor to measurements, both should be used complementarily

EMC Simulation for Power Electronics

Power Electronics designers require a deep breadth of knowledge across many disciplines – circuit design, magnetics, semiconductor devices, thermal management, control theory, PCB layout, EMI…

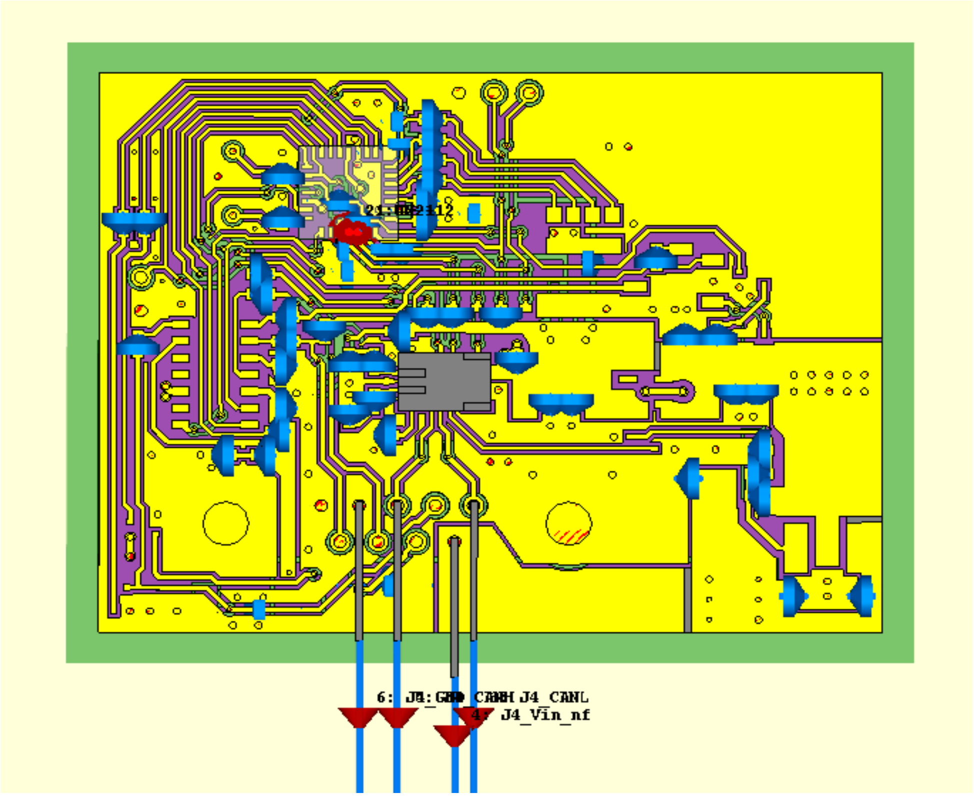
EMI continues to be a major problem! Especially for Switched Mode Power Supply (SMPS) devices

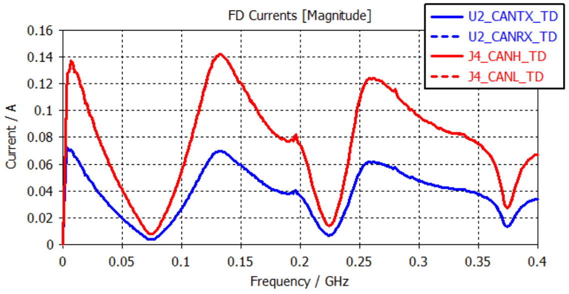
Concepts well known, yet it can still be difficult to pass EMC regulations



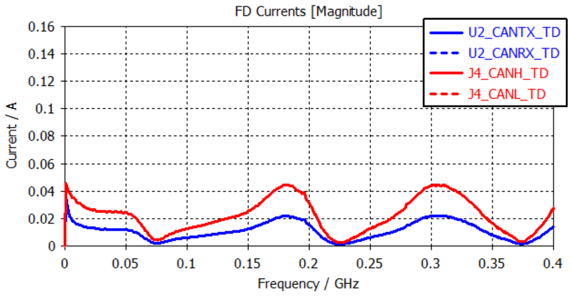
EMC Simulation for Power Electronics

PCB with CAN Interface, Noise Currents due to BCI on Power Wires





Filter off

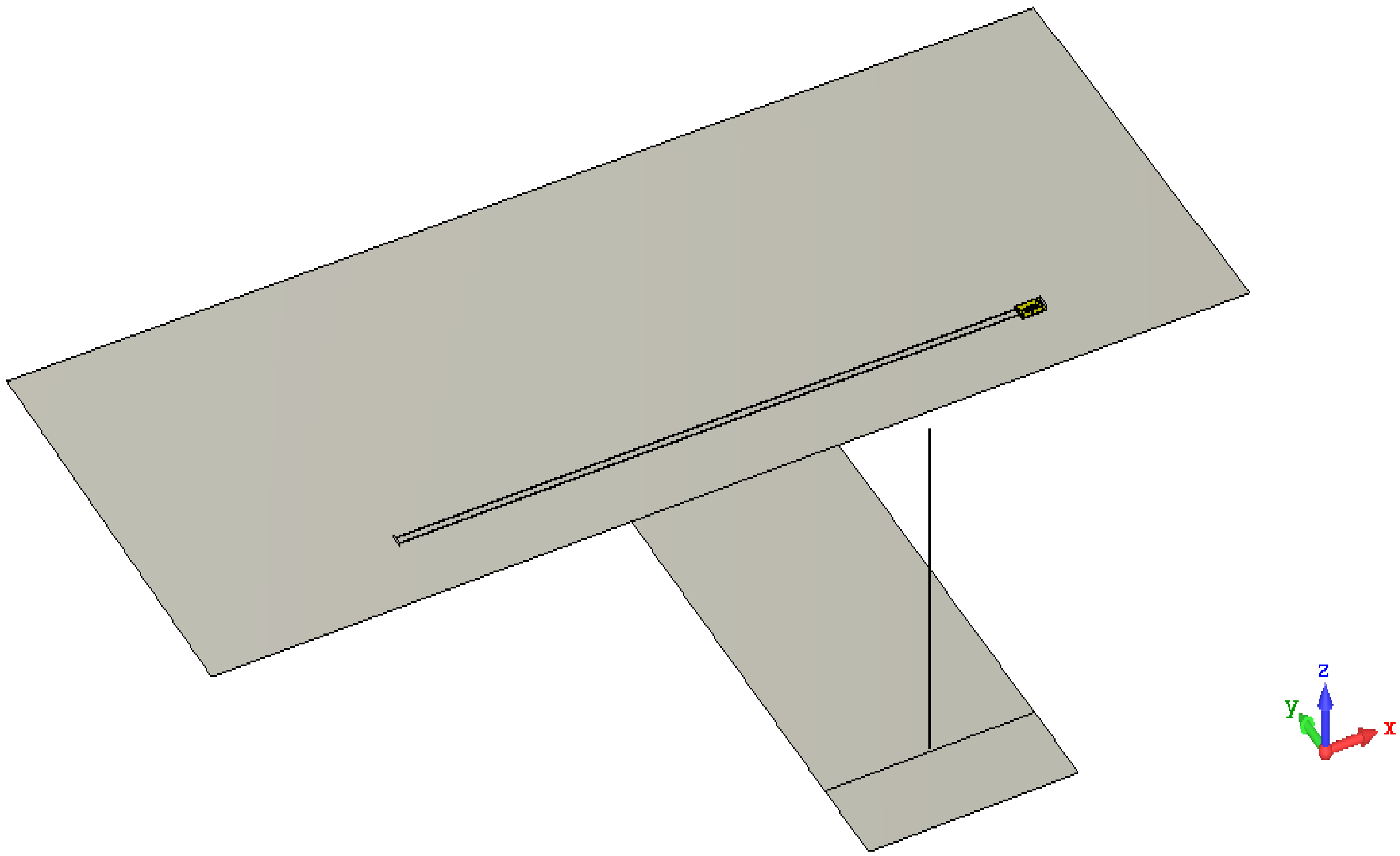


Filter on

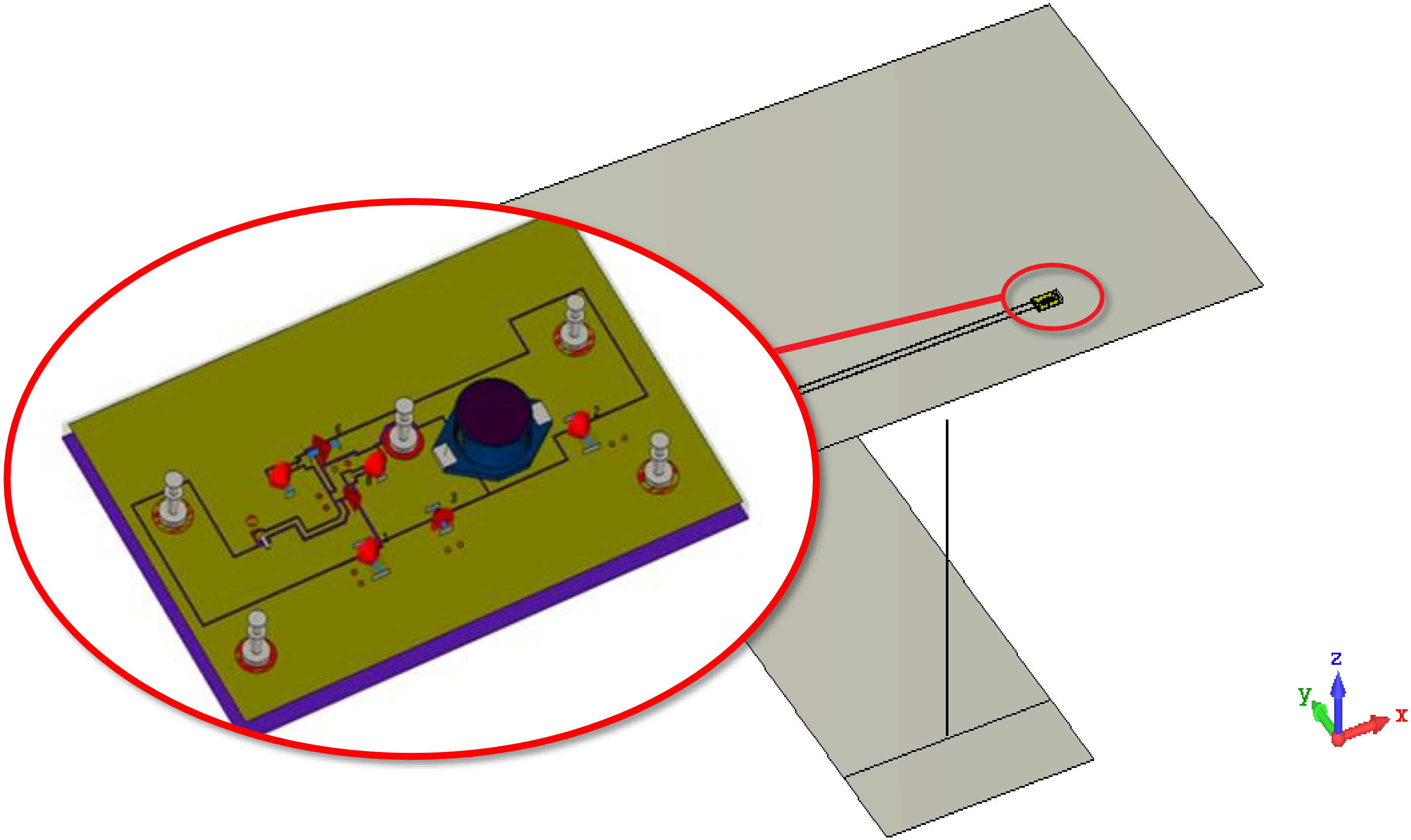
EMC Simulation for Power Electronics

CISPR-25 RE Setup

EMC Simulation for Power Electronics



EMC Simulation for Power Electronics



Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

- Effect of EMI filter

Radiated Emission of a DC-DC Buck Converter

- RE as a near field coupling and the effect of shielding

Summary and Q&A

Coupled 3D Field and Circuit Simulation

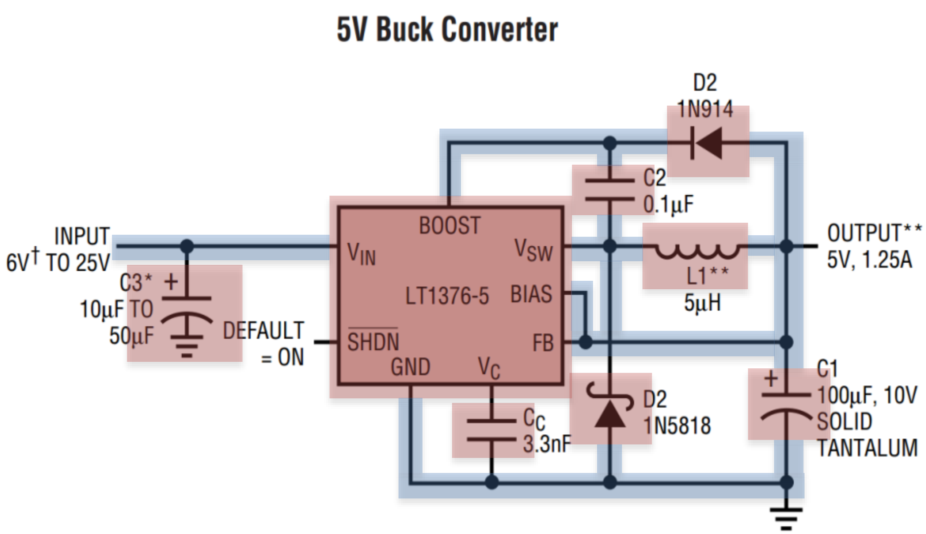
Model Geometry → 3D EM Simulation → Circuit Setup → Circuit Simulation

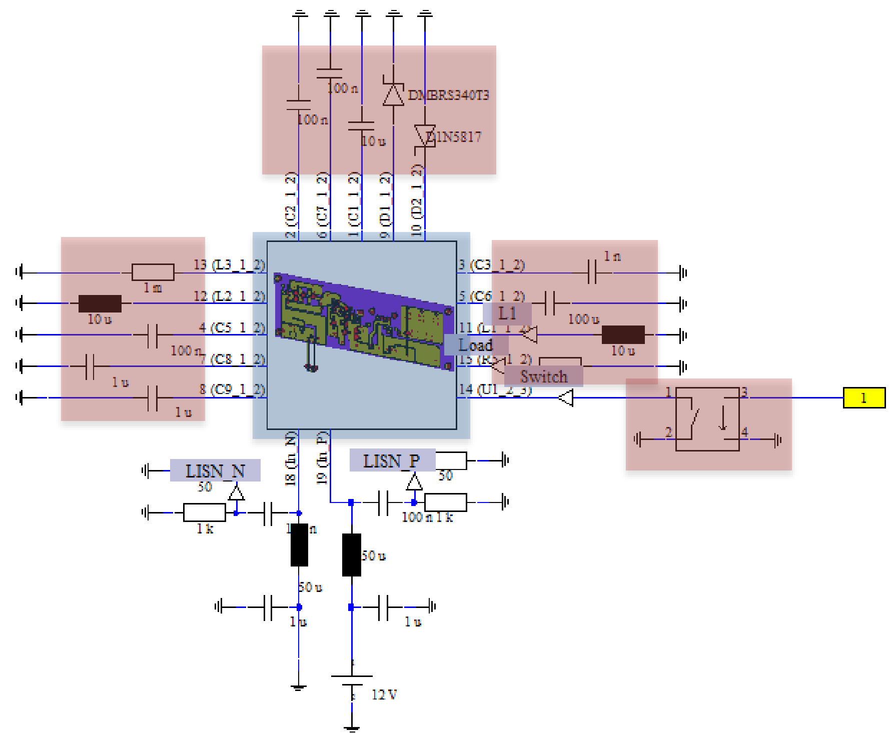
Coupling is not only one way!

Model Geometry ↔ 3D EM Simulation ↔ Circuit Setup ↔ Circuit Simulation

Coupled 3D Field and Circuit Simulation

Left: Buck Converter Data Sheet Schematic
Right: Coupled 3D-Circuit Model Schematic





For more information…

http://emclive2014.com/technical-program-2/

Simulation of PCB Emissions
October 15th 2014

www.cst.com/Events/Webinars

Filter for **Archive**

Simulation for EMC Performance in Modern Electronics
November 6th 2014

EMC Simulation of a Motor Control
September 24th 2015

Getting Ahead with Coupled 3D Field and Circuit Simulation
February 18th 2016

Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

- Effect of EMI filter

Radiated Emission of a DC-DC Buck Converter

- RE as a near field coupling and the effect of shielding

Summary and Q&A

Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

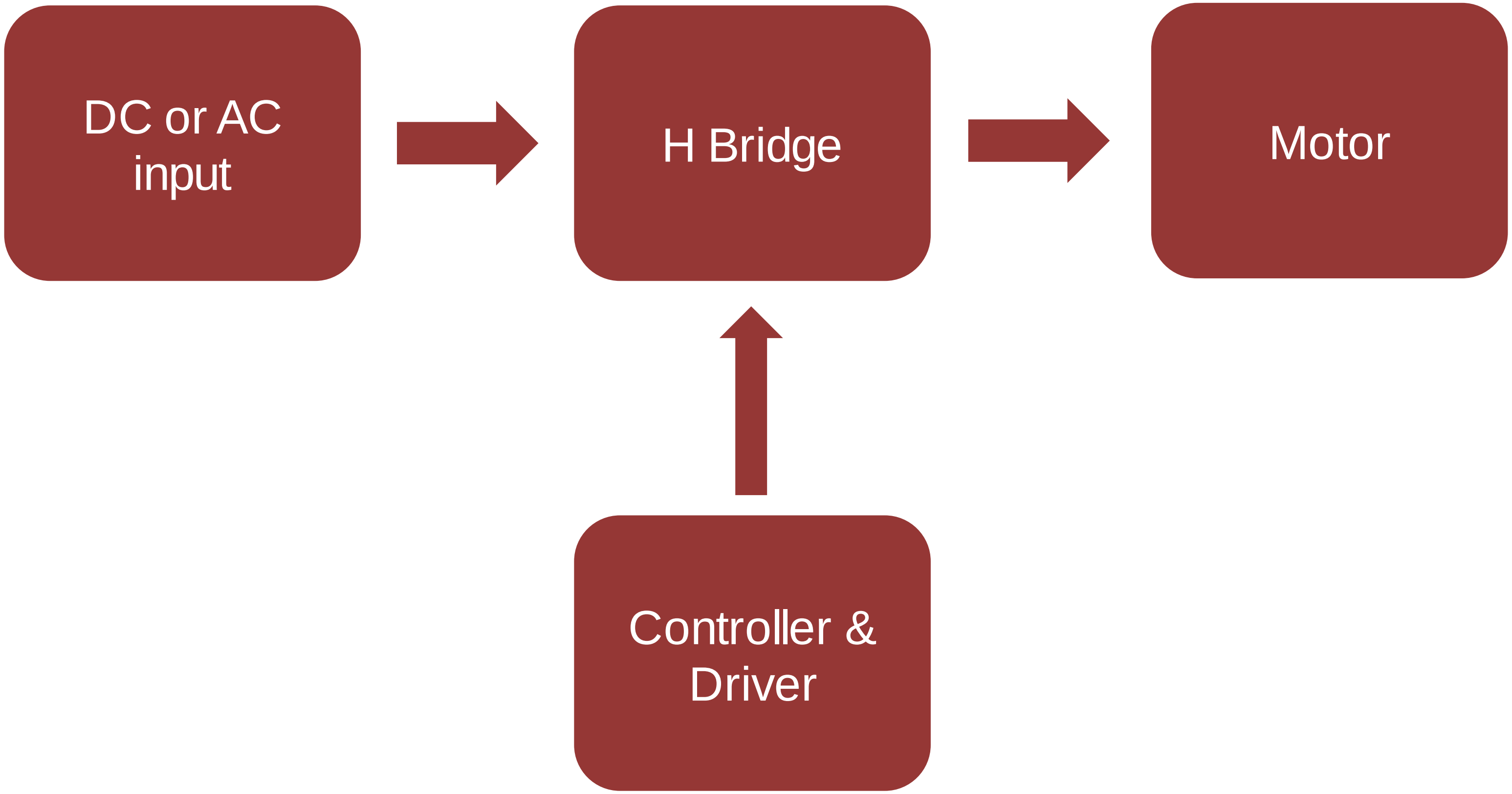
- Effect of EMI filter

Radiated Emission of a DC-DC Buck Converter

- RE as a near field coupling and the effect of shielding

Summary and Q&A

Variable Frequency Drive



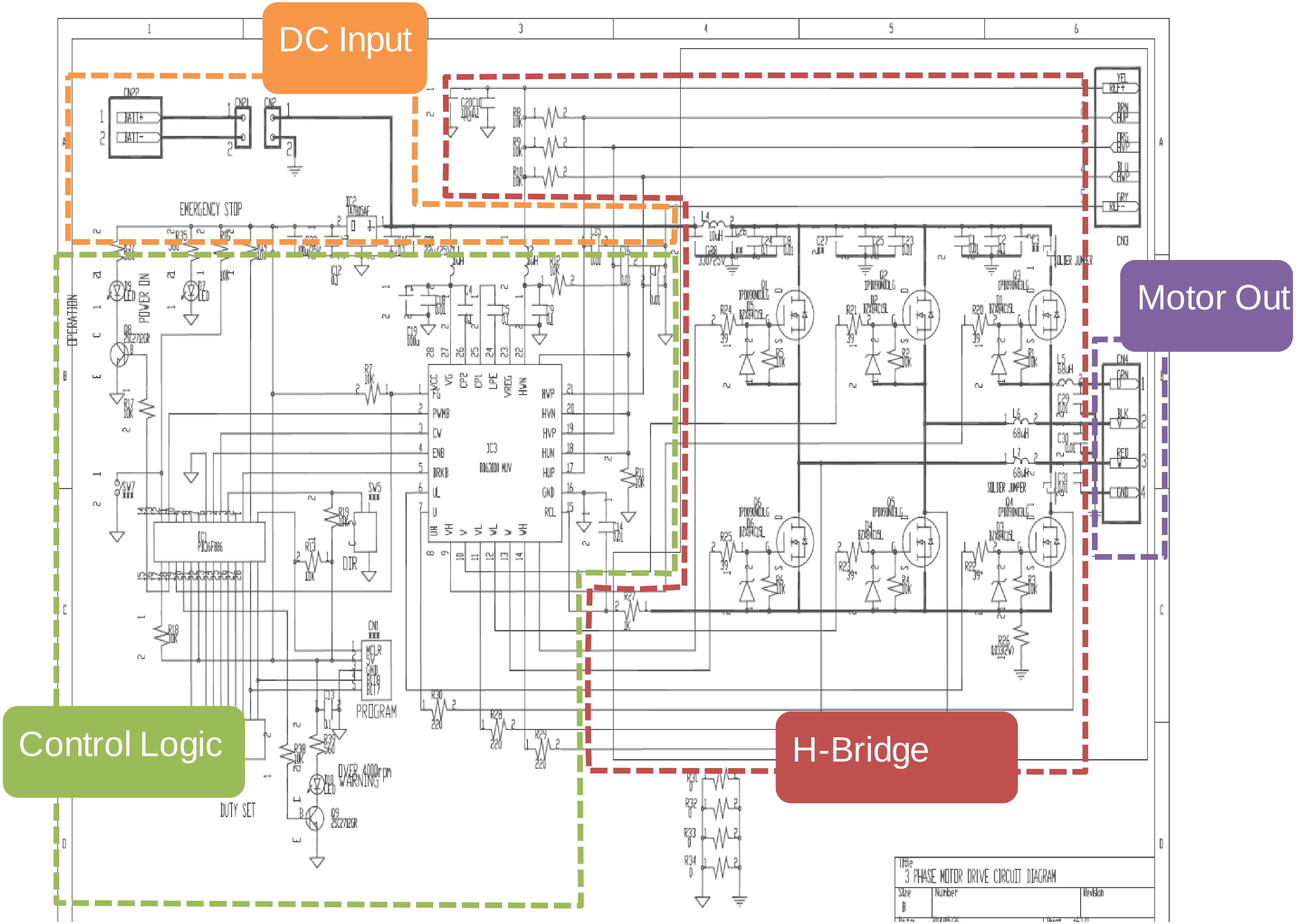
Variable Frequency Drive

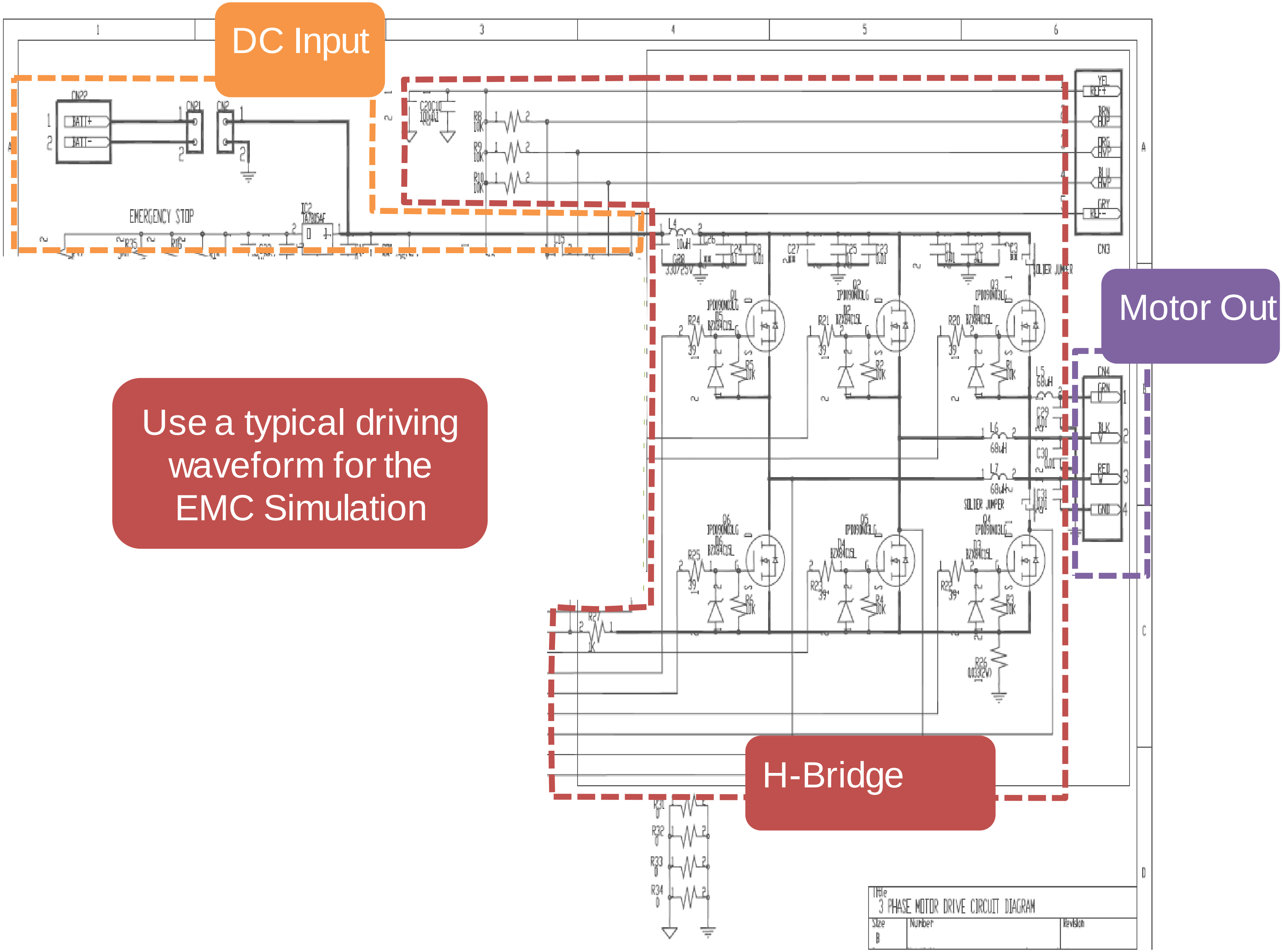
Properties

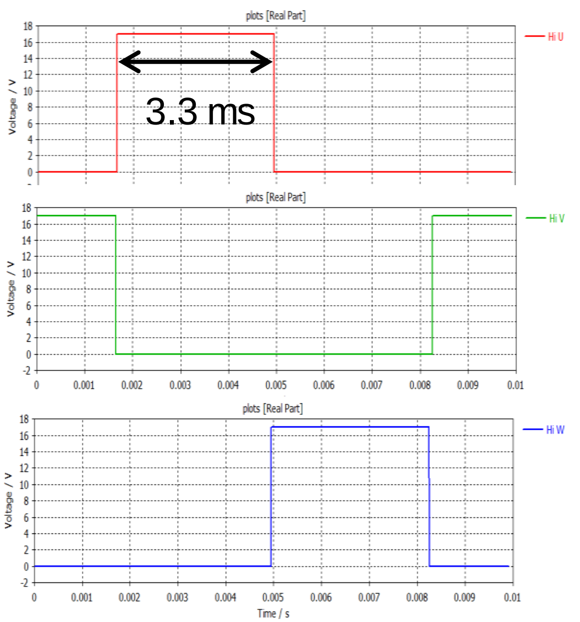
- Energy efficiency
- Speed regulation
- Torque regulation
- Low maintenance effort

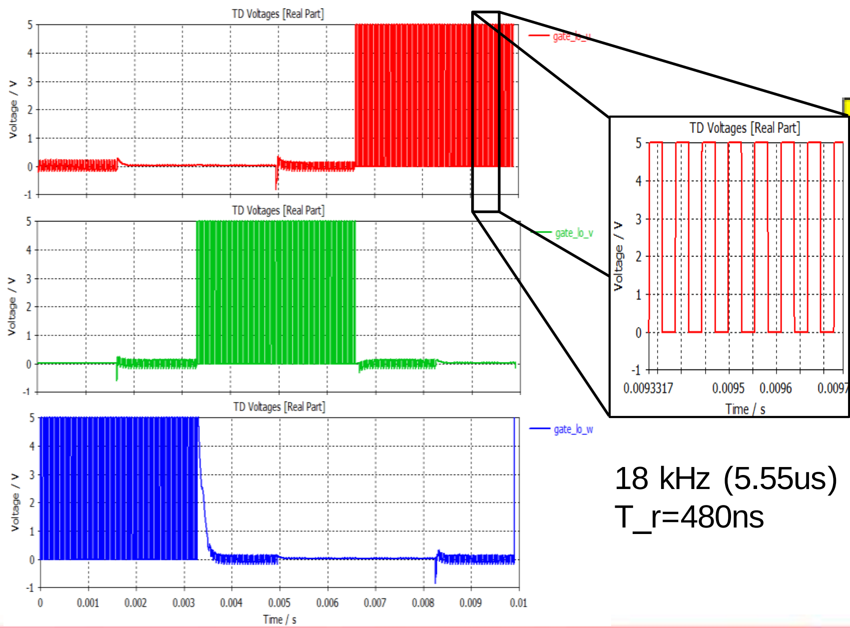
Automotive Application Areas

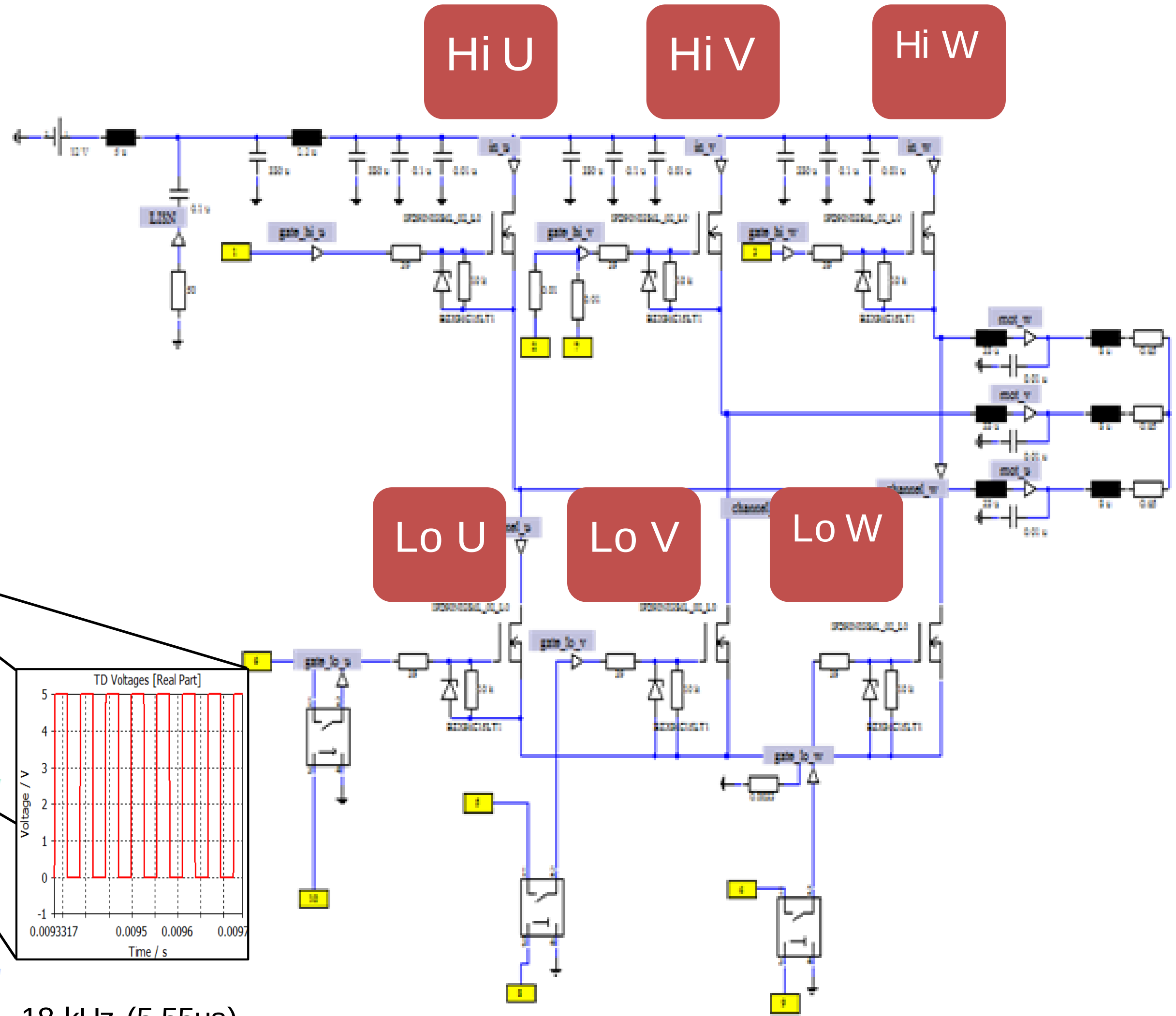
- Fuel pumps
- Motor cooling fans
- Electric engine


DC Input
Motor Out
Control Logic
H-Bridge
EMERGENCY STOP
POWER ON
OPERATION
DIR
PROGRAM
DUTY SET
OVER 4000rpm WARNING
3 PHASE MOTOR DRIVE CIRCUIT DIAGRAM

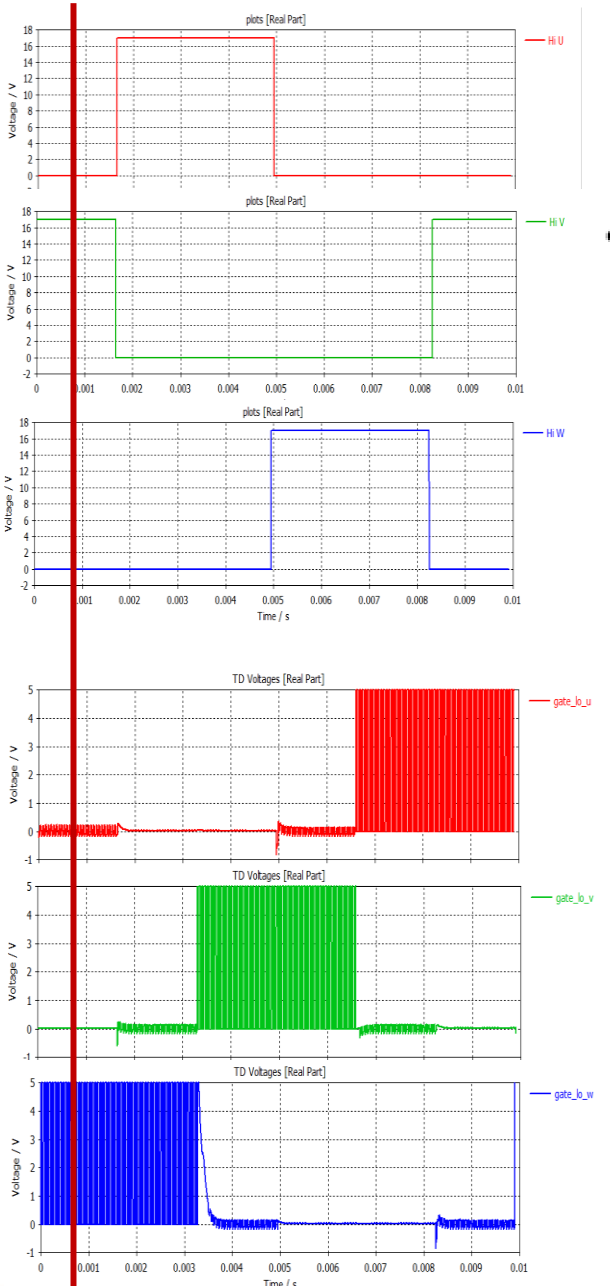

DC Input
Motor Out
Use a typical driving waveform for the EMC Simulation
H-Bridge
EMERGENCY STOP
3 PHASE MOTOR DRIVE CIRCUIT DIAGRAM

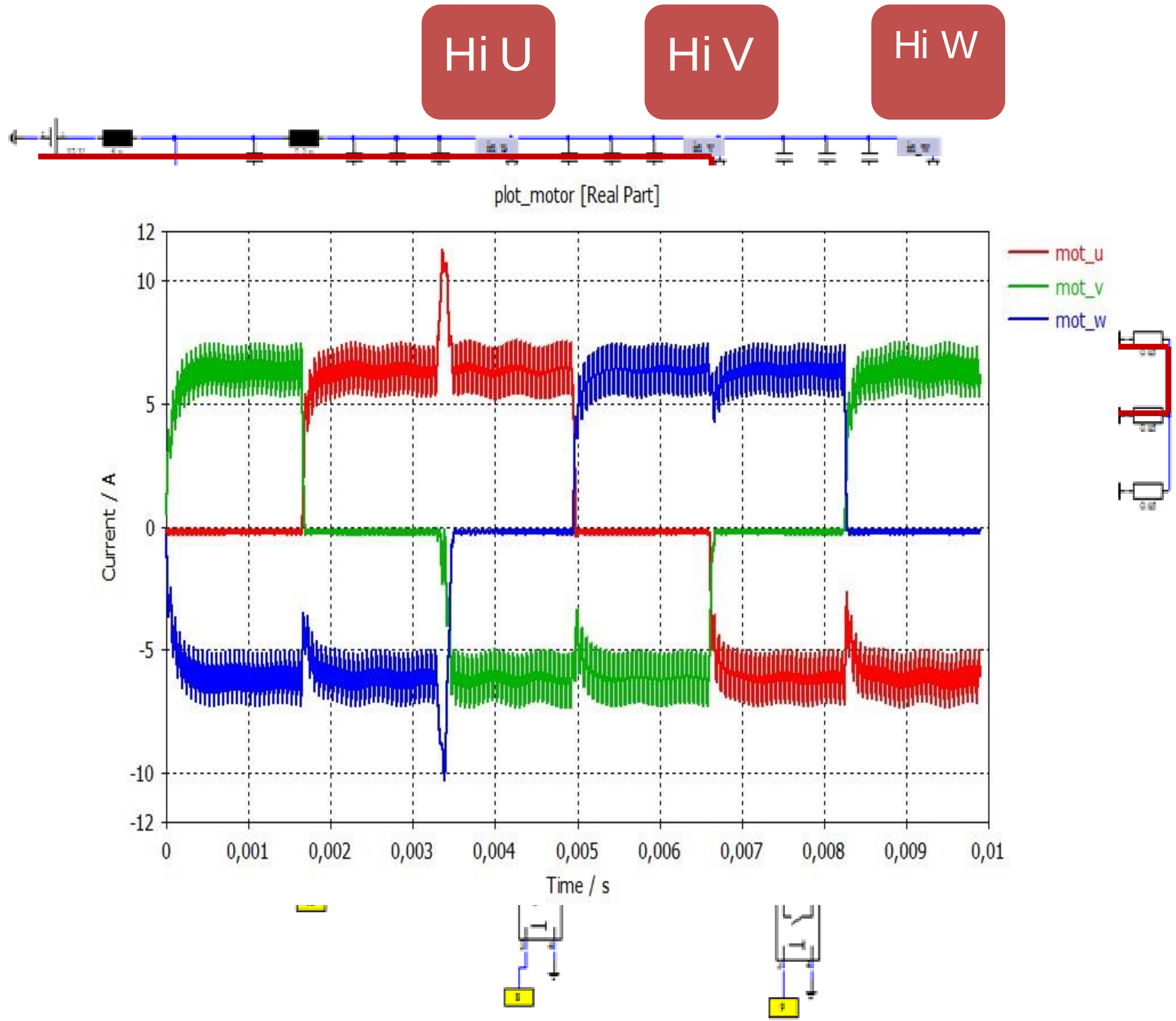






18 kHz (5.55us)
T_r=480ns

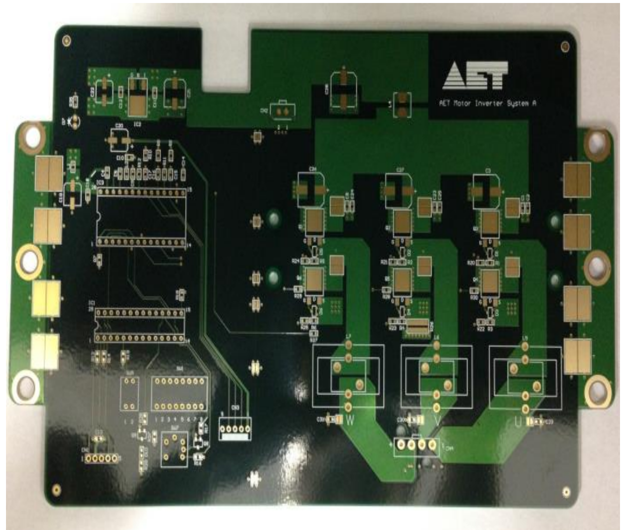

plots [Real Part]
Voltage / V
Hi U
plots [Real Part]
Voltage / V
Hi V
plots [Real Part]
Voltage / V
Hi W
Time / s
TD Voltages [Real Part]
Voltage / V
gate_lo_u
TD Voltages [Real Part]
Voltage / V
gate_lo_v
TD Voltages [Real Part]
Voltage / V
gate_lo_w
Time / s

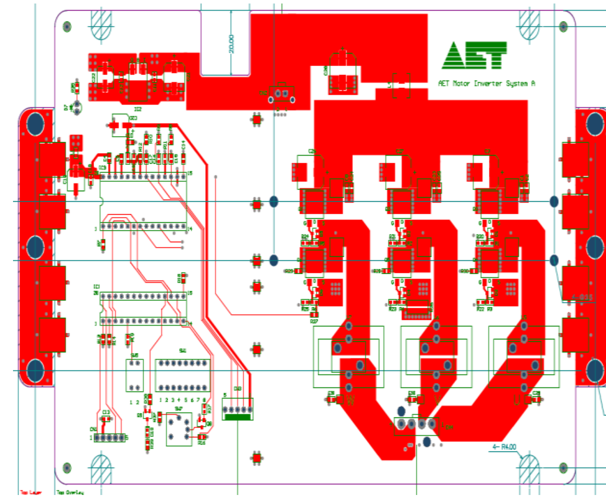

Hi U
Hi V
Hi W
plot_motor [Real Part]
Current / A
mot_u
mot_v
mot_w
Time / s

Prototypes with Different PCB Layout

Good Design

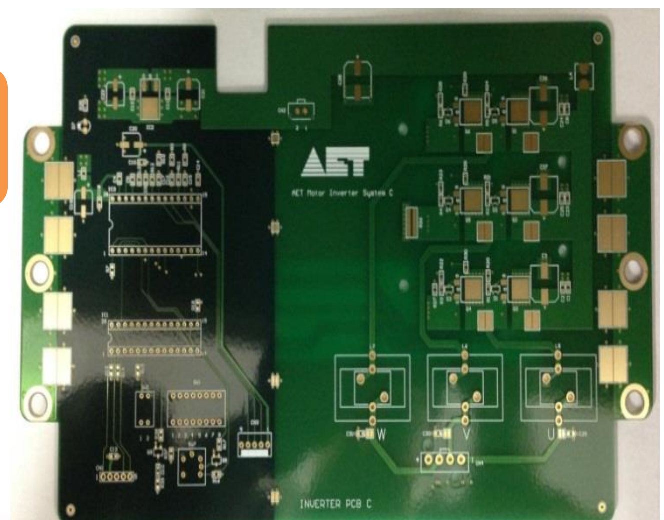
- Wide trace
- Balanced length

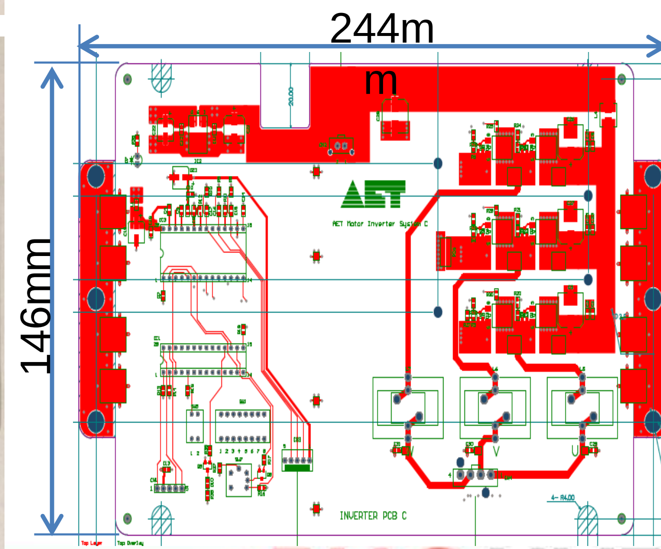


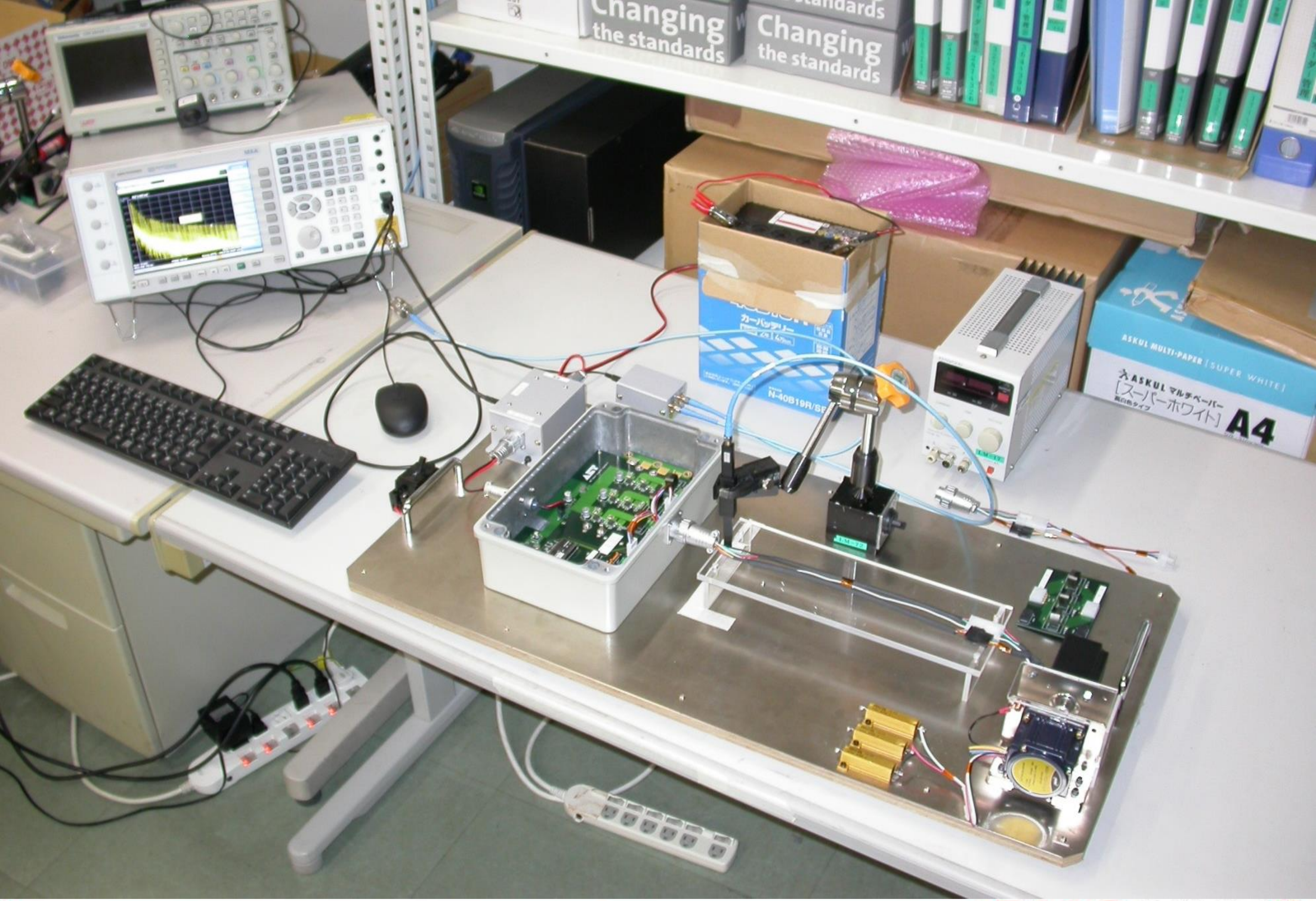


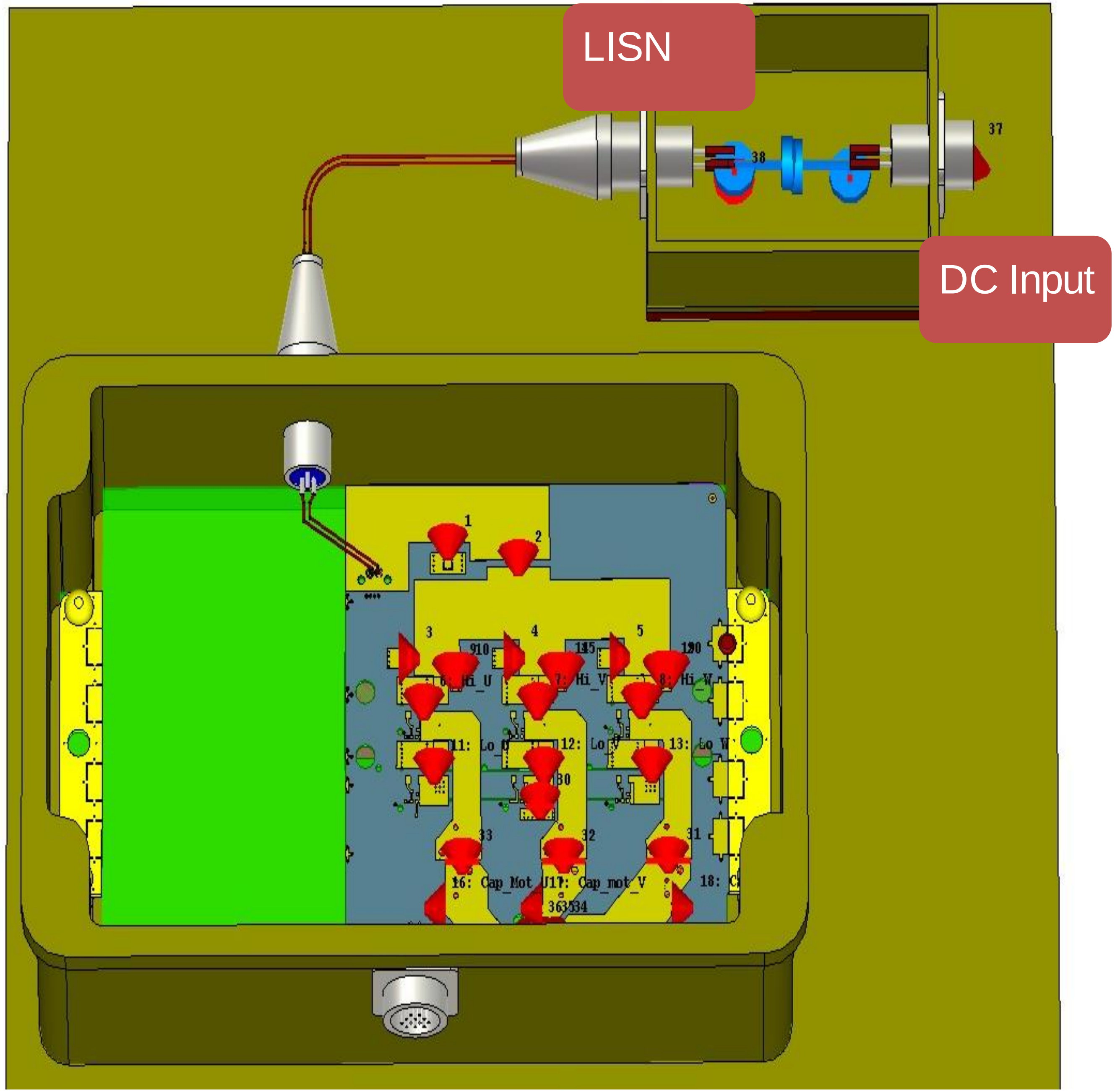
Bad Design

- Narrow trace
- Unbalanced length



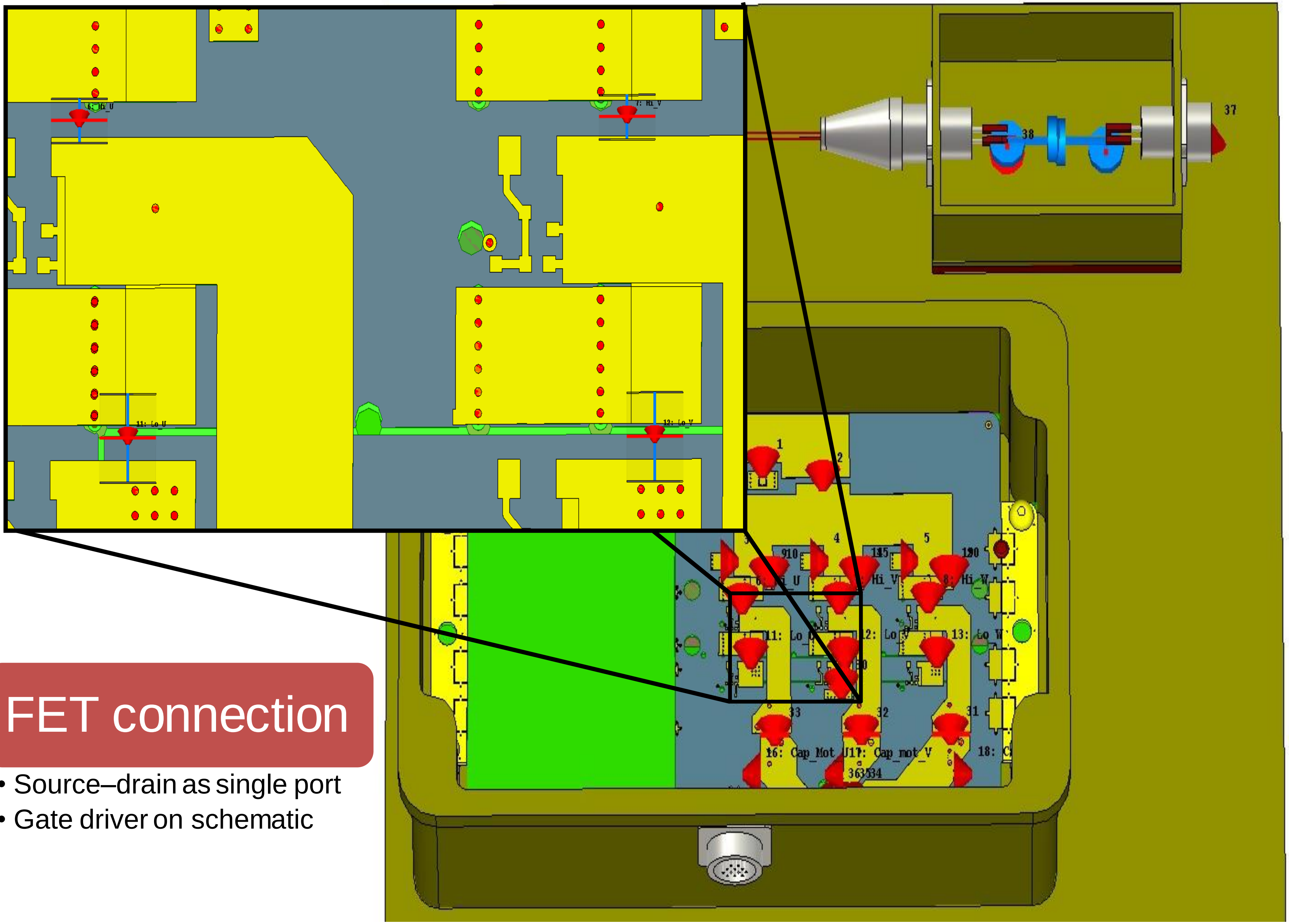



Changing
the standards
Changing
the standards
カーバッテリー
N-40B19R/SE
ASKUL MULTI-PAPER [SUPER WHITE]
ASKUL マルチペーパー
[スーパーホワイト]
A4



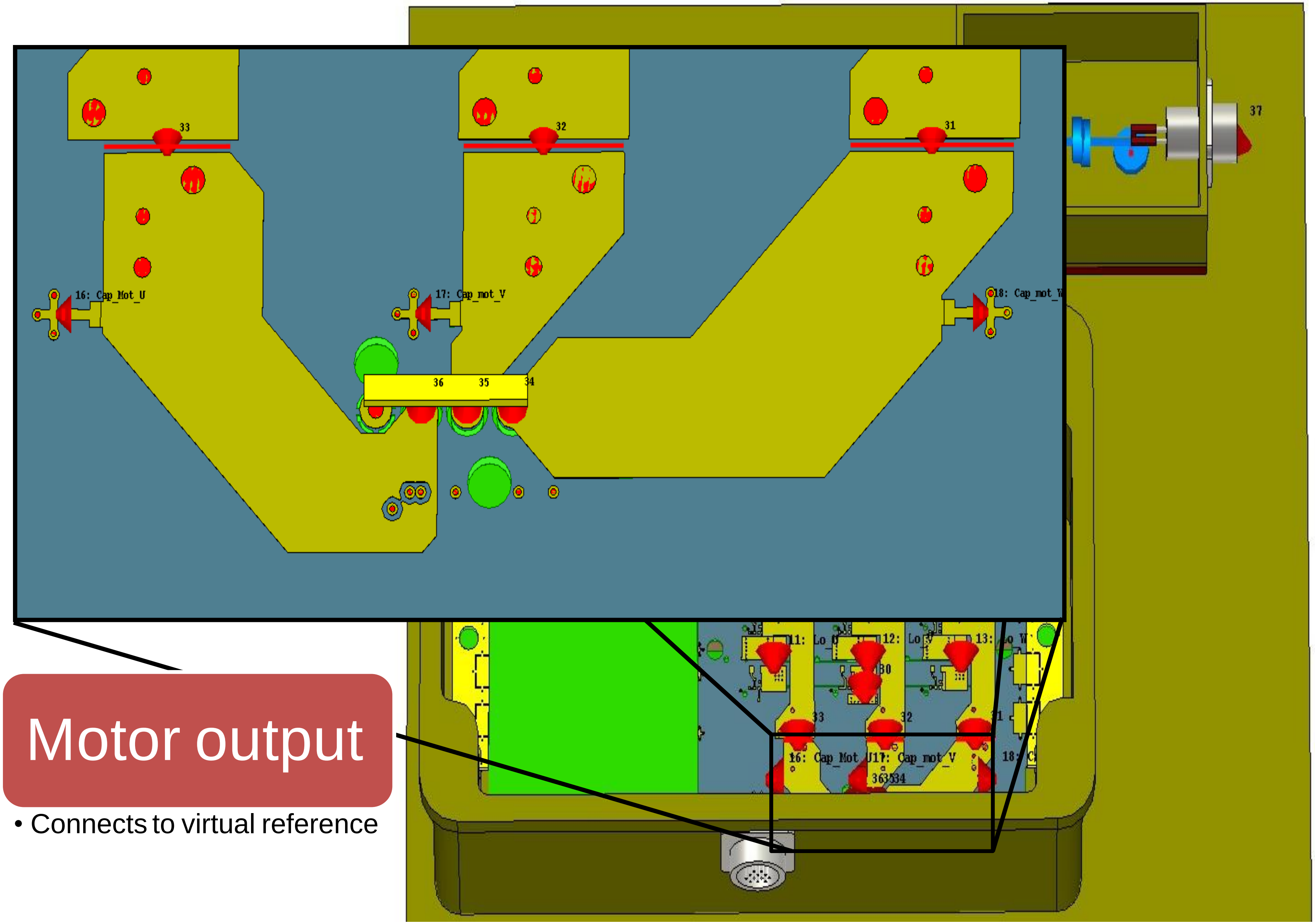
Port Placement

- All lumped components for filtering are replaced by ports



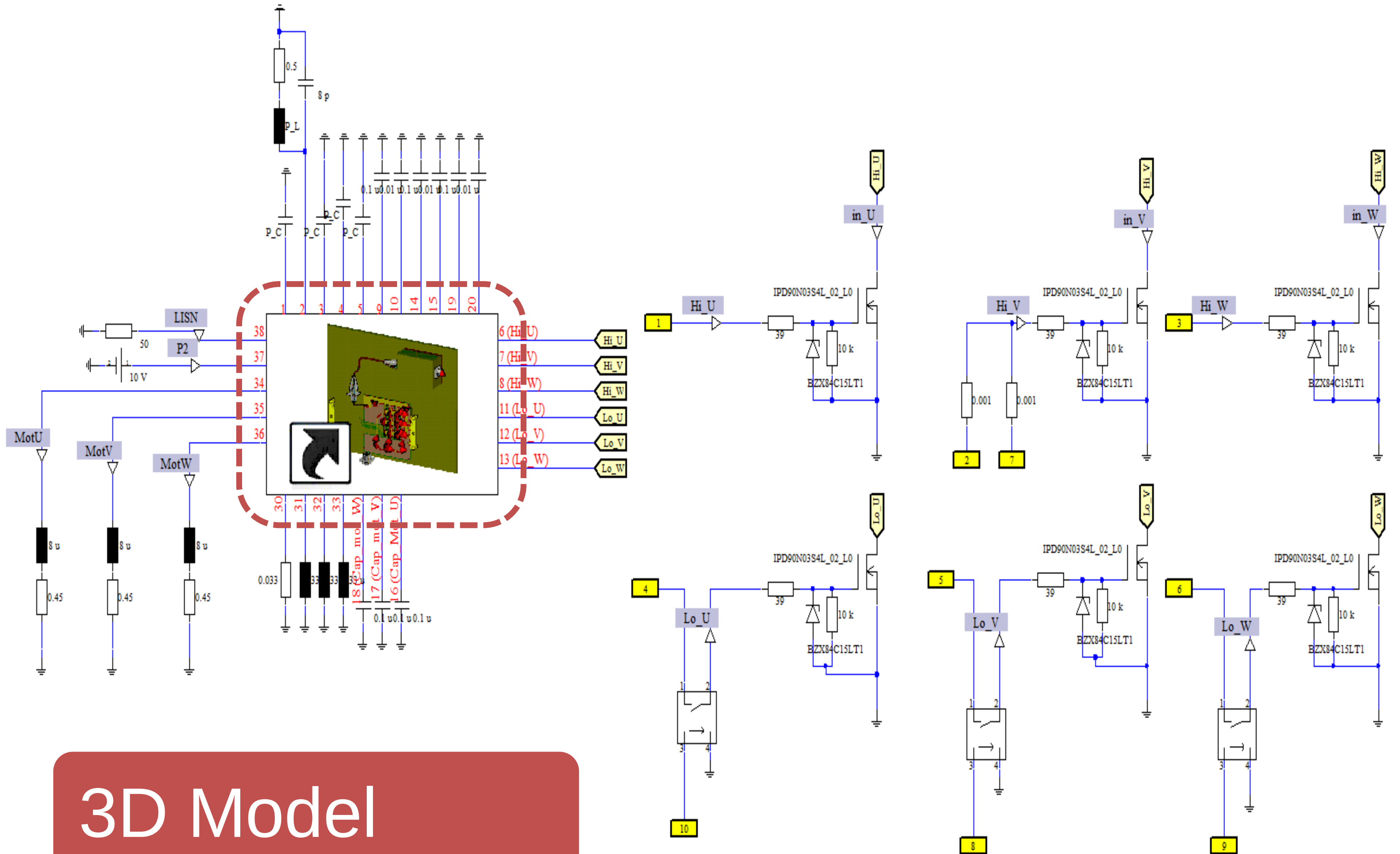
FET connection

- Source–drain as single port
- Gate driver on schematic



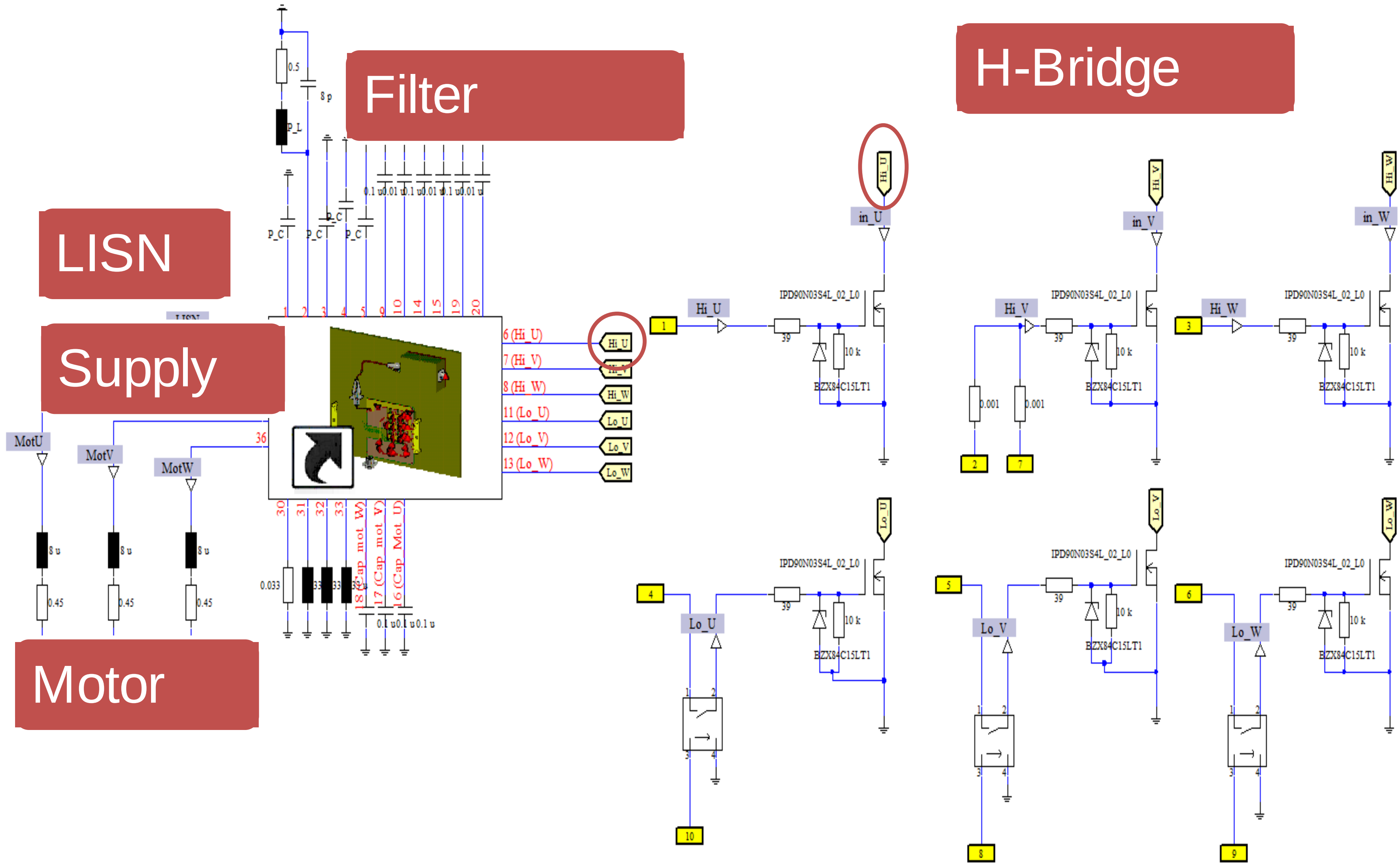
Motor output

- Connects to virtual reference



LISN
P2
10 V
MotU
MotV
MotW
Hi_U
Hi_V
Hi_W
Lo_U
Lo_V
Lo_W
in_U
in_V
in_W
IPD90N03S4L_02_L0
BZX84C15LT1

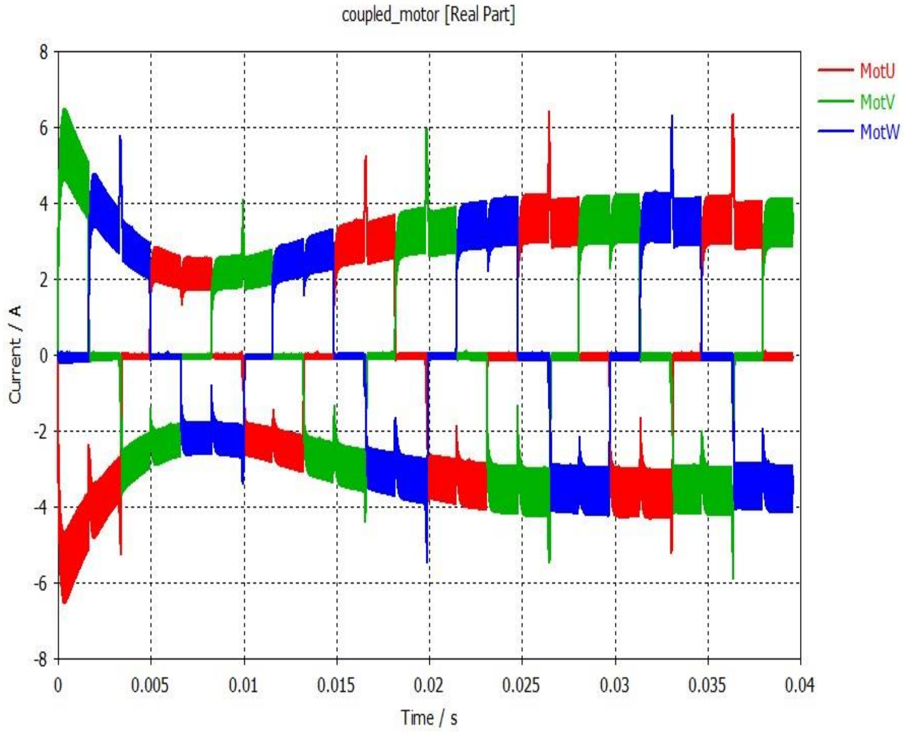
3D Model

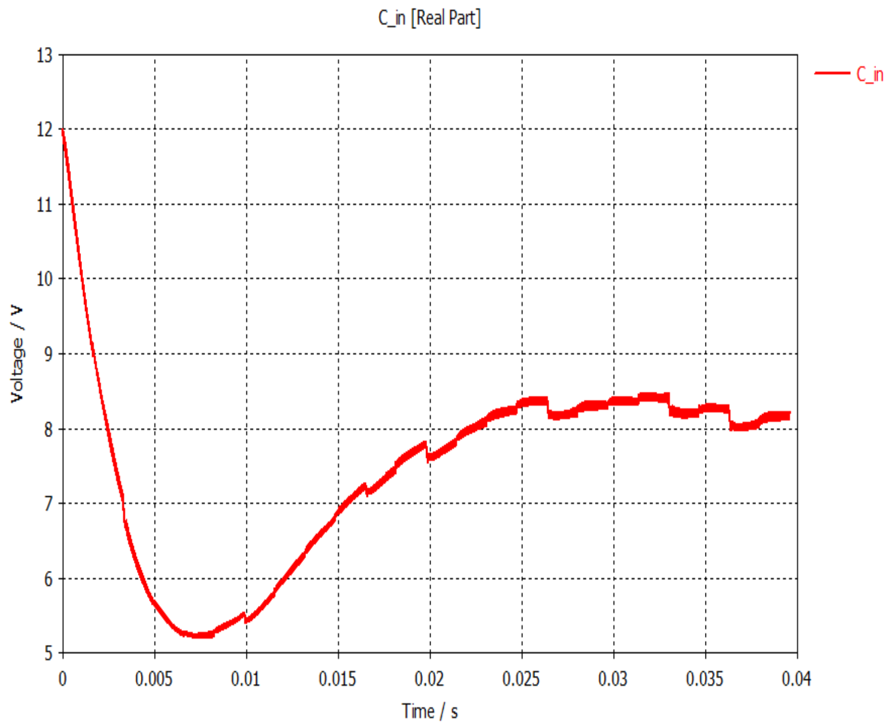

Filter
H-Bridge
LISN
Supply
Motor

Coupled Simulation Results

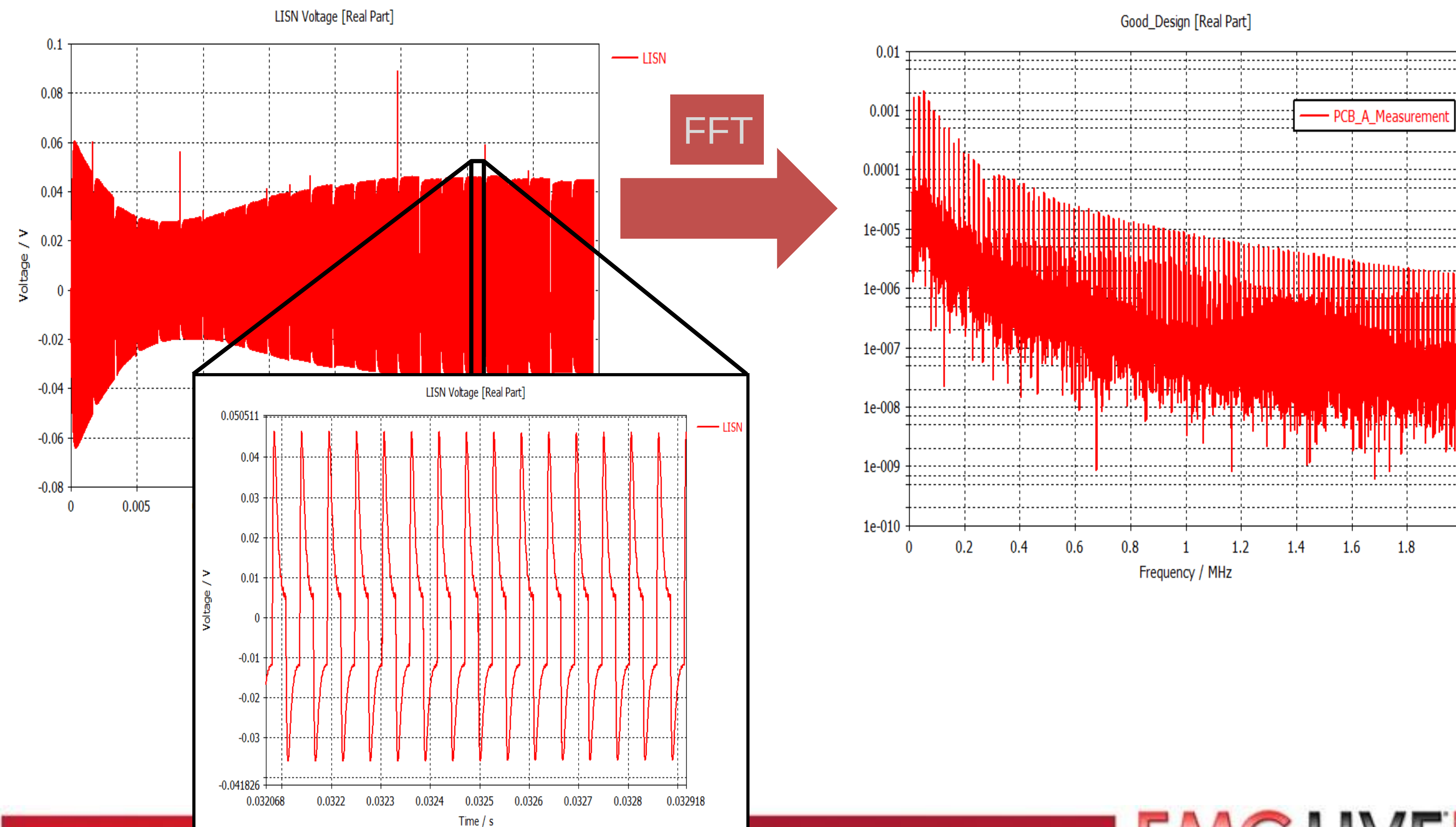
4 rotations

Input Voltage



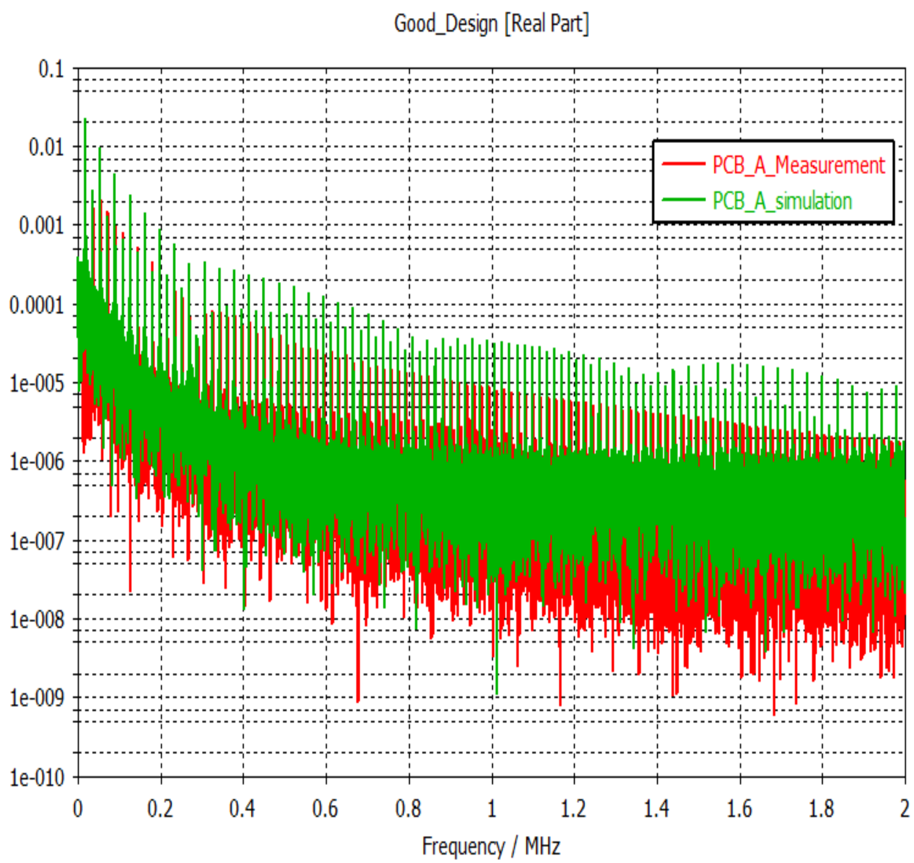


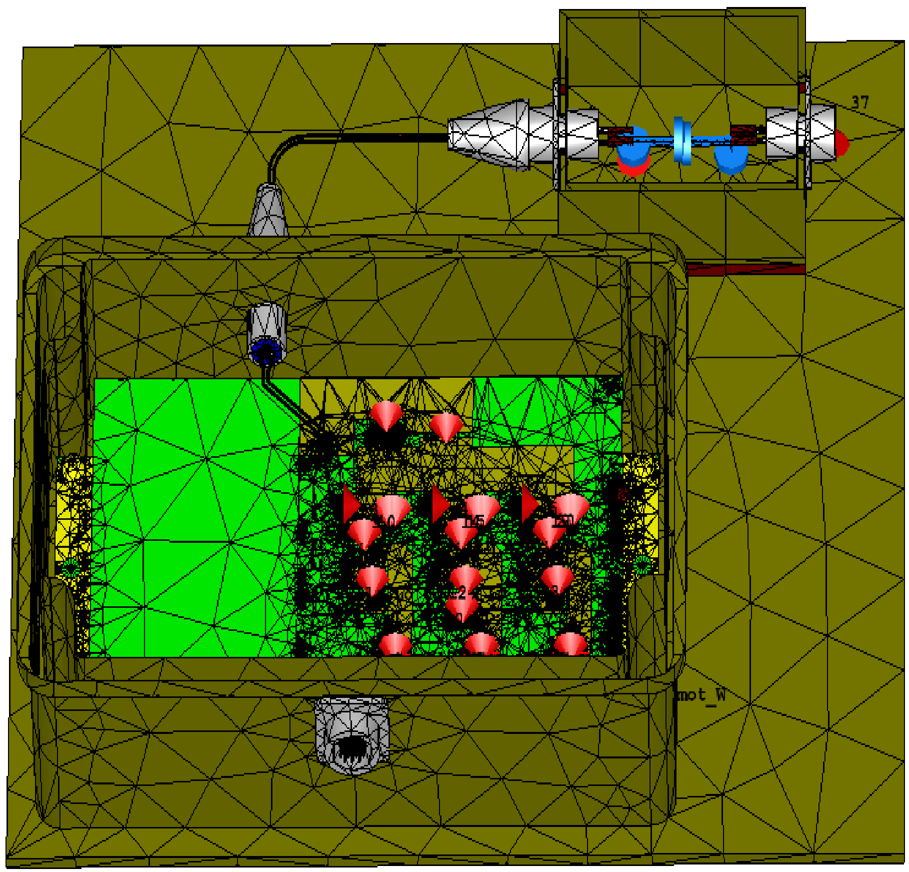
Coupled Simulation Results

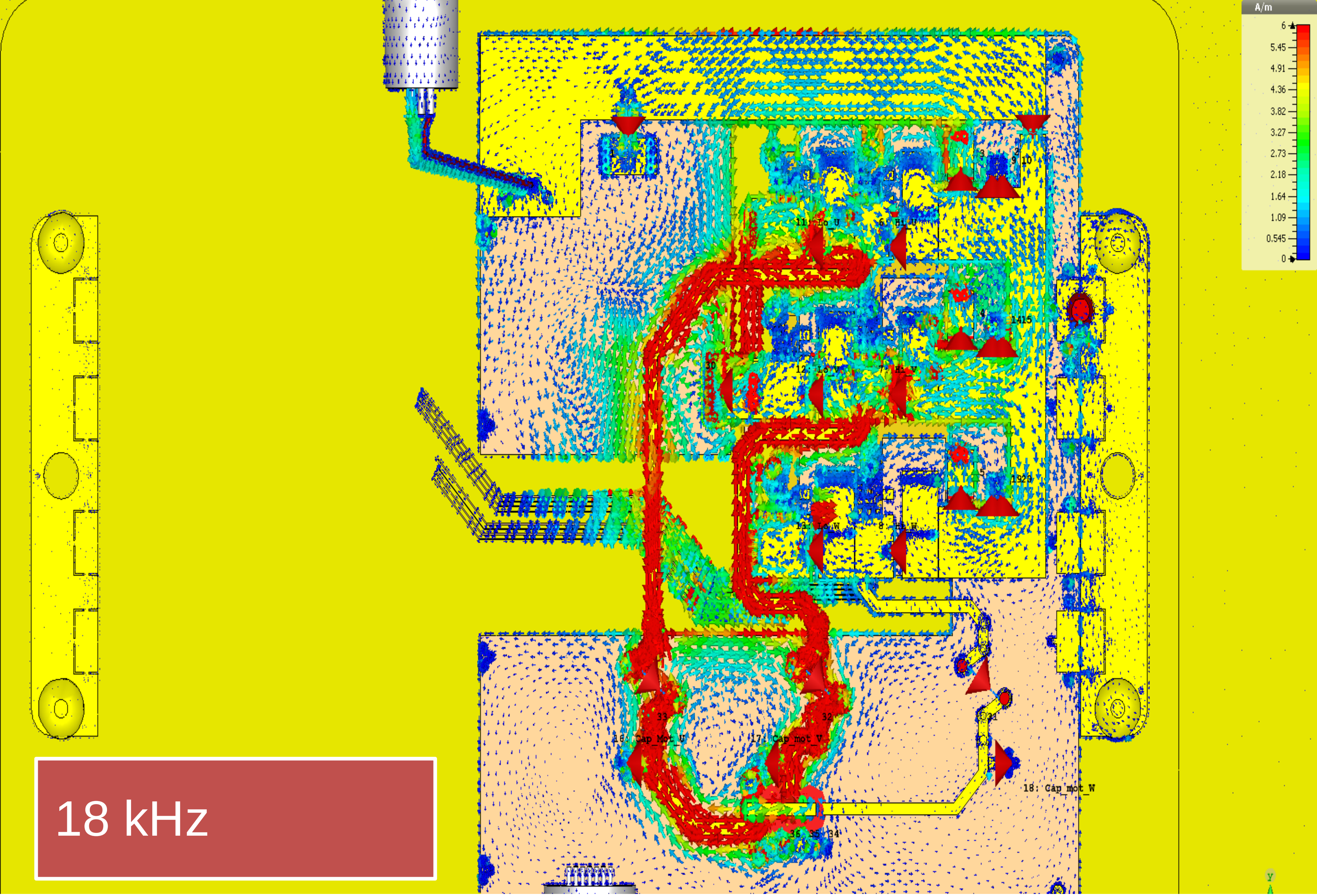


Motor Control

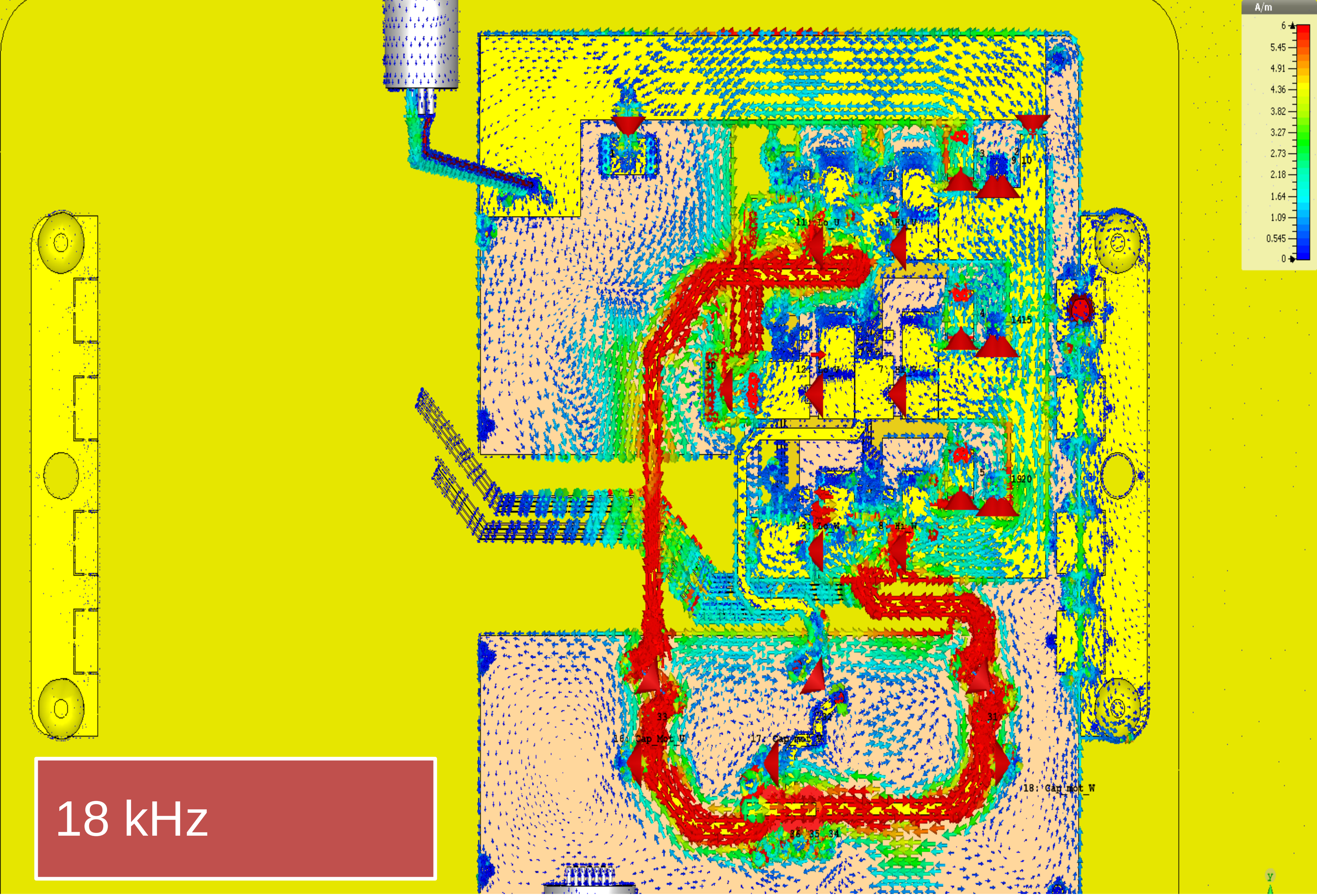
Simulation Model and Comparison to Measurements



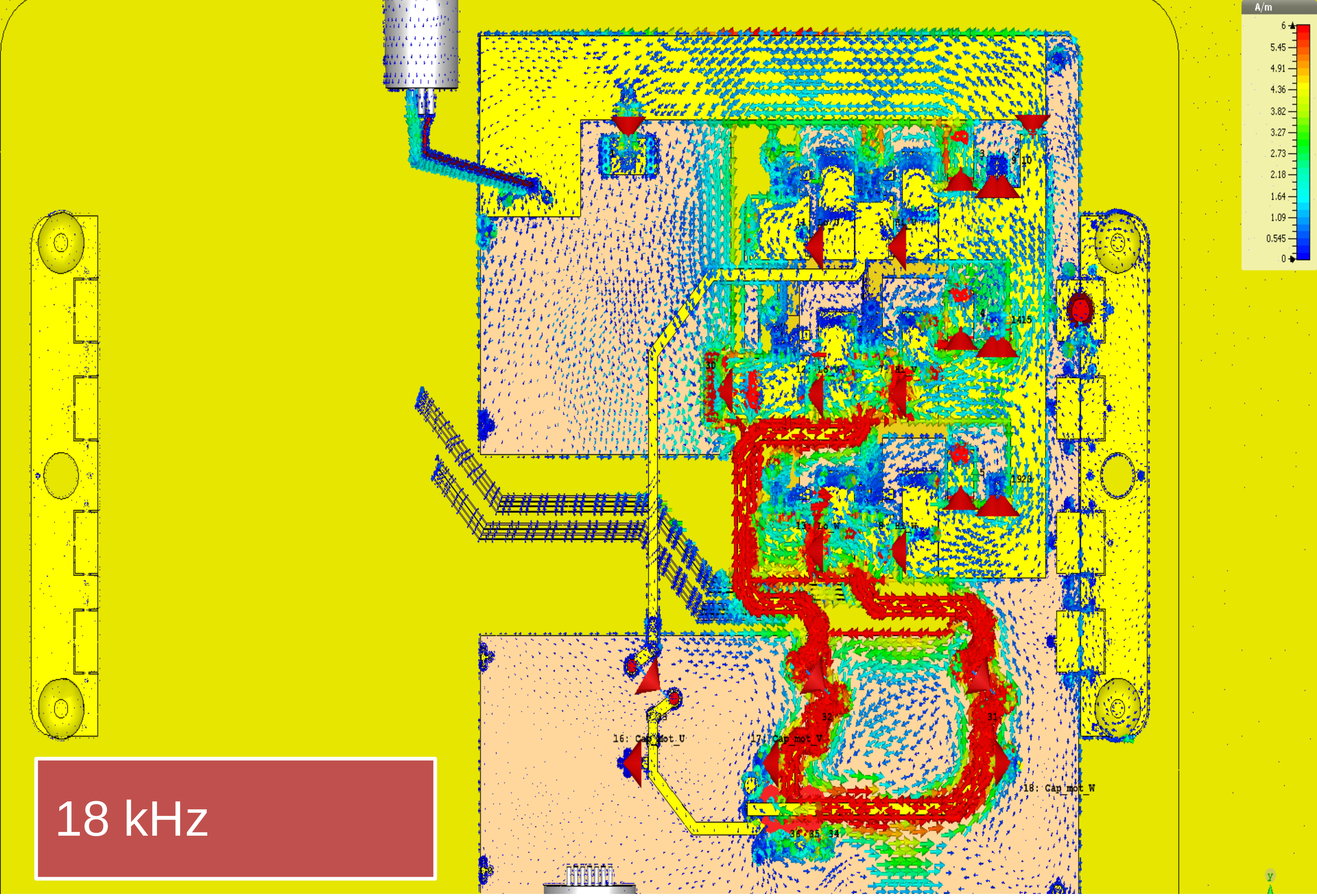



A/m
6
5.45
4.91
4.36
3.82
3.27
2.73
2.18
1.64
1.09
0.545
0
11: Lo_U
6: Hi_U
12: Lo_V
7: Hi_V
13: Lo_W
8: Hi_W
16: Cap_Mot_U
17: Cap_mot_V
18: Cap_mot_W

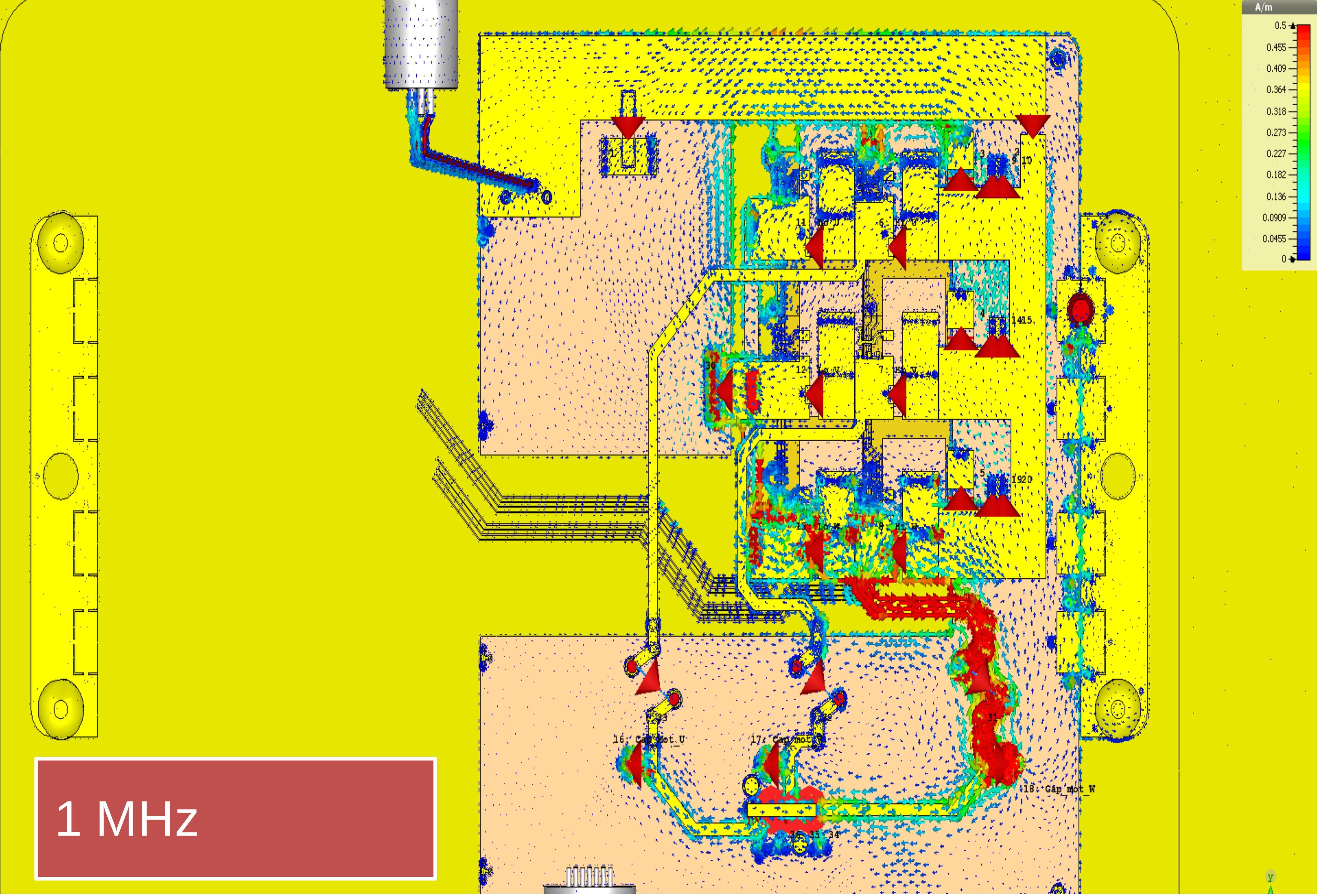
18 kHz



18 kHz


A/m
6
5.45
4.91
4.36
3.82
3.27
2.73
2.18
1.64
1.09
0.545
0
16: Cap_mot_U
17: Cap_mot_V
18: Cap_mot_W

18 kHz


A/m
0.5
0.455
0.409
0.364
0.318
0.273
0.227
0.182
0.136
0.0909
0.0455
0
16: Cap_mot_U
17: Cap_mot_V
18: Cap_mot_W

1 MHz

Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

- Effect of EMI filter

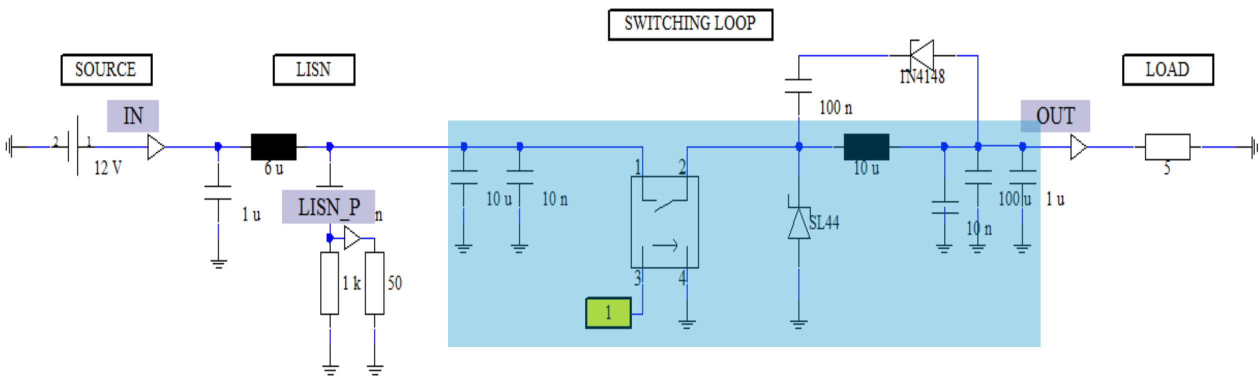
Radiated Emission of a DC-DC Buck Converter

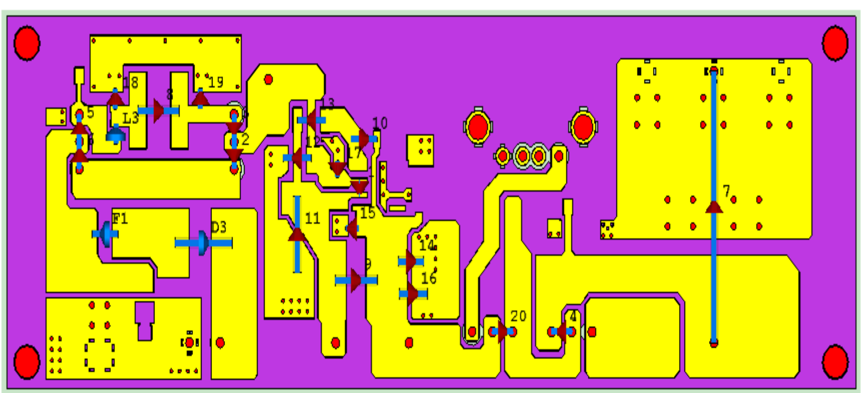
- RE as a near field coupling and the effect of shielding

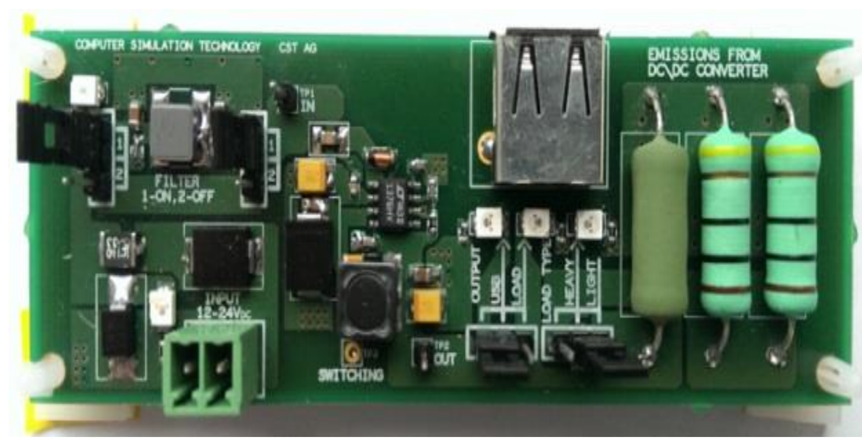
Summary and Q&A

Emission from Voltage Converter

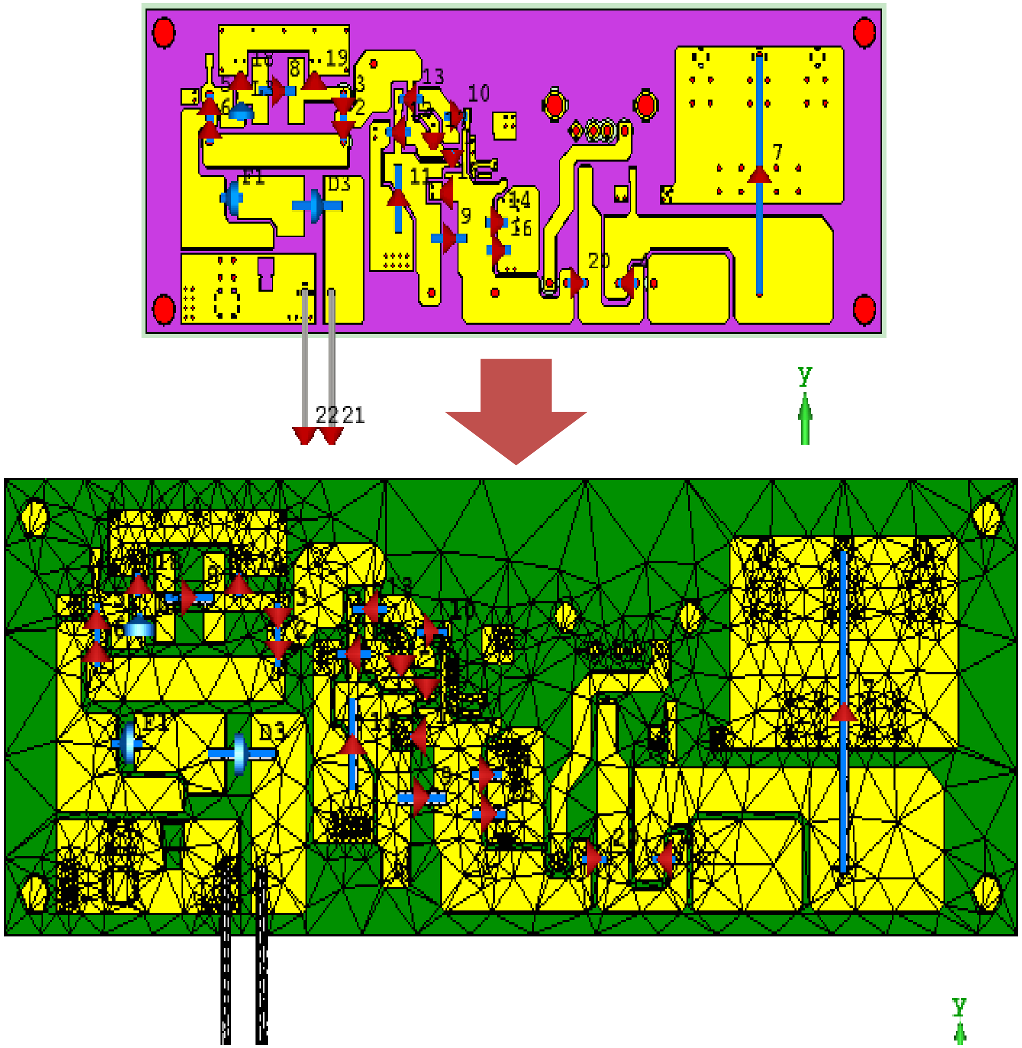
Step down buck converter designed at CST



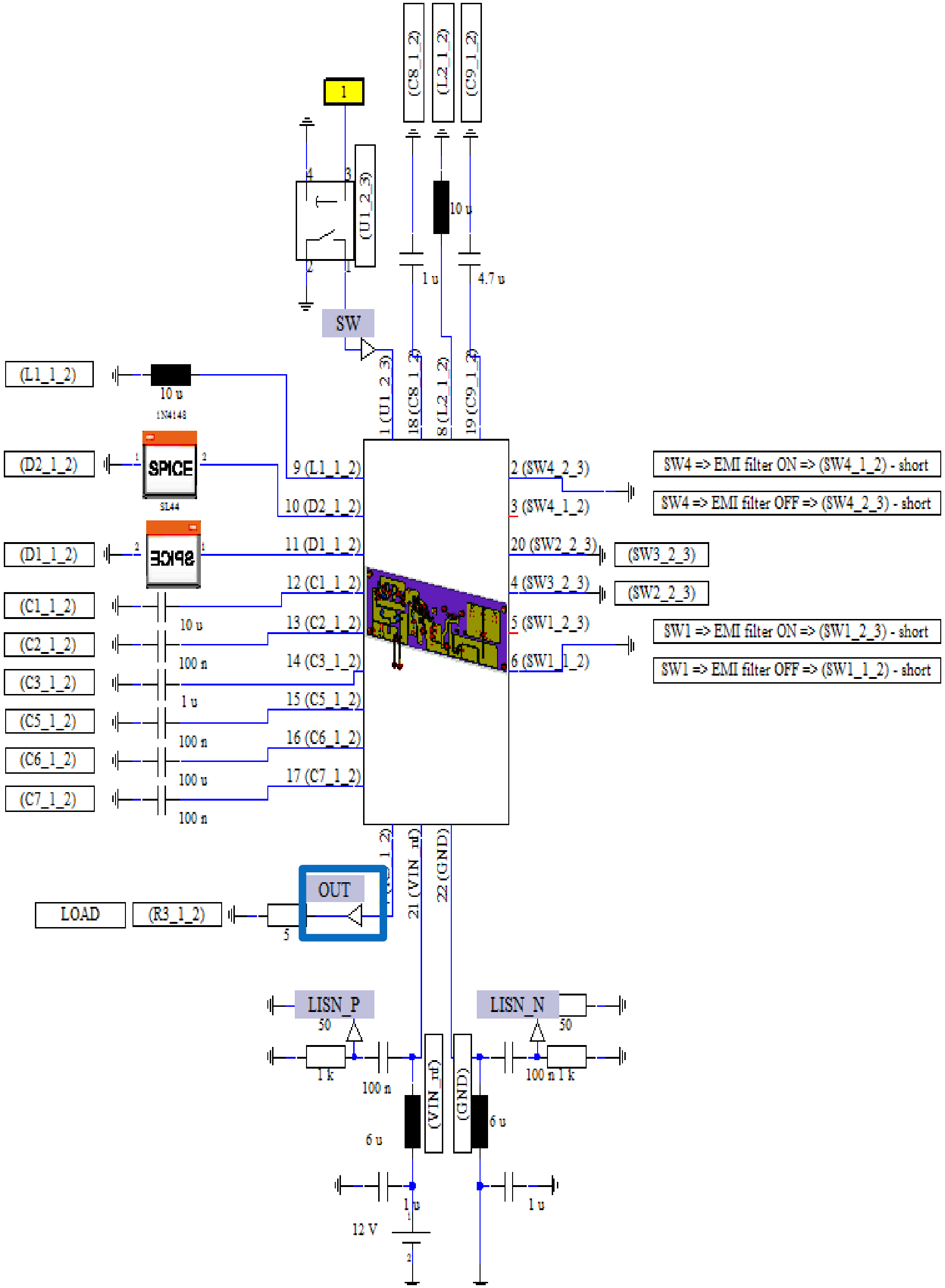




Model Discretization (Tetrahedral Mesh)



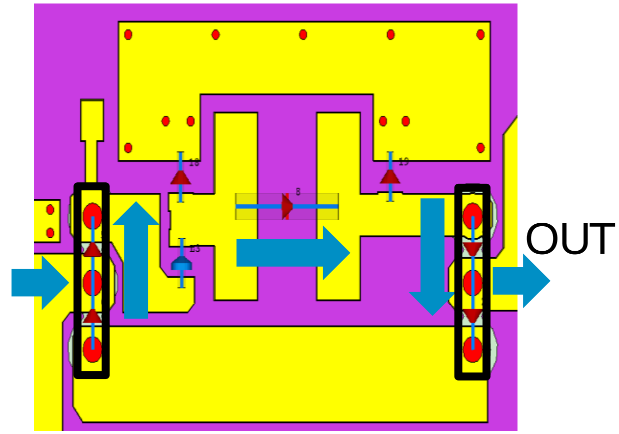
Schematic

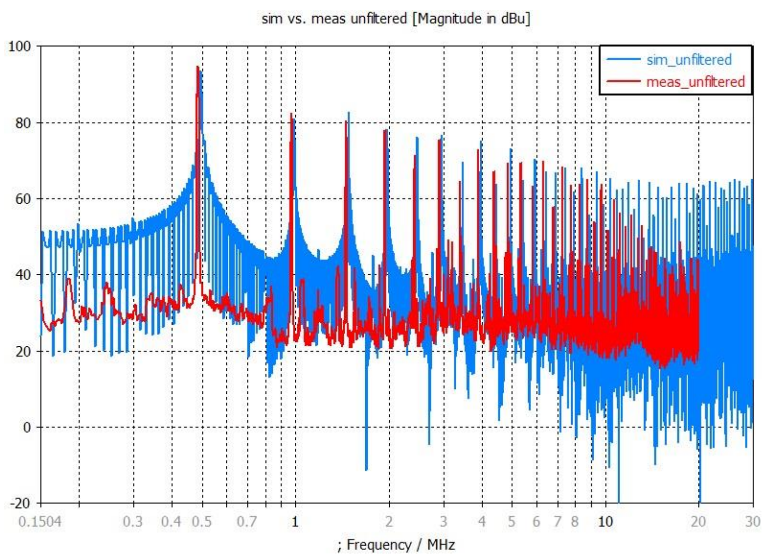


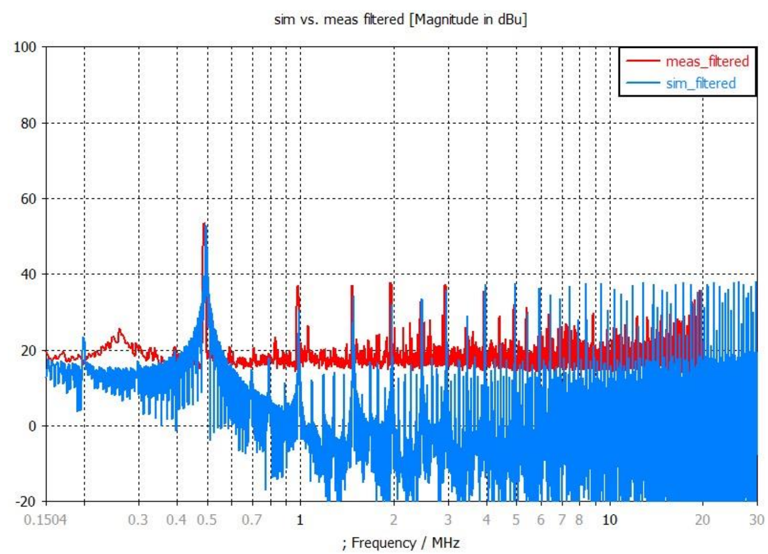
EMI filter enabled:
Pins: SW1_2_3, SW4_1_2 -> shorted
SW1_1_2, SW4_2_3 -> left open

EMI filter disabled:
Pins: SW1_2_3, SW4_1_2 -> left open
SW1_1_2, SW4_2_3 -> shorted

Emission from Voltage Converter

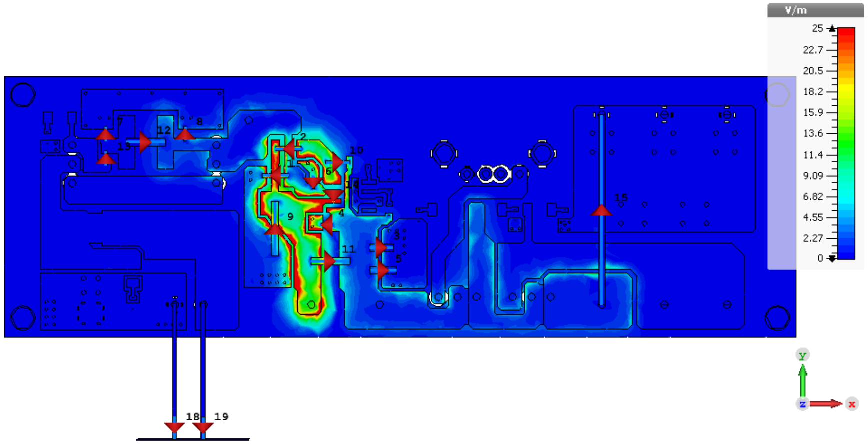




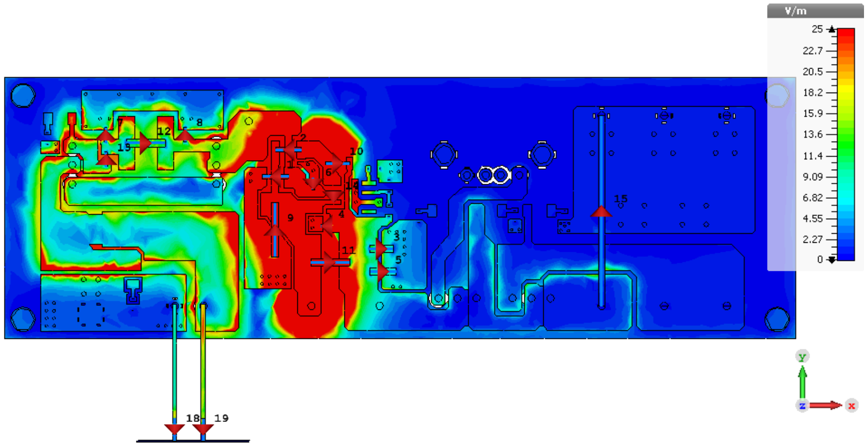


Emission from Voltage Converter

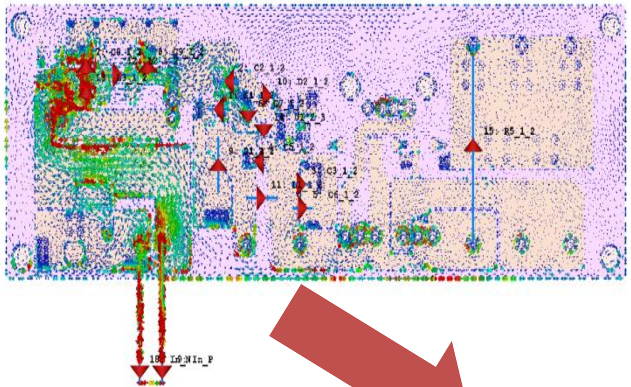
Electric field at 488 kHz

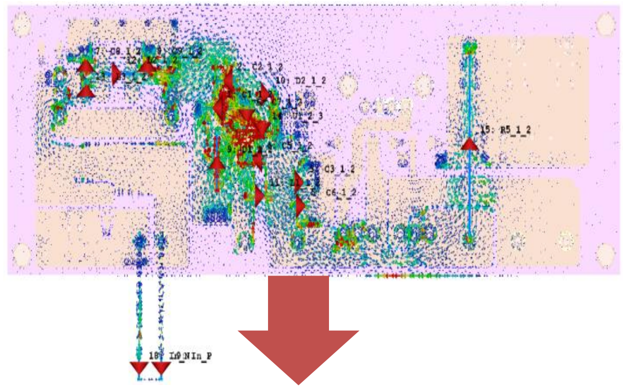


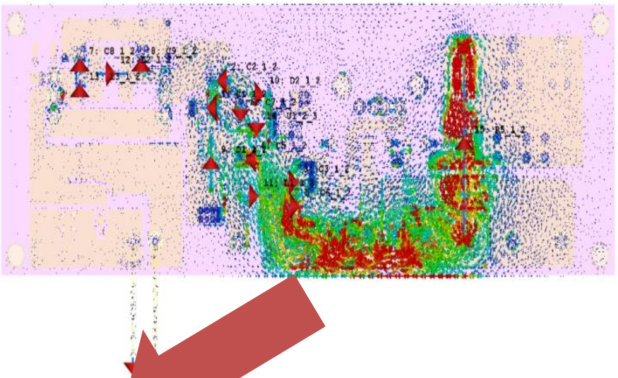
Filter on



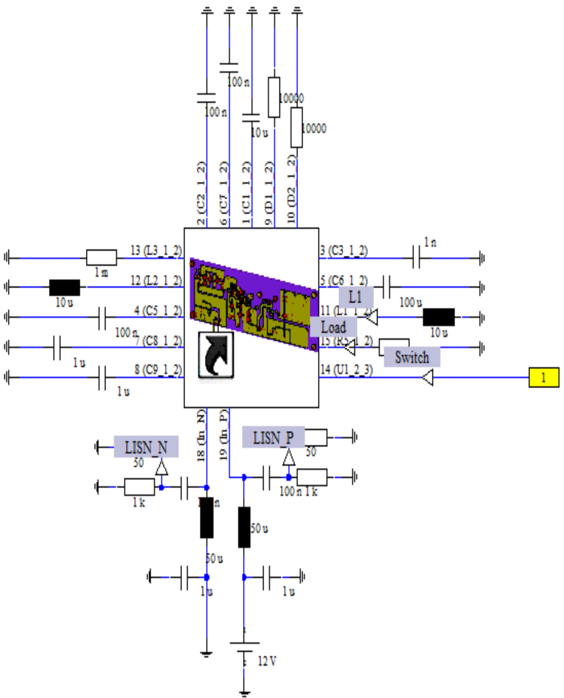
Filter off

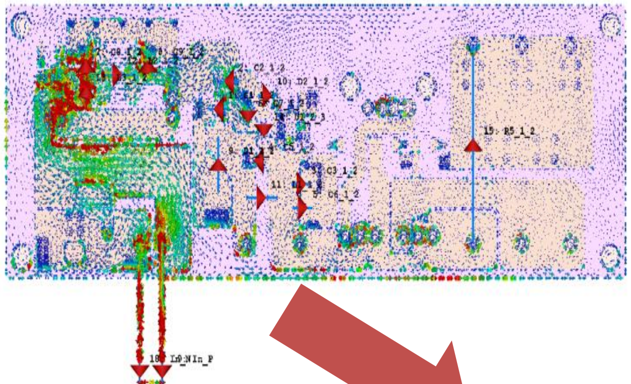


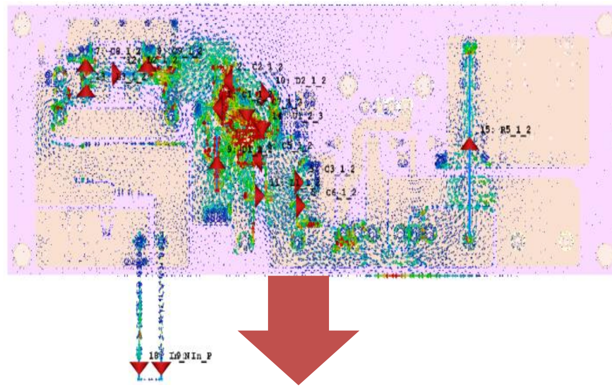


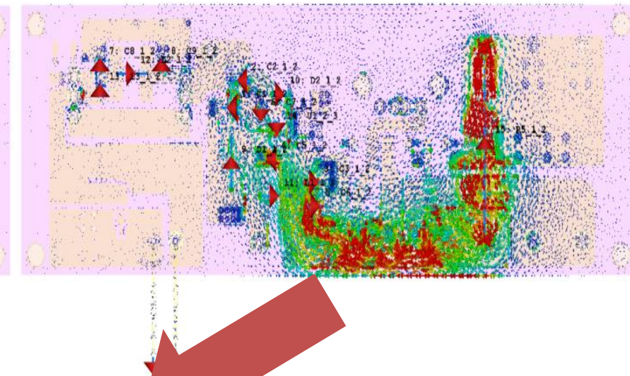


Combine Results

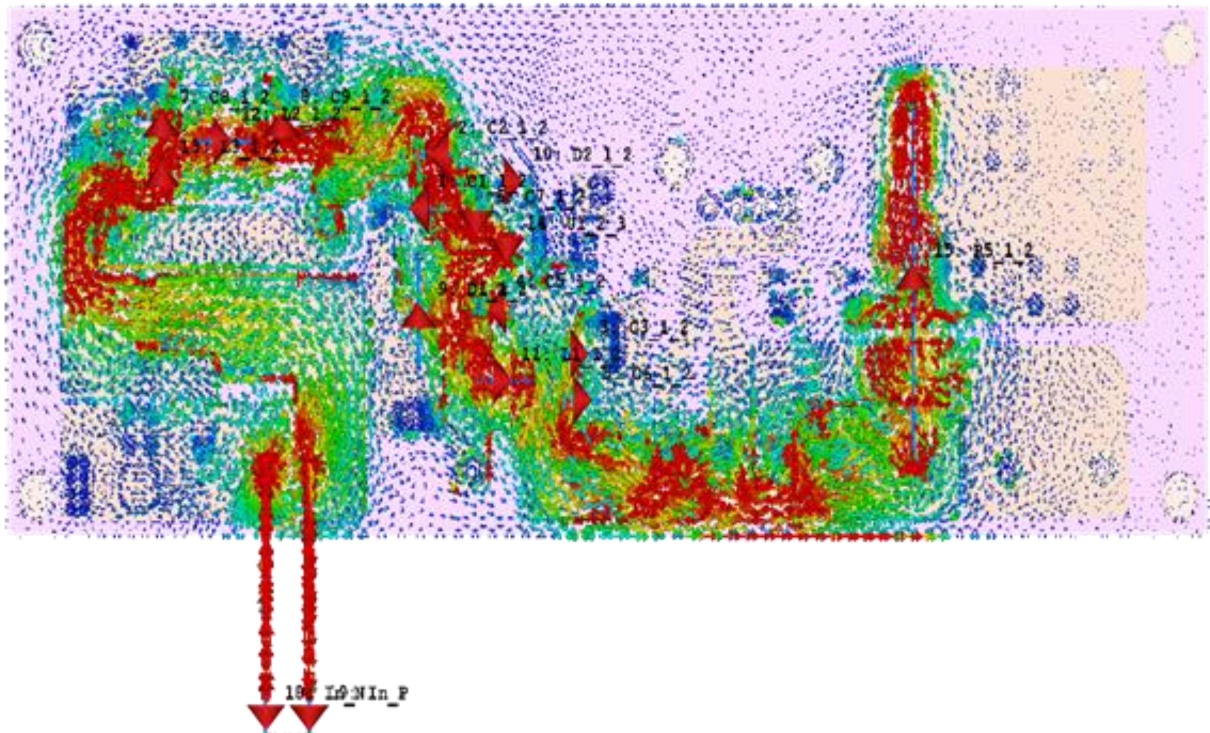








Combine Results



Agenda

Introduction and Motivation

Coupled 3D Field and Circuit Simulation

Conducted Emission of a Motor Control

- Variable frequency drive, the effect of PCB layout

Conducted Emission of a DC-DC Buck Converter

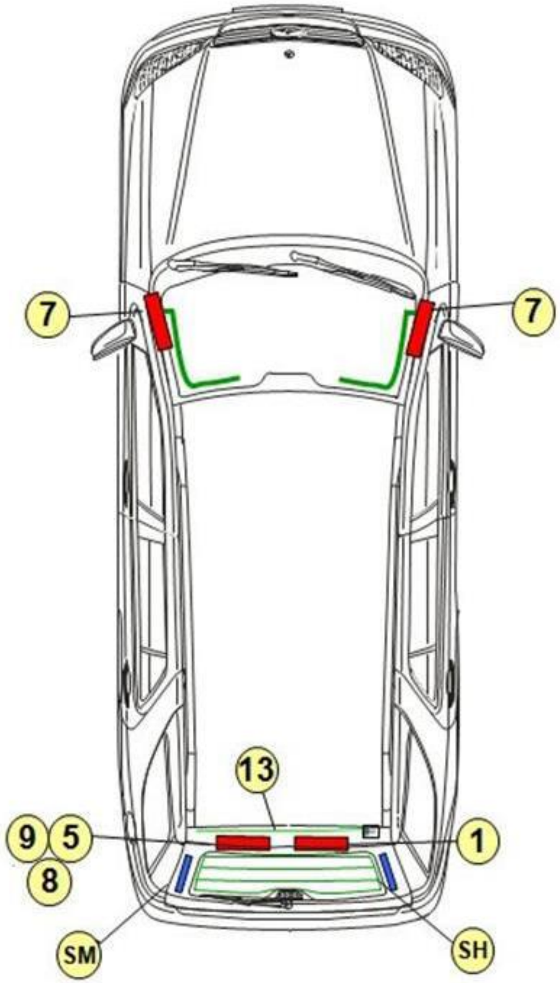
- Effect of EMI filter

Radiated Emission of a DC-DC Buck Converter

- RE as a near field coupling and the effect of shielding

Summary and Q&A

EM Field Coupling from Buck Converter to AM/FM Antennas



(1) AM, FM1

(5) FM2

(7) TV

(8) FM2, TV

(9) FM2, DAB III

(13) AM

In modern automobiles there are as many as 20-30 antennas and the number will continue to increase in coming years.

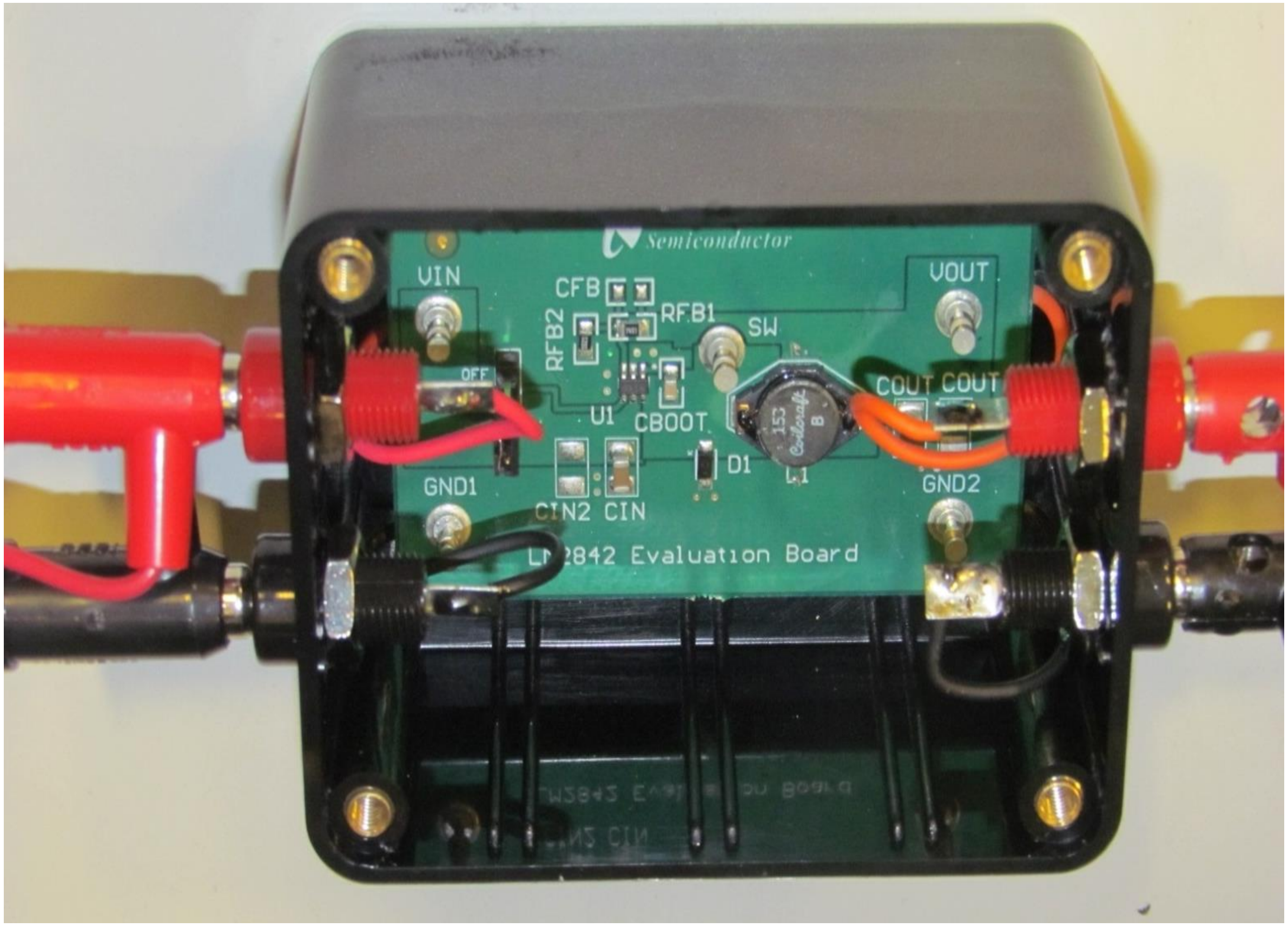
AM Radio Reception Inside of a Car

Buck Converter OFF

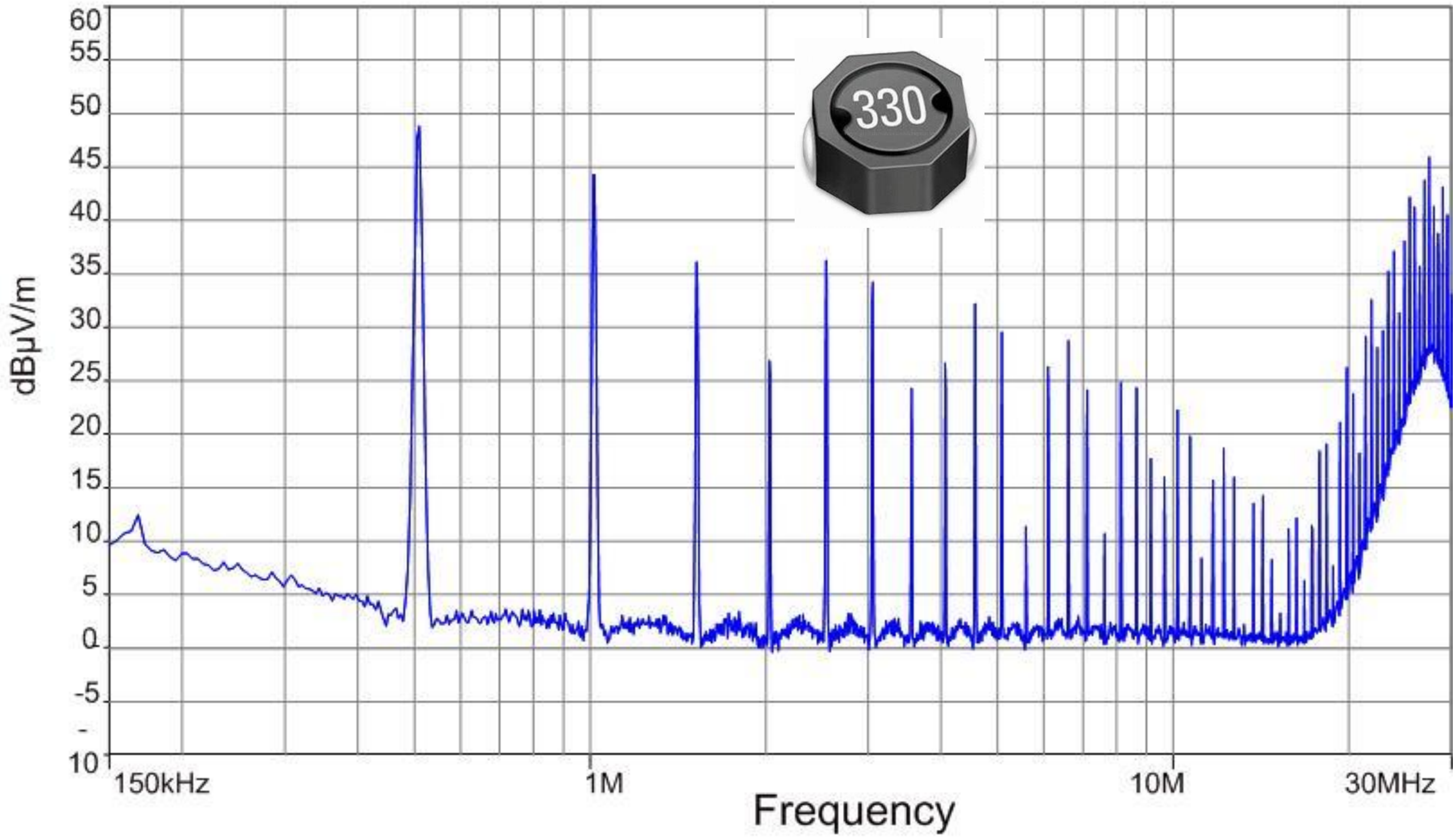
Buck Converter ON

Courtesy of Cyrous Rostamzadeh – Bosch, Plymouth, MI

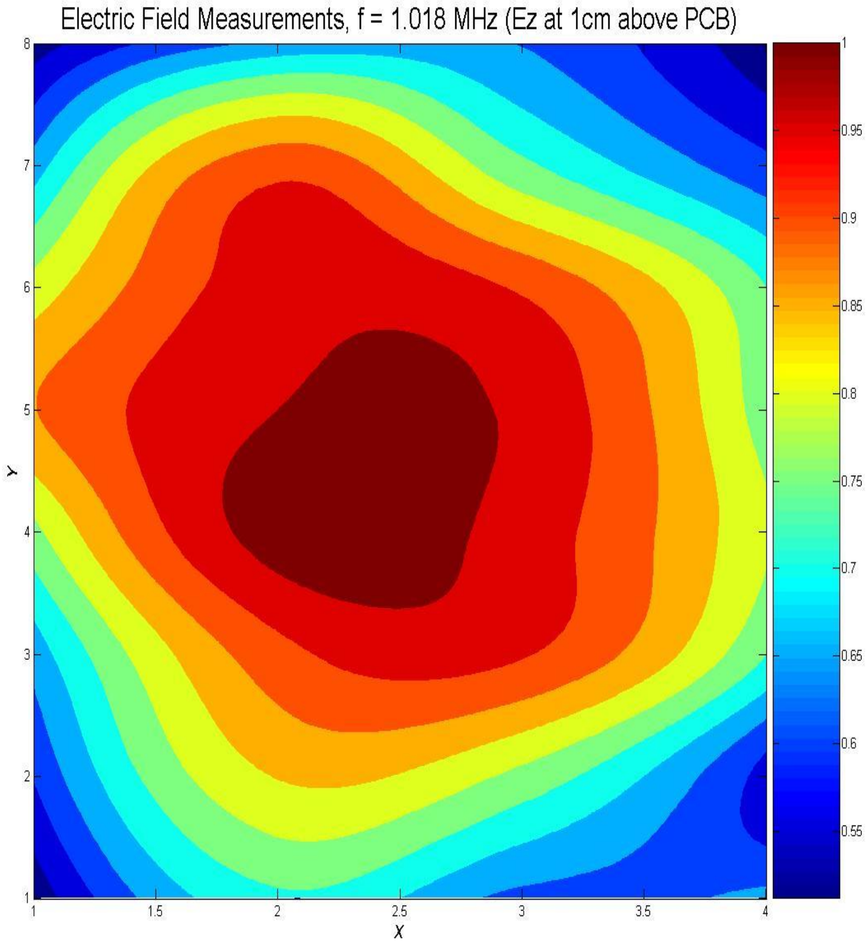
DUT: DC-DC Buck Converter, Eval Board



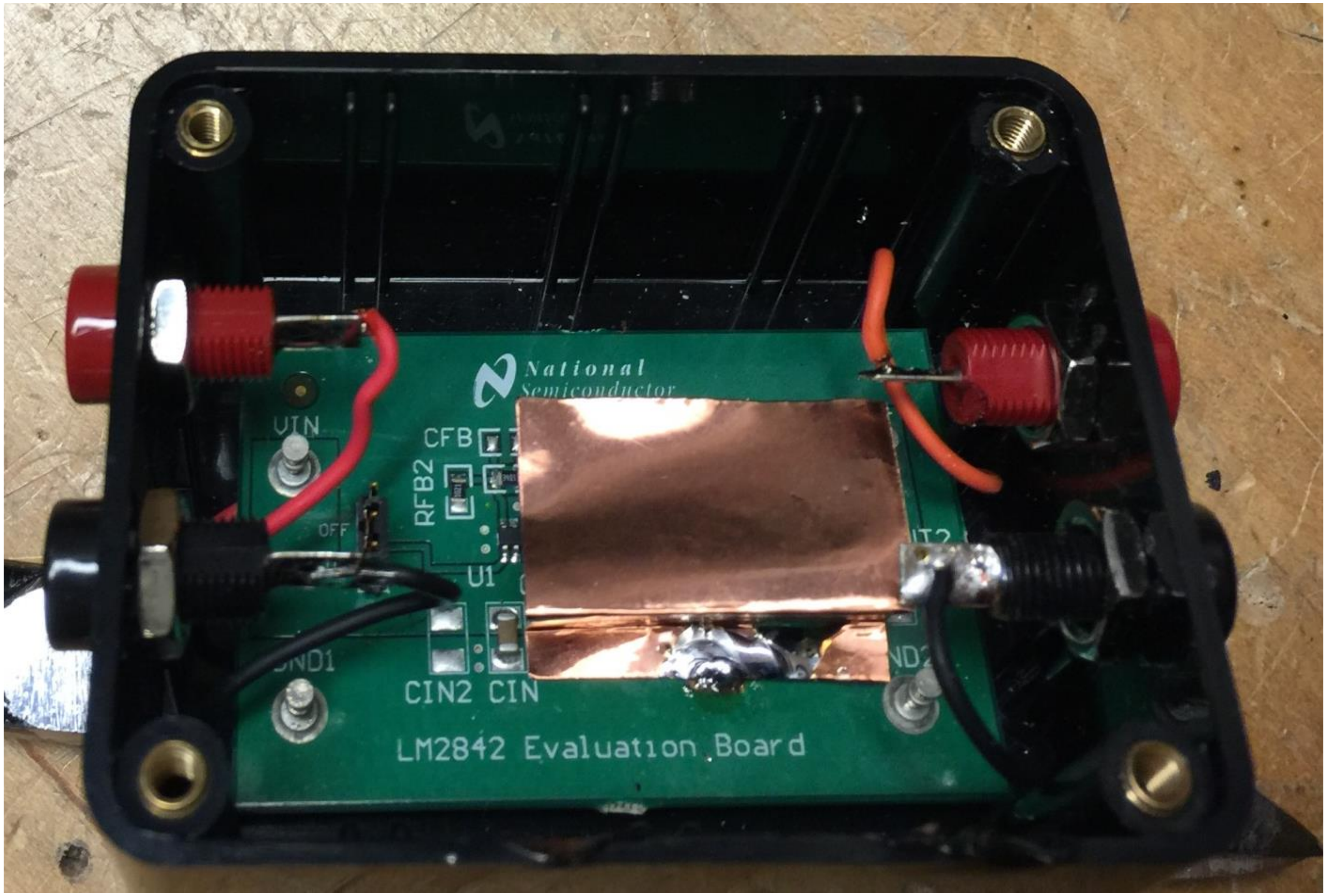
150 kHz - 30 MHz, Unshielded Inductor L1, (Resolution Bandwidth 9 kHz, Average Detector)



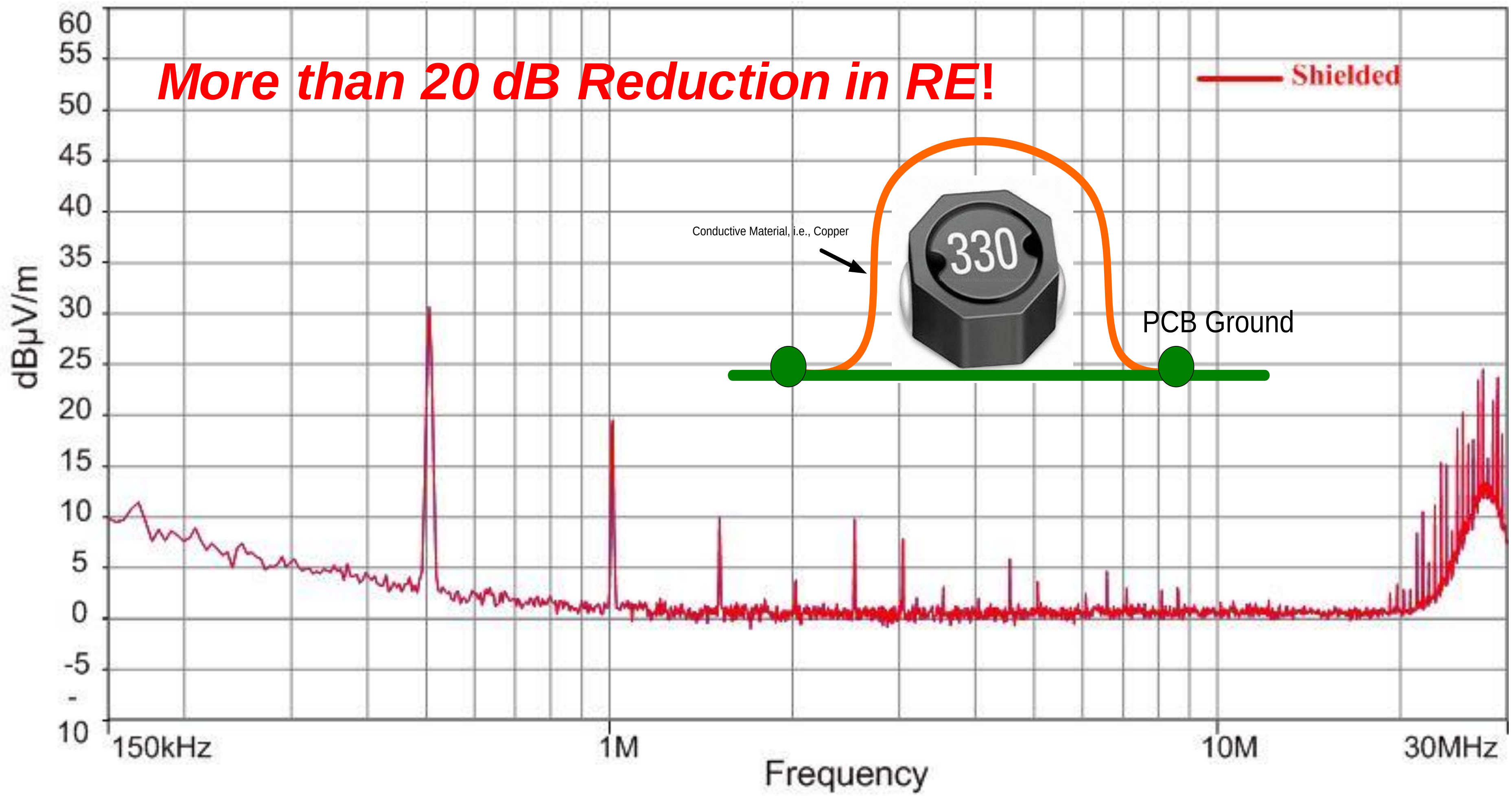
Nearfield Probe Measurement at 1 MHz



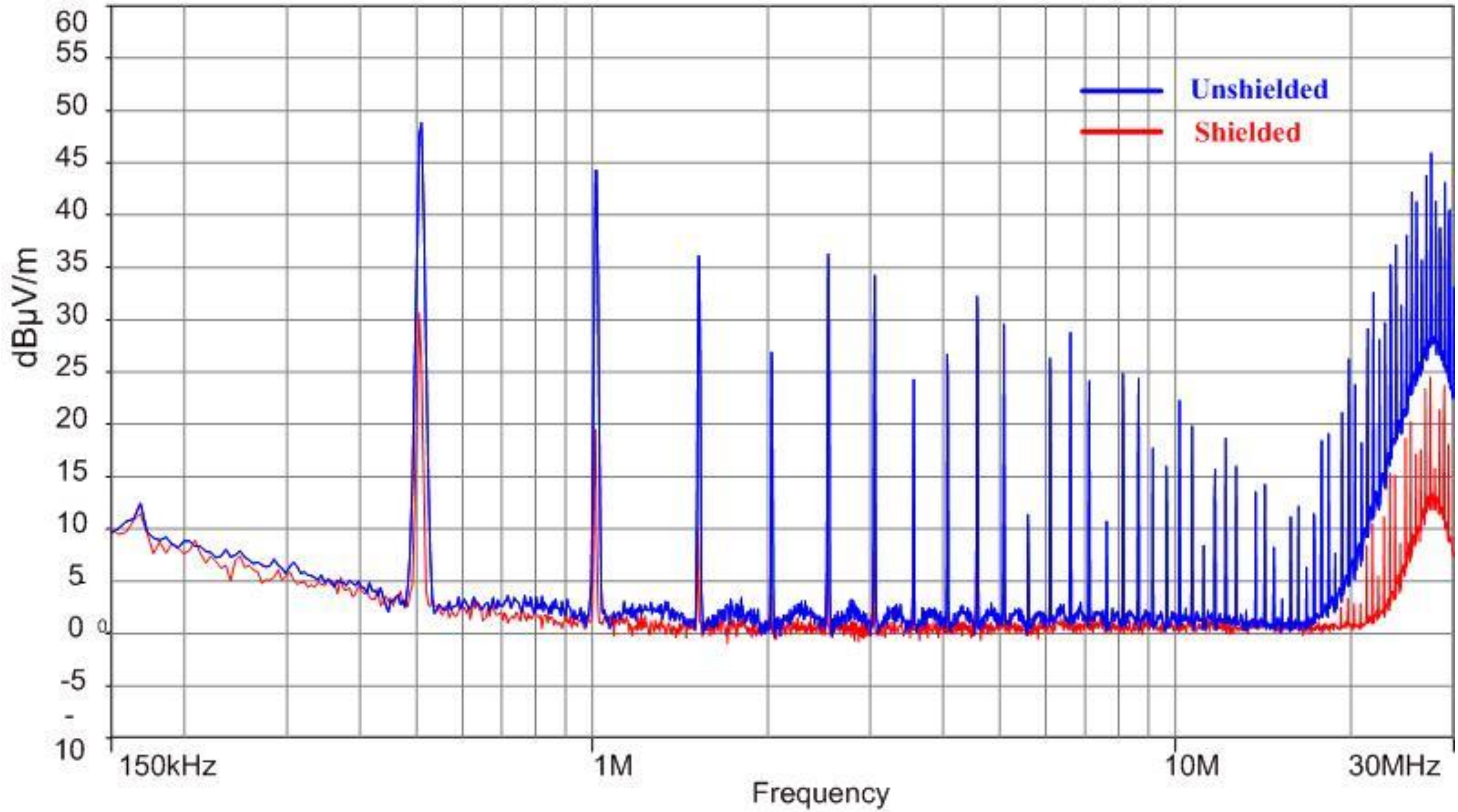
Copper Shield over L1 and SW Node

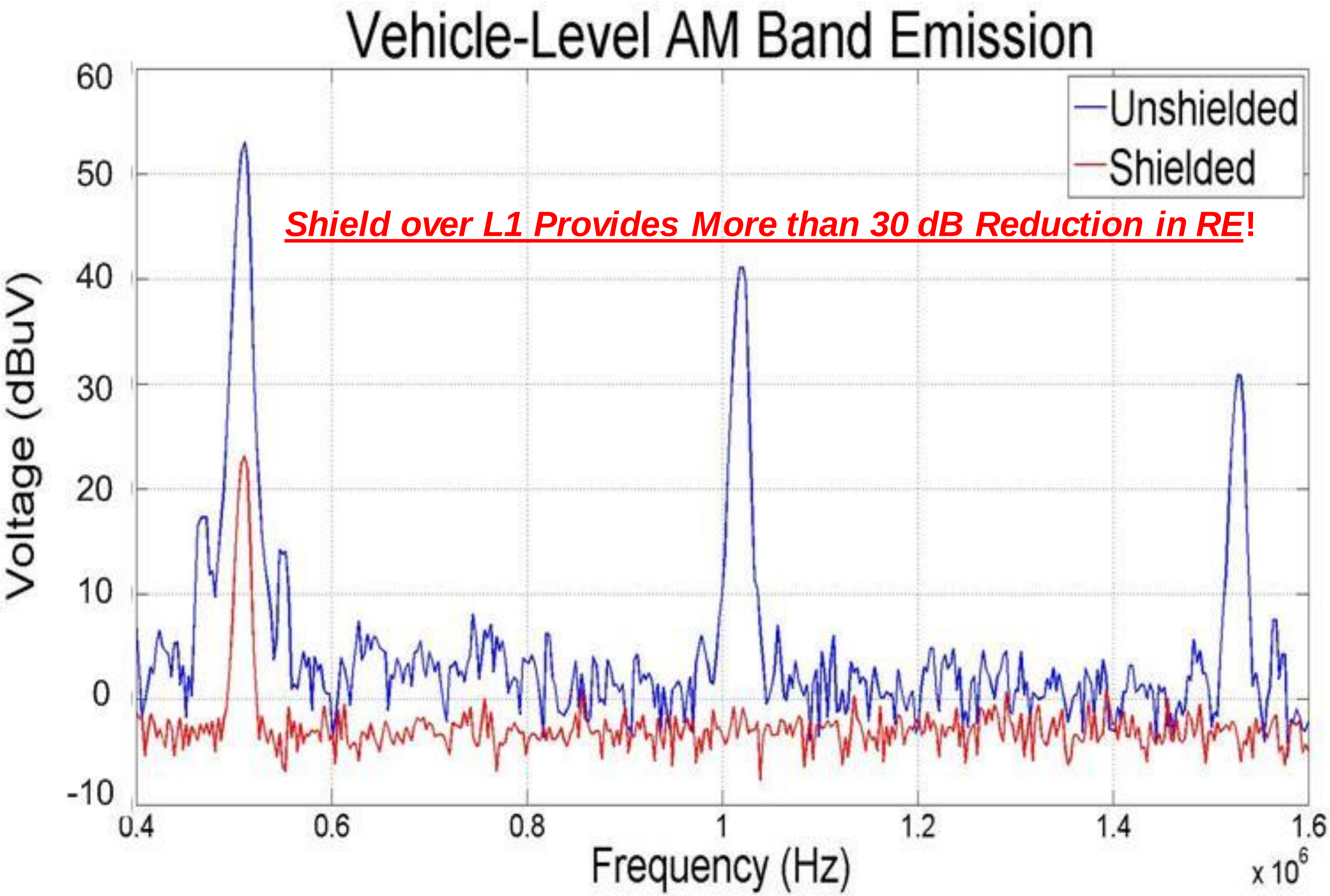


150 kHz - 30 MHz, Shielded Inductor L1, (Resolution Bandwidth 9 kHz, Average Detector)



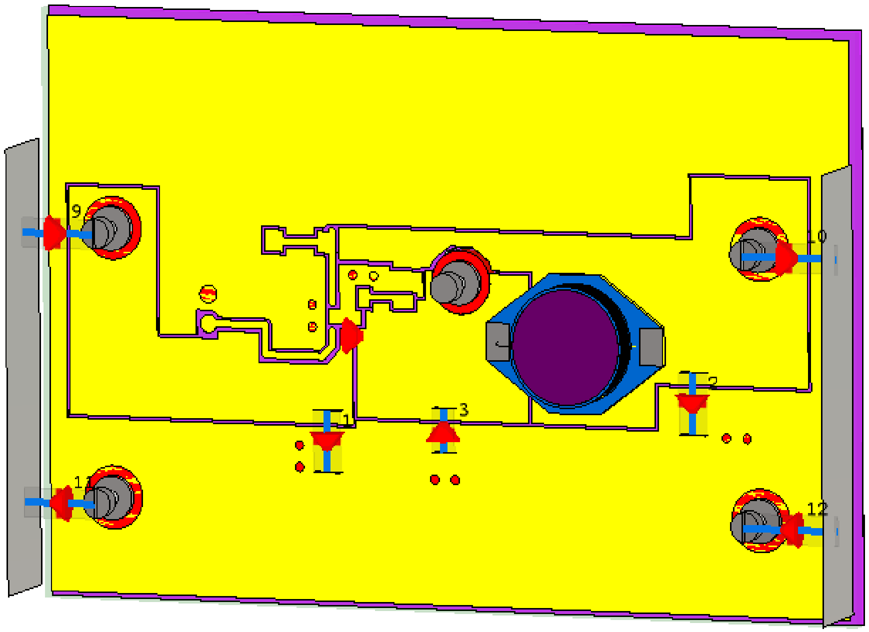
150 kHz - 30 MHz, Unshielded Inductor L1 vs. Shielded Inductor L1 Comparison (Resolution Bandwidth 9 kHz, Average Detector)





Vehicle-Level AM Band Emission
Unshielded
Shielded
Shield over L1 Provides More than 30 dB Reduction in RE!
Voltage (dBuV)
60
50
40
30
20
10
0
-10
0.4
0.6
0.8
1
1.2
1.4
1.6
Frequency (Hz)
x 10^6

Modeling for Further Investigation



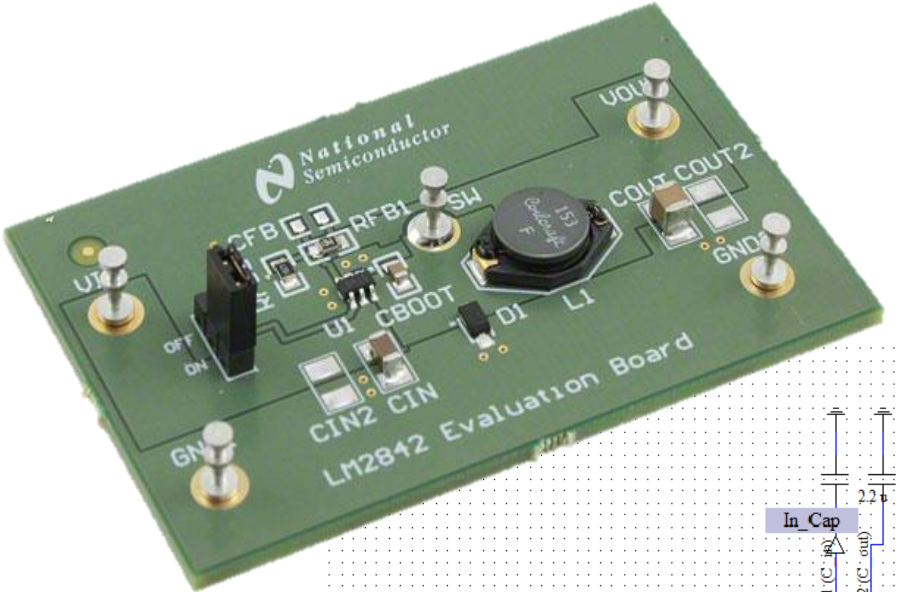
Instrumental to answer "what-if" scenarios?

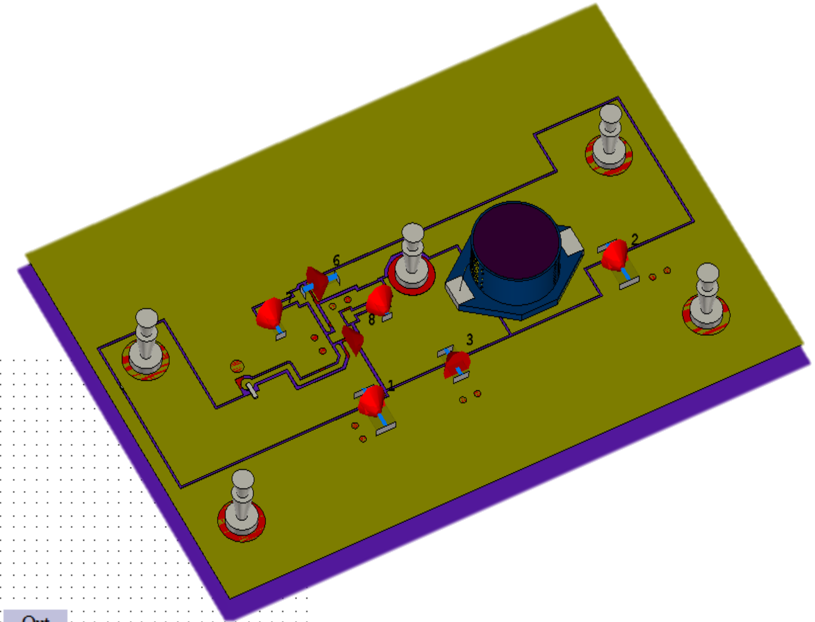
Exploit optimum SW Node "high dv/dt" trace area (parameterize geometry).

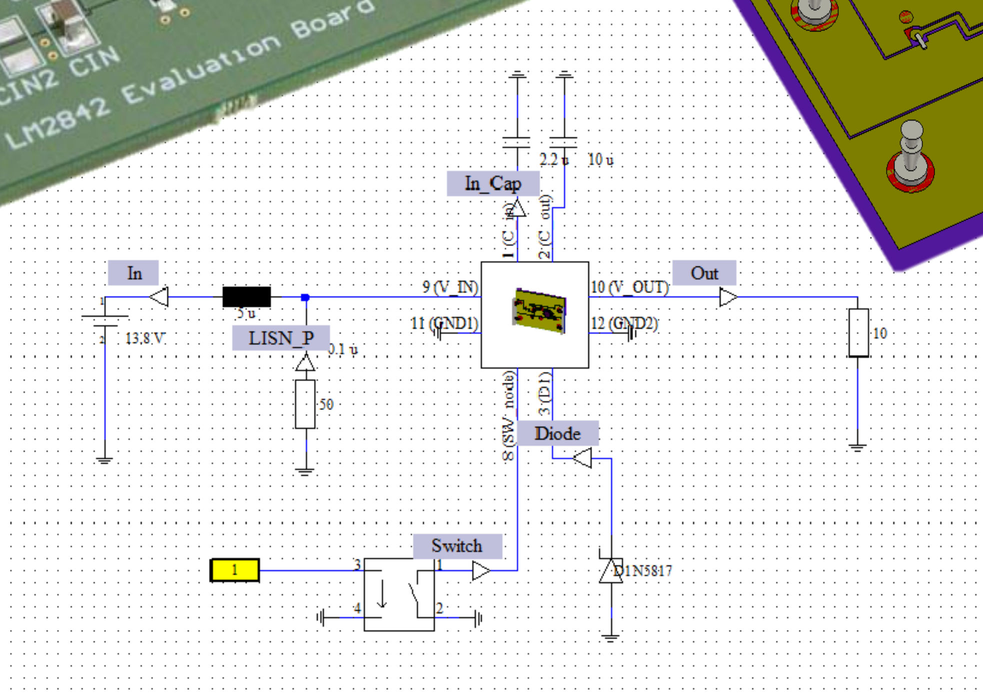
Extract parasitic inductances from PCB geometry.

Explore Shielding requirements "Shielding Effectiveness" for Compliance.

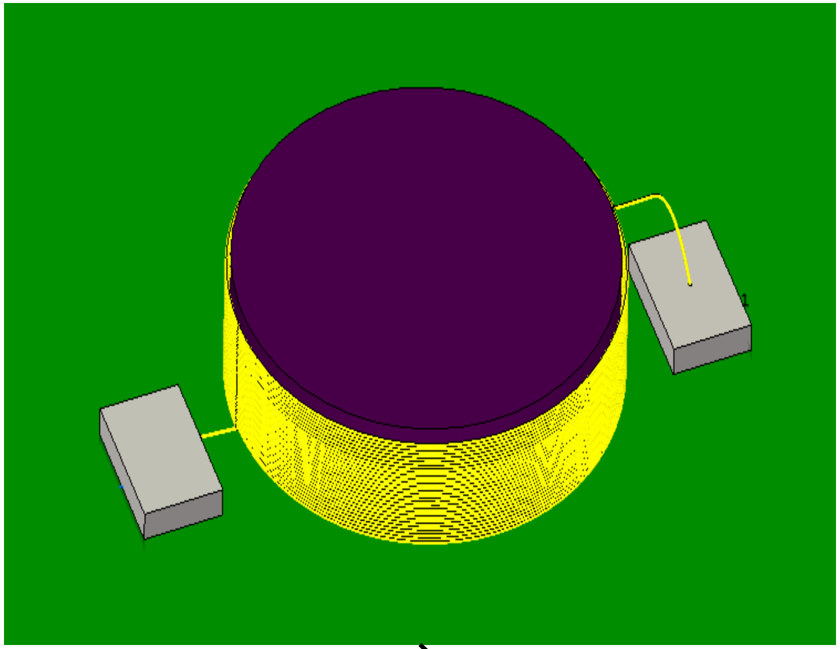
PCB Prototype vs. Model



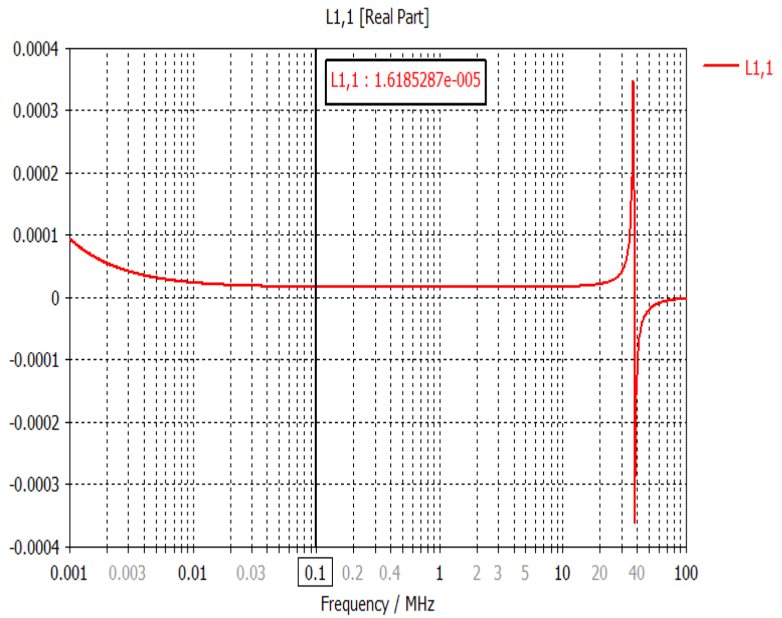




Inductor Coil Design

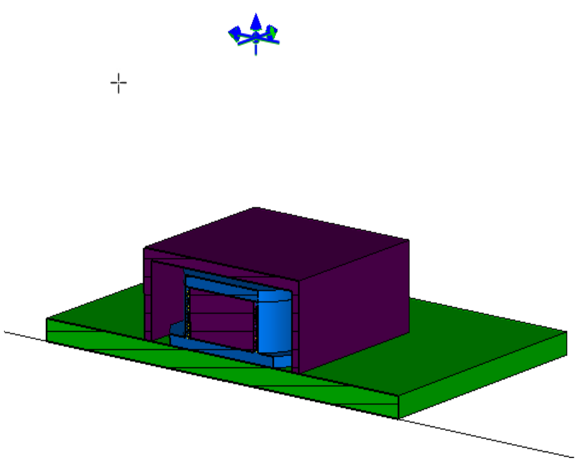


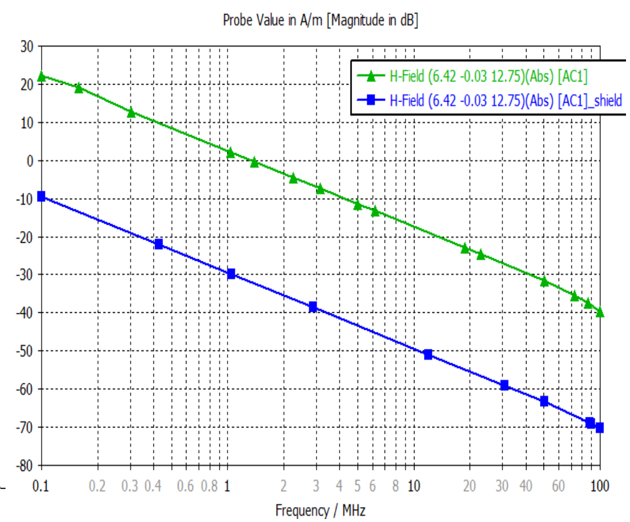
The coil was designed so that it matches the specifications. Inductance is 15 uH.

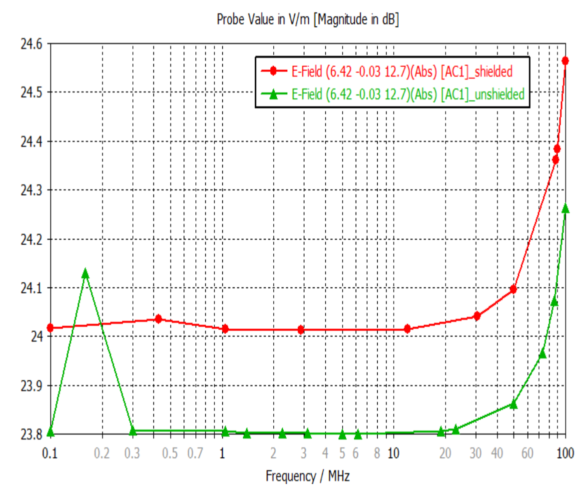


Inductor Model, Magnetic Shield

We have placed a Mue=1000 material box around the inductor. This does clearly reduce the H field above the inductor (30dB), little effect on E Field (0.2dB).

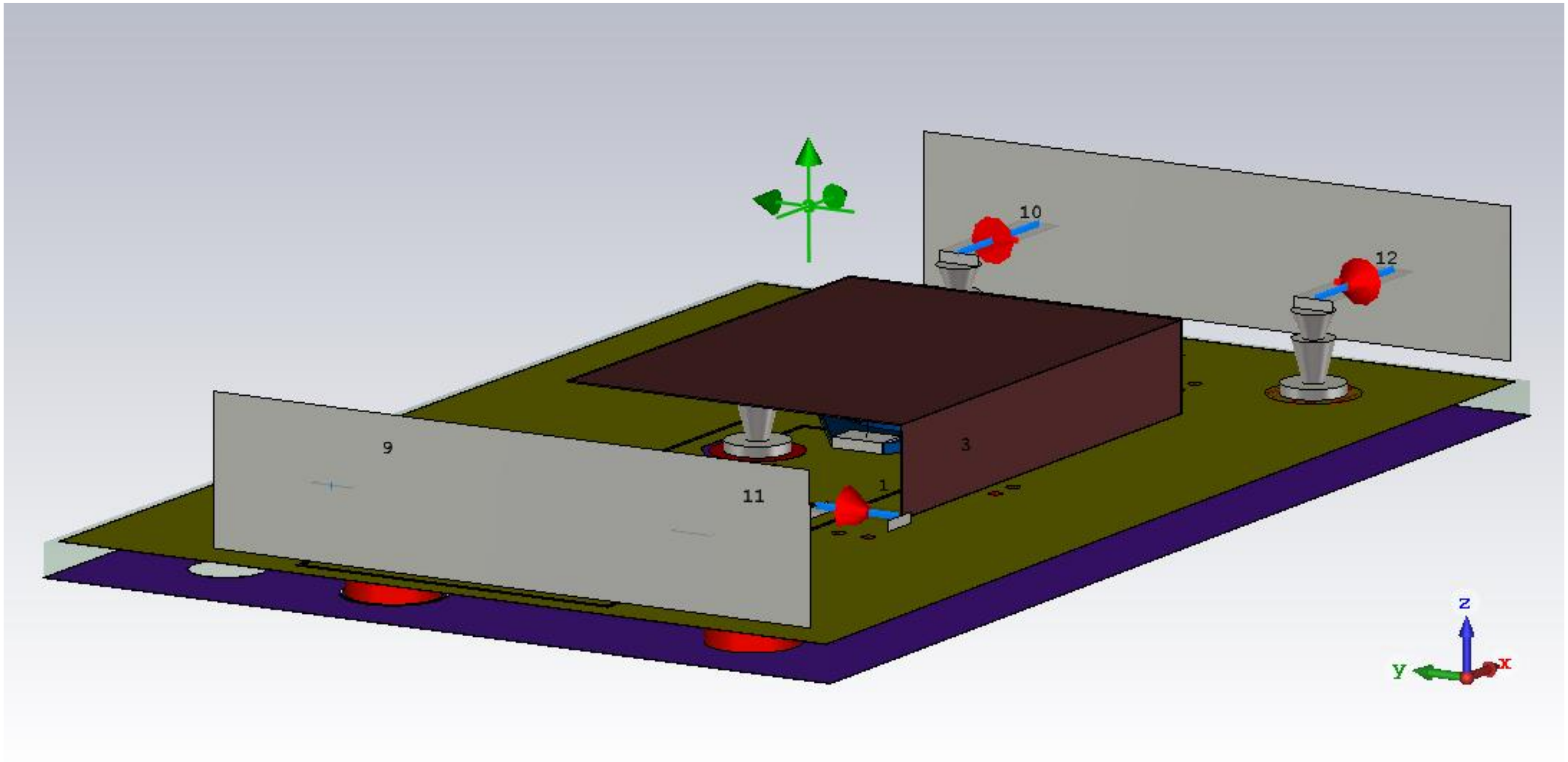






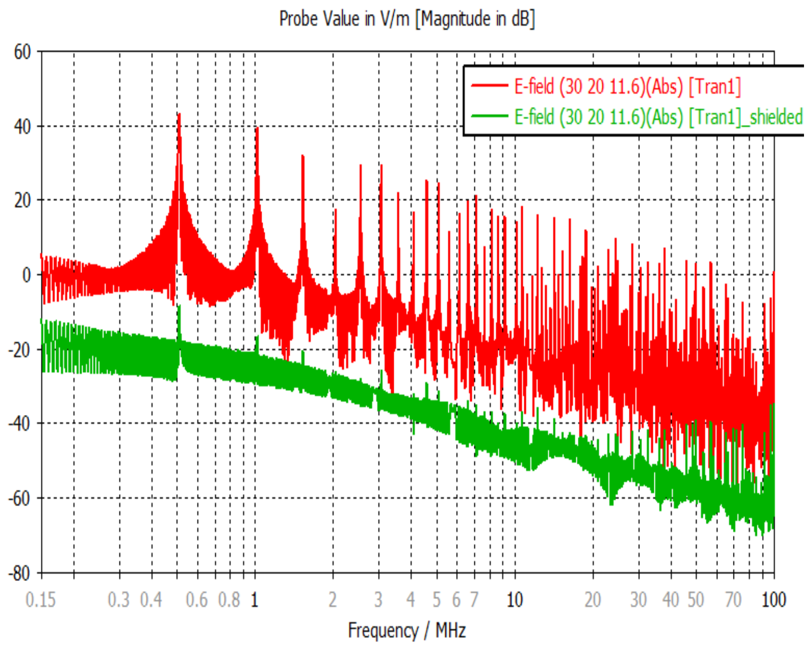
Inductor Shielded with Metal Sheet

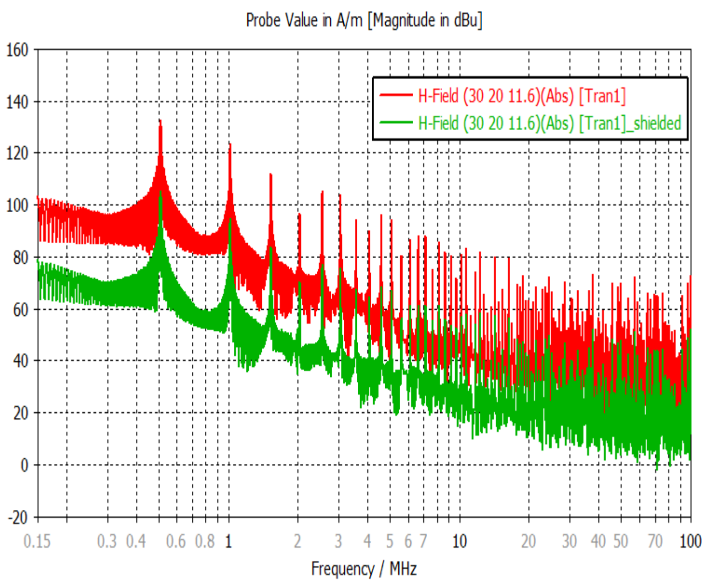
Adding a long shield above the inductor and the switch node does reduce the E and H field 1 cm above the PCB



Inductor Shielded with Metal Sheet

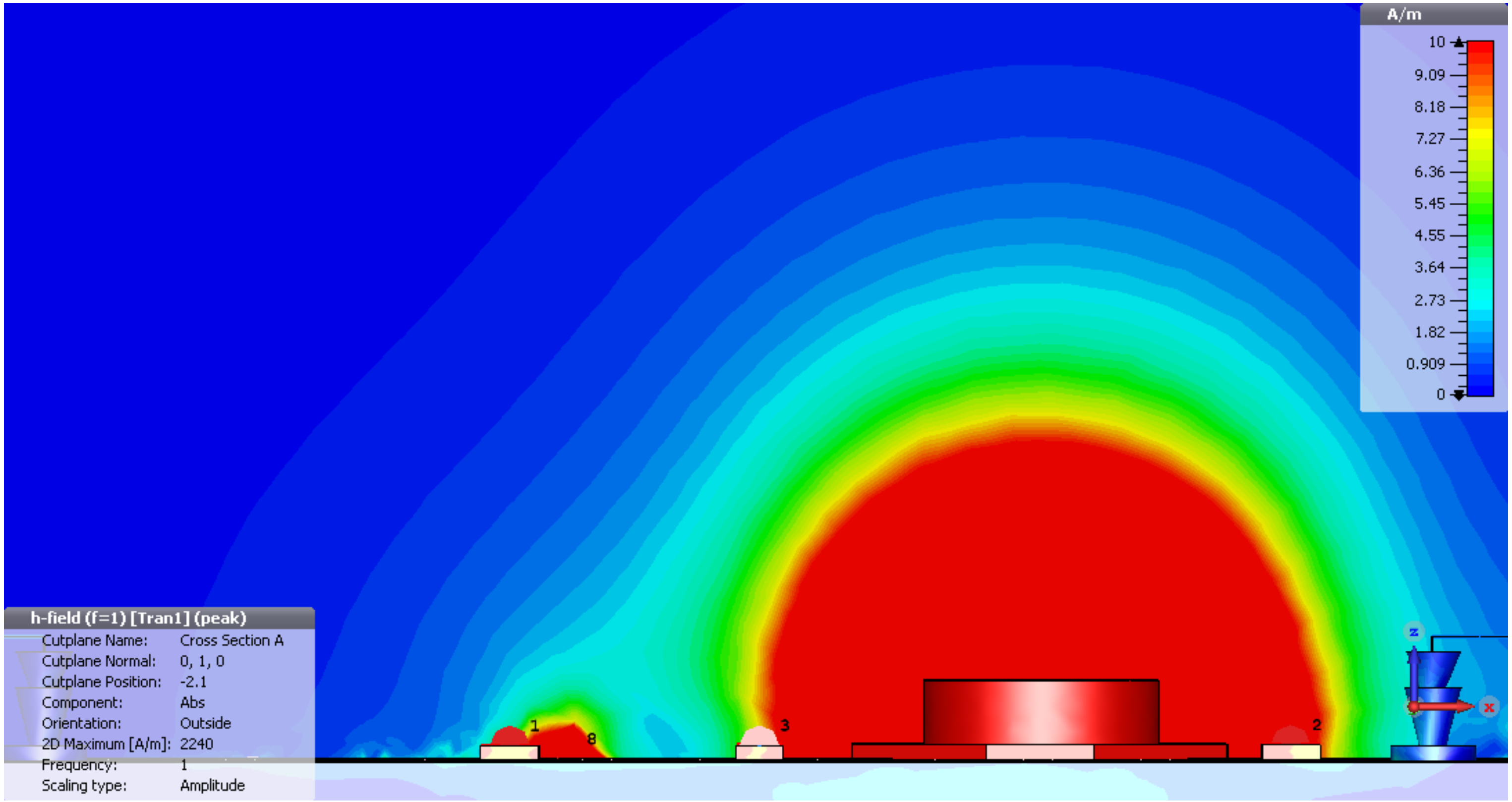
Adding a long shield above the inductor and the switch node does reduce the E and H field 1 cm above the PCB





H-Field, 1 MHz, Side View

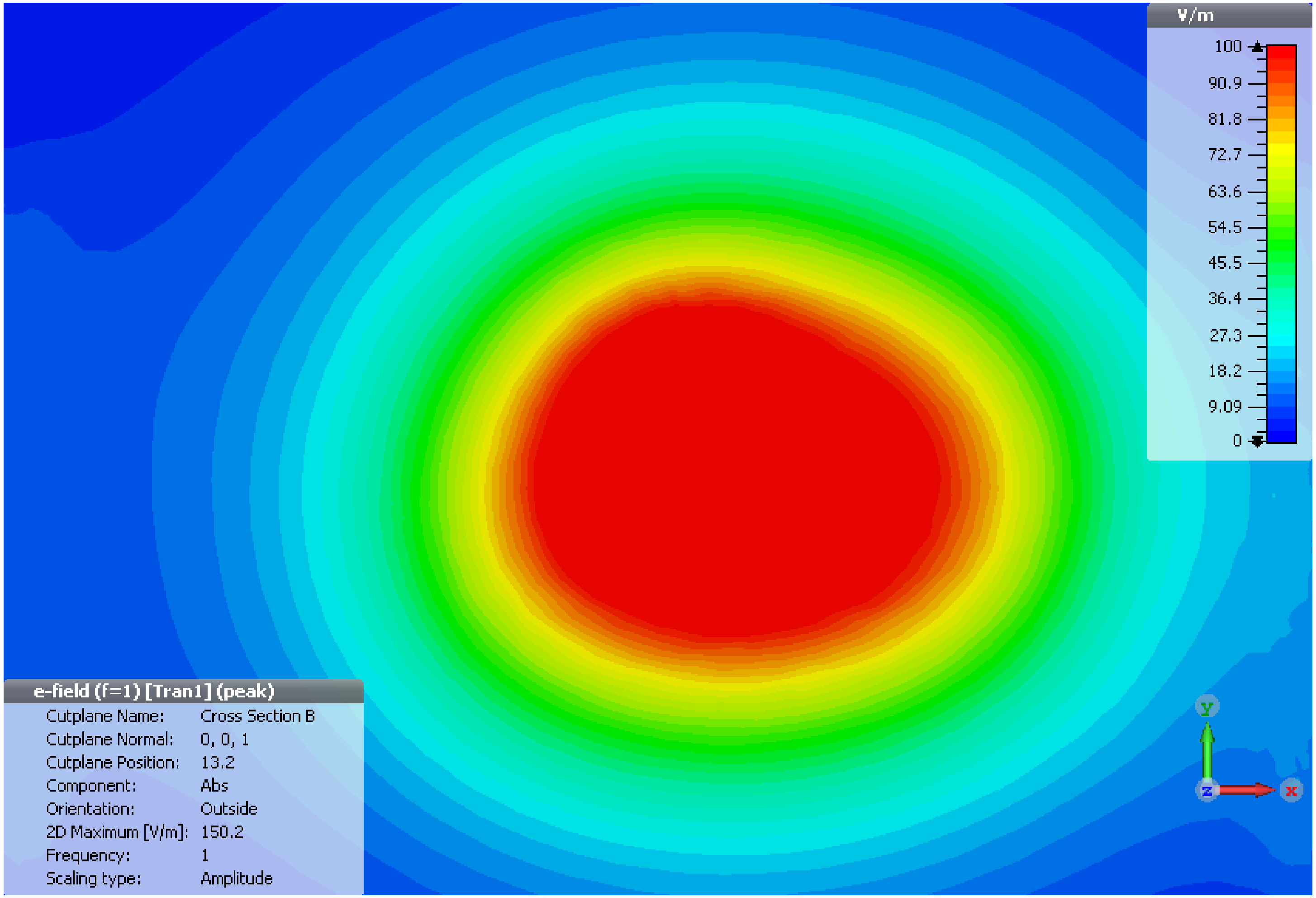
Unshielded



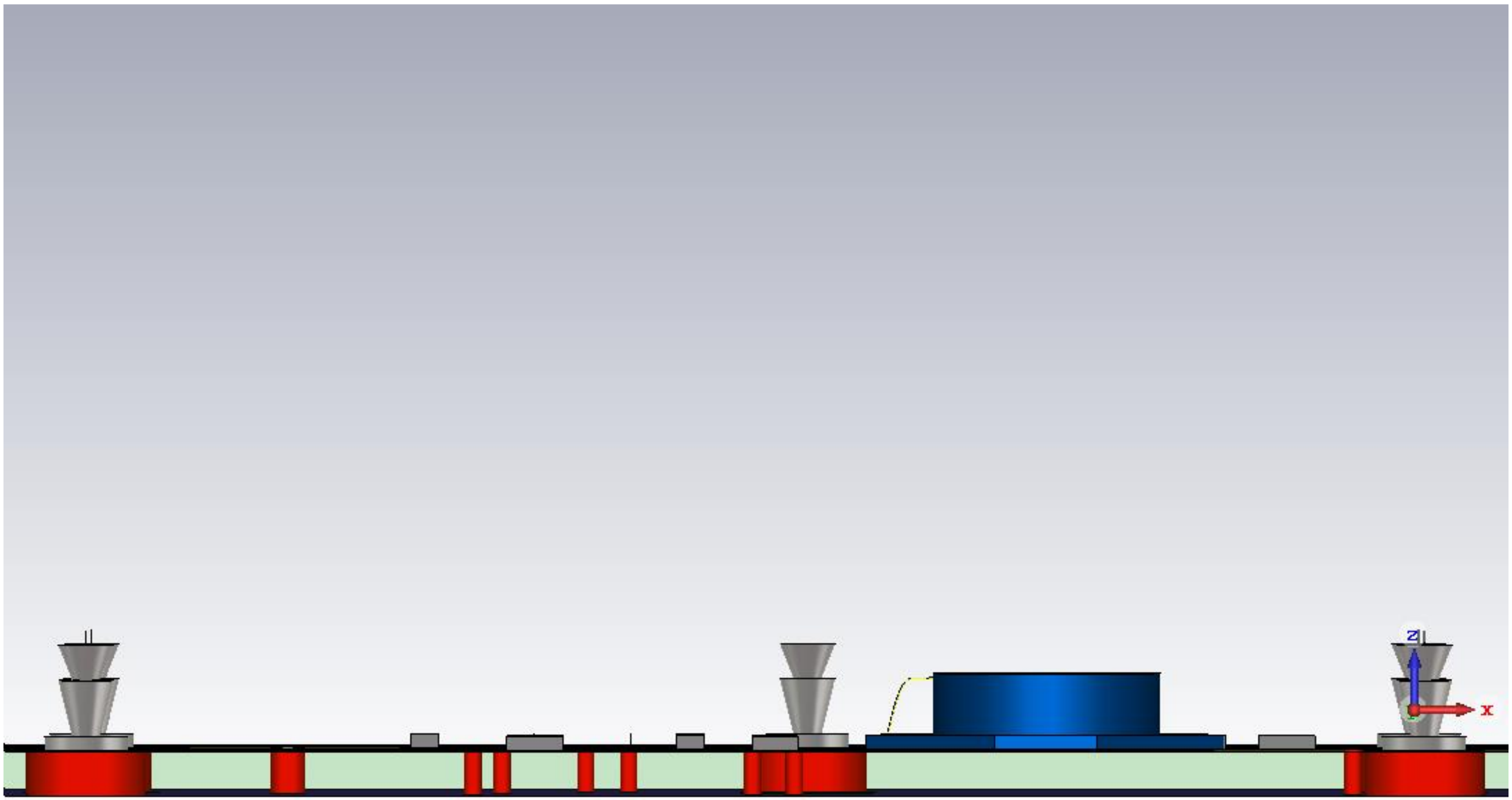
H-Field, 1 MHz, Side View

Magnetically Shielded

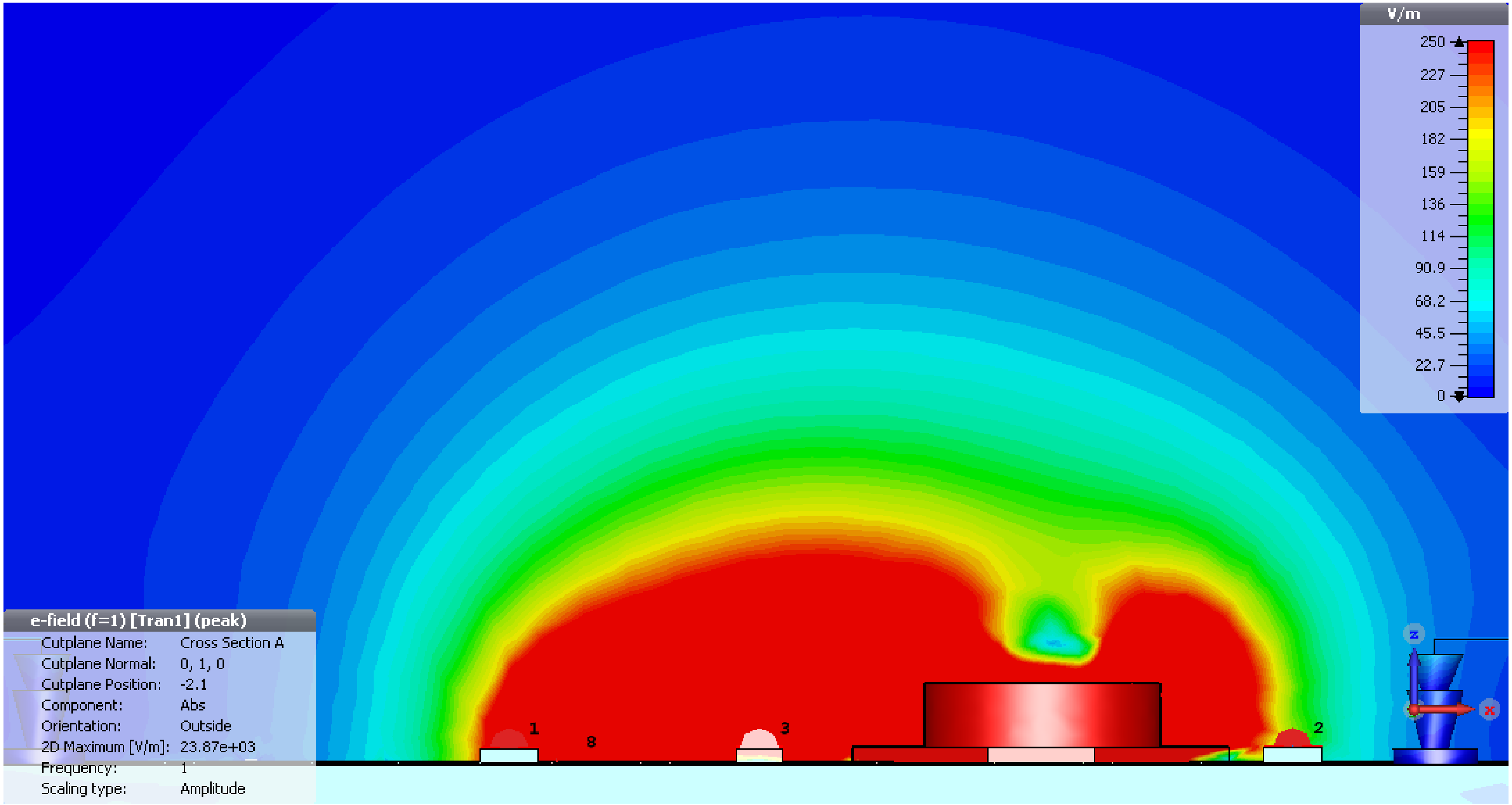
Unshielded, Ez 1cm above PCB



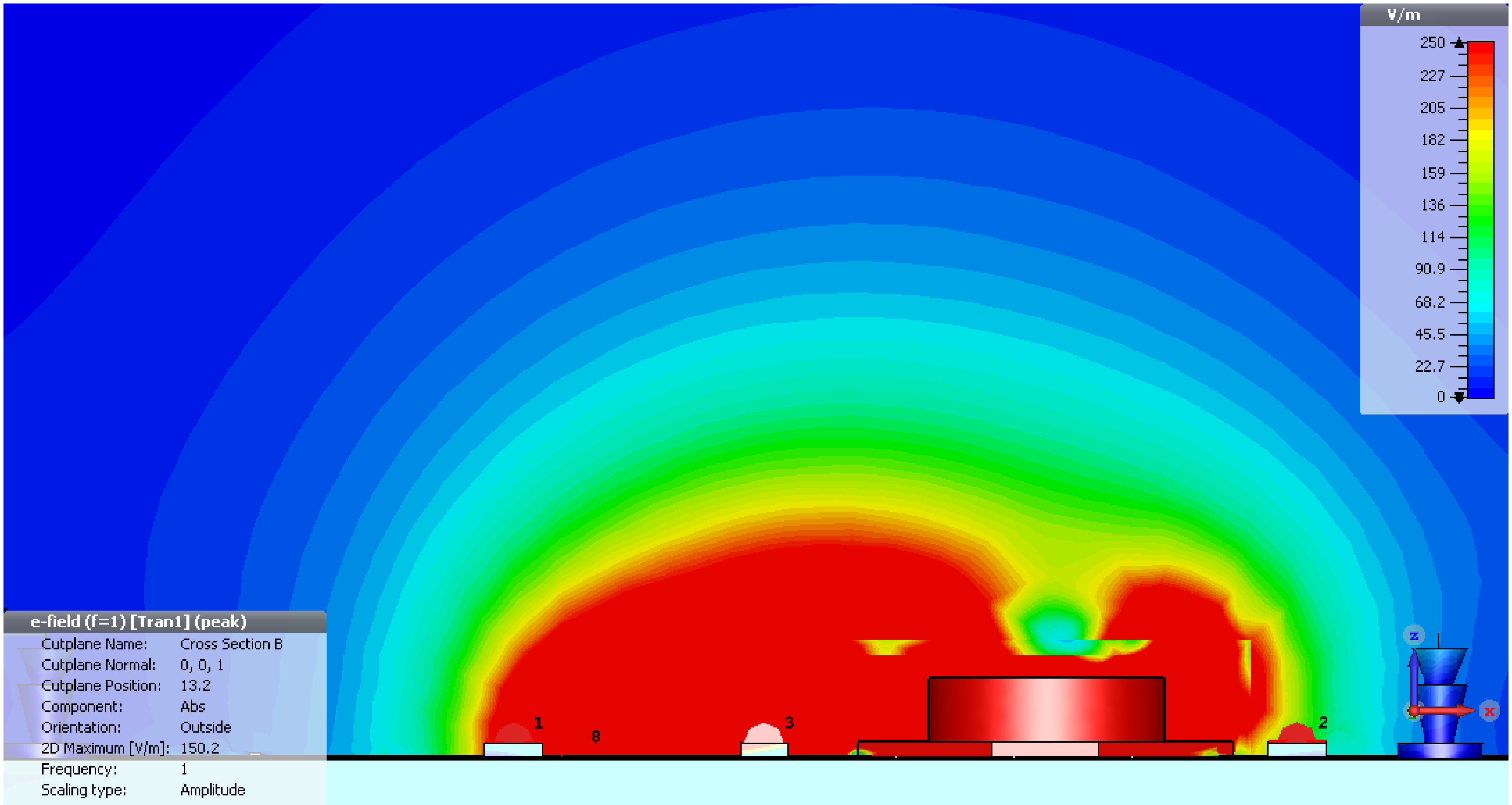
E-field, 1 MHz, Side View



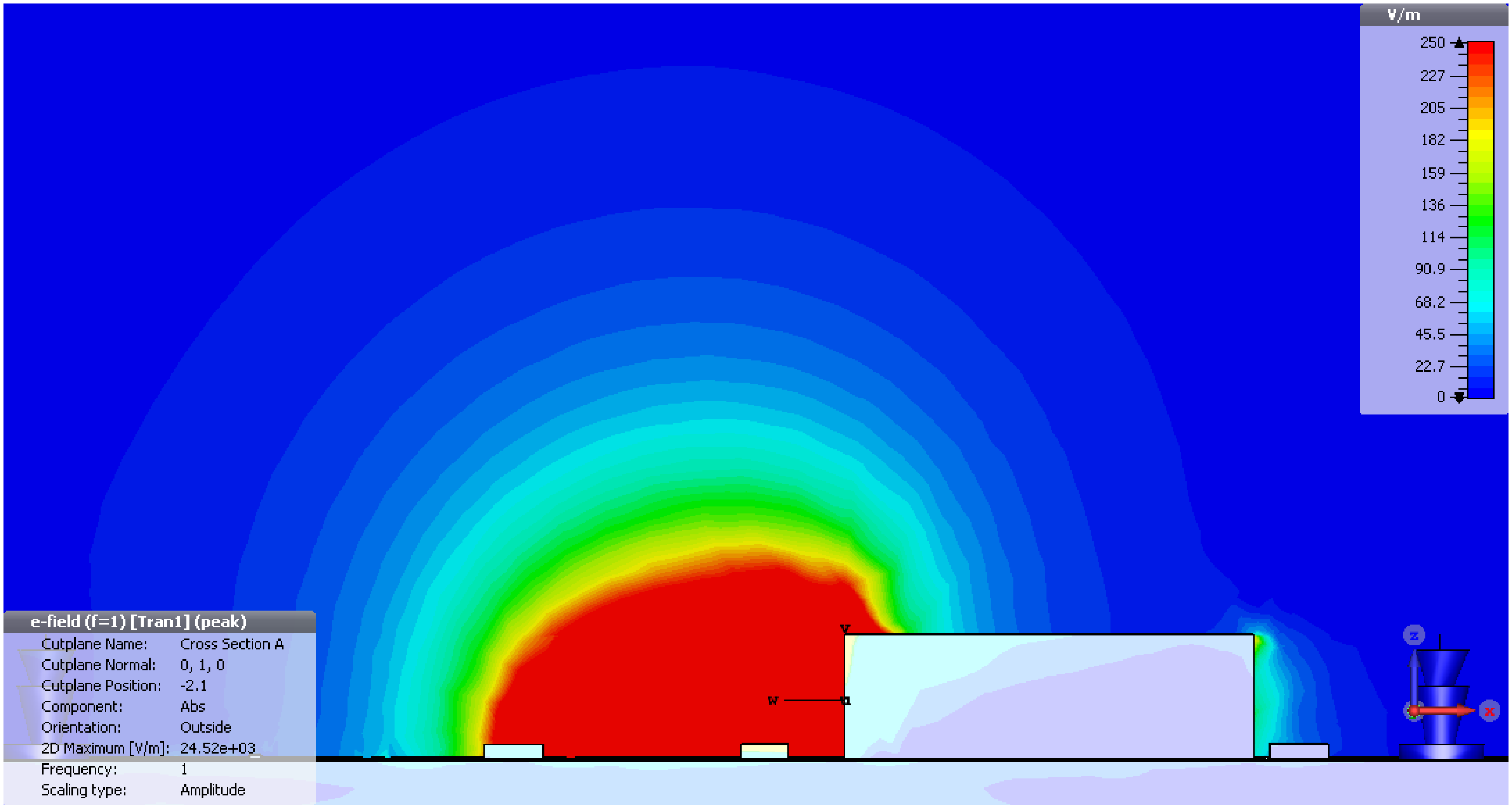
No Shielding



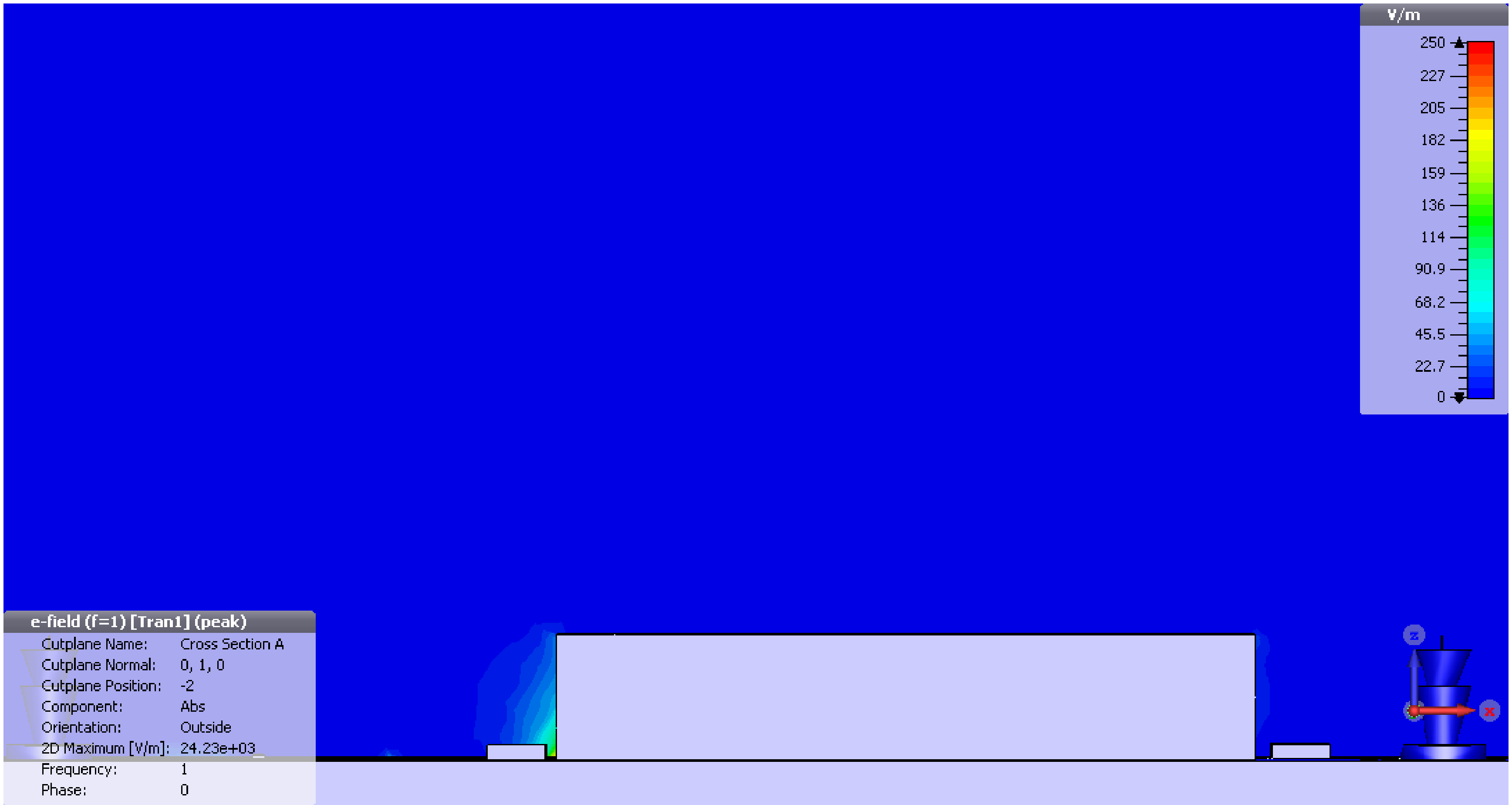
Magnetic Shield over Inductor



Electric Shield over Inductor only



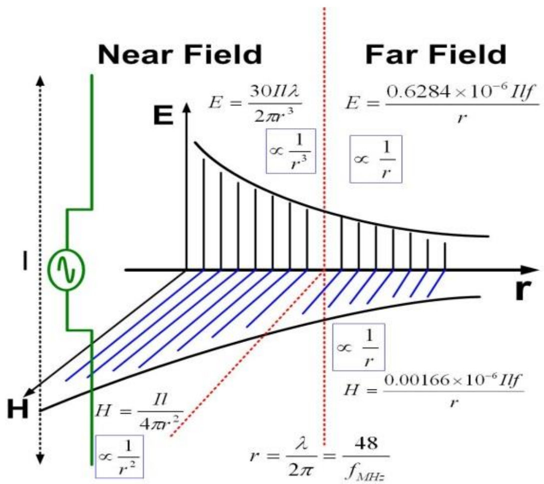
Electric Shield over Inductor + SW Node



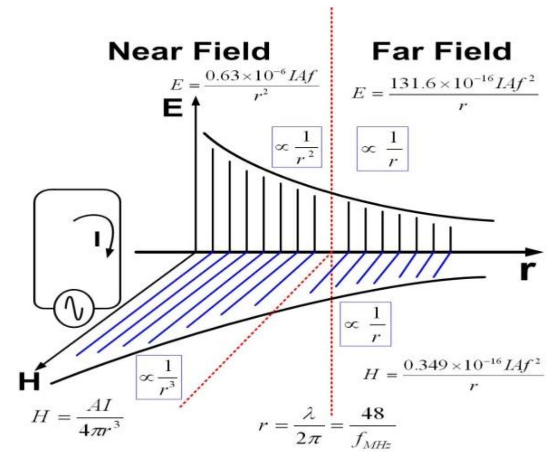
Near Field Coupling

Noise coupling phenomena below 30 MHz (deep in Near-Field Zone) with vehicle antenna is via E and H fields. E and H fields coexist at all times regardless of noise source impedance as seen here.

"Electric Field Source"



Magnetic Field Source"



H-Field Shielded Inductor + using low inductance capacitor and practicing best EMI guidelines, i.e., reduction of mounting inductance is NOT sufficient. L1 and SW node trace <u>MUST be shielded using a conductive material (i.e., copper) and bonded to PCB Ground</u>.

Agenda

- Introduction and Motivation
- Coupled 3D Field and Circuit Simulation
- Conducted Emission of a Motor Control
  - Variable frequency drive, the effect of PCB layout
- Conducted Emission of a DC-DC Buck Converter
  - Effect of EMI filter
- Radiated Emission of a DC-DC Buck Converter
  - RE as a near field coupling and the effect of shielding
- **Summary and Q&A**

Summary

Coupled 3D Field and Circuit Simulation has created new possibilities for EMC design

Can be very useful in the design for power electronics (motor control, converters, inverters, etc.) where EMI is becoming more prevalent

Conducted Emission of a Motor Control – PCB layout effects

Conducted Emission of a DC-DC Buck Converter – Filtering effects

Radiated Emission of a DC-DC Buck Converter – Shielding effects

Many types of mitigation techniques can be investigated and experimented with on virtual prototypes, long before testing occurs

Q&A

Thank you for your attention!

Any questions?

Thanks for attending!

Don’t miss our Test Bootcamp!
November 16, 2016
www.emclive2016.com