iMAPS New England 43rd Symposium & Expo

Investigation of Electromagnetic Field Coupling from DC-DC Buck Converters to Automobile AM/FM Antennas

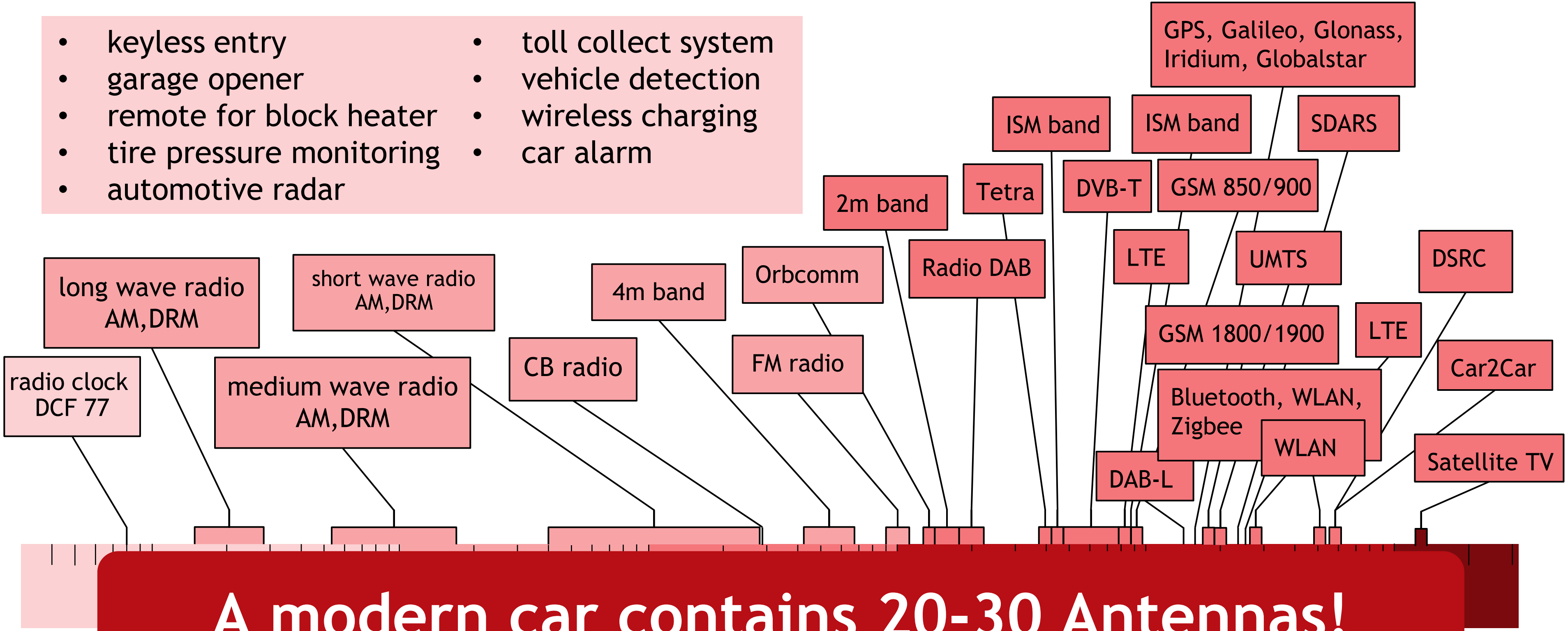
Patrick DeRoy, CST of America, Framingham, Massachusetts, USA
Andreas Barchanski, CST AG, Darmstadt, Germany
Cyrous Rostamzadeh, Bosch, Plymouth, Michigan, USA
Behrouz Abdolali, Crouse, Tehran, Iran

Outline

- Introduction and Motivation – SMPS EMI
- CISPR25 RE Test and Nearfield Probe Measurements
- Buck Converter Operation and RF Current Paths
    - Time Domain Waveforms, Parasitic Inductances and Loop Inductance Calculations
- AM Band Noise and Mitigation
    - Effect of Shielding, Electric and Magnetic Shields
- Glass Antennas and Vehicle Level Measurements
    - Near field coupling interaction
- Computational Modeling and Analysis
- Summary and Q&A

Modern Automobile = Complex Electromagnetic Environment

- keyless entry
- garage opener
- remote for block heater
- tire pressure monitoring
- automotive radar
- toll collect system
- vehicle detection
- wireless charging
- car alarm



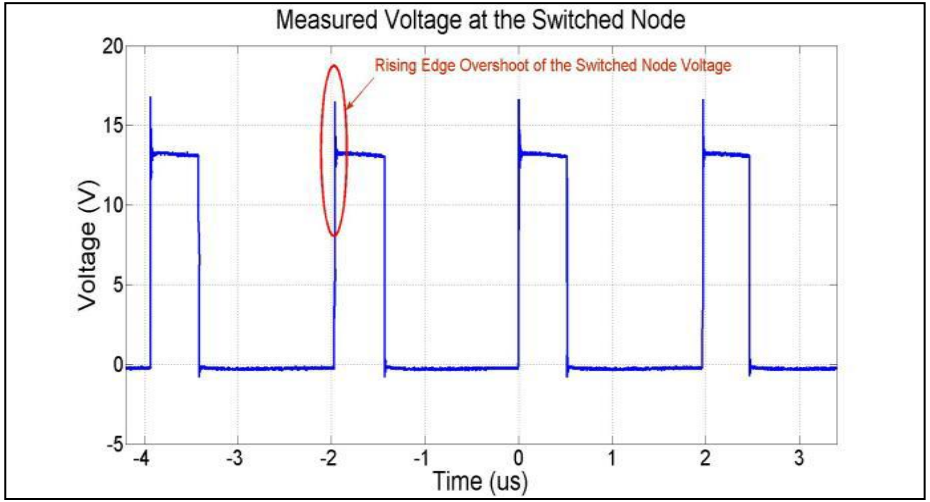
A modern car contains 20-30 Antennas!

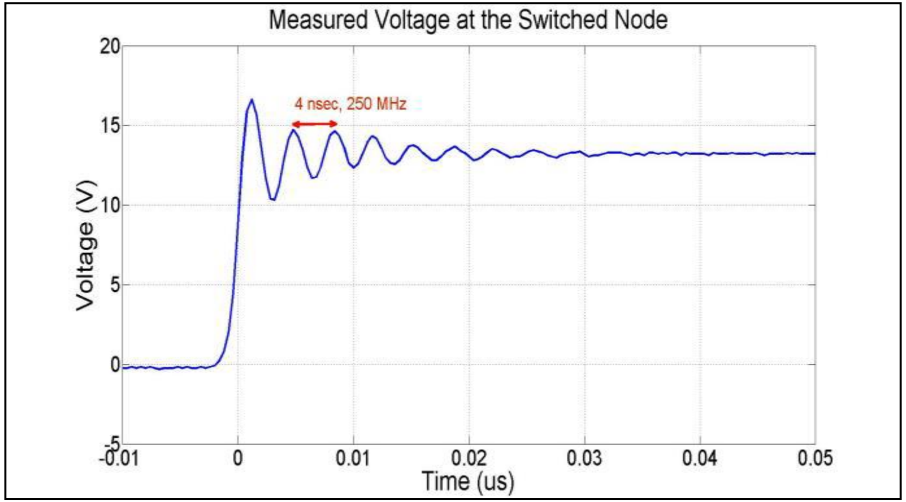
Switched Mode Power Supply EMI

Power Electronics designers require a deep breadth of knowledge – 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

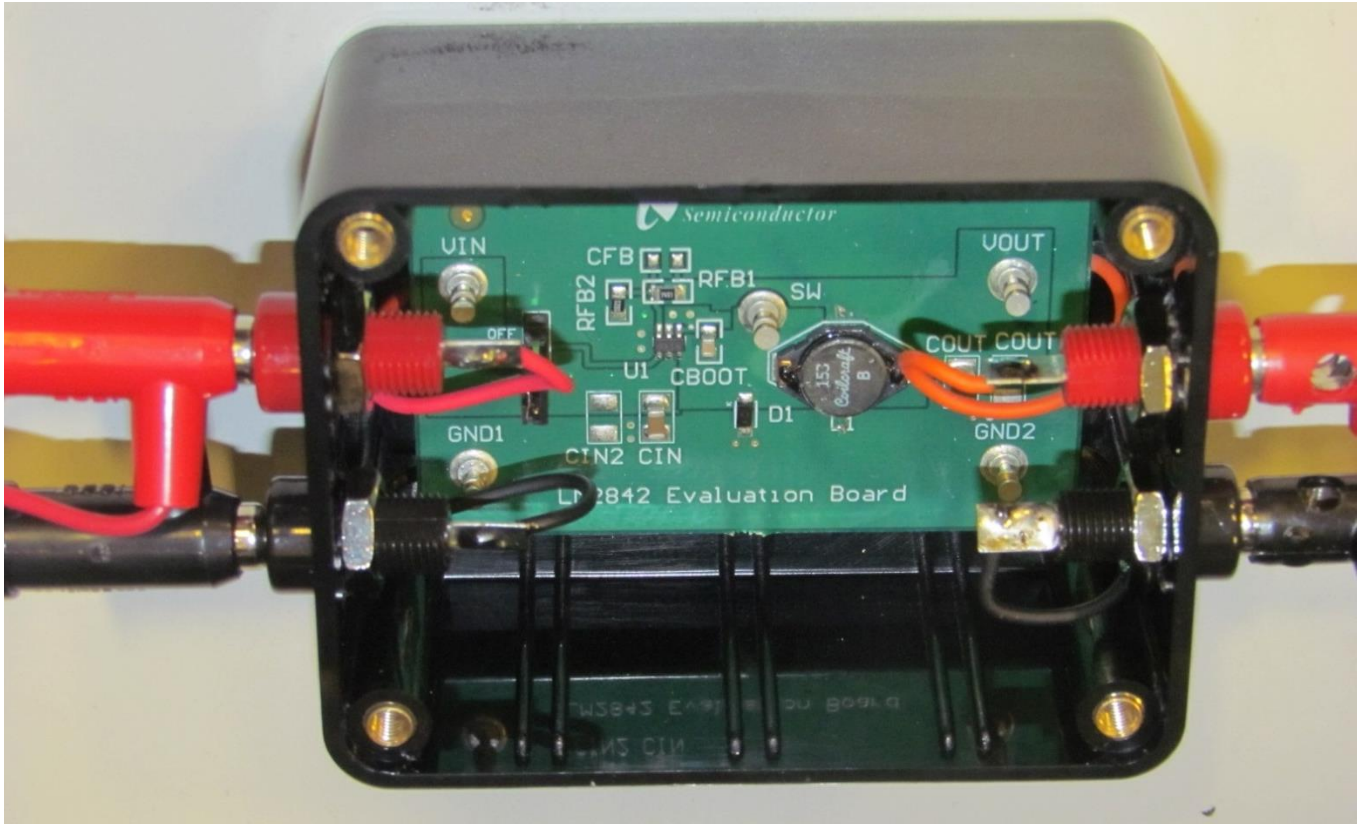
Concepts well known, yet it can still be difficult to pass EMC regulations – and it's only getting more difficult



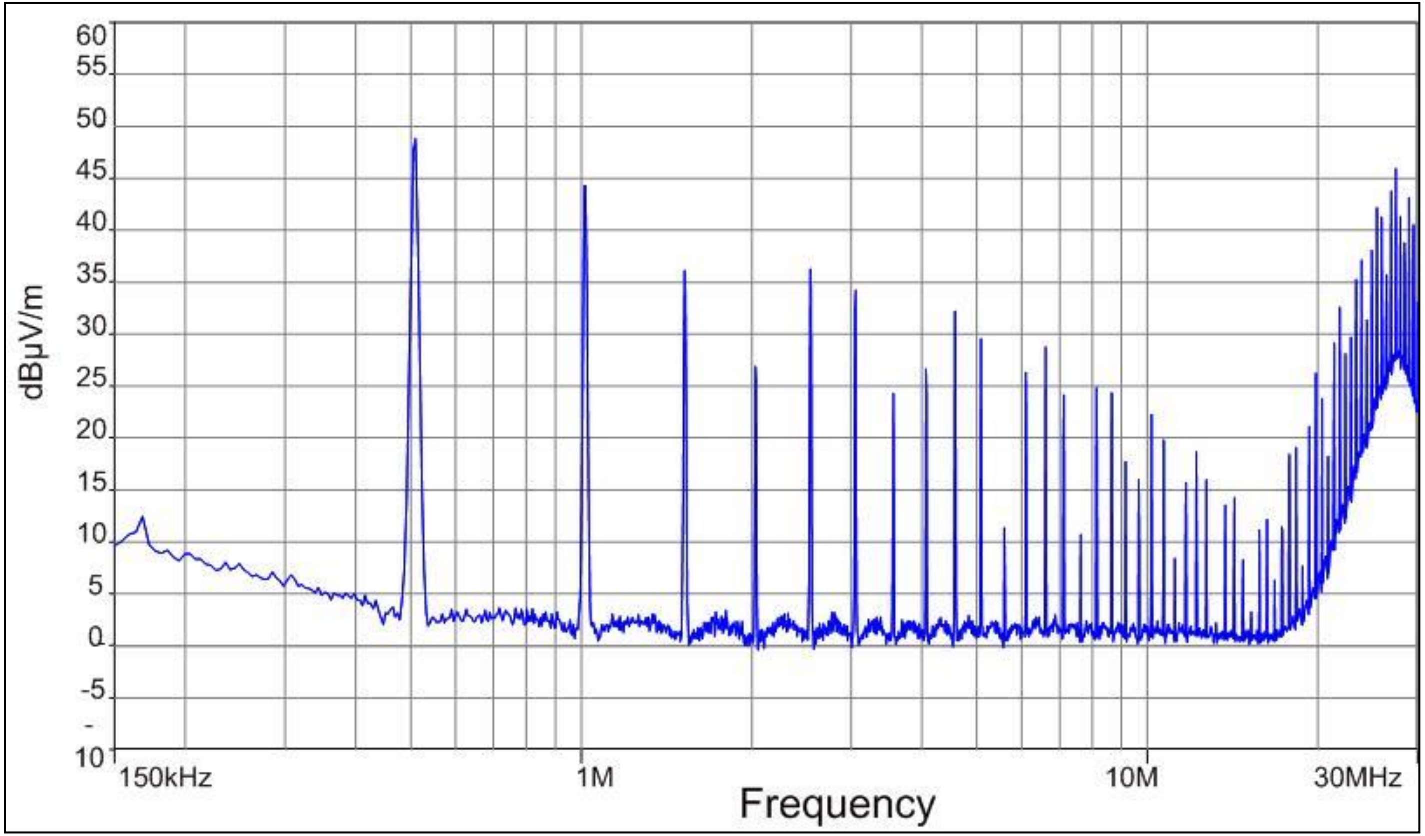


CISPR25 Radiated Emissions Test

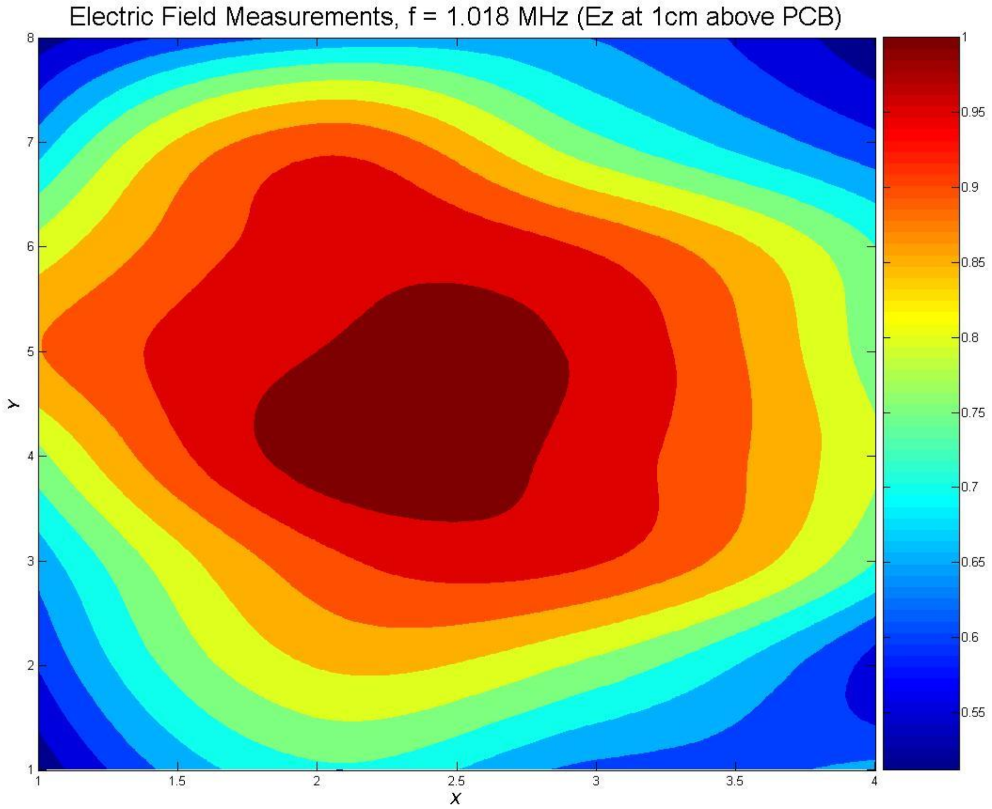
DUT: DC-DC Buck Converter, Eval Board



Measured Results – 150kHz – 30 MHz

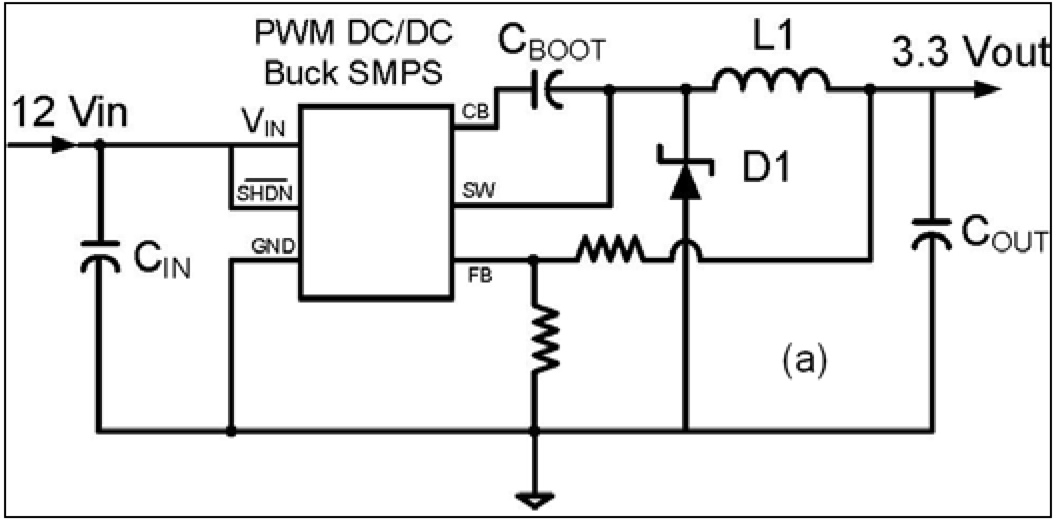


Nearfield Probe Measurement at 1 MHz



DC-DC Buck Converter Block Diagram

Switching Frequency ~ 500 kHz

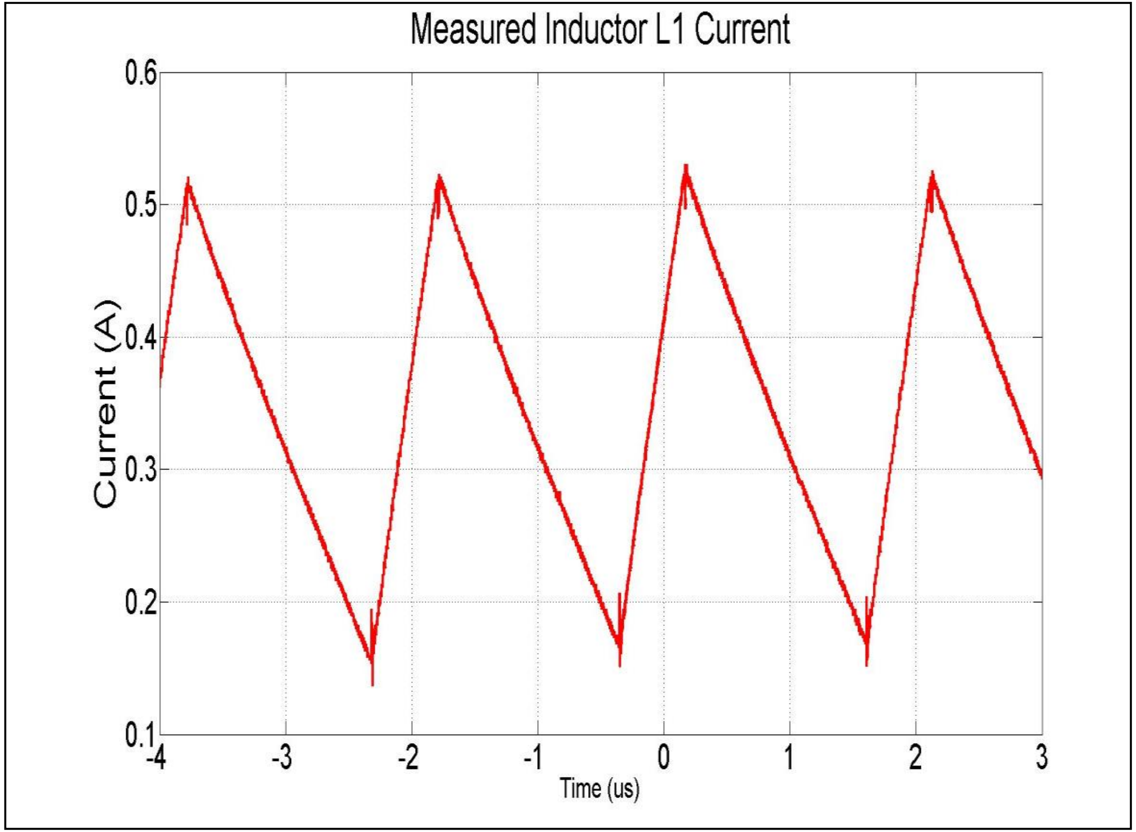


L1 Energy Storage Inductor (Magnetically Shielded) ⇛

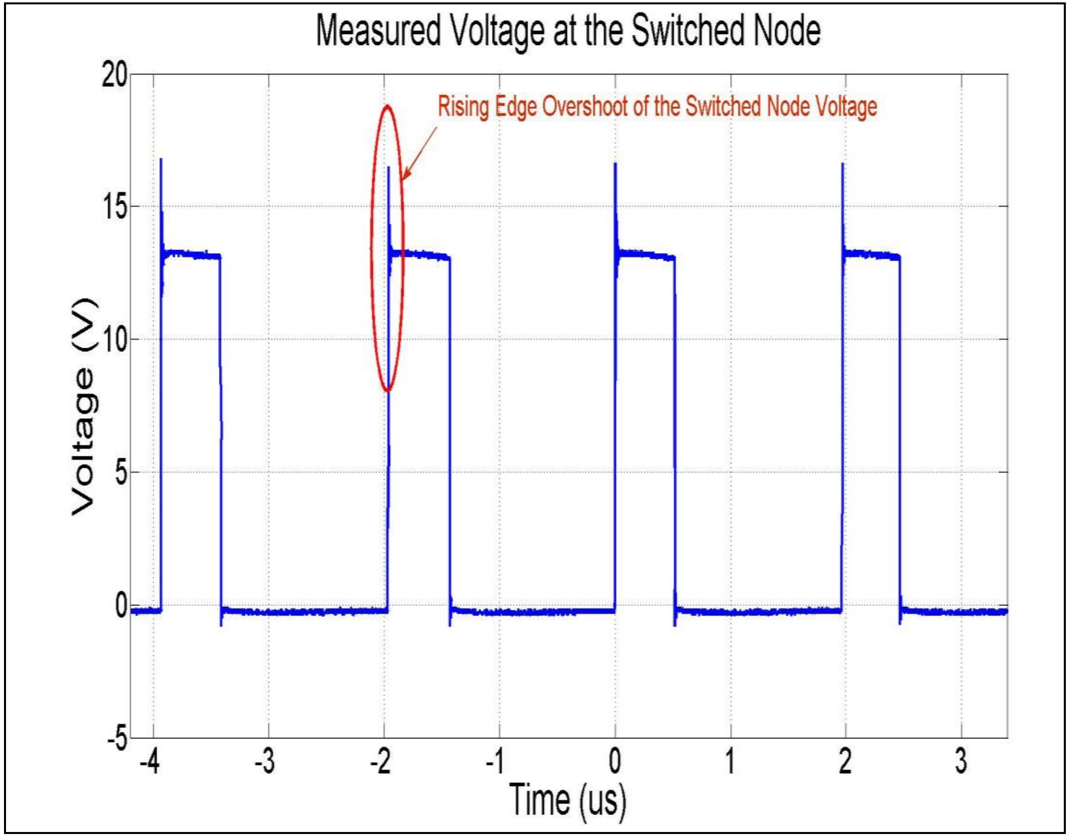
D1 Free-Wheel or Catch Diode (Switch)

SW Switch Node (CAUTION High dV/dt)

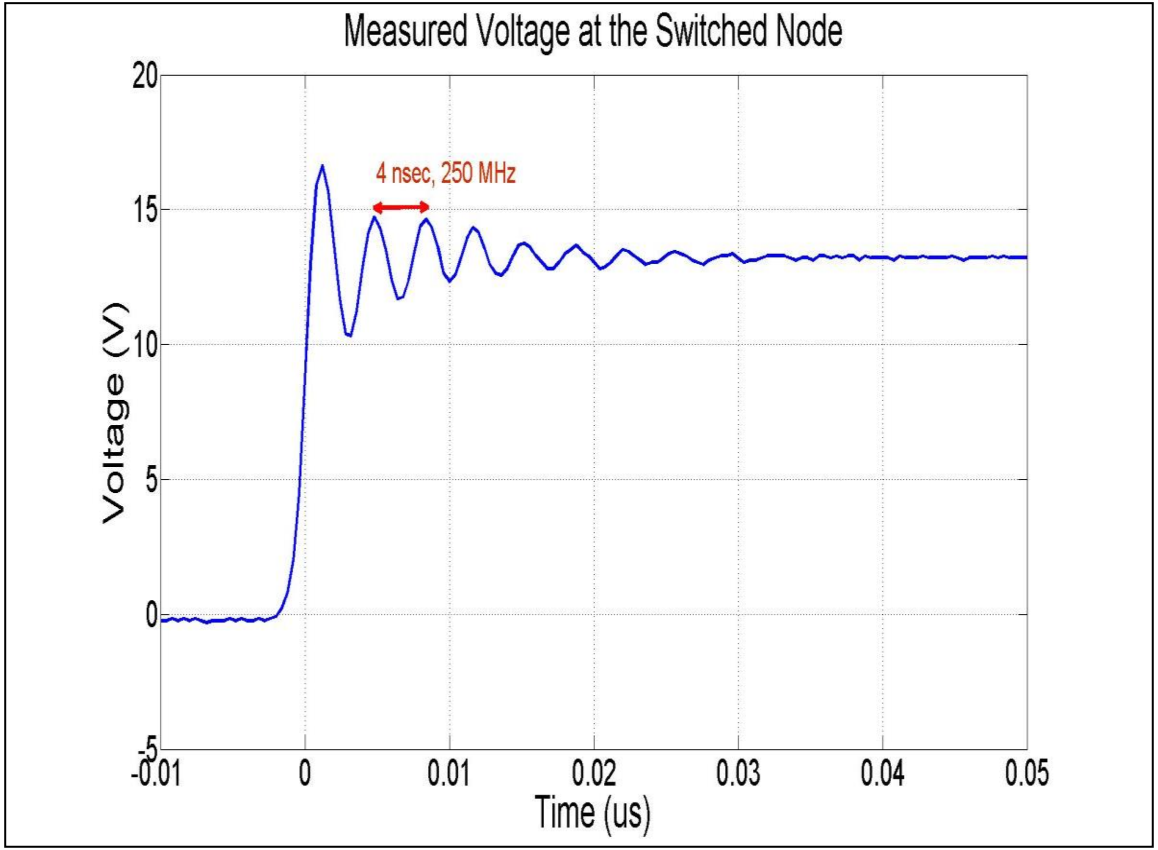
Inductor Current vs. Time



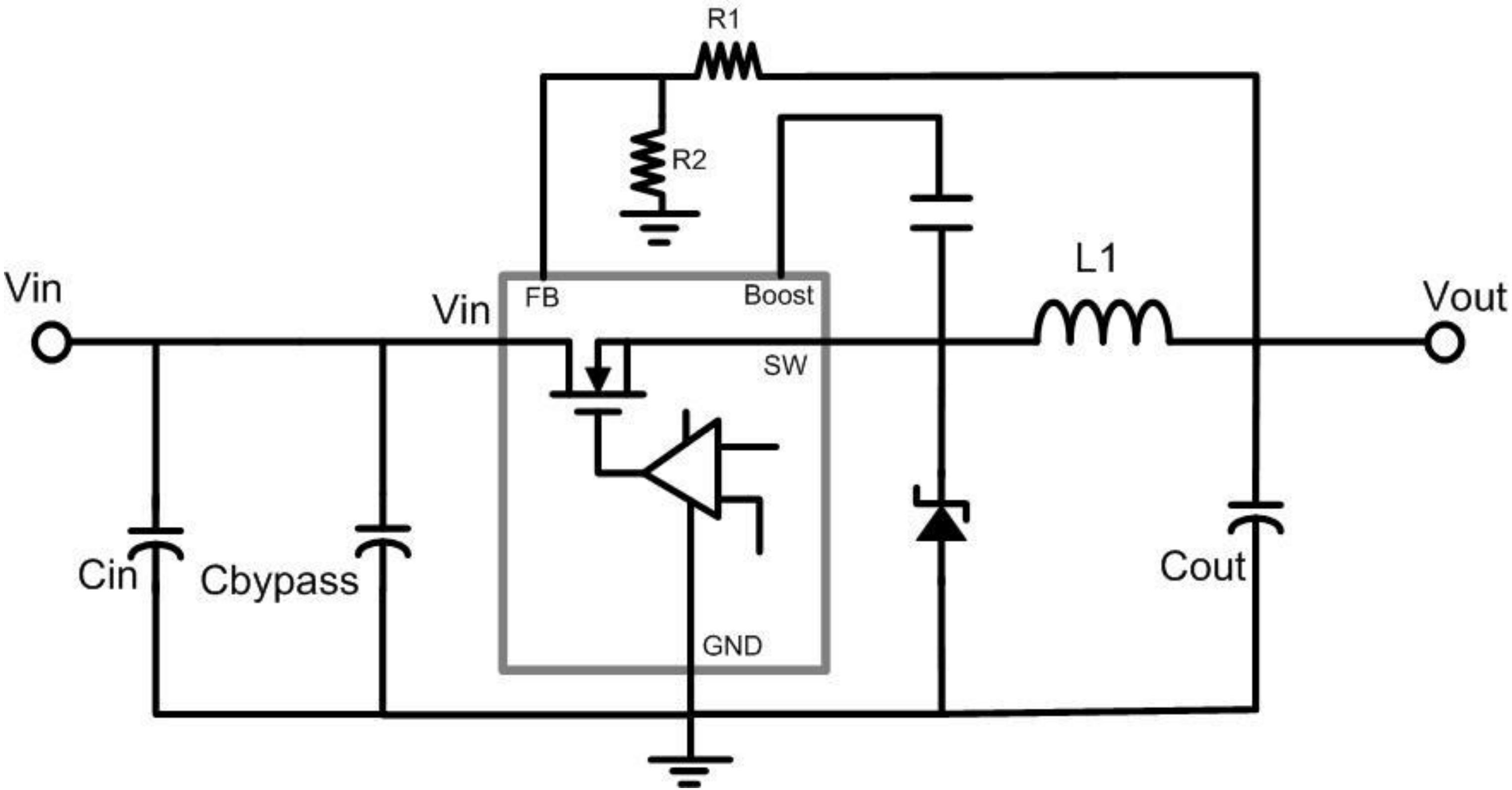
Switch Node Voltage Overshoot



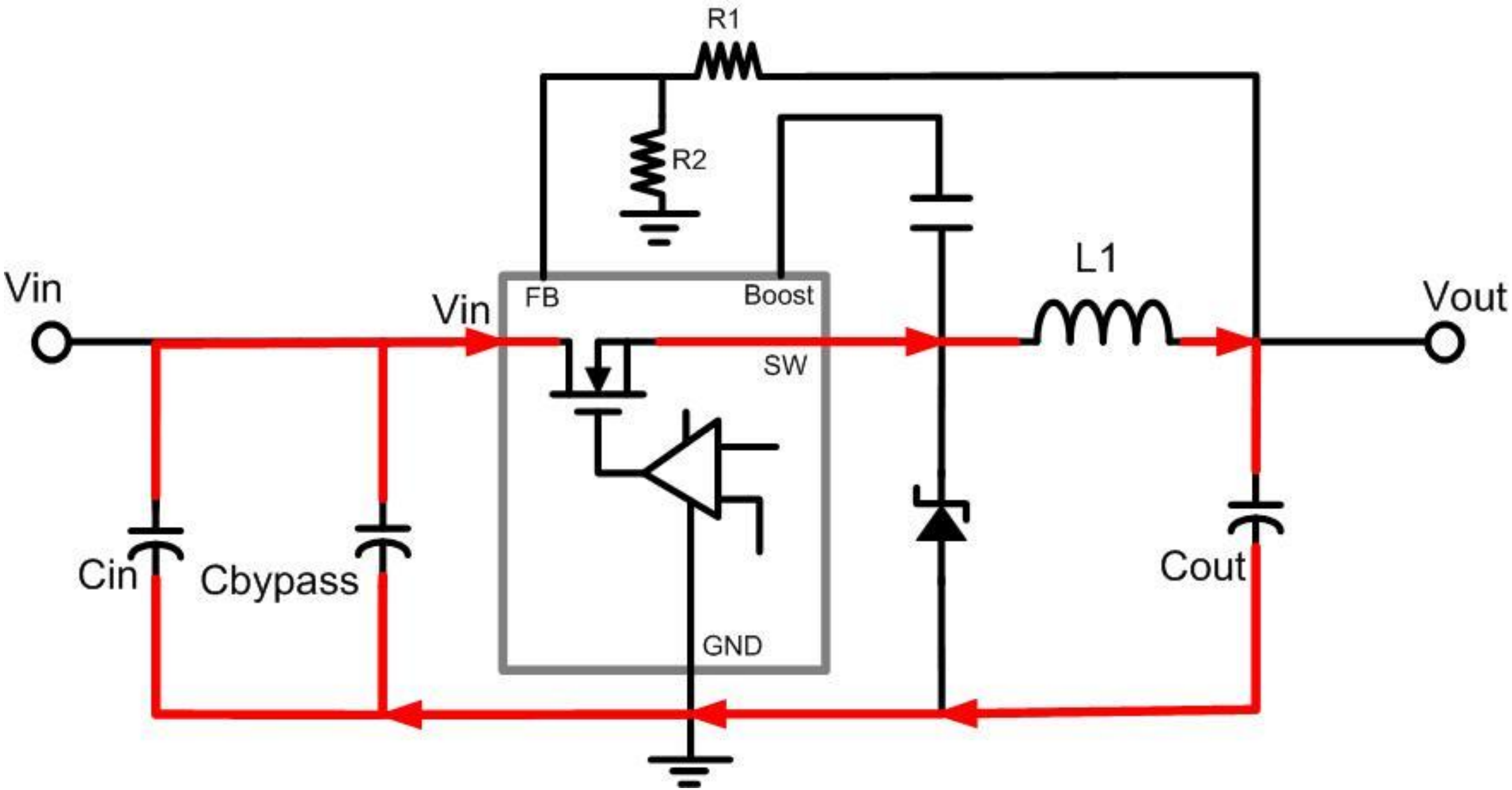
Zoomed: 4ns Ringing



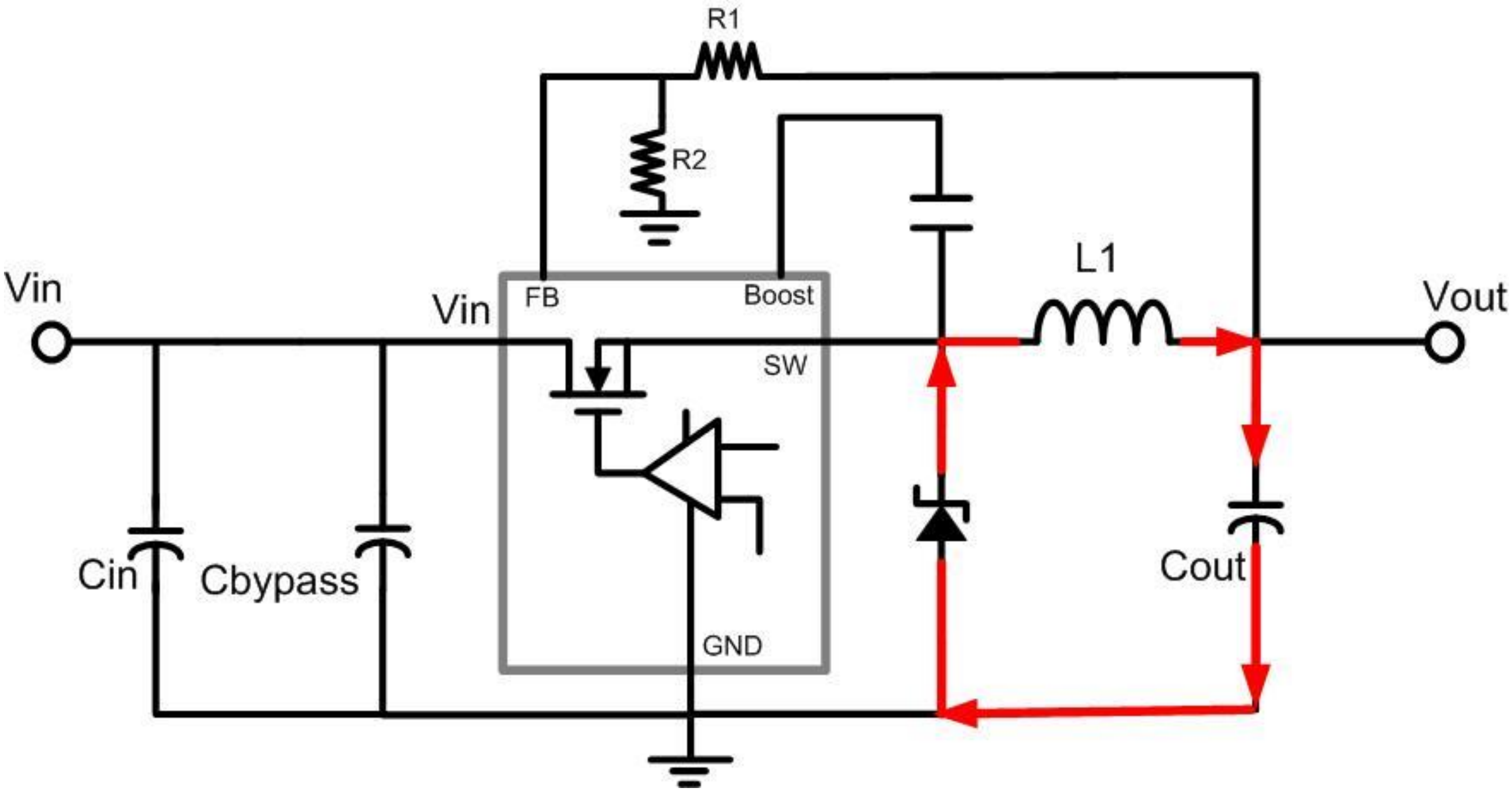
RF Current Paths



FET Switch ON, Schottky Diode OFF

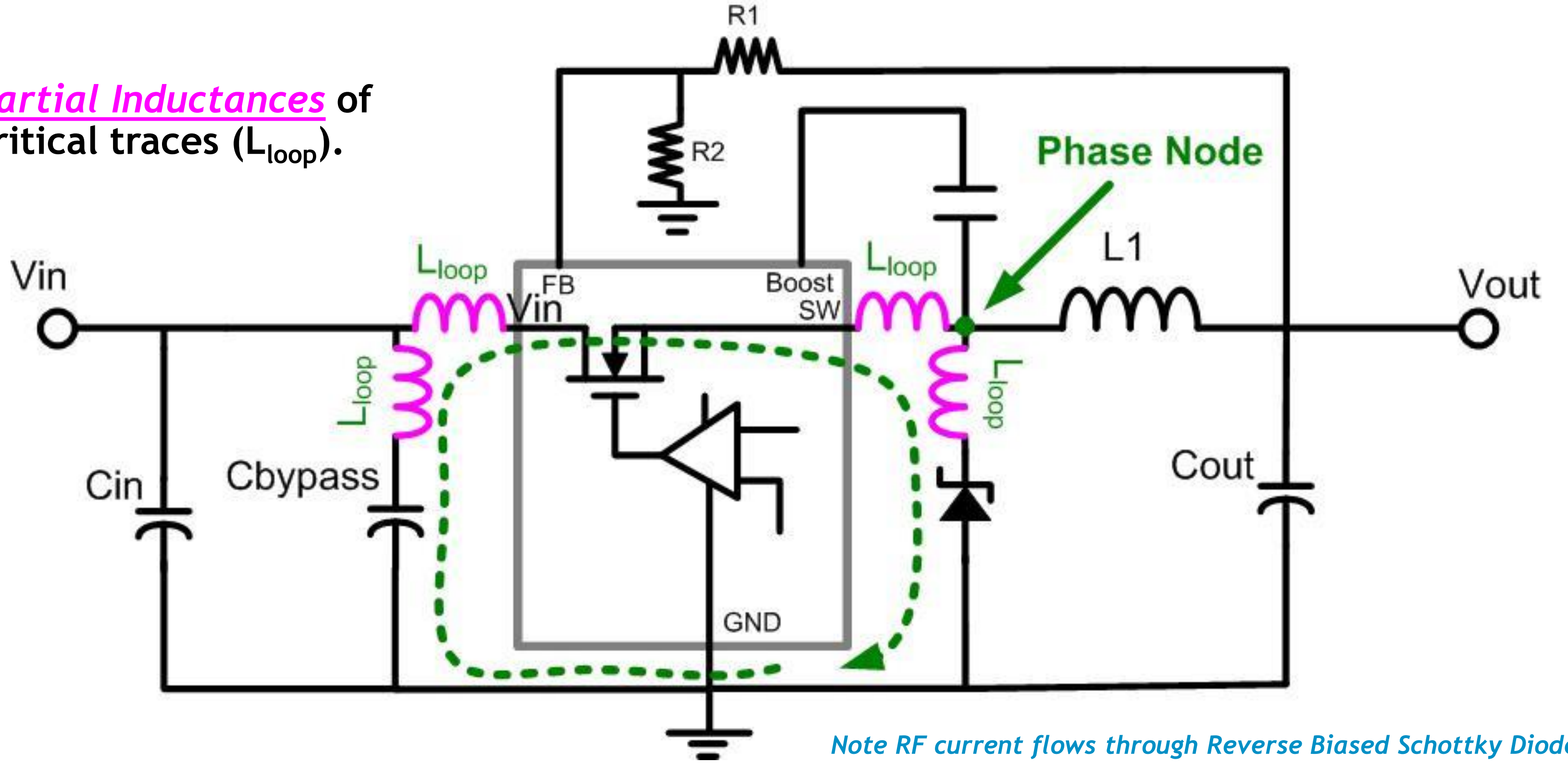


FET Switch OFF, Schottky Diode ON



RF Current Circulation Causes 4ns Ringing

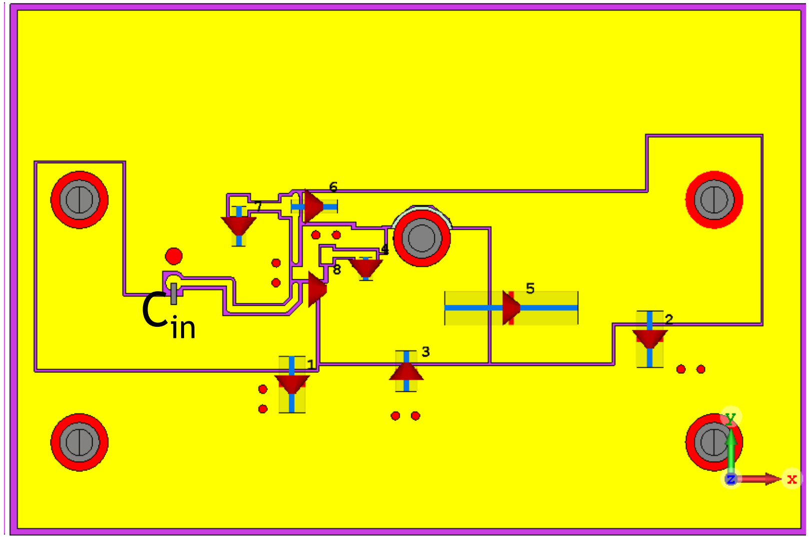
Partial Inductances of critical traces (L_{loop}).



Note RF current flows through Reverse Biased Schottky Diode through diode's junction capacitance ~ 125 pF

Loop Inductance Calculation

CST MWS – 3D PCB Model

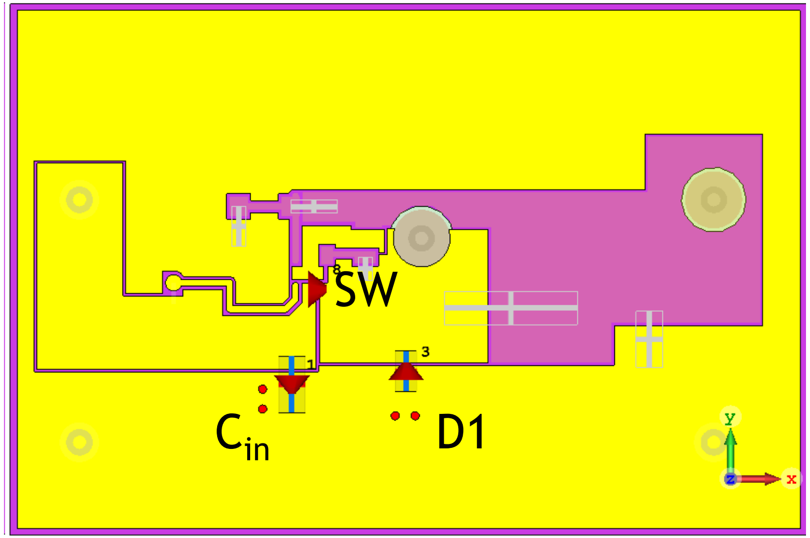


L_{loop} calculated to be 3.15 nH.

$$f_{res} = \frac{1}{2\pi\sqrt{\sum L_{loop} C}} = \frac{1}{2\pi\sqrt{3.15nH \times 125pF}} = 253.65MHz$$

Loop Inductance Calculation

CST MWS – 3D PCB Model



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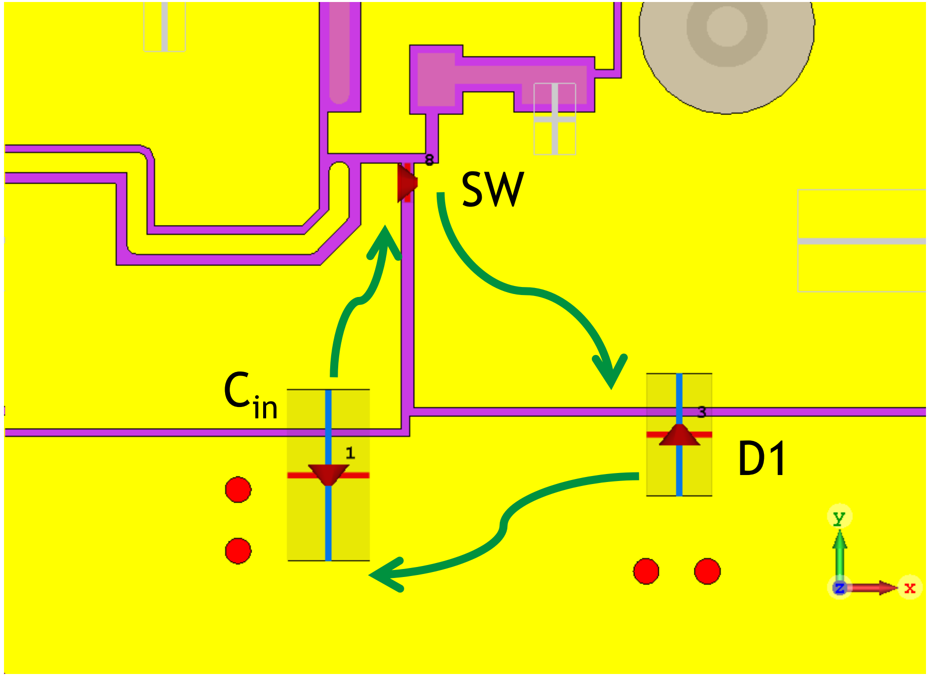

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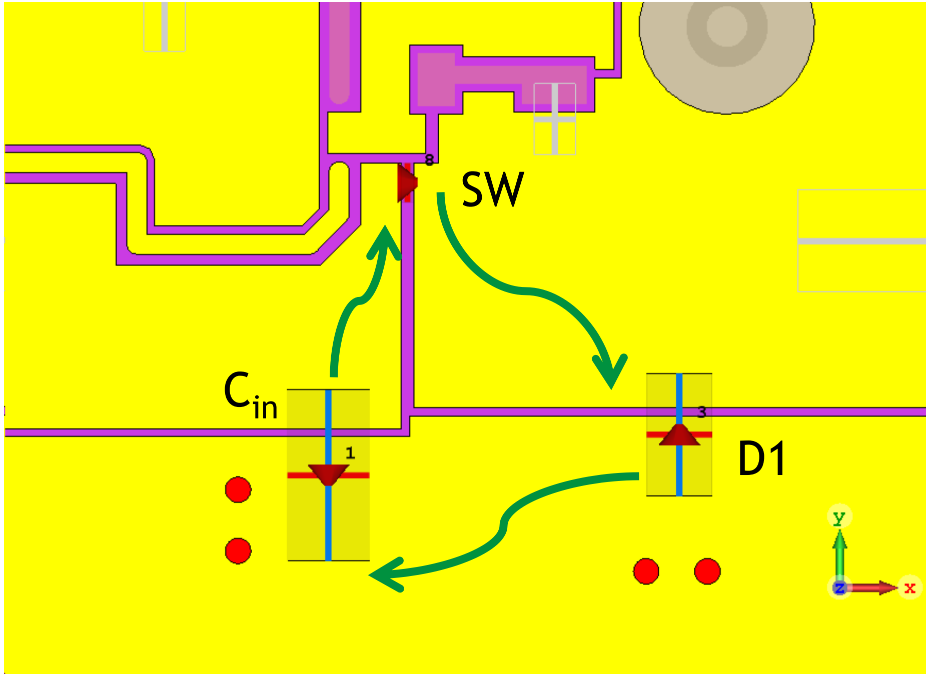
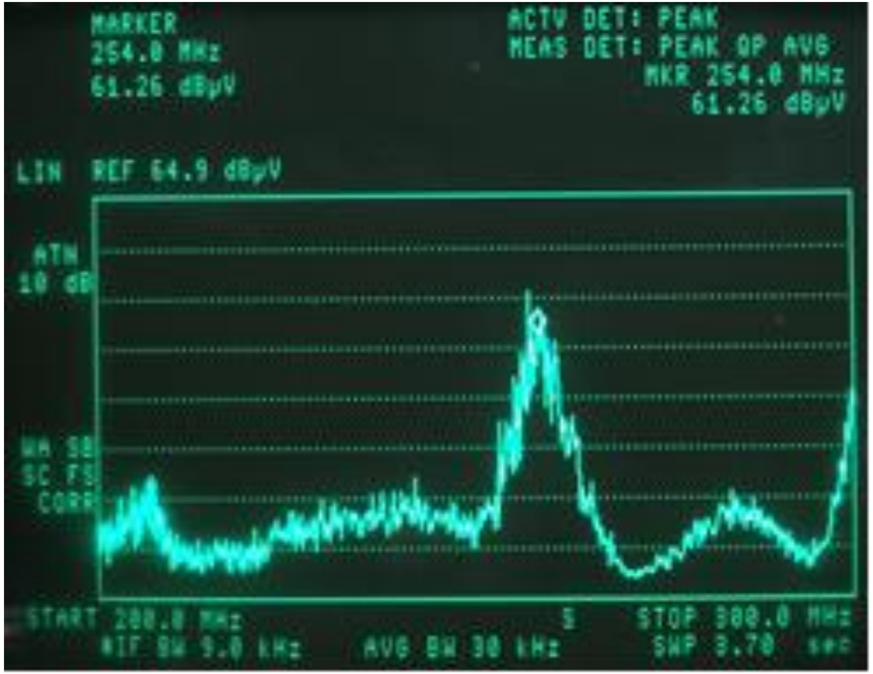




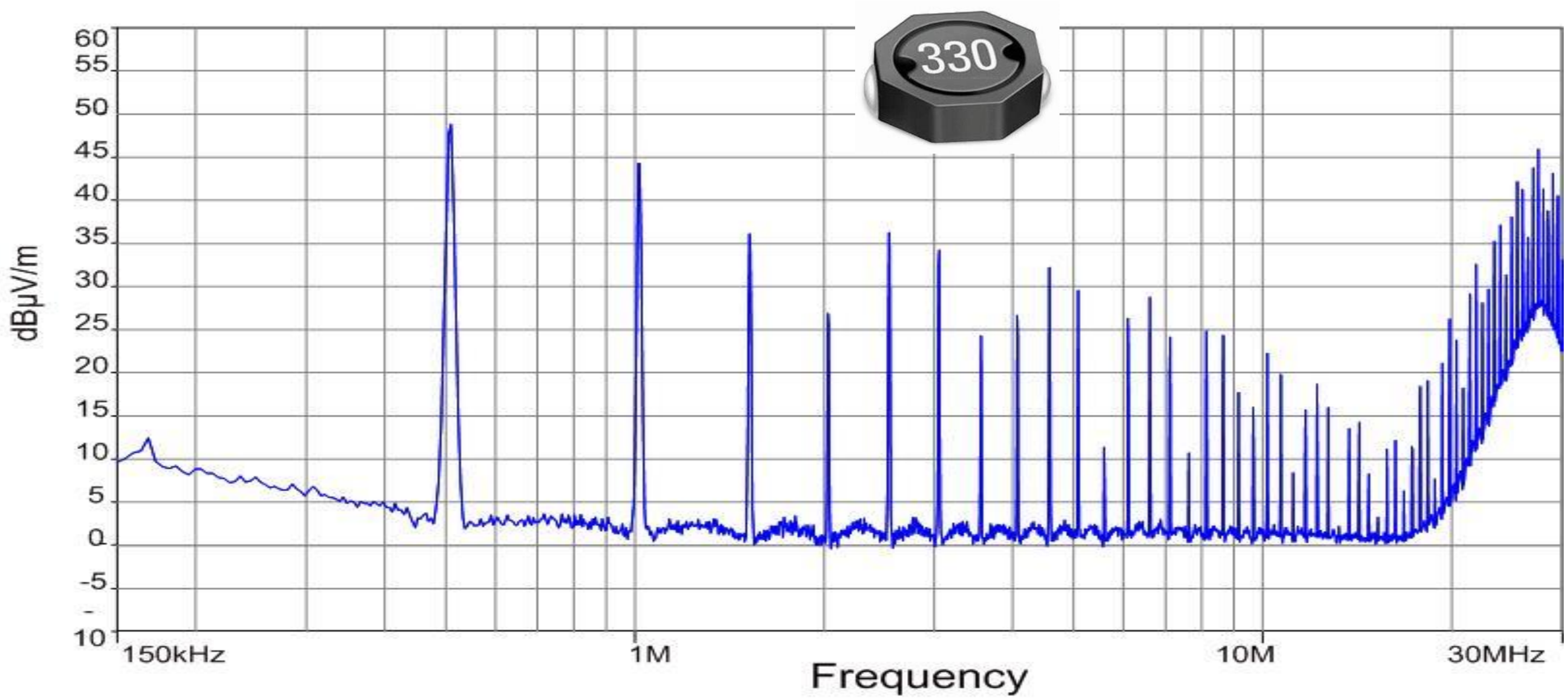
H-Field Measurement at 2 cm above the loop area (254 MHz Resonance)

AM Band Noise and Mitigation

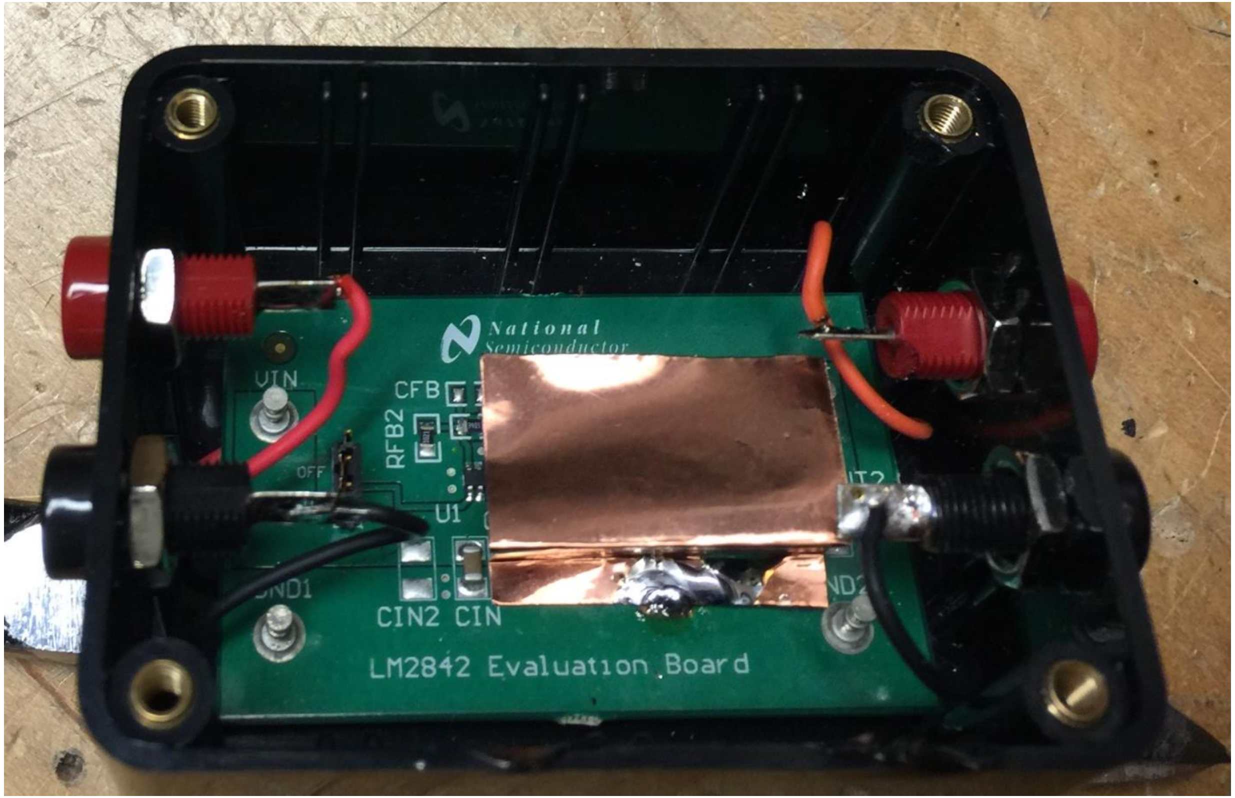
Inductor L1 is Magnetically Shielded, Encapsulated in Ferrite as seen here

This is not good enough for RE!
We need to provide *E-Field Shield* (Faraday Cage) and connect the shield to PCB Ground!

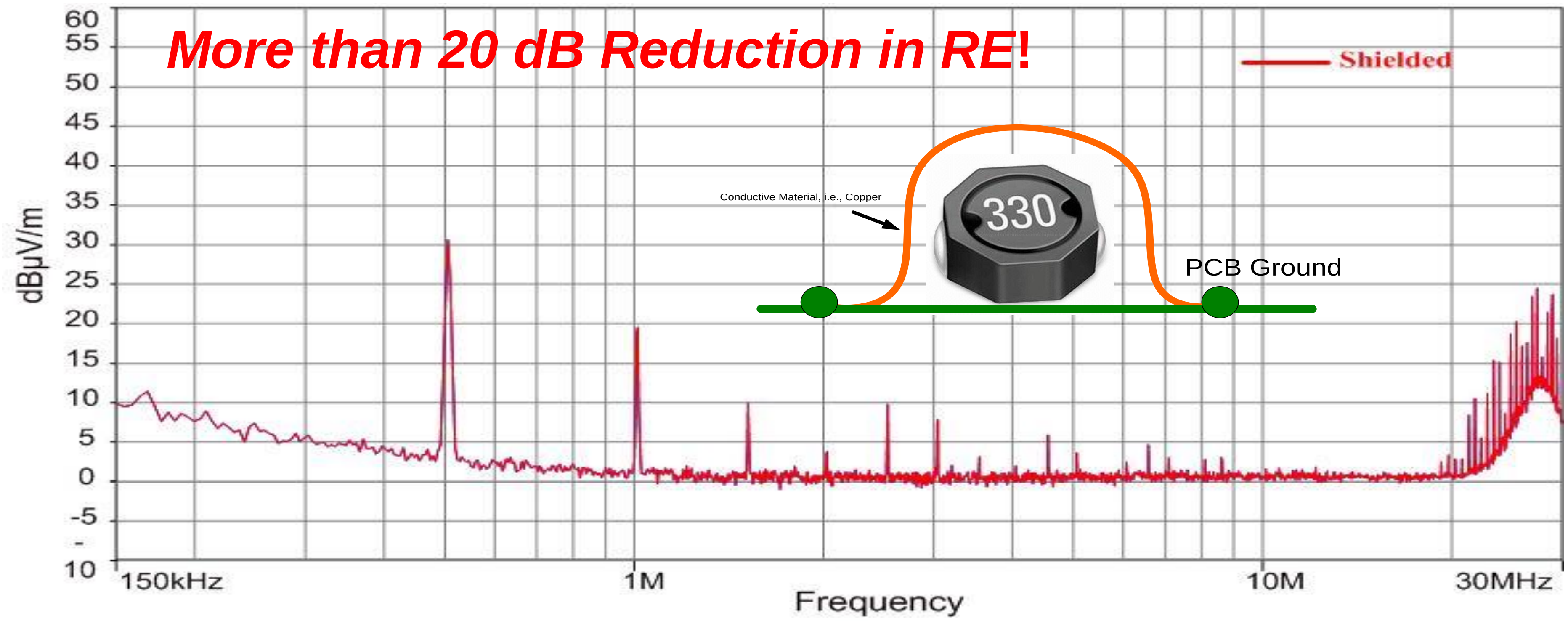
150 kHz - 30 MHz, Unshielded Inductor L1, (Resolution Bandwidth 9 kHz, Average Detector)



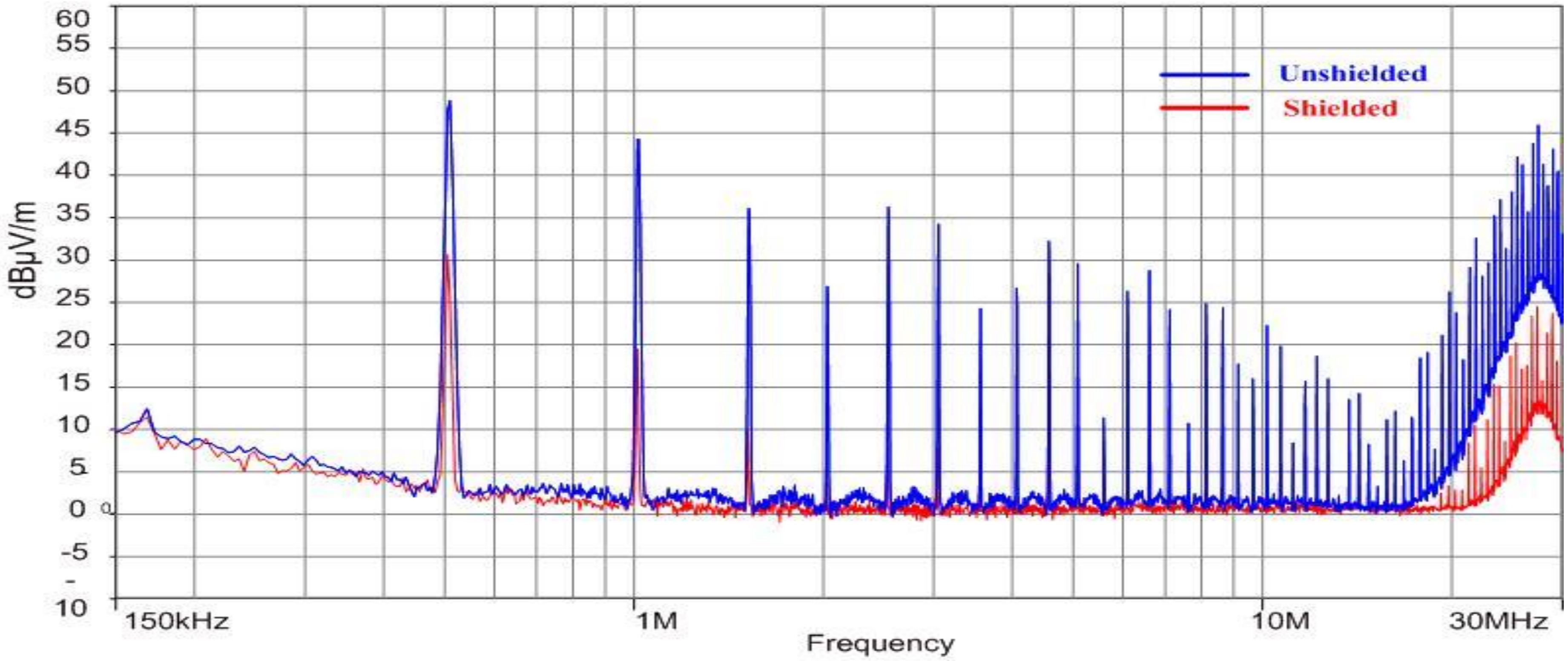
Copper Shield over L1 and SW Node



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

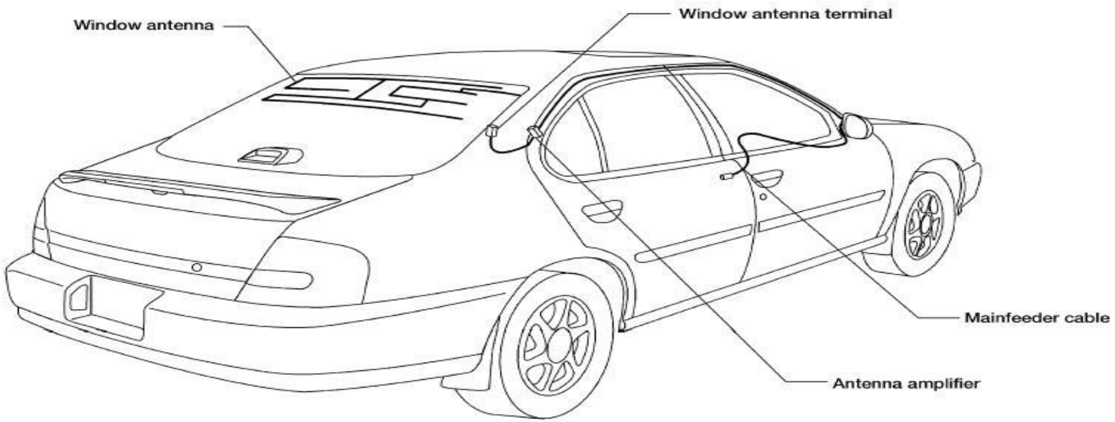


150 kHz - 30 MHz, Unshielded Inductor L1 vs. Shielded Inductor L1 Comparison (Resolution Bandwidth 9 kHz, Average Detector)



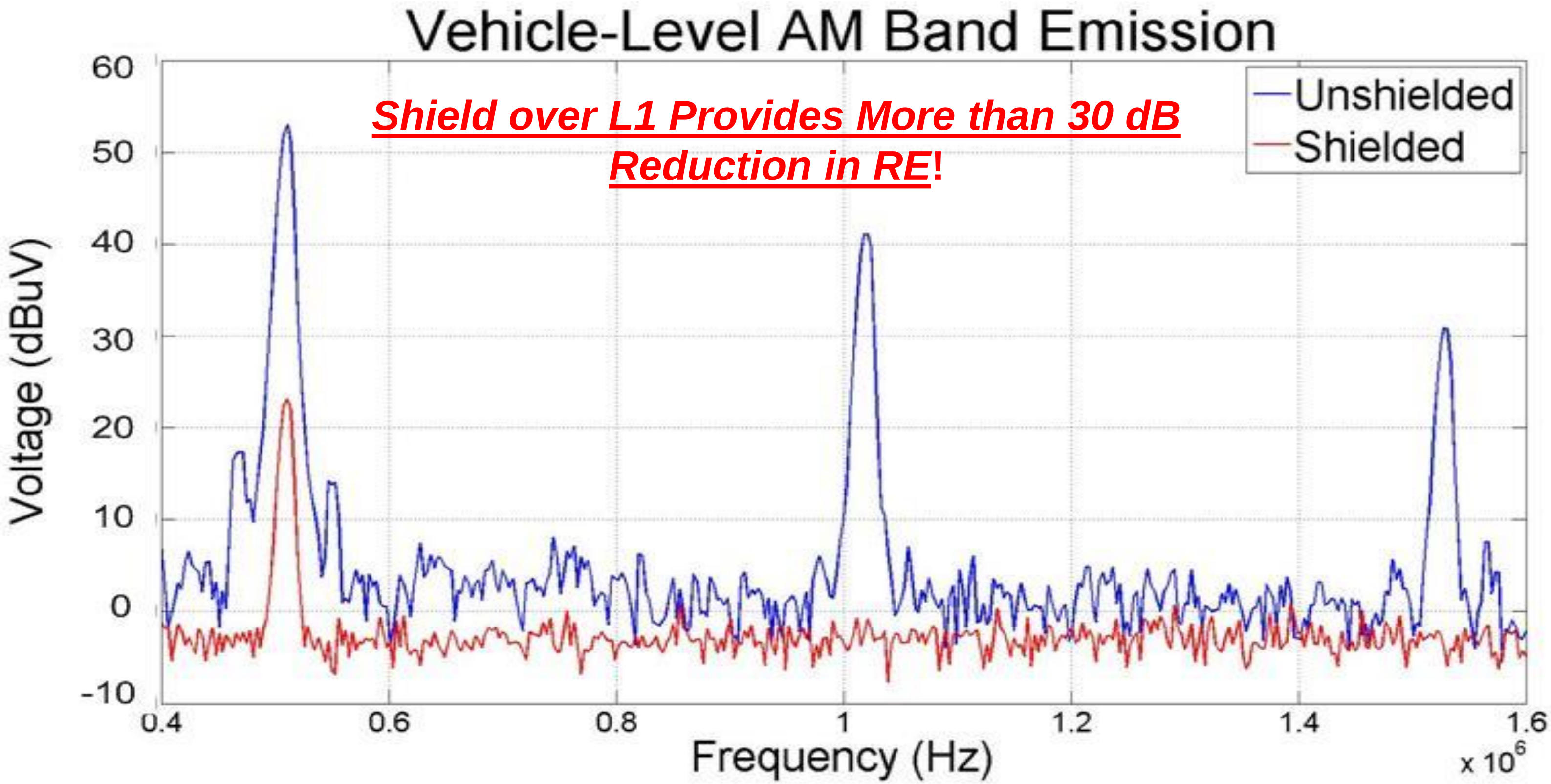
Vehicle Level AM Band RE Measurement

Antenna Cable is removed from Radio and connected to EMI Receiver via an Impedance Matching Network in large semi-anechoic chamber).



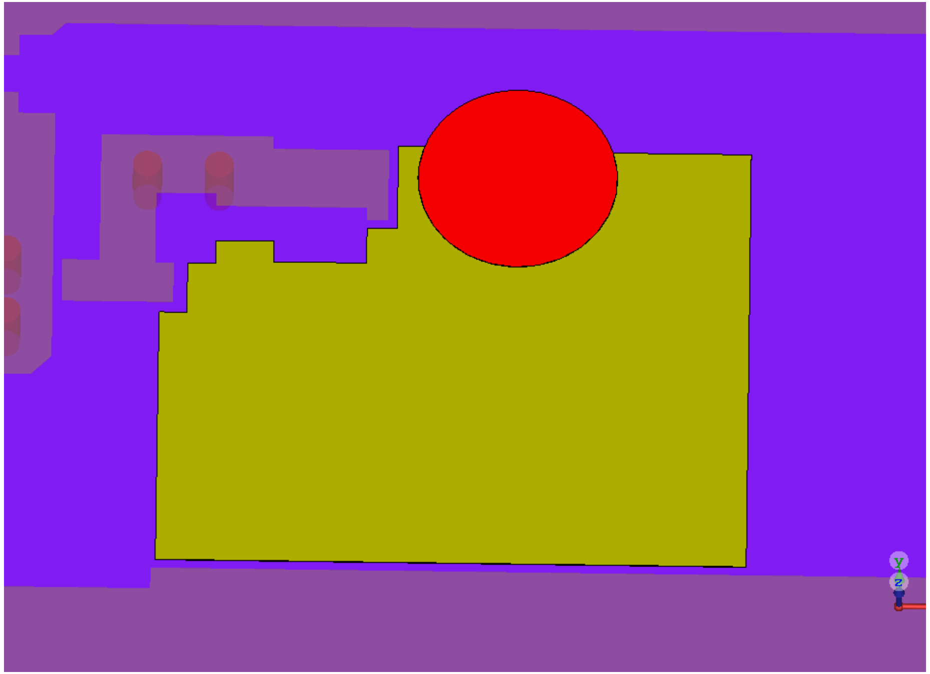
DC-DC Buck Converter with 10 Ω load is powered from vehicle Battery Supply (accessible from cigarette lighter outlet). It was placed ~ 1 meter away from rear glass antenna

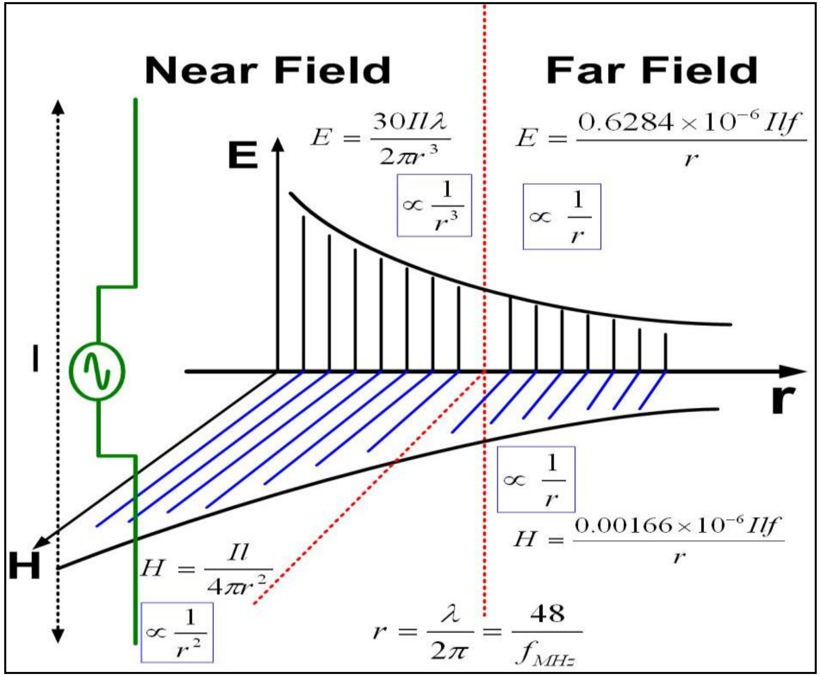
Reduction in Emission due to Shield



Near Field Coupling Interaction

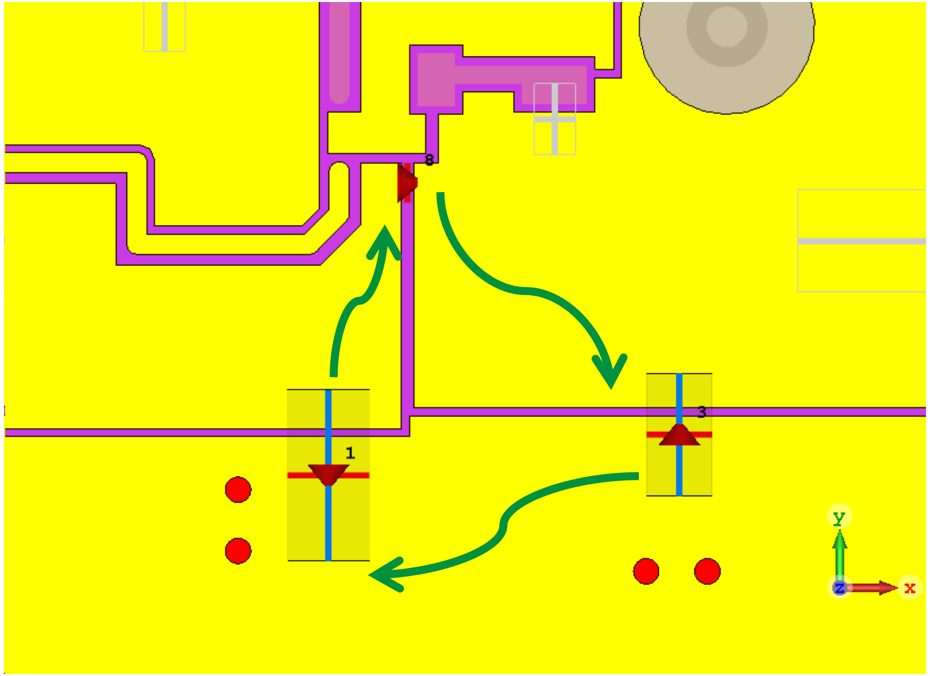
“Electric Dipole – E-Field Antenna”

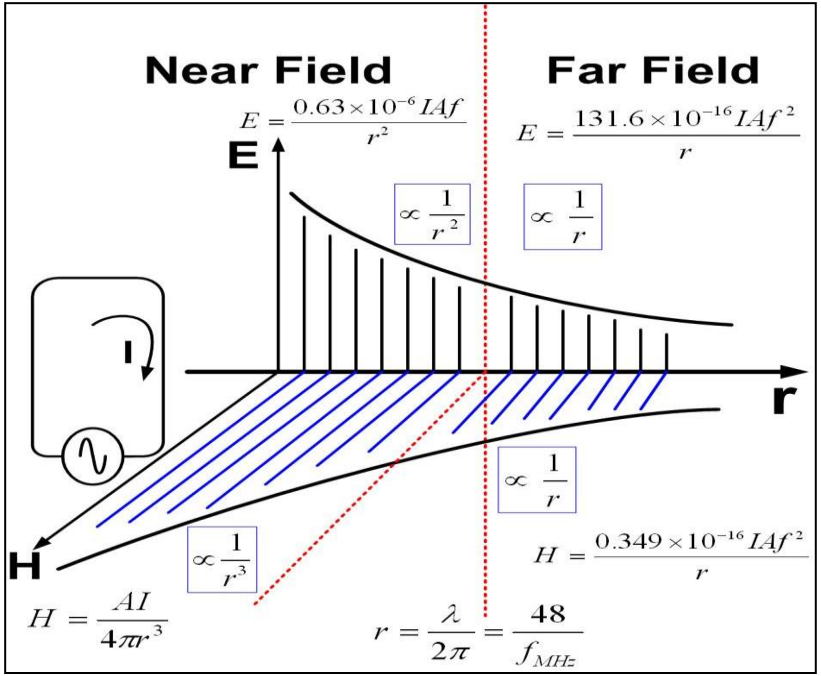




Near Field Coupling Interaction

"Magnetic Dipole – Loop Antenna"





Audio Recording in Nissan Altima

Courtesy of Cyrous Rostamzadeh, Bosch

Buck Converter OFF

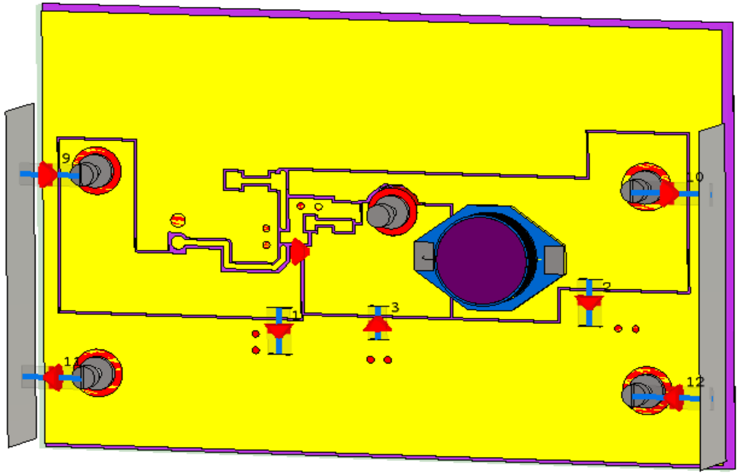
Buck Converter ON

AM 1000 kHz

January 6, 2016

Plymouth, Michigan

Modeling for Further Investigation



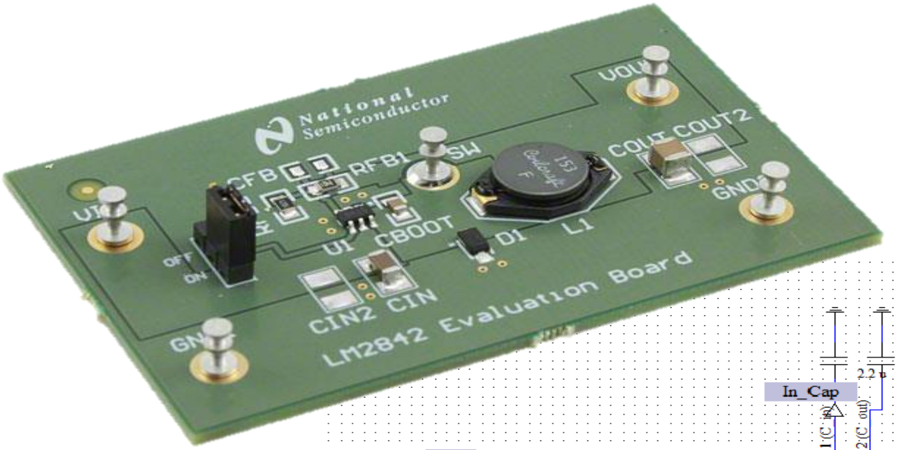
Instrumental to answer "what-if" scenarios?

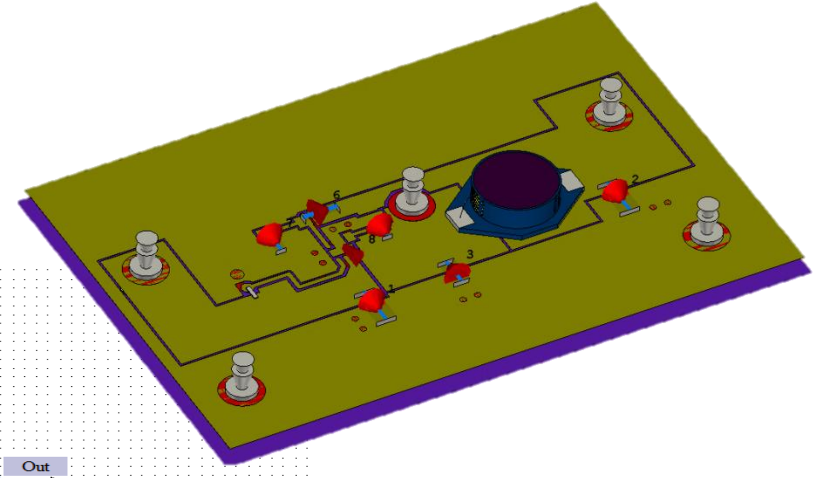
Exploit optimum SW Node "high dv/dt" trace area (parameterize geometry).

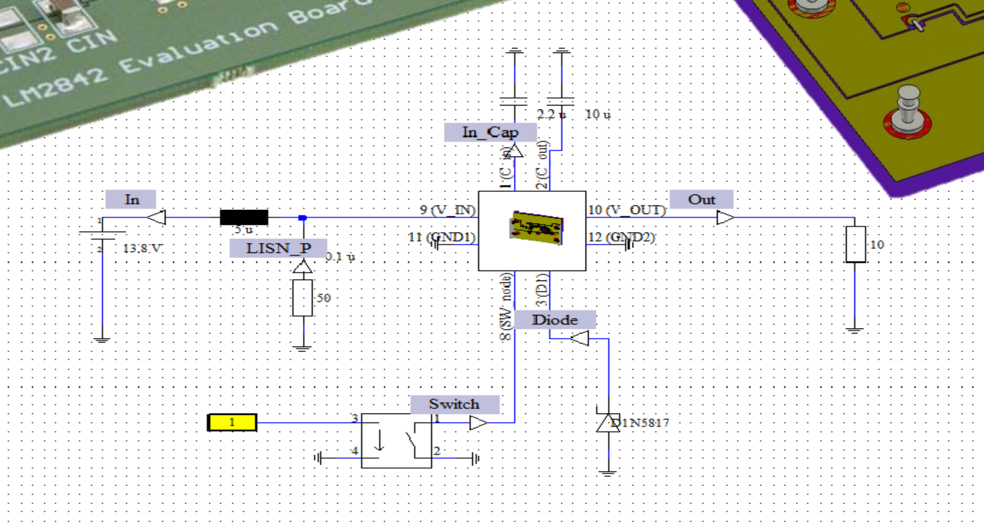
Extract parasitic inductances from PCB geometry.

Explore Shielding requirements "Shielding Effectiveness" for Compliance.

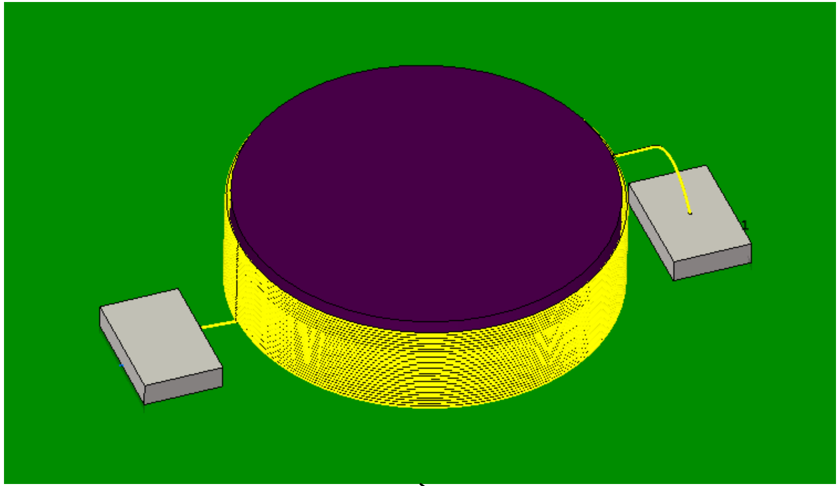
PCB Prototype vs. Model



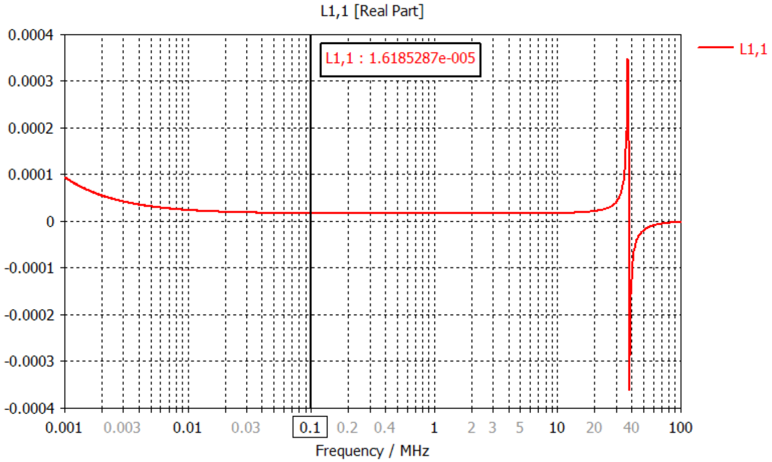




Inductor Coil Design

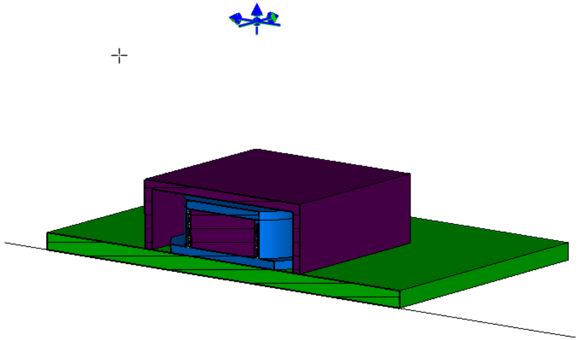


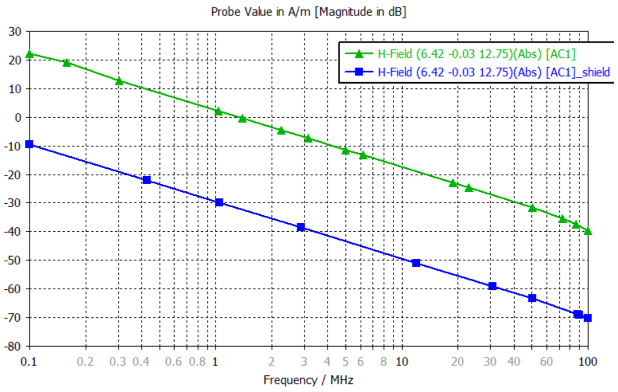
The coil was designed so that it matches the specifications. Inductance is 15 uH.

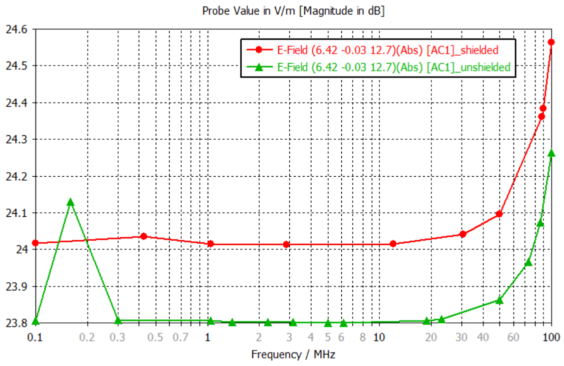


Inductor Model, Magnetic Shield

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).

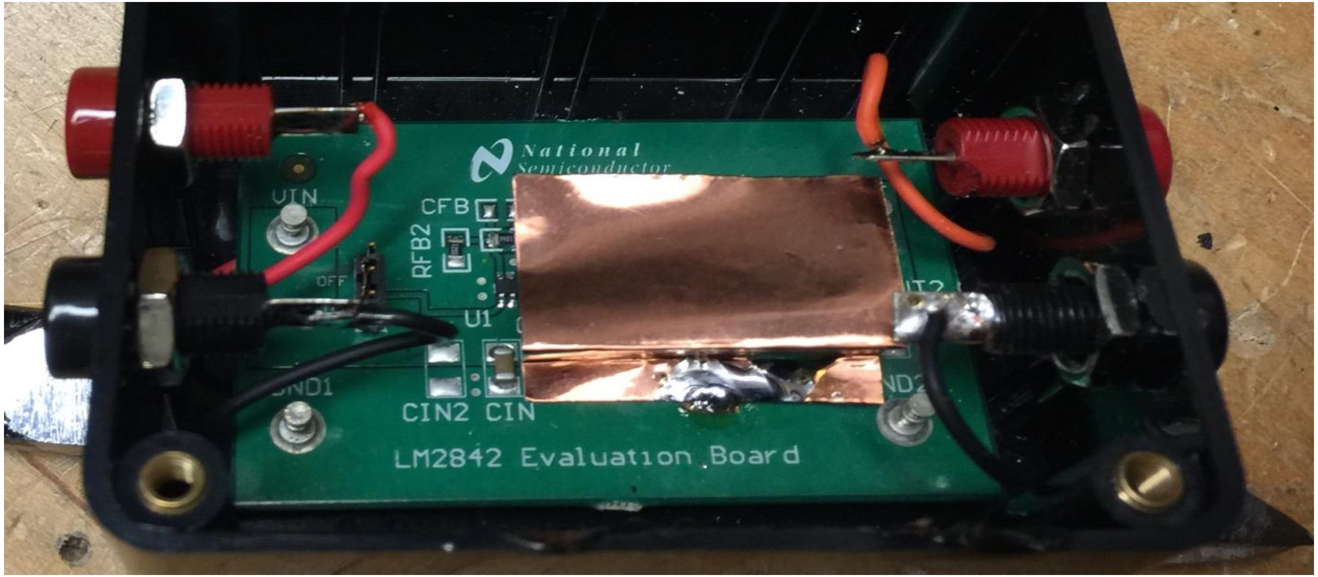






Inductor Shielded with Metal Sheet

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



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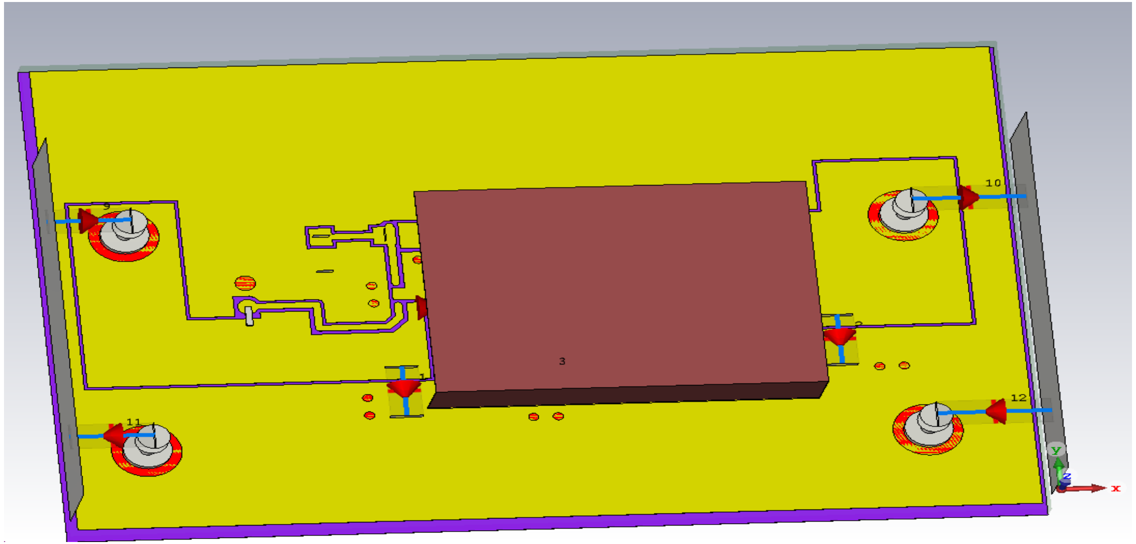

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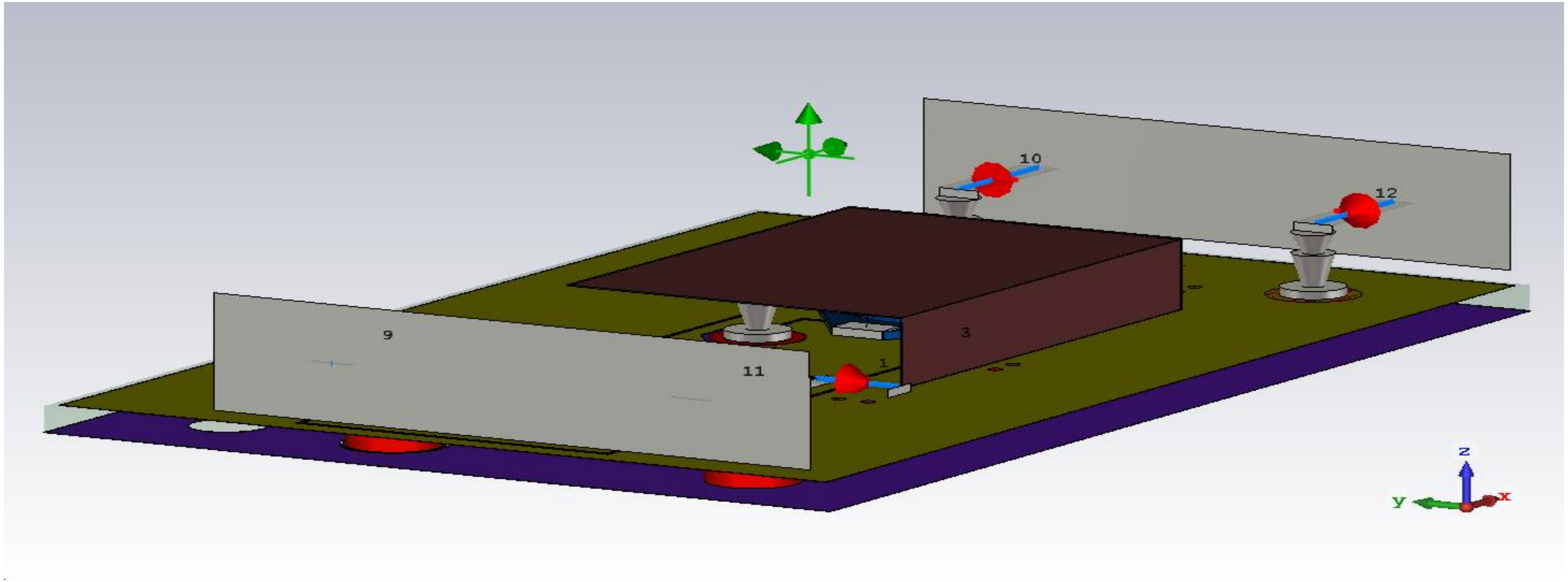

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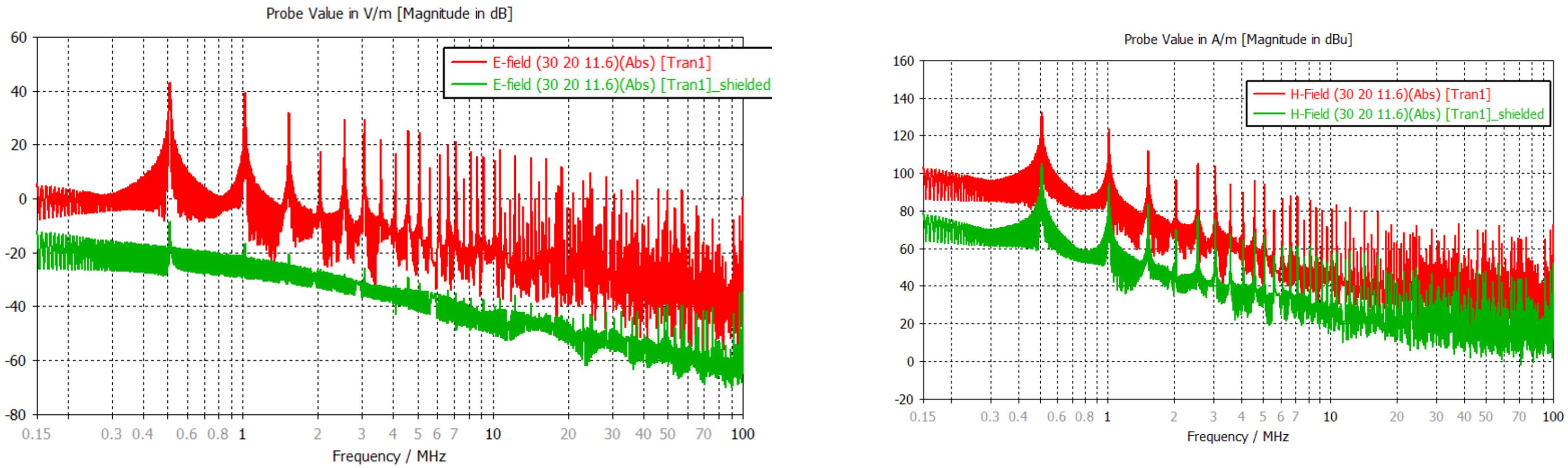
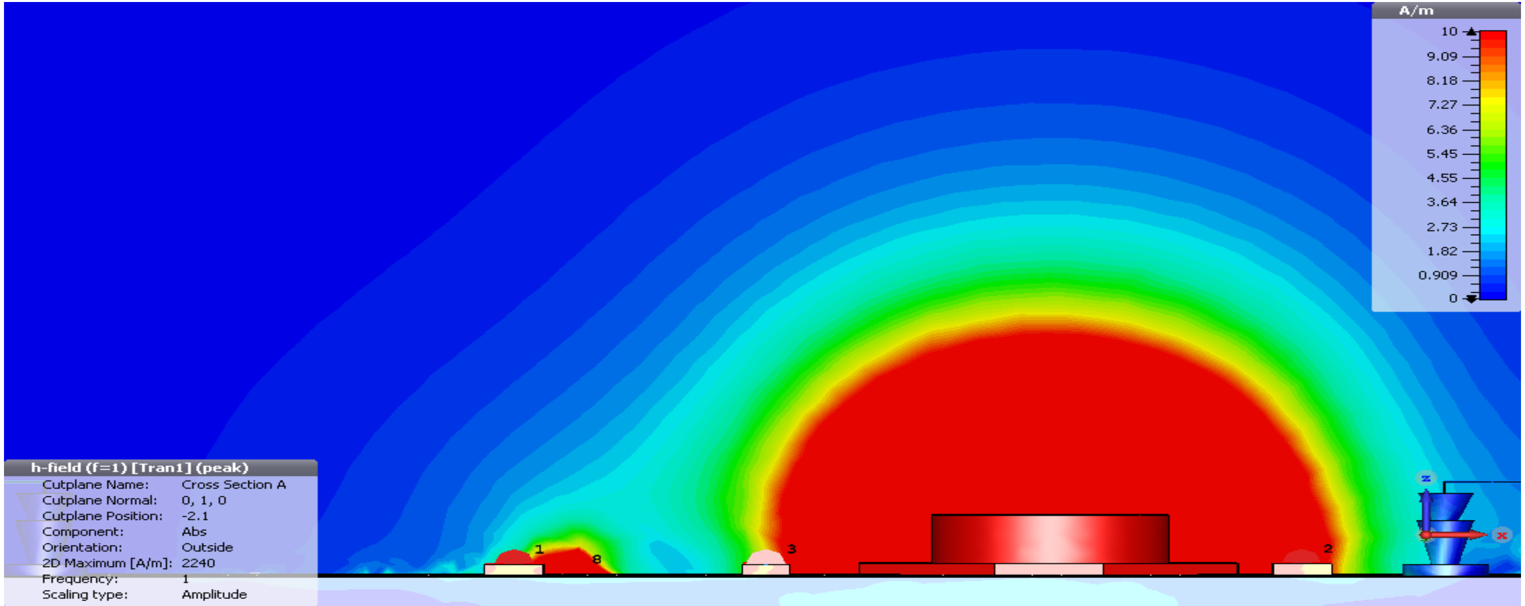


H-Field, 1 MHz, Side View

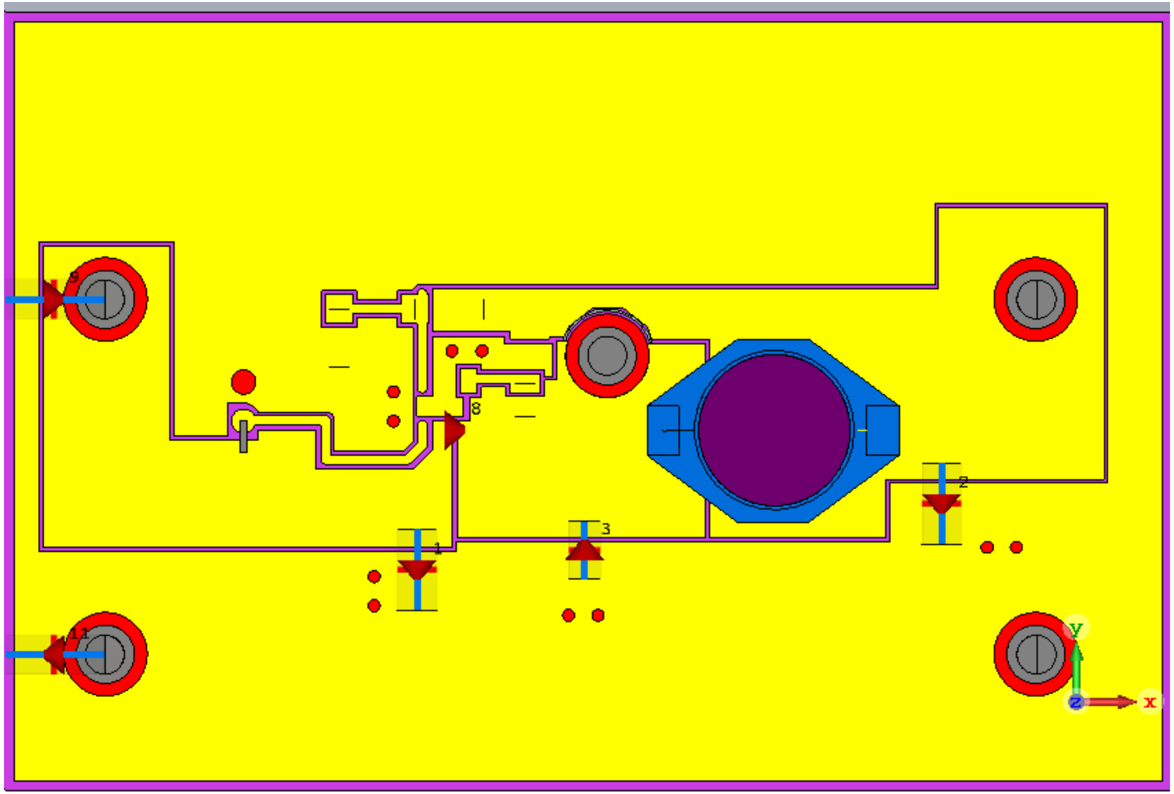
Unshielded



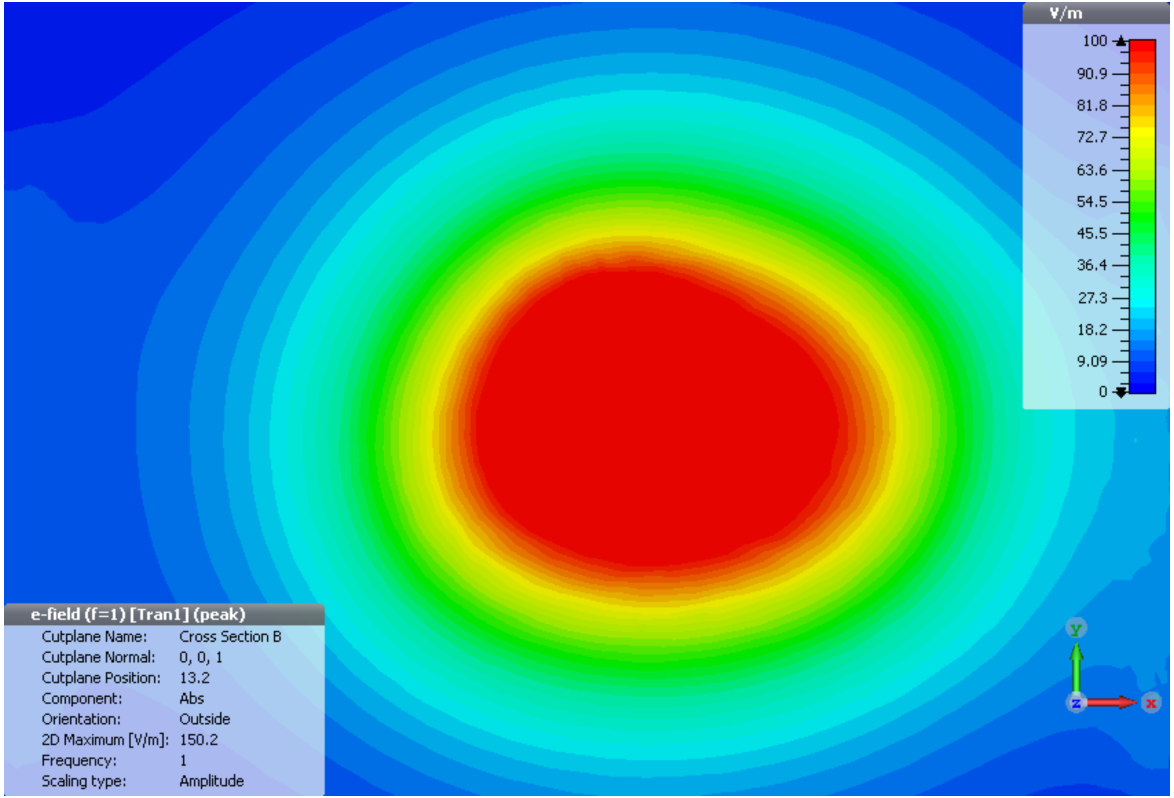
H-Field, 1 MHz, Side View

Magnetically Shielded

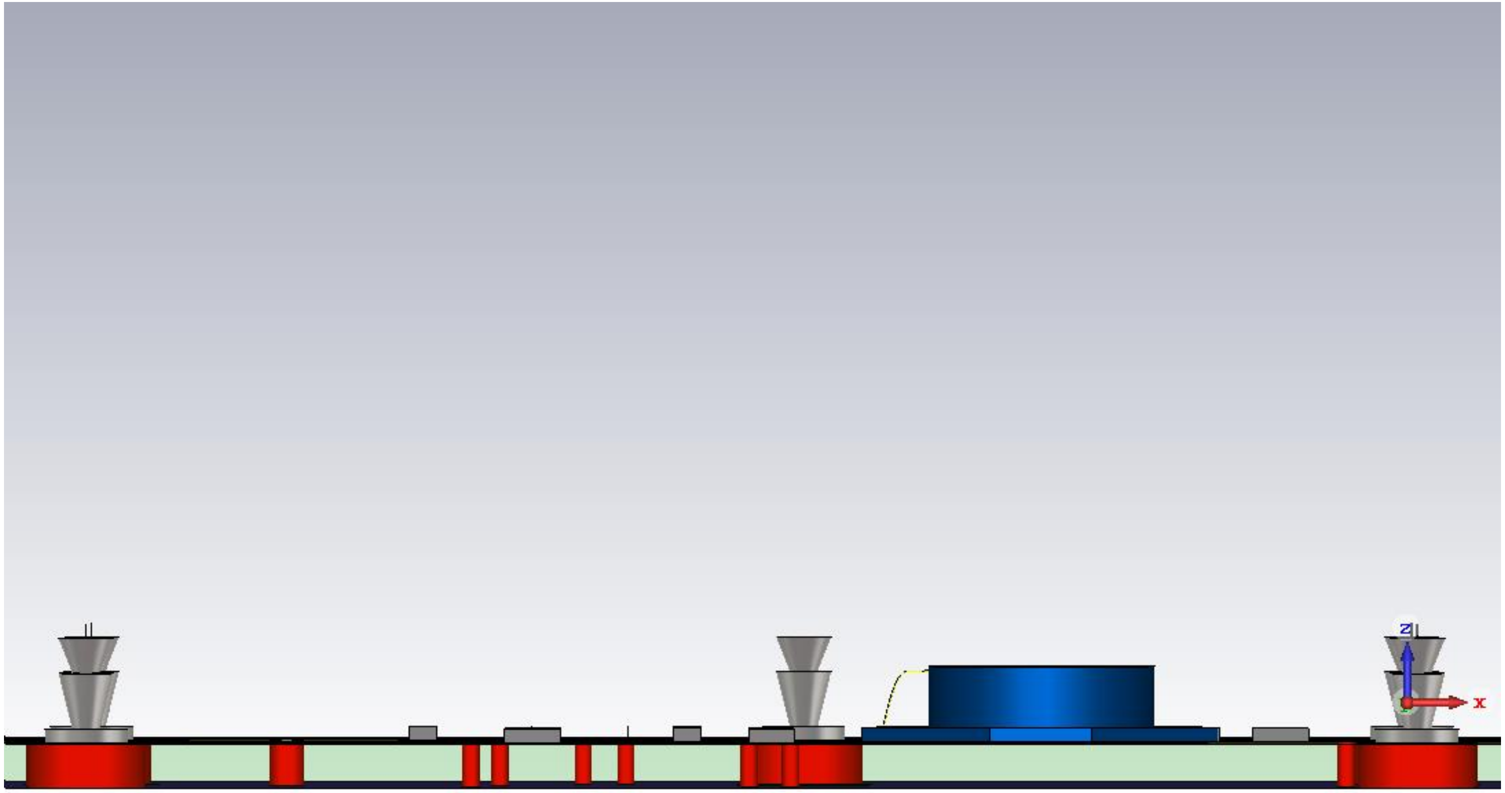
Unshielded, Ez 1cm above PCB



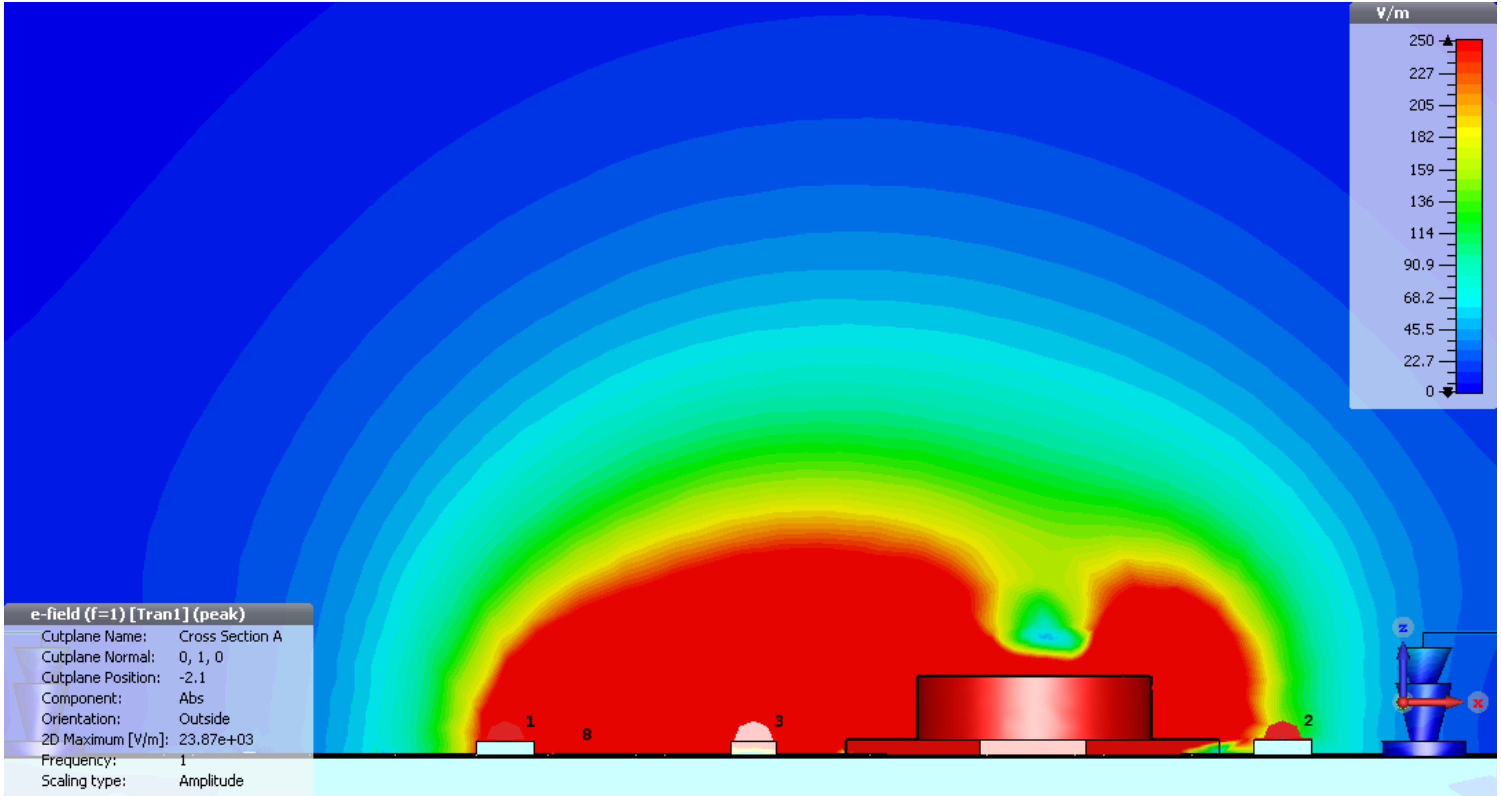
Unshielded, Ez 1cm above PCB



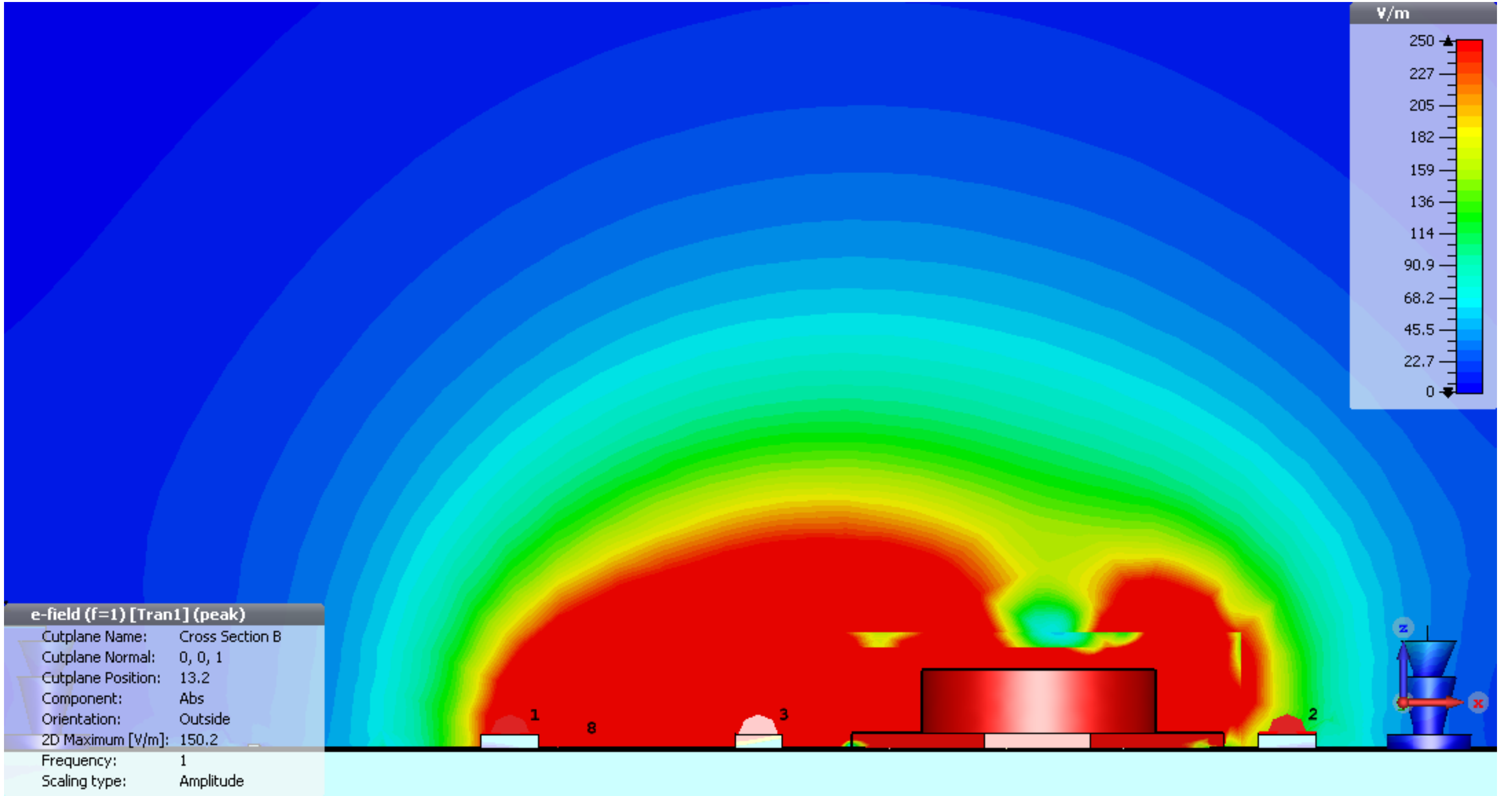
E-field, 1 MHz, Side View



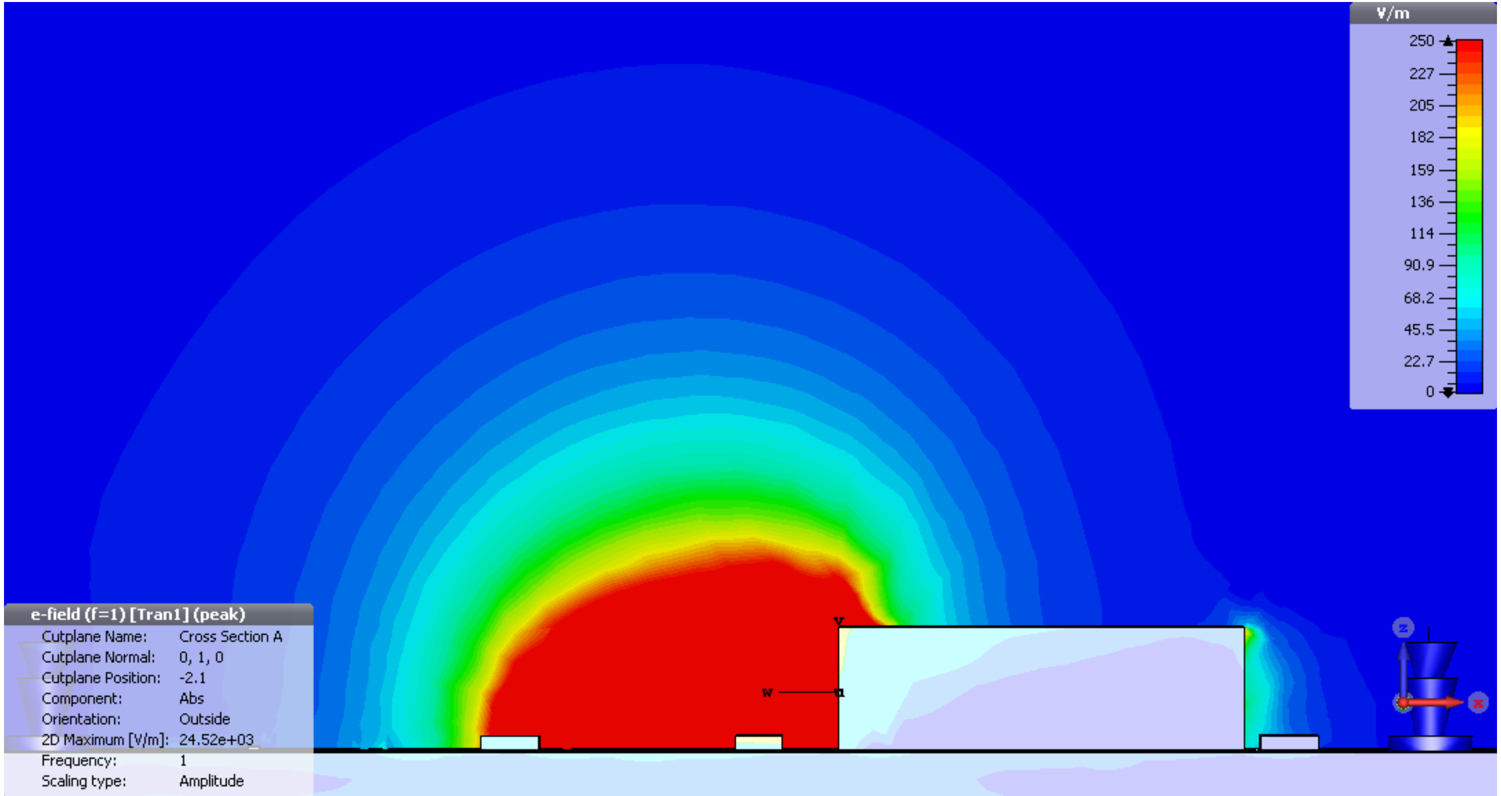
No Shielding



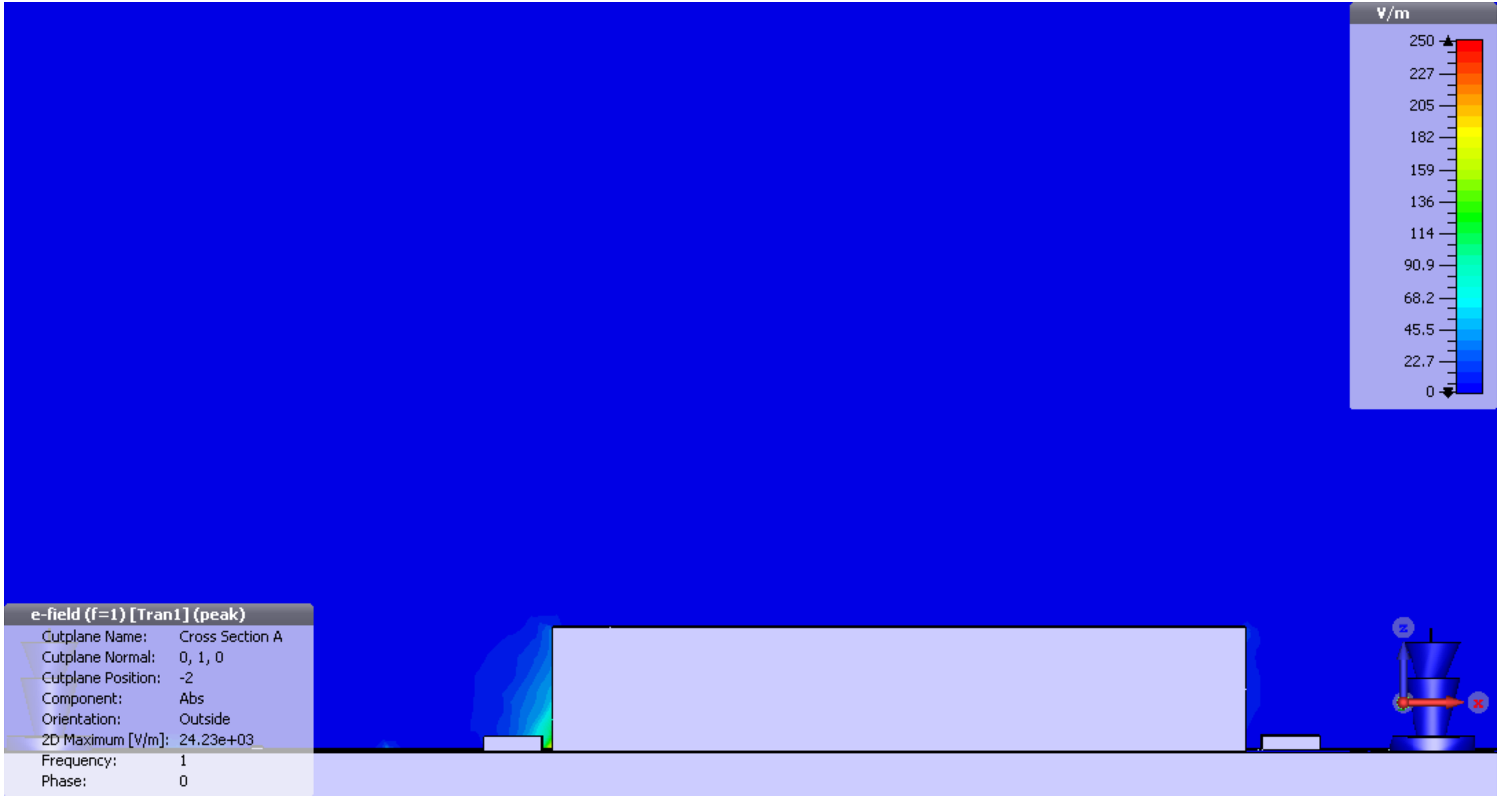
Magnetic Shield over Inductor



Electric Shield over Inductor only



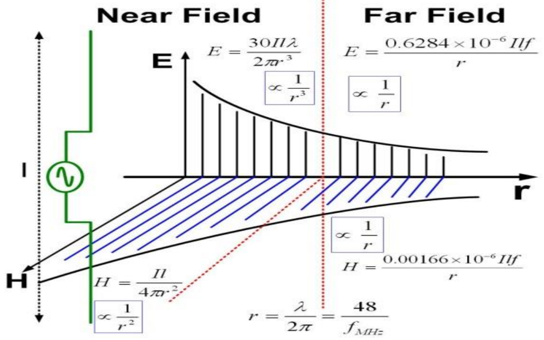
Electric Shield over Inductor + SW Node



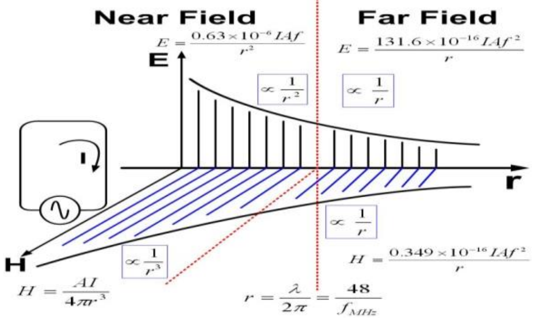
Near Field Coupling

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>.

Summary

SMPS EMI is a real problem, especially for automotive (ever more complex electromagnetic environment)

Time domain measurements revealed higher frequency noise, near field probes revealed AM Band noise – two different effects (E and H fields)

Must take care with PCB layout and high dV/dt of Switch Node

Shielding of inductor and large switch node trace proven to reduce emissions

Validation and verification of experimental findings with CEM simulation software