KEYSIGHT

# Electromagnetic Analysis of PCB Parasitic Effects in High Speed Switching Circuits


**Francesco Palomba, Technical Support Manager**

**June 12, 2025**

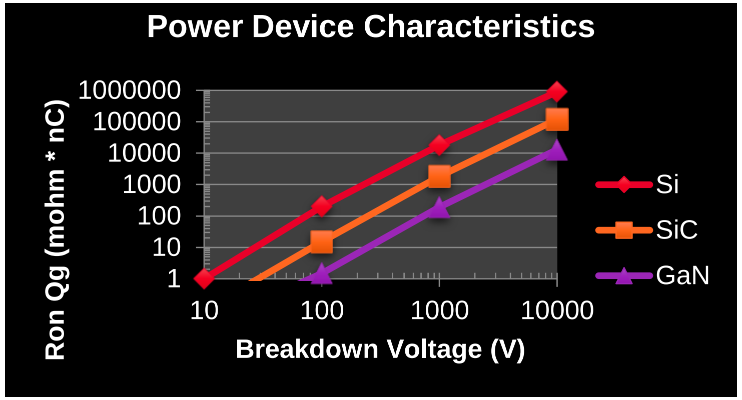
# Power Electronics: Trends That Drive Design

ET2025
XXXIX RIUNIONE ANNUALE DEI RICERCATORI DI ELETTROTECNICA
12 - 13 Giugno Villasimius (CA)

Higher Power Densities (power delivered/unit size)

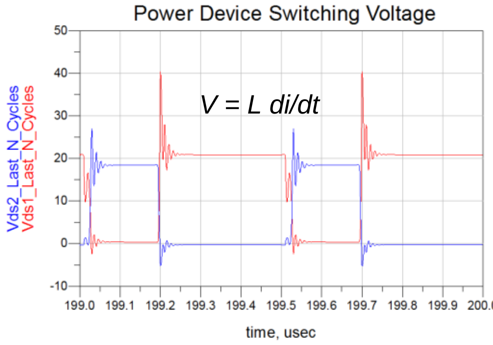
LITTLE BOX CHALLENGE

Higher efficiency, shrinking form factor



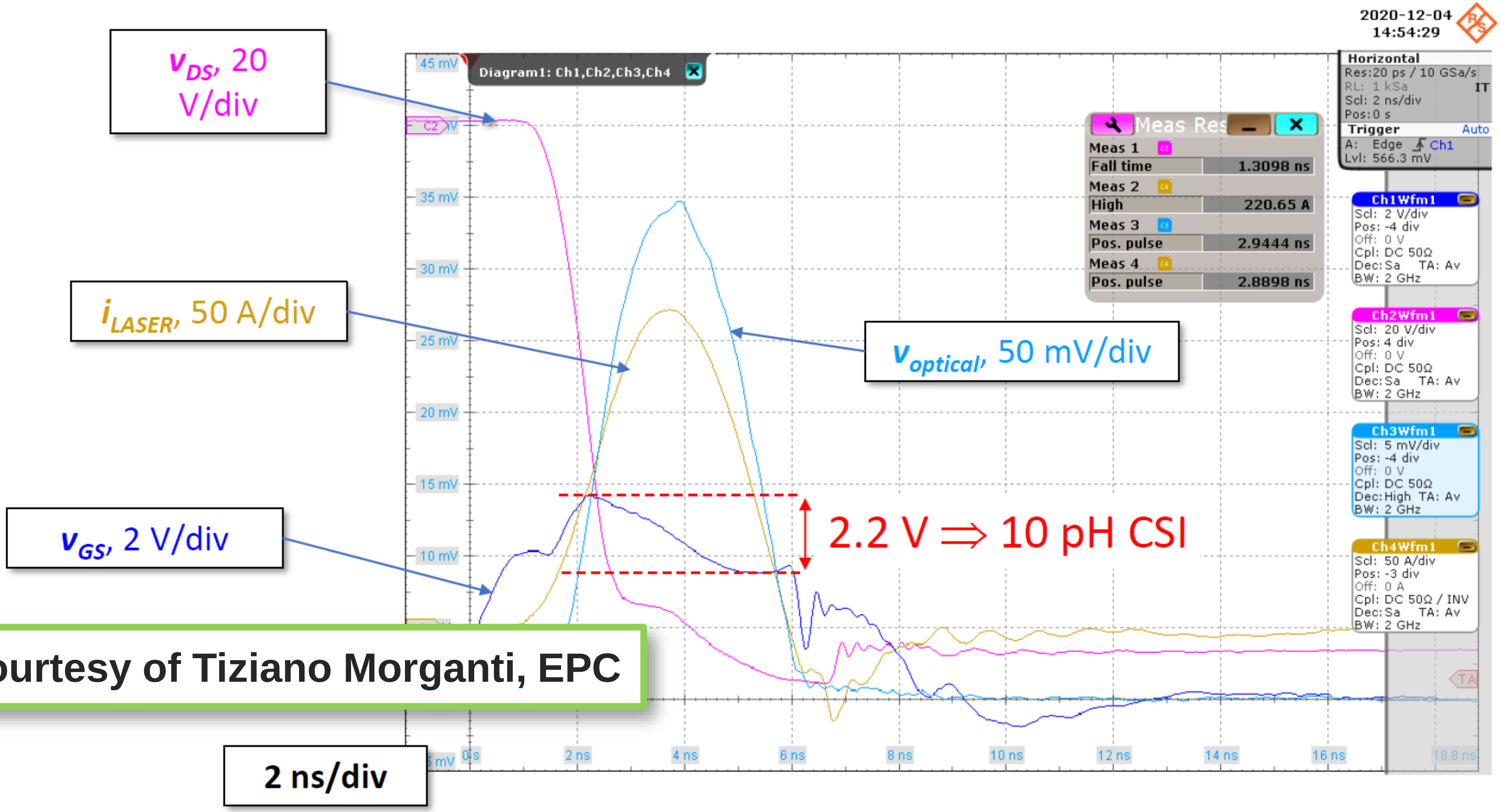

Higher clock frequencies, faster switching edges

Need for newer device technologies (GaN, SiC)




Device models, layout parasitics, EMI, di/dt, thermal mgmt

# Measurement of EPC9150 215 A laser driver




**Courtesy of Tiziano Morganti, EPC**

**Measured**

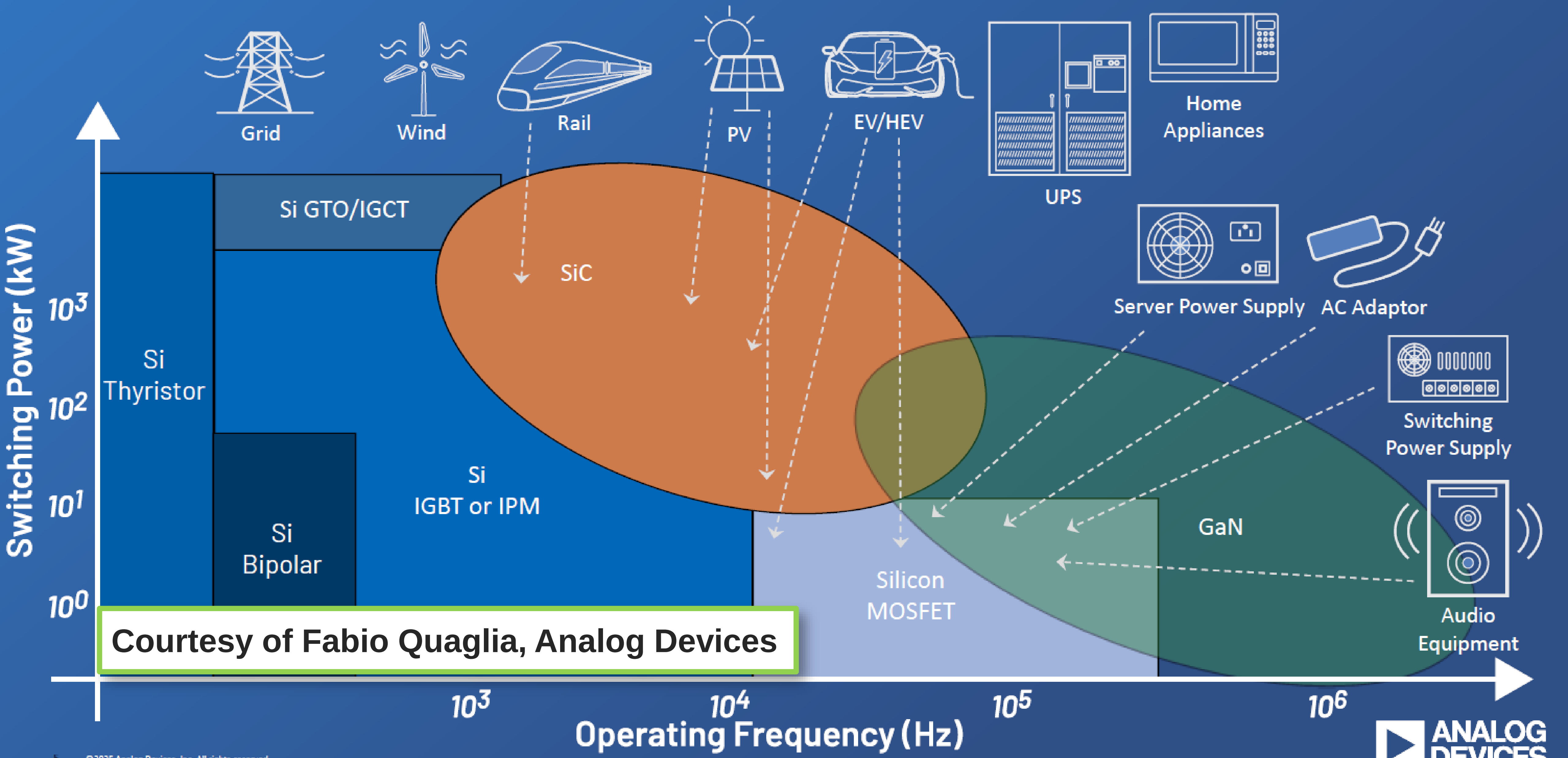
$I_{pk}$ = 221 A

$t_{PW}$ = 2.94 ns

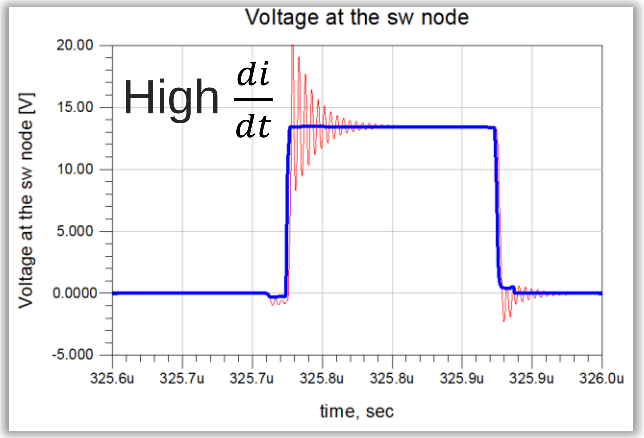
EPC2034C

200 V, 6 mΩ

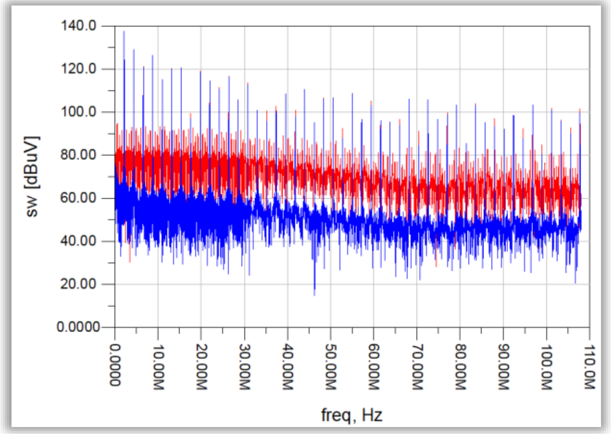
# Power Device Competitive Zone



# High Frequency Effects




Red with Layout



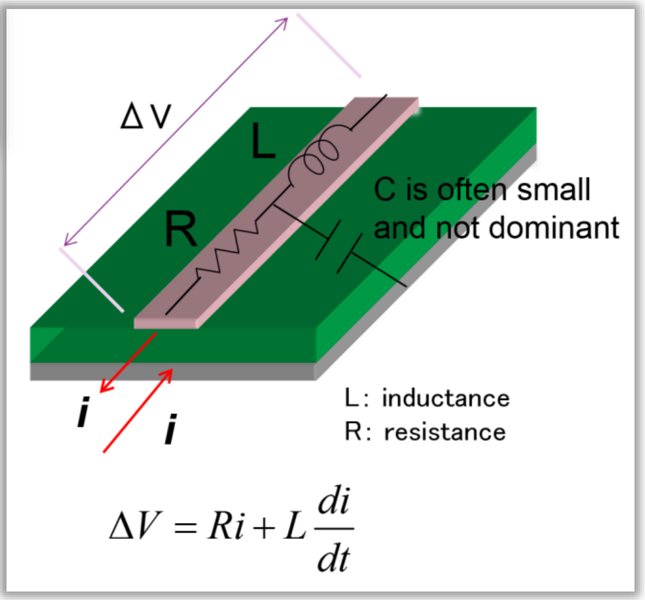

Blue without Layout

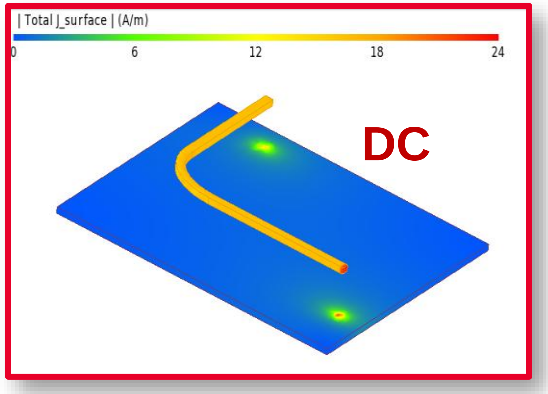
| Skin Depth vs Frequency | | |
|---|---|---|
| Frequency | microns | mils |
| 10 KHz | 661 | 26 |
| 100 KHz | 209 | 8.2 |
| 1 MHz | 66 | 2.6 |
| 10 MHz | 21 | 0.8 |
| 100 MHz | 7 | 0.3 |

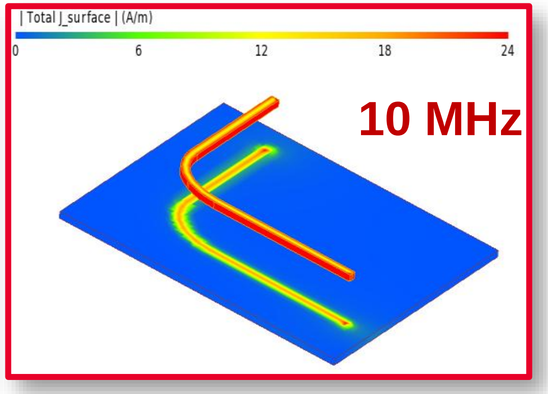
| Skin Resistance vs Frequency | |
|---|---|
| Frequency | mohms |
| 1 MHz | 5 |
| 10 MHz | 12 |
| 100 MHz | 40 |
| 1000 MHz | 224 |

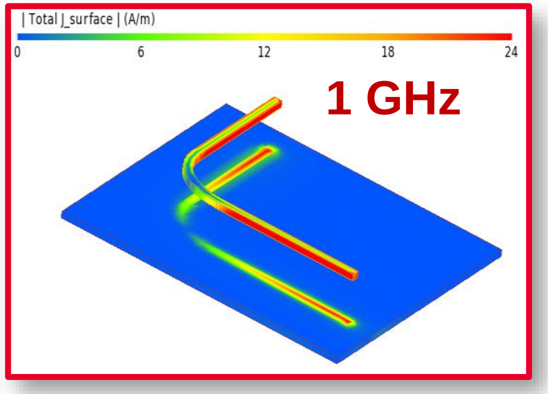
$$\frac{dI}{dt} \geq \frac{1A}{ns}$$

$$\Delta V = R(f)i + L\frac{di}{dt}$$



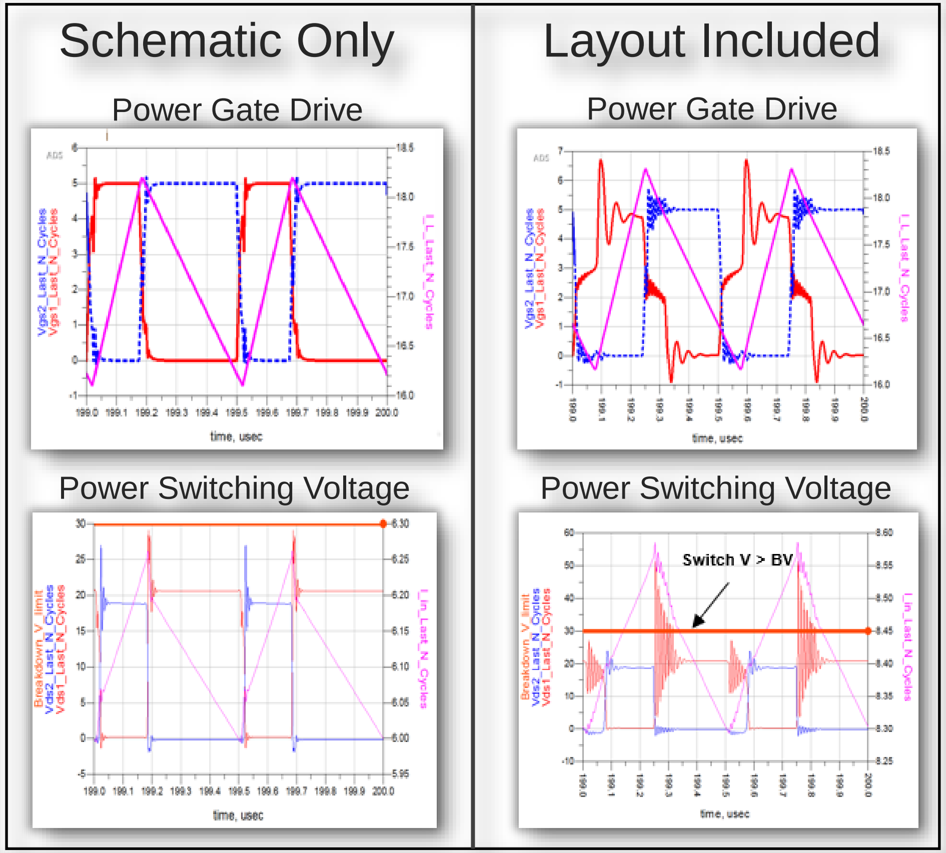



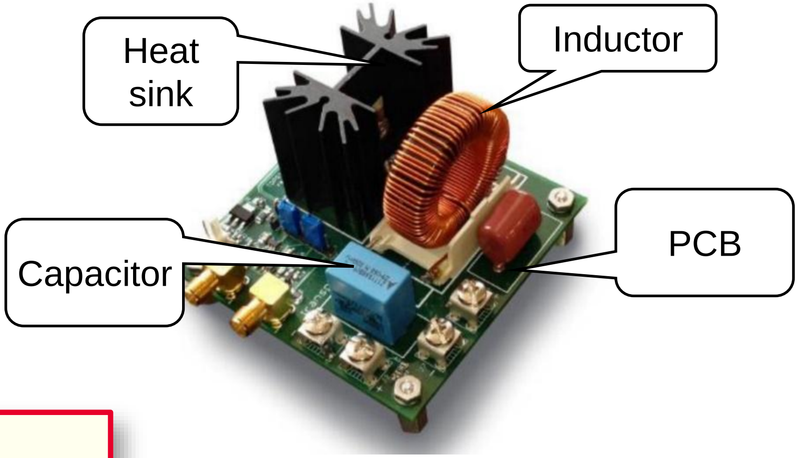



# Challenges SMPS Design

## Technical Challenges

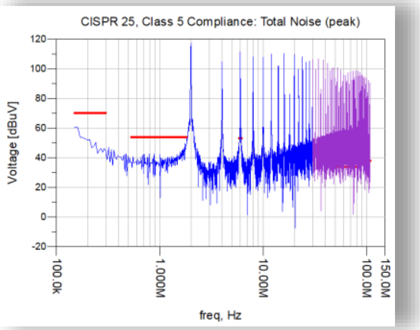
- Layout parasitics can cause spikes
- $V_{spike} = L_{parasitic}\ di/dt$



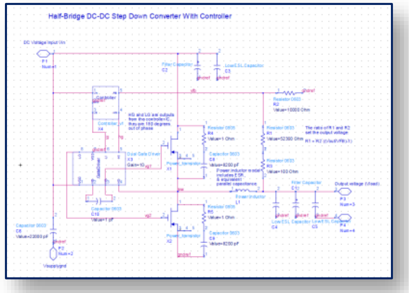

***Major risks***

- Destruction
- Heat
- Malfunction
- Disruption
- Low Efficiency
- Radiation
- EMC Problems

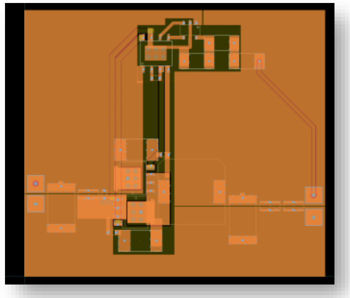


# ADS-PEPro Workflow

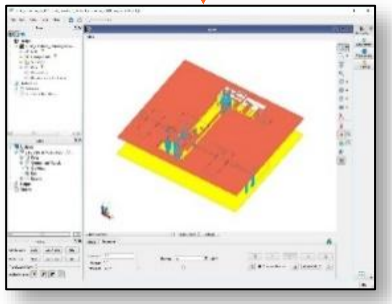
Schematic design



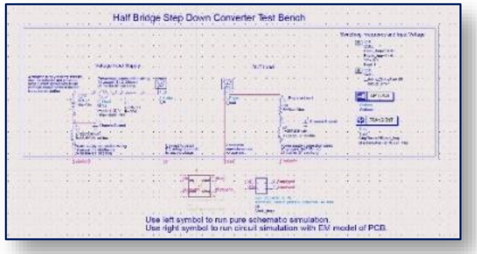

Layout design

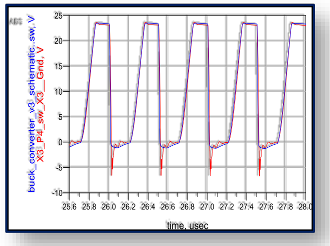


EM analysis / parasitic extraction



EM-circuit cosimulation



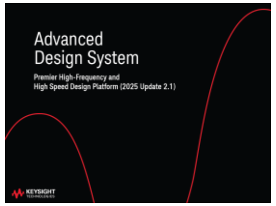




ADS schematic : Circuit verification → ADS Layout : Layout verification → PCB EM analysis → Post Layout : verification using testbench → Prototype

Modify PCB design

Modify Schematic design

Analysis by circuit and PCB S-parameter
(Enable to create PSPICE model from S-parameter)



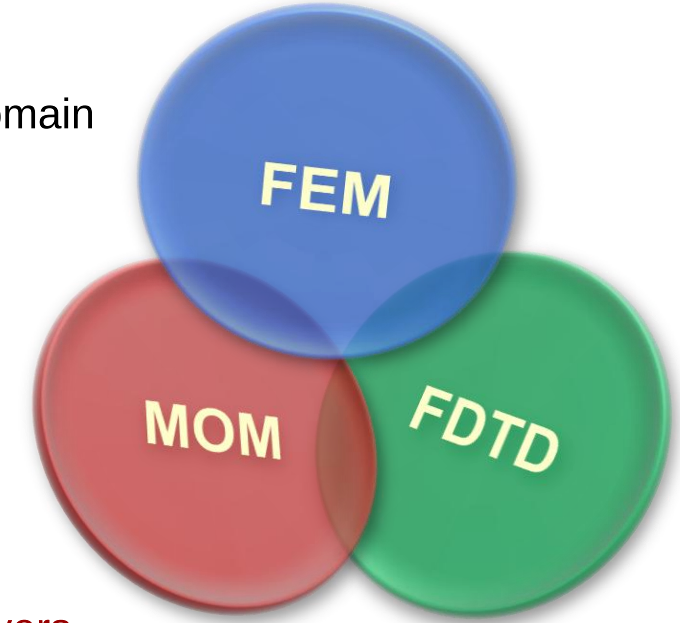
# 3D EM Simulation Technologies



FEM - Finite Element Method

MOM - Method of Moments

FDTD - Finite Difference Time Domain Method



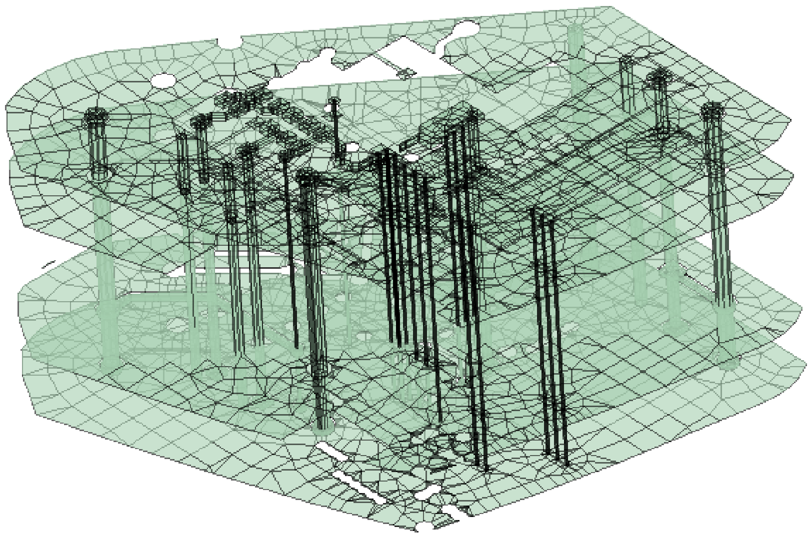

- Arbitrary 3D structures
- Frequency Domain
- Full Wave EM Simulations
- Direct, Iterative Solvers
- Multiport Simulations at no Additional Cost
- High Q
- ADS or EMPro UI

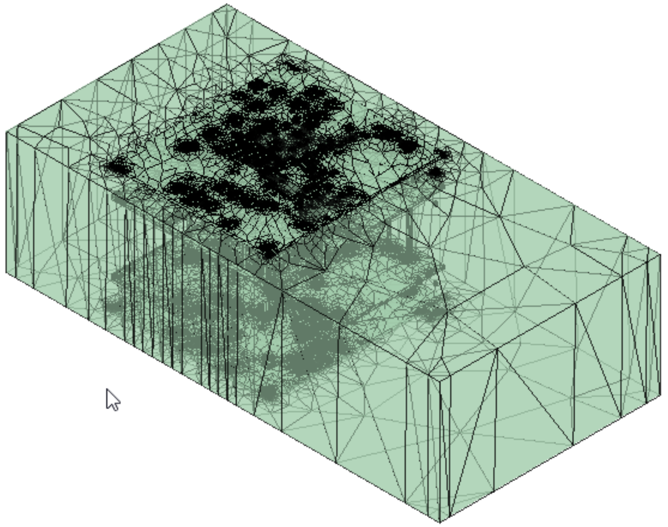
- Restricted 3D Structures
- Frequency Domain
- Full-Wave and Quasi-Static Simulations
- Dense & Compressed Matrix Solvers
- Multiport Simulations at no Additional Cost
- High Q
- ADS UI

- Arbitrary 3D structures
- Time Domain
- Full Wave EM Simulations
- Handles much larger and complex problems (e.g., complete mobile phone)
- Each port requires separate simulation
- GPU based hardware acceleration
- EMPro UI

# Electromagnetic Simulation Results







## 1 MoM

- Planar Mesh only for conductors
- Pre-computed mesh
- It solves for currents and voltages
- It provides S-parameters, Current Density and Far Field

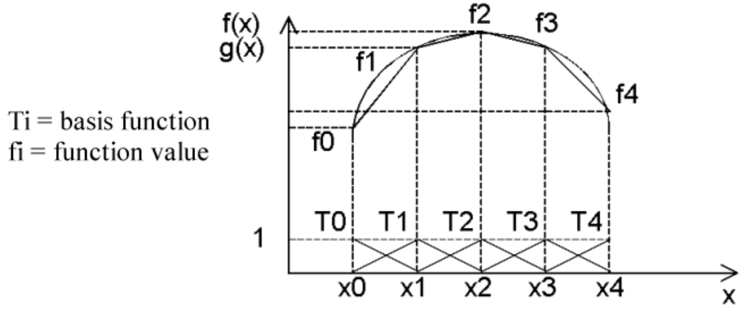
## 2 FEM

- Volume mesh for the full geometry
- Mesh refinement
- It solves for E and H
- It provides S-parameters, Near Field, Far Field

# Method of Moments

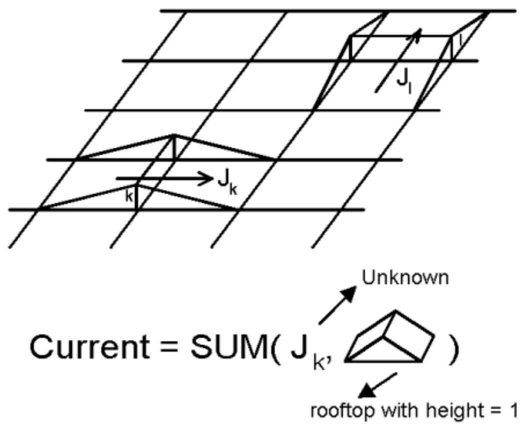
## Basis Functions

- Mesh is used to define rooftop approximating functions for the edge currents
- Amplitudes (f0, f1, f2, …) are unknown and must be computed
- Current is assumed to vary along direction of travel and be constant across the other direction (think of how current moves on a TL)



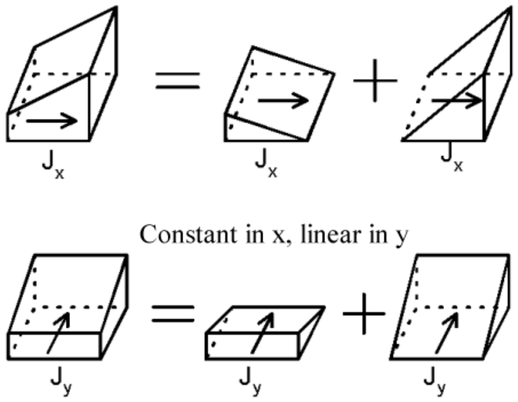

$$f(x) = f_0 * T_0(x) + f_1 * T_1(x) + f_2 * T_2(x) + f_3 * T_3(x)$$

the_02.gif




the_06.gif

Constant in y, linear in x

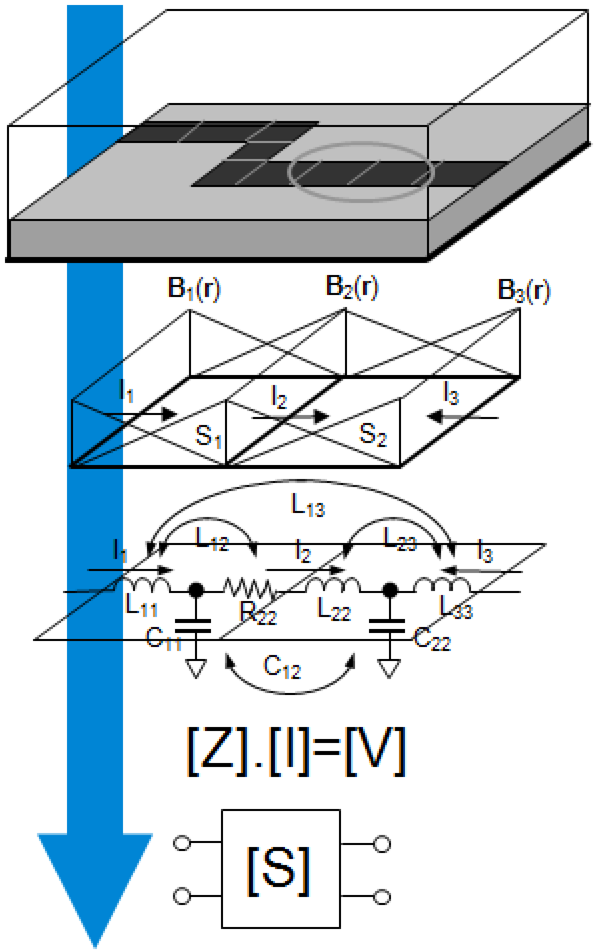


Constant in x, linear in y

the_05.gif

# Full Wave Method of Moments – Momentum uWave






- Full wave electric & magnetic Green's functions

$$e^{-jk|\mathbf{r}-\mathbf{r'}|}$$

- MoM problem can be mathematically thought of as a **3D equivalent circuit network with frequency-dependent R's, L's, and C's**
- An **impedance matrix** is created and then solved that allows us to obtain the current amplitudes based on the excitations at the ports

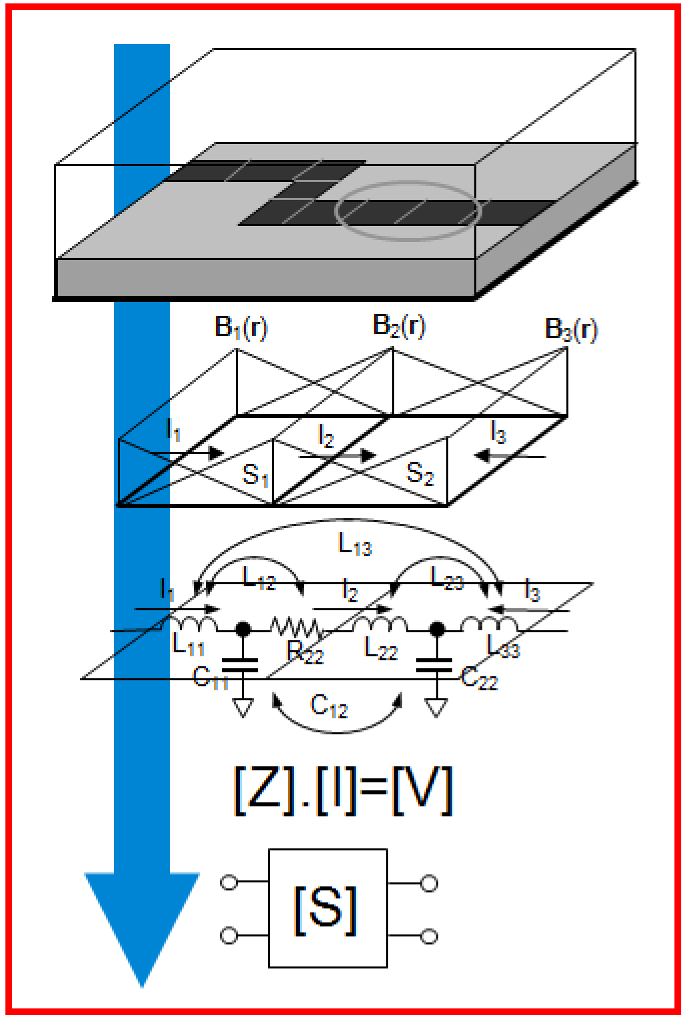
$$Z_{ij}^{L} = j\omega L_{ij}(\omega) = \iint_{S_i} dS \iint_{S_j} dS' \, G_m(\omega, \mathbf{r}-\mathbf{r'}) \, \mathbf{B}_i(\mathbf{r}) \cdot \mathbf{B}_j(\mathbf{r'})$$

$$Z_{ij}^{C} = \frac{1}{j\omega C_{ij}(\omega)} = \iint_{S_i} dS \iint_{S_j} dS' \, G_e(\omega, \mathbf{r}-\mathbf{r'}) \, \nabla \cdot \mathbf{B}_i(\mathbf{r}) \, \nabla \cdot \mathbf{B}_j(\mathbf{r'})$$

$$Z_{ij}^{R} = R_{ij}(\omega) = Z_S(\omega) \iint_{S_i} dS \iint_{S_j} dS' \, \delta(\mathbf{r}-\mathbf{r'}) \, \mathbf{B}_i(\mathbf{r}) \cdot \mathbf{B}_j(\mathbf{r'})$$

See *R. F. Harrington, Field Computation by Moment Methods* . Maxillan, New York (1968).

# Quasi Static Method of Moments – MomentumRF




**Low Frequency approximation :**

$$e^{-jk|\mathbf{r}-\mathbf{r}'|} \approx 1 - jk\,|\mathbf{r}-\mathbf{r}'|$$

- Electro- and magnetostatic Green's functions
- Quasi-static frequency scaling (jω, 1/jω)
- L's and C's are real and frequency independent
- R's are complex (DC loss + skin effect $\sqrt{\omega}$)

**[Z] matrix load is frequency independent !**

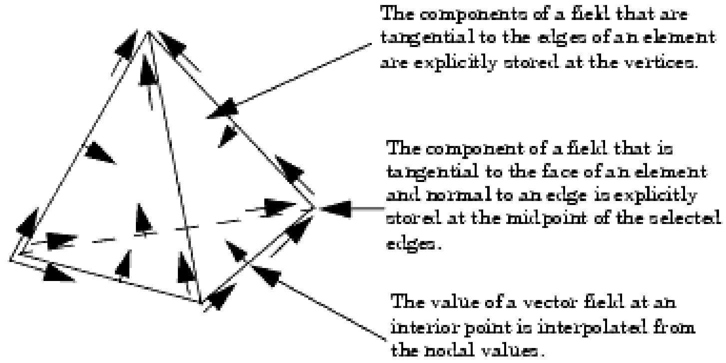
$$Z^L_{ij} = j\omega L_{ij} = j\omega \iint_{S_i} dS \iint_{S_j} dS'\, G_m(\mathbf{r}-\mathbf{r}')\,\mathbf{B}_i(\mathbf{r})\cdot\mathbf{B}_j(\mathbf{r}')$$

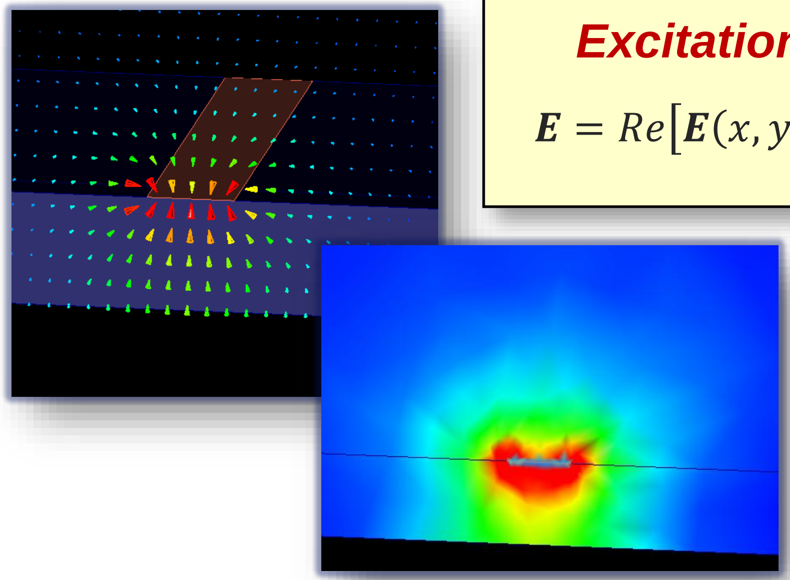
$$Z^C_{ij} = \frac{1}{j\omega C_{ij}} = \frac{1}{j\omega} \iint_{S_i} dS \iint_{S_j} dS'\, G_e(\mathbf{r}-\mathbf{r}')\,\nabla\cdot\mathbf{B}_i(\mathbf{r})\,\nabla\cdot\mathbf{B}_j(\mathbf{r}')$$

$$Z^R_{ij} = R_{ij}(\omega) = Z_s(\omega) \iint_{S_i} dS \iint_{S_j} dS'\, \delta(\mathbf{r}-\mathbf{r}')\,\mathbf{B}_i(\mathbf{r})\cdot\mathbf{B}_j(\mathbf{r}')$$

# FEM





**Excitation field**

$$\boldsymbol{E} = Re\left[\boldsymbol{E}(x,y)e^{j\omega t-\gamma z}\right]$$

- **2D Problem to define the excitation**

$$\nabla \times \left(\frac{1}{\mu_r}\nabla \times \boldsymbol{E}(x,y)\right) - k_0^2\varepsilon_r\boldsymbol{E}(x,y) = 0 \qquad k_0 = \sqrt{\mu_0\varepsilon_0}$$

- **Full 3D equation for E**

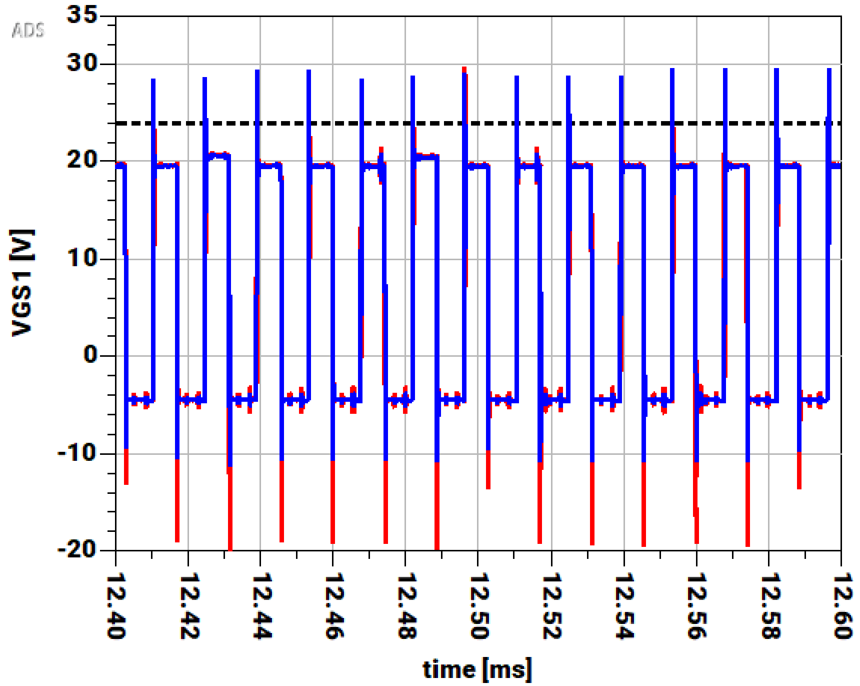
$$\nabla \times \left(\frac{1}{\mu_r}\nabla \times \boldsymbol{E}(x,y,z)\right) - k_0^2\varepsilon_r\boldsymbol{E}(x,y,z) = 0$$

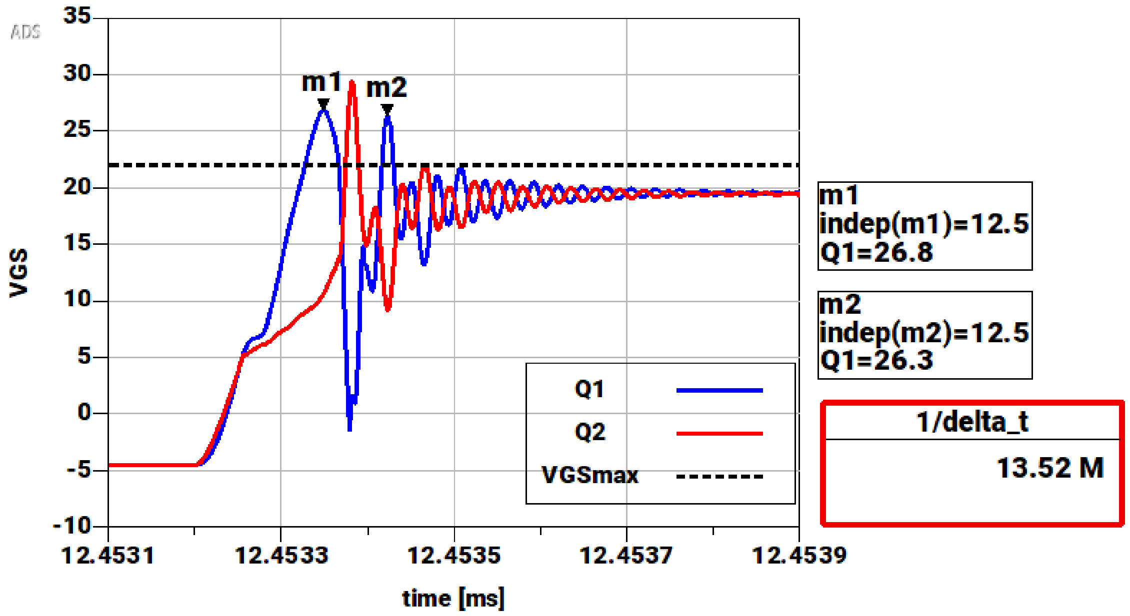
- **Multiply by the phasor to obtain the physical field**

$$\boldsymbol{E}(x,y,z,t) = Re\left[\boldsymbol{E}(x,y,z)e^{j\omega t}\right] \qquad \boldsymbol{H} = \frac{\nabla \times \boldsymbol{E}}{-j\omega\mu}$$

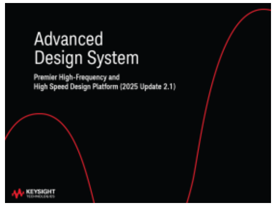
# Simulation Results

## Voltage Overshoot



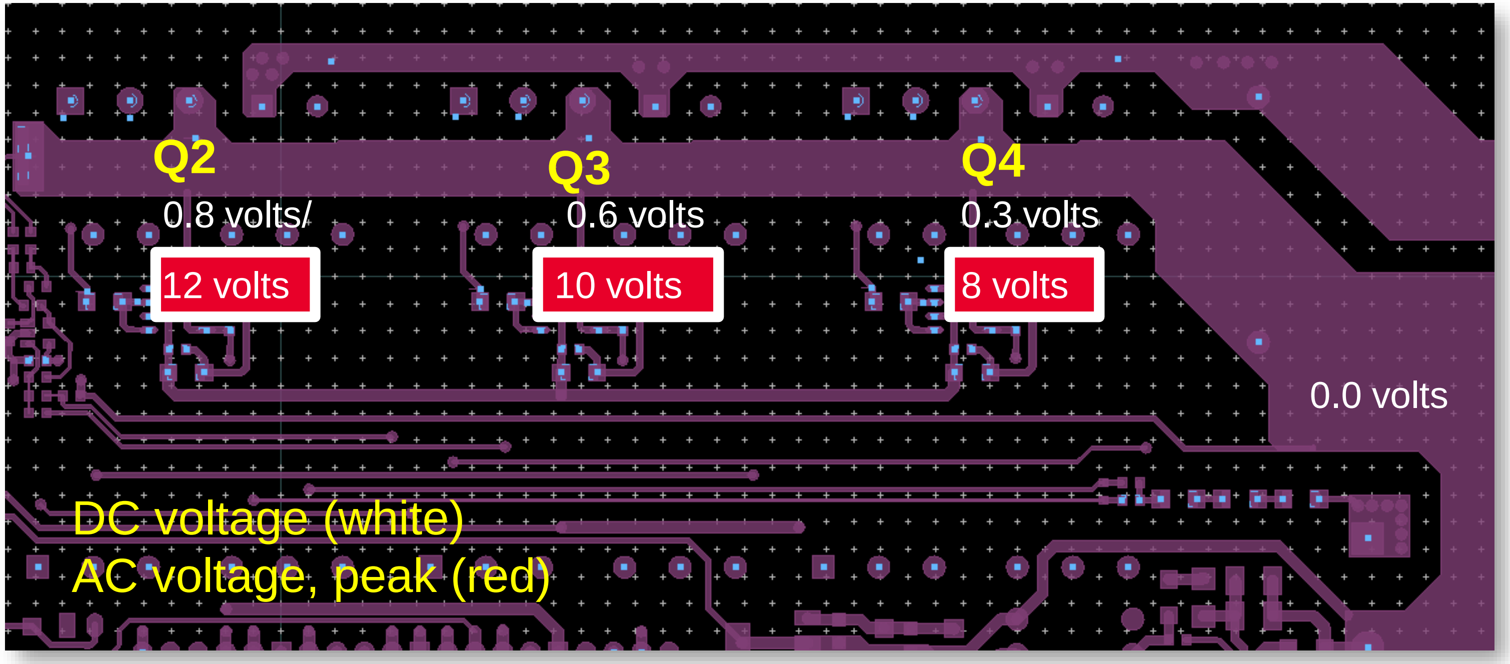



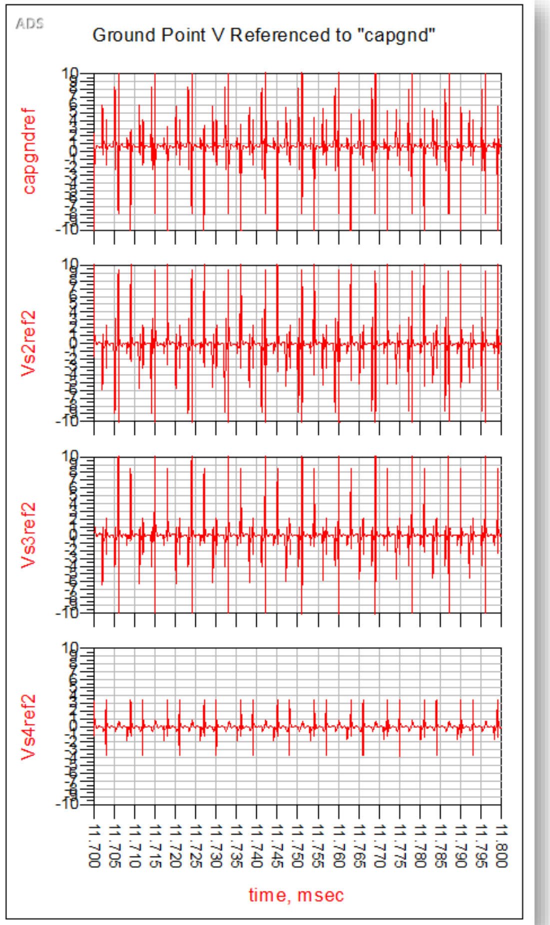

Palomba F., Gennaro F., Pavone M., Aiello N., Aiello G., Cacciato M.: Analysis of PCB parasitic effects in a Vienna Rectifier for an EV battery charger by means of Electromagnetic Simulations, **EPE'19 ECCE Europe ISBN: 978-9-0758-1530-6**



# Simulation Results

## Ground Bouncing




Root causes:

- Ohmic Losses - IR drop
- di/dt

Impact:

- Noise generation
- False Commutation
- Device failure

# Simulation Results

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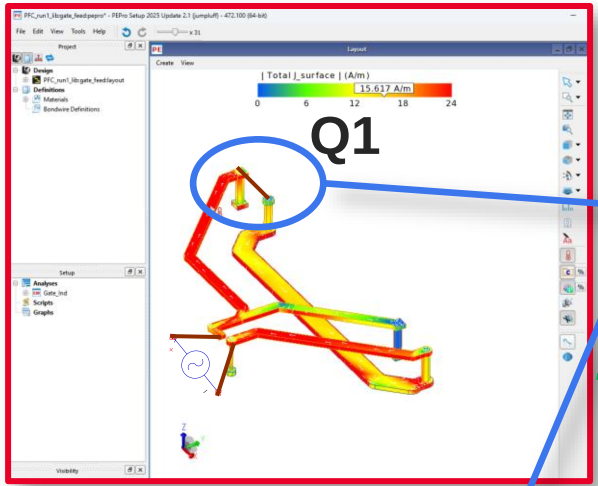
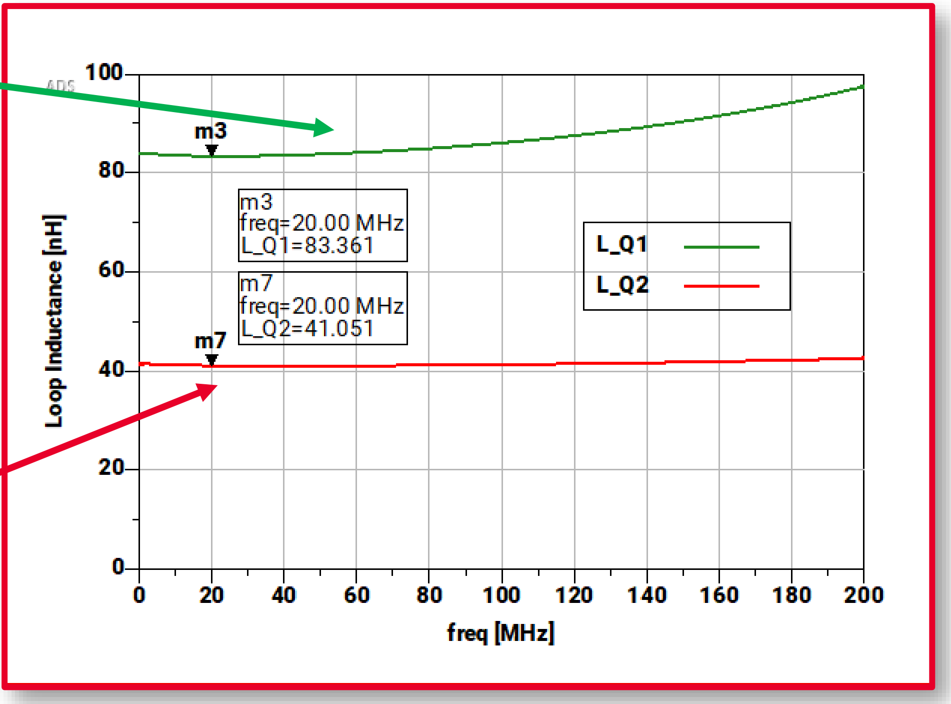
## Control Line Inductance



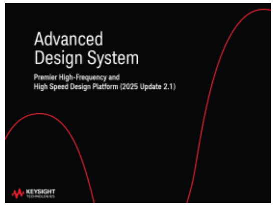

Ideal Short


1. EM simulation of Control Lines
2. Replace the MOSFET with a short
3. Extract the Line Impedance from $S_{1,1}$




$$Z_{trace} = Z_0 \frac{1 + S_{1,1}}{1 - S_{1,1}}$$

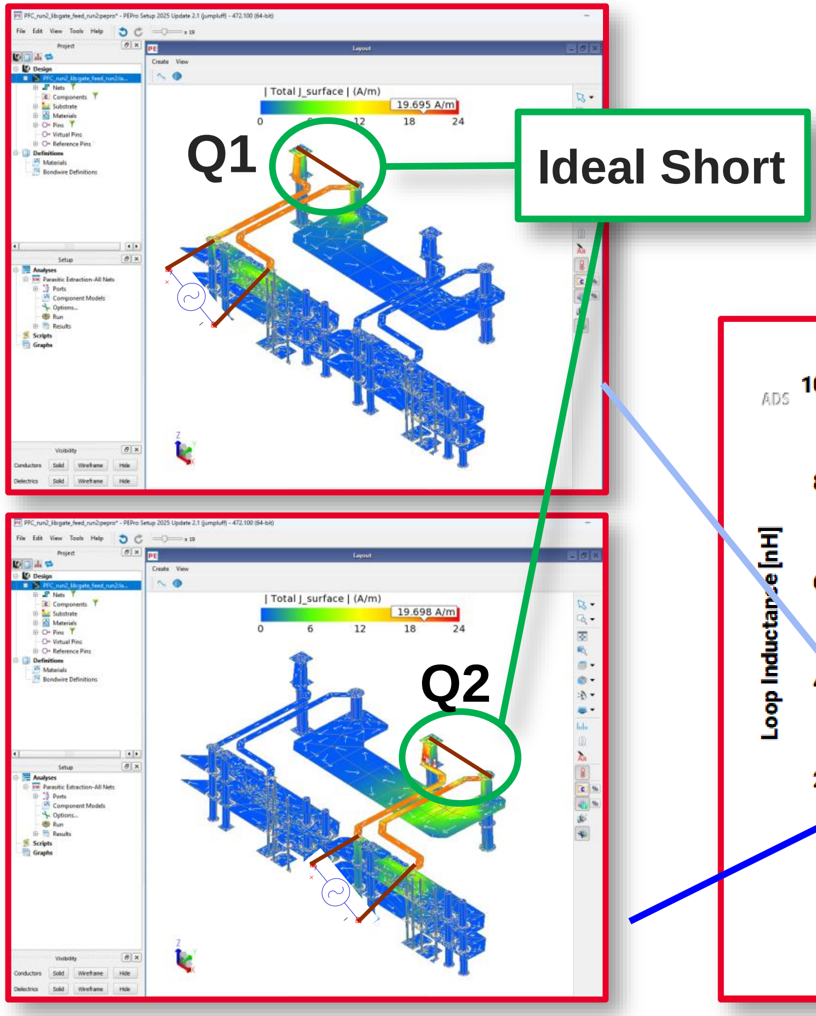
$$L_{trace} = \frac{Im[Z_{trace}]}{2\pi f}$$

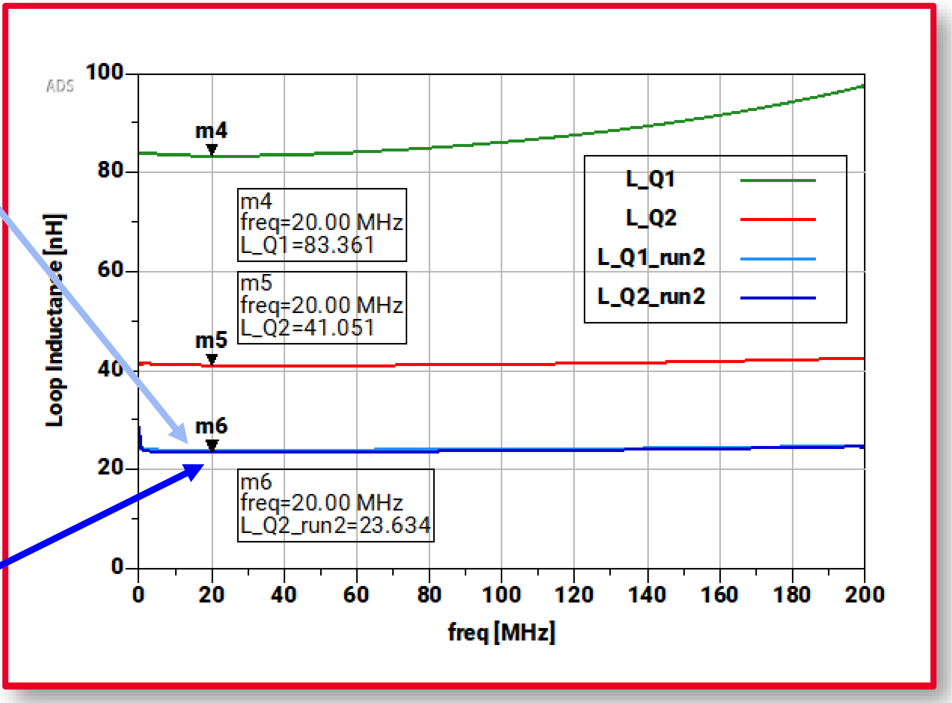


# Simulation Results

## Control Lines Inductance – Redesign

- Control Lines redesign to obtain:
  - Balanced Circuit
  - Lower Parasitic Inductance

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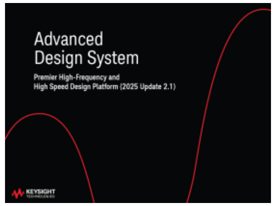
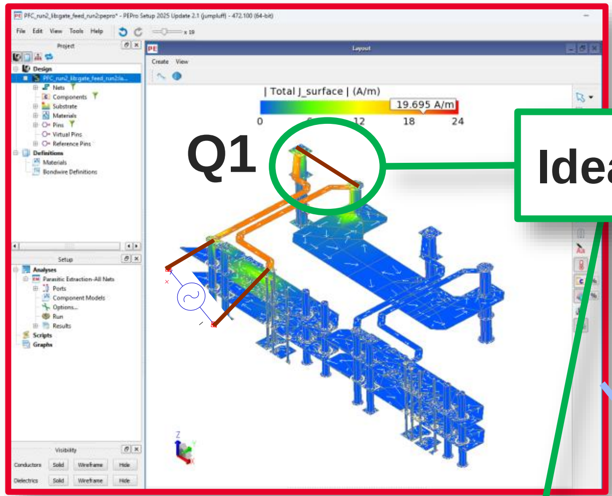


# Simulation Results

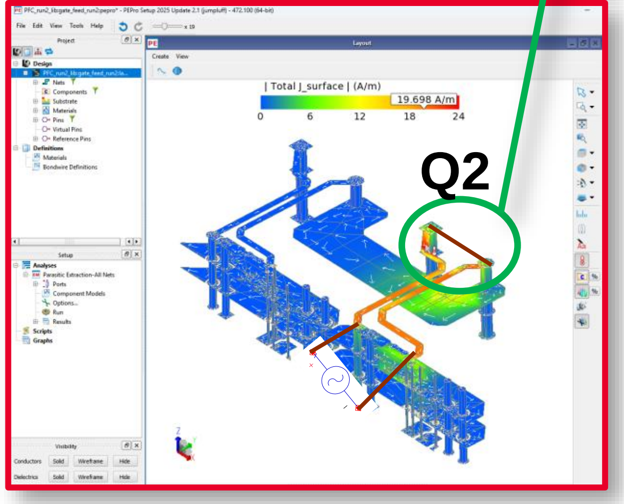
## Control Lines Inductance – Redesign

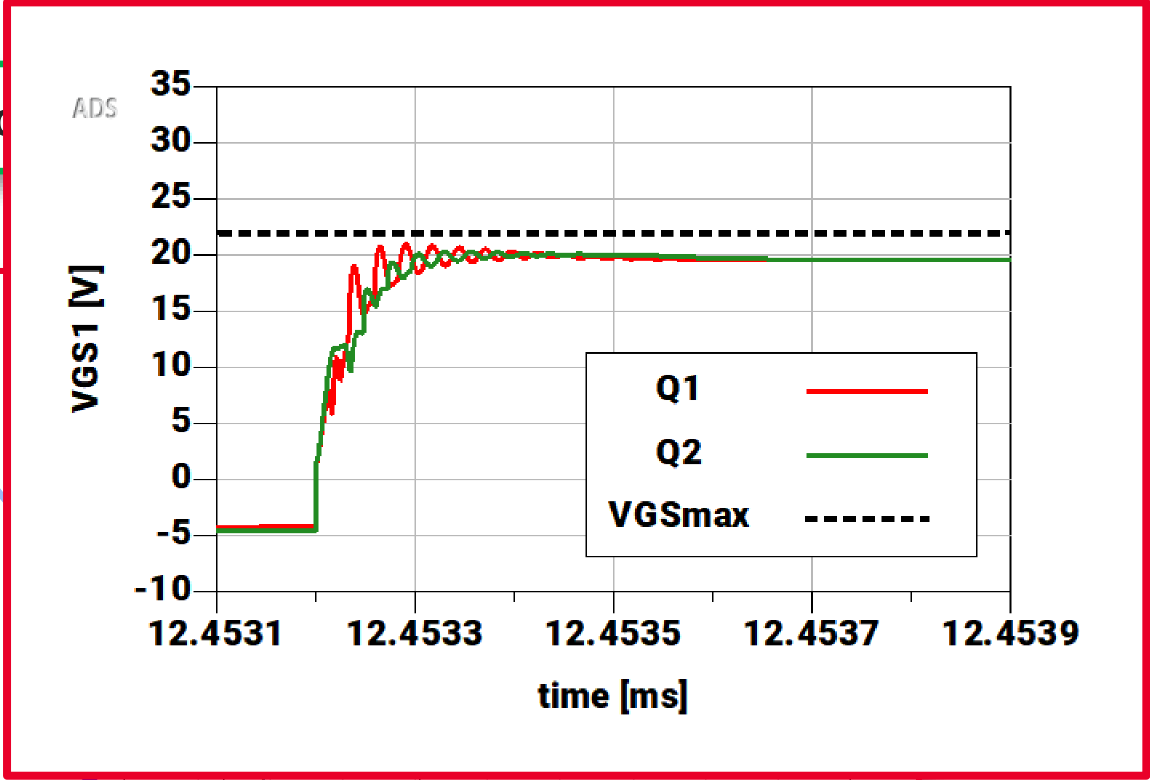
- Control Lines redesign to obtain:

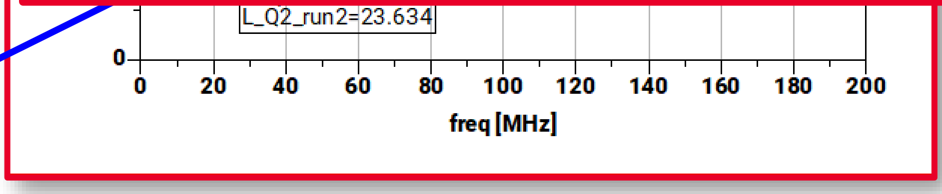
nce




Ideal Sh

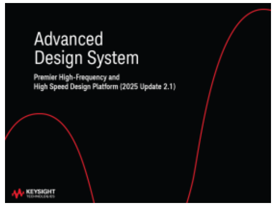


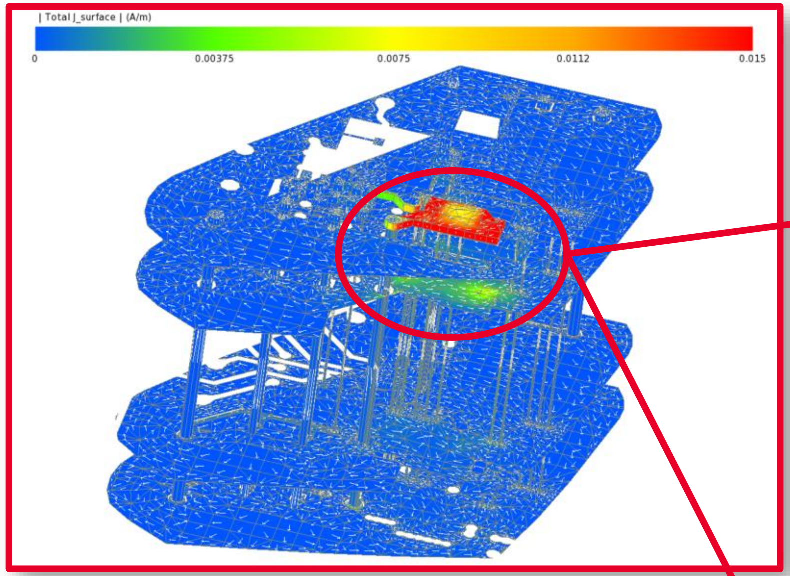

$$= Z_0 \frac{1 + S_{1,1}}{1 - S_{1,1}}$$

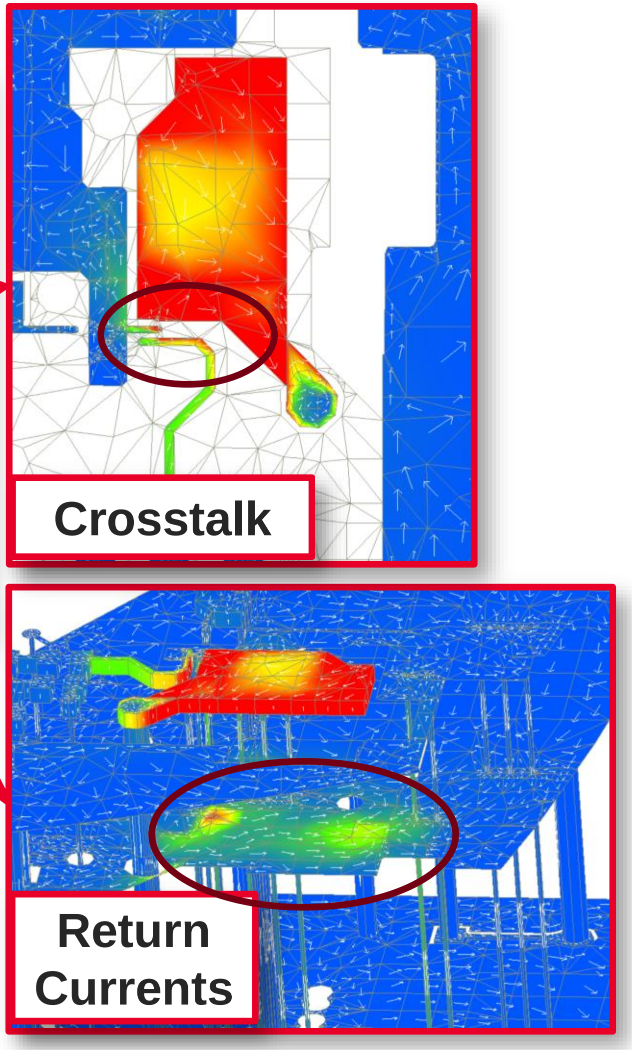
$$= \frac{Im[Z_{trace}]}{2\pi f}$$



# Simulation Results

## Crosstalk and Return Currents



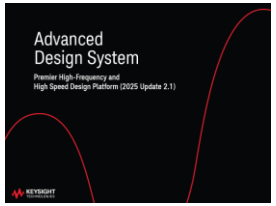

Deep insight on

- ➢ Current distribution
- ➢ Coupled signals
- ➢ Return currents

**SPI 2025**
**BEST PAPER AWARD**

| 10:50 – 12:10 | SESSION 7<br>CROSS TALK & NOISE REDUCTION / MEMRISTORS<br>Chair: Jose Schutt-Aine |
|---|---|

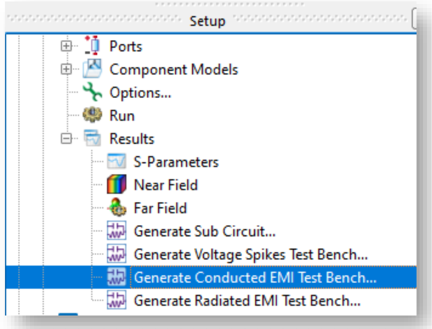
10:50
Nicola Femia (1), Giulia Di Capua (2), Antonio Maffucci (2)
*(1) University of Salerno, Italy; (2) University of Cassino and Southern Lazio, Italy*
Power-to-Control Crosstalk in Power Electronic Circuits

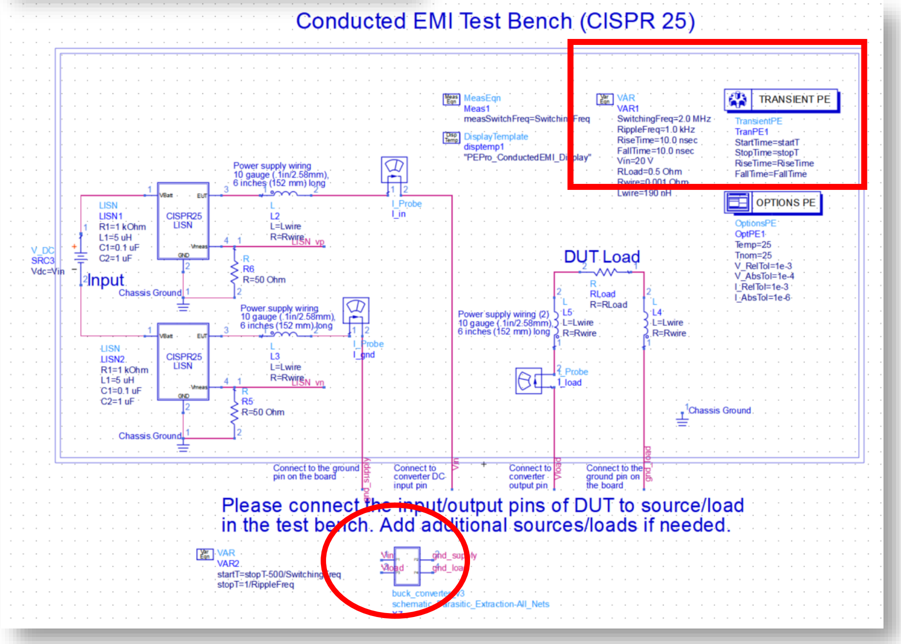


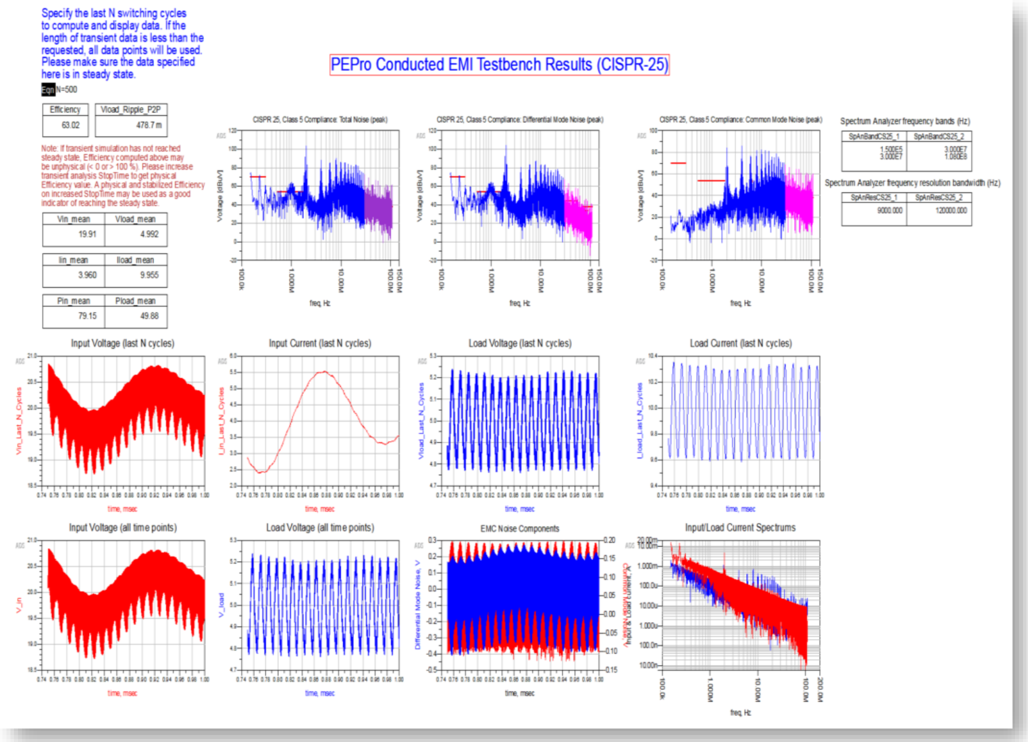
# Simulation Results

## Conducted EMI test

- ➢ Dedicated Analysis for Conducted EMI test
- ➢ SMPS noise calculated from the Linear Impedance Stabilization Network (LISN) output according to the. CISPR-25.



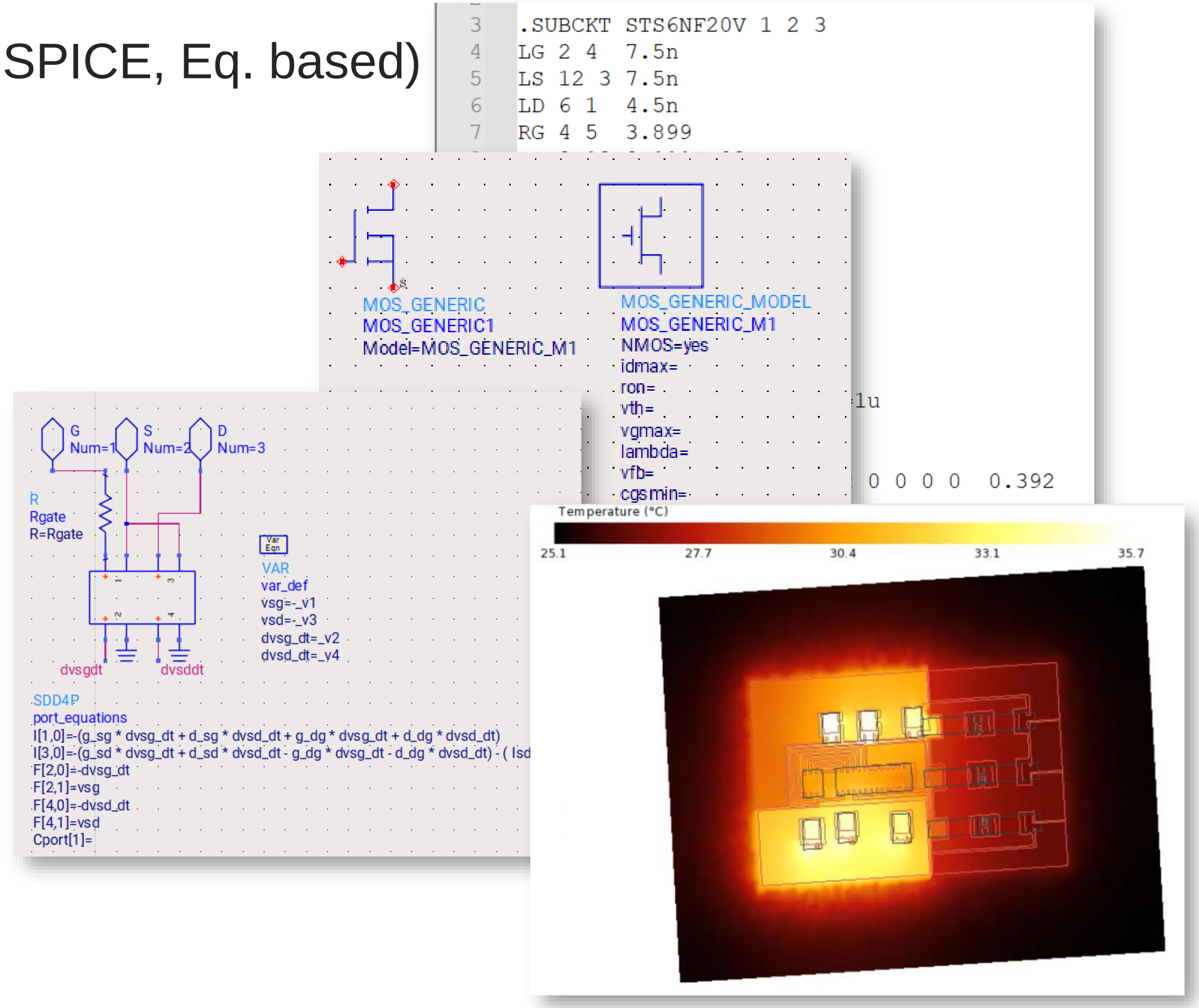




The EM analysis result of the board and the mounted parts are automatically placed as a sub circuit.

# Design challenges and Future Developments



- MOSFET/diode modeling (behavioral, SPICE, Eq. based)
- Modelling of Drivers and other PMIC
- S-par vs lumped models
- Low Frequency Extraction
- Thermal and Electrothermal Analysis
- Radiated EMI Simulation Accuracy
- Stability Analysis
- AI driven design

# “All models are wrong, but some are useful”

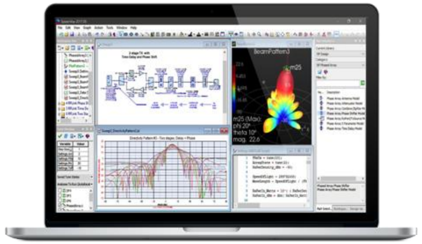
**George Box, 1976**

# Keysight EDA University Program

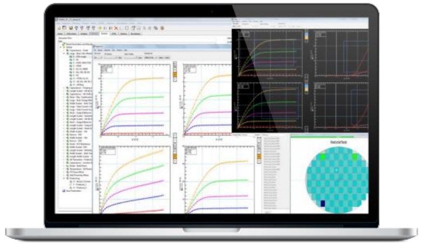
## Providing Industry-Grade Software to Support Universities

- Suite of EDA tools are used by top companies for
  - **RF and Microwave, High-Speed Digital Design**
  - **Power Electronics Design and EMI Analysis**
  - **System-level Simulation**
- Industry-leader with 65% market share[1]
- Giving students access to industry-standard tools
  - **Provided at low cost to universities**
  - Students can request license for their computer
- To be 'industry-ready', students need to understand the full design flow
  - Design and simulation at the component / device level
  - Test and measurements
  - Easy to move through workflow using PathWave
- Works with Keysight's RF/Microwave and High-Speed Digital Student Certification Programs

PathWave Advanced Design System (ADS)

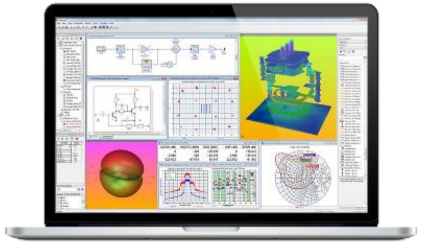


PathWave System Design (SystemVue)

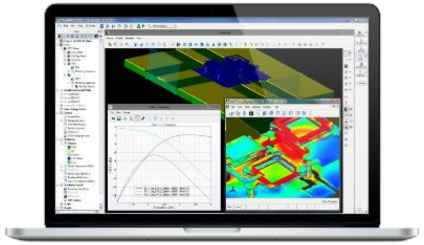


PathWave Device Modeling (IC-CAP, MBP, MQA)

PathWave RFIC Design (GoldenGate)

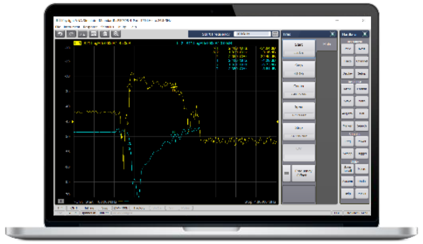


PathWave RF Synthesis (Genesys)



PathWave EM Design (EMPro)

PathWave Vector Signal Analysis (VSA)[2]



Keysight VNA Simulator (Standard, S94050B)[2]

[1]Industry: RF Design and Simulation, Source: Pedestal Research (Jan. 2020)
[2]Not branded under 'PathWave Design', but application is part of PathWave Design University W2130UU bundle

# Thank you