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1931 Congrescentrum Den Bosch

POWER ELECTRONICS 2017

Fields to Circuits

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Contents

- Project Background
- Introduction: Design of PE system
- Problem: High Freq. behavior prediction
- Solution: 3D sim. → Circuit sim.
- Results

Project Background

Multi-frequency, Modular, Multilevel Converter (M3C)

- TUD: prof. J.A. Ferreira & PhD M. Gagiç
- Power Electronics
- Architecture and hardware building of M3C

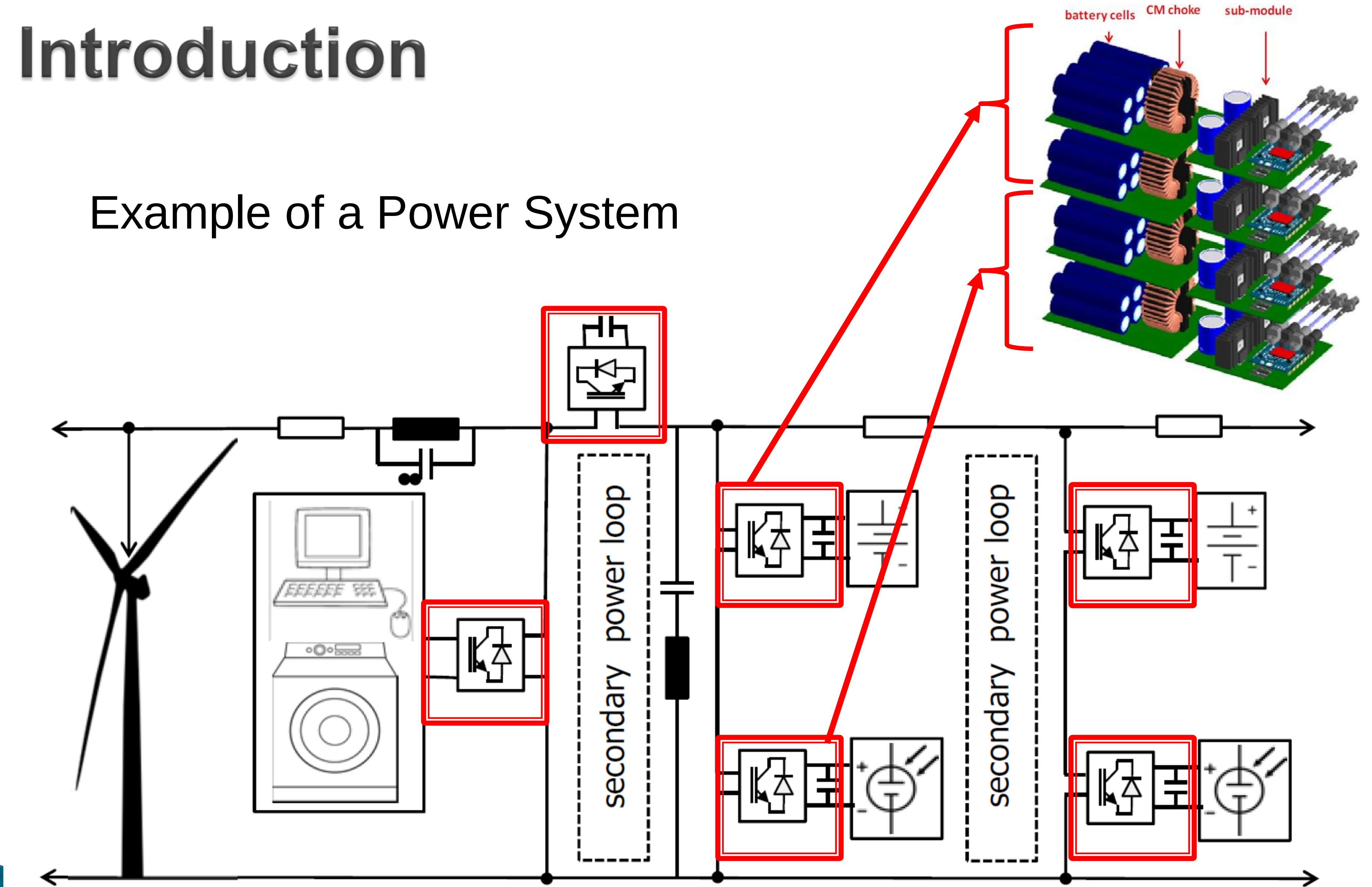
- Utwente: prof. F. Leferink & PhD N. Moonen
- Electro-Magnetic Compatibility
- EMI mitigation of fast switching semiconductors as applied in M3C

Introduction

- Designing Power Electronic Systems

Introduction

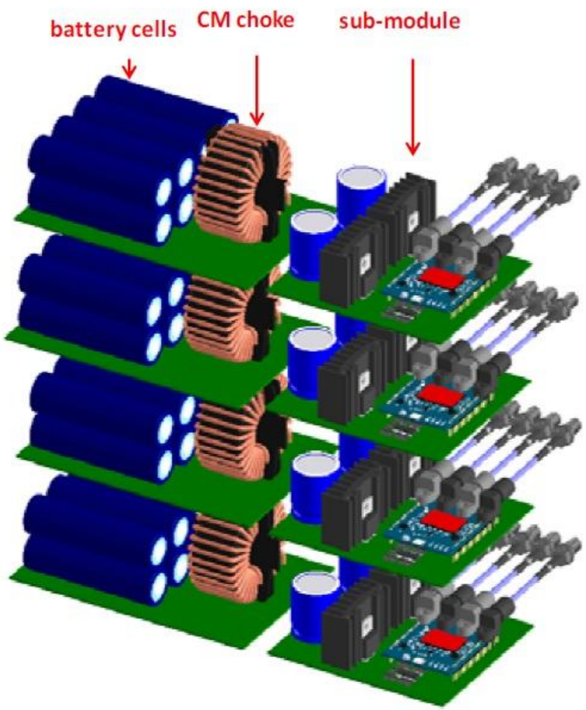
Example of a Power System



Introduction

- Goal: Accurately **predict** circuit/system behavior

- Power Electronics
  - Switching Modules
    - Conducted EMI, low-frequency (harmonics)
  - Rise and Fall times:
    - di/dt → Magnetic Field
    - dv/dt → Electric Field

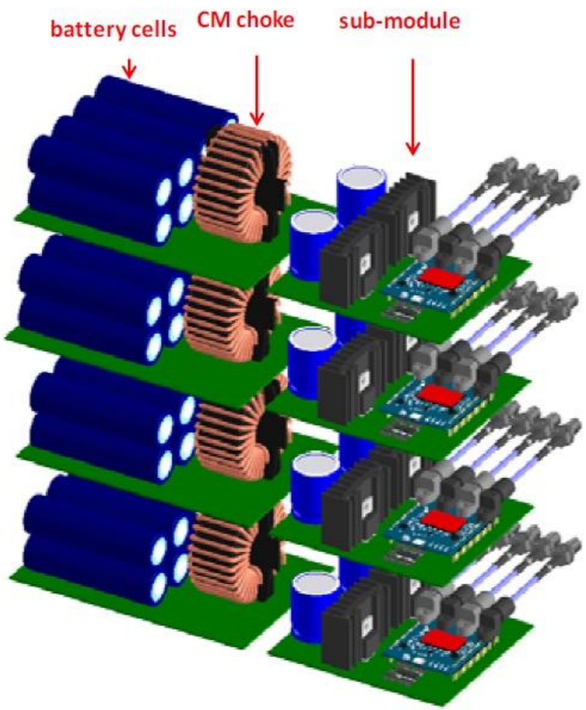


Produces EMI from: Hz to GHz!

Introduction

- Difficulty:
  - High frequency behavior (MHz-GHz)

- Problem:
  - Coupling effects!
    - Implementation dependent
    - Difficult to model

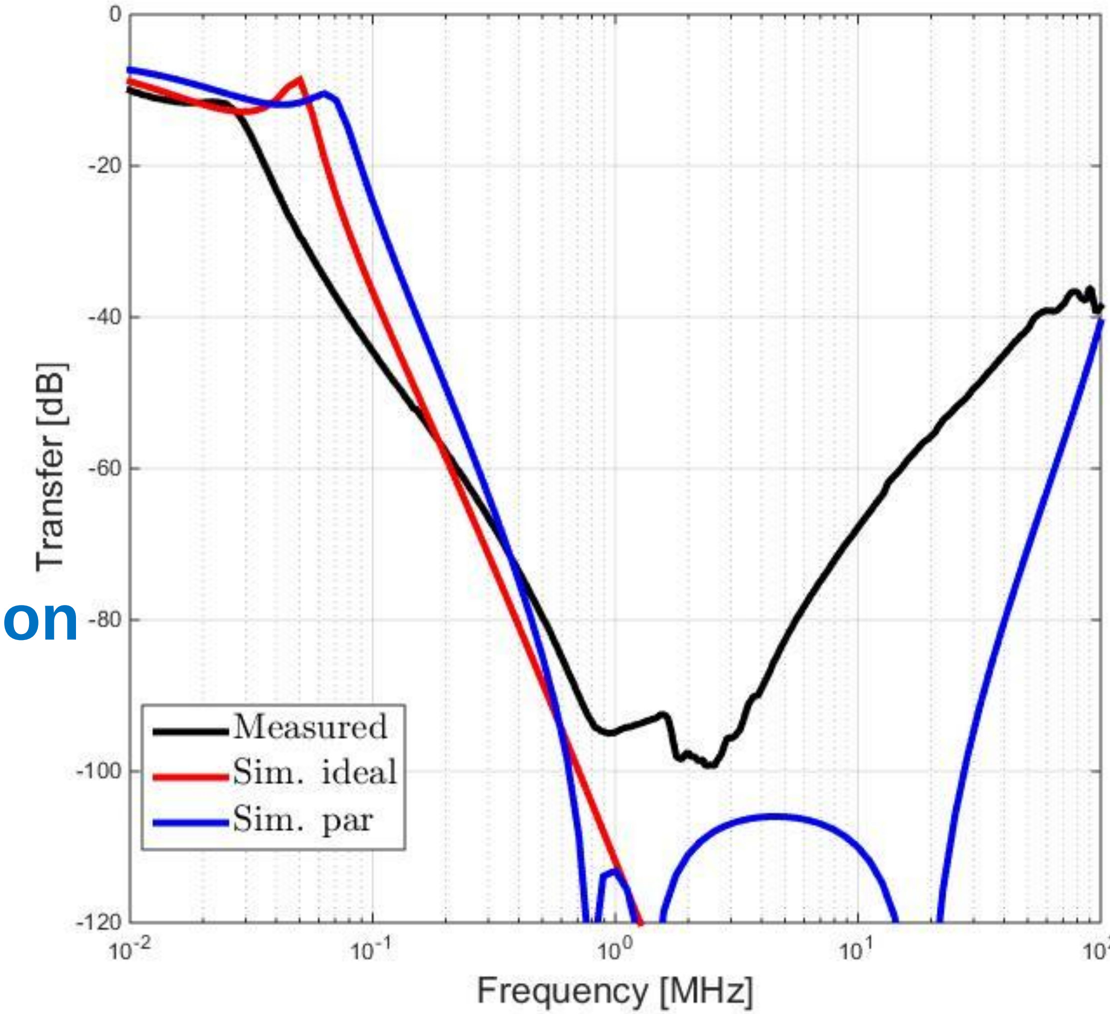


Problem

- Predicting High Frequency behavior

Problem

- Circuit simulators



Ideal Simulation

Self-Parasitic Simulation

Measurement

Only low frequency prediction

EM Field and circuit-theory

- Circuit theory assumes a lot!
  - No Fields
  - Ideal conductors, infinitely short and Z=0
  - Circuits don't create a surface
  - Circuits are small compared to wavelength

- In Practice: Circuits are NOT small compared to wavelength
- So: Kirchhoff's laws don't apply anymore (or at least are incomplete)

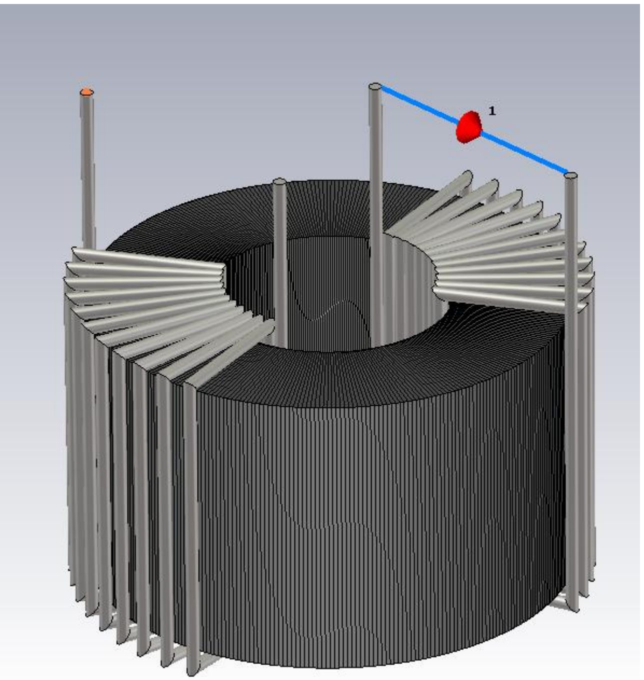
Use Fields!

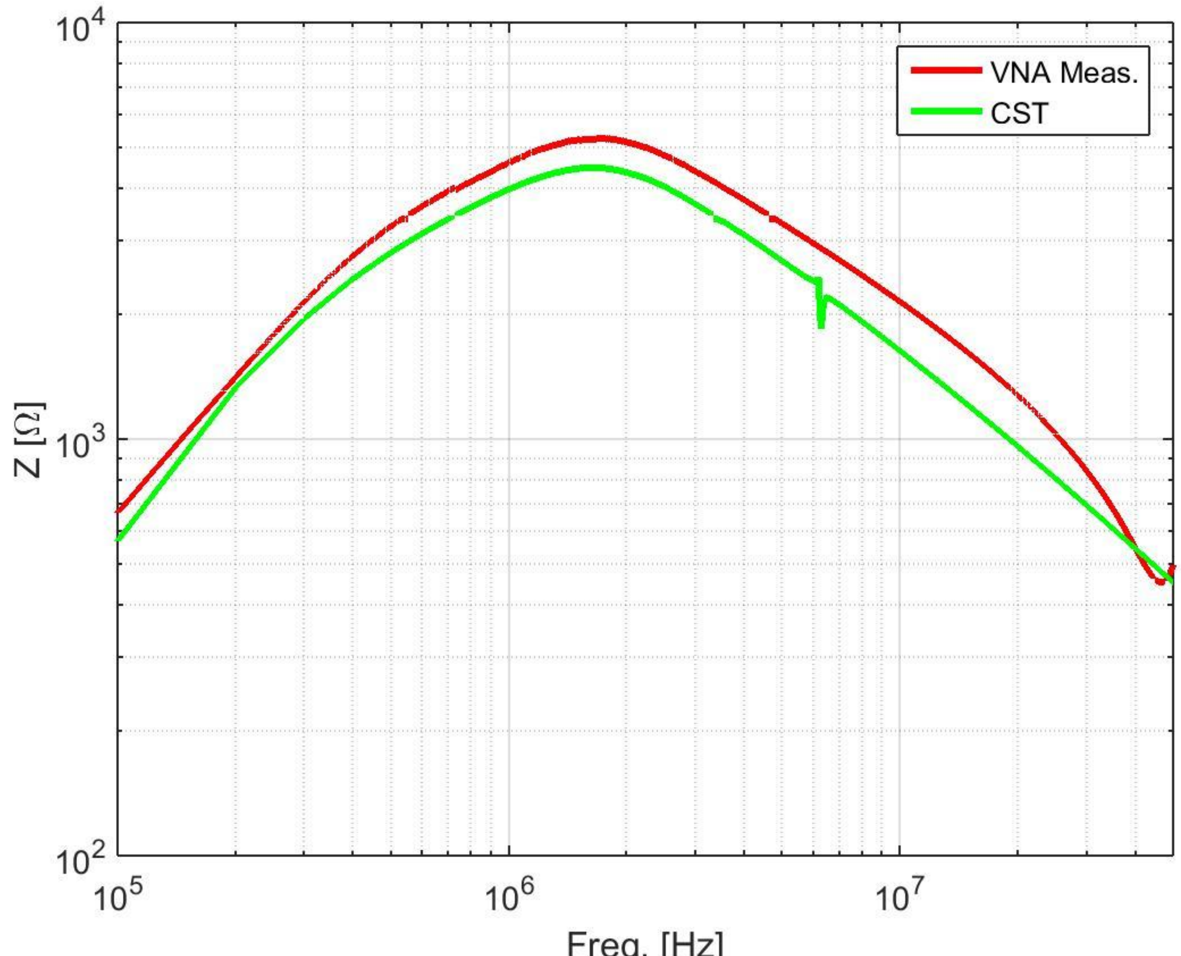
Field Solvers

- 3D simulation

Common Mode Choke

- Complex full Model
  - Visual Basic - scripting

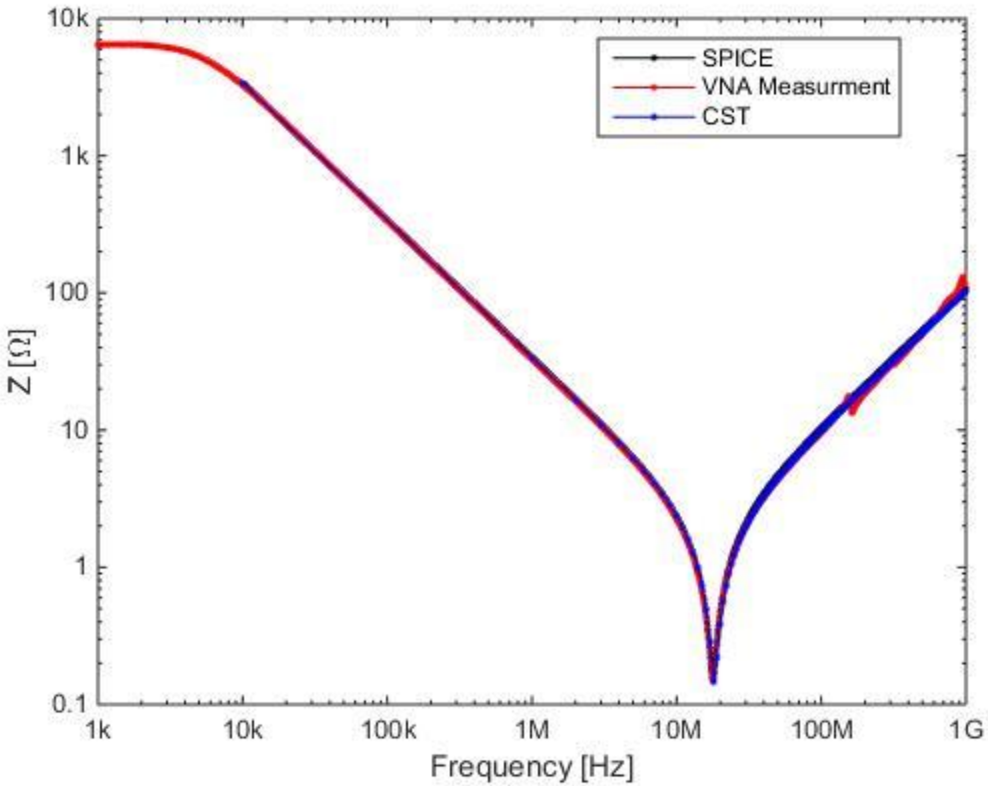


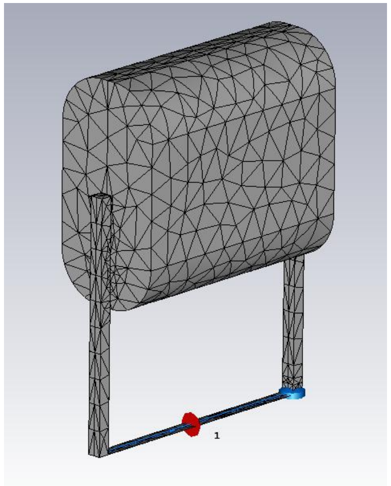


3 Million Meshcells!!
3 days simulation time

Capacitors

- Simplified Models: C + ESL + ESR

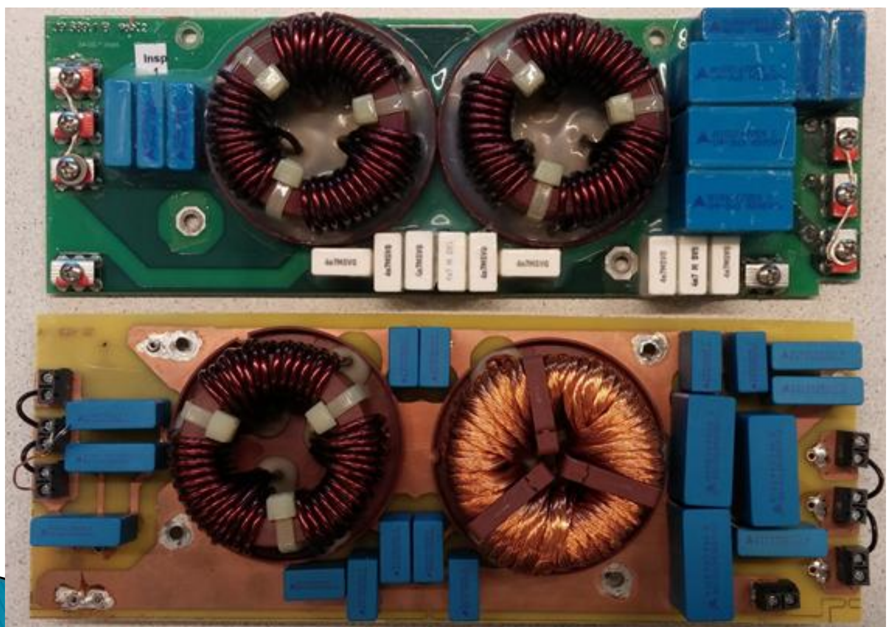


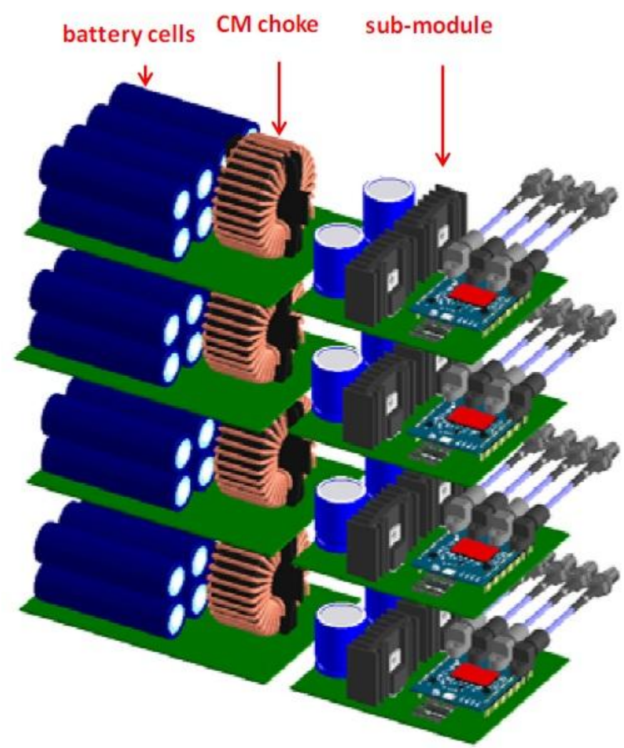


8.000 Meshcells
Sim time: 69 sec

Problem

- Complex 3D simulation of full system/device
  - Time consuming
  - Computational expensive
  - Difficult to model properly ← Needs Expertise and Experience!
  - Many components!





Solution

COMBINE!

- **Circuit simulators**
  - **Fast**
  - **Easy/intuitive modelling.**

- **3D EM field simulators**
  - **Slow**
  - **Difficult/complex modelling**

- **Represent Fields into equivalent circuit components**

EM Field and circuit-theory

- Fields: Maxwell equations ← Difficult
- Solution: circuit-theory
- Circuit-theory
  - L: Stores magnetic field energy
  - C: Stores electric field energy
- Advantage of Circuit-theory:
  - Kirchhoff's laws,
  - Causality is clear
- Availability of powerful tools:
  - analysis
  - optimization
  - synthesis

Field2Circuit

- From Fullwave to circuit models

Outline of Process

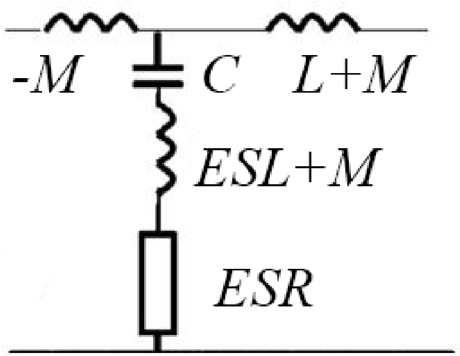
- Determine Coupling magnitude (1x)
  - Via 3D simulation with simplified model

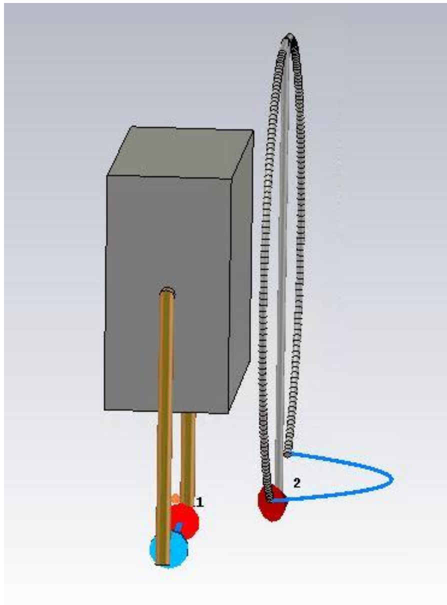
- Explore impact of different configurations in **Circuit Simulator**

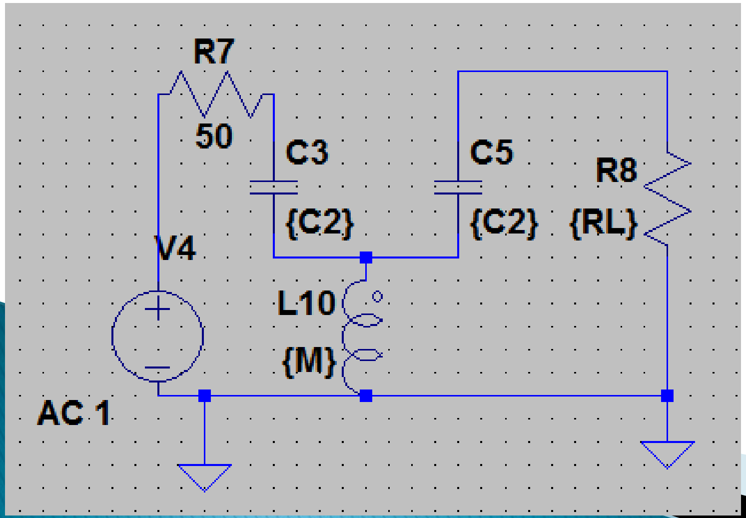
- Build “optimized” system/circuit accordingly

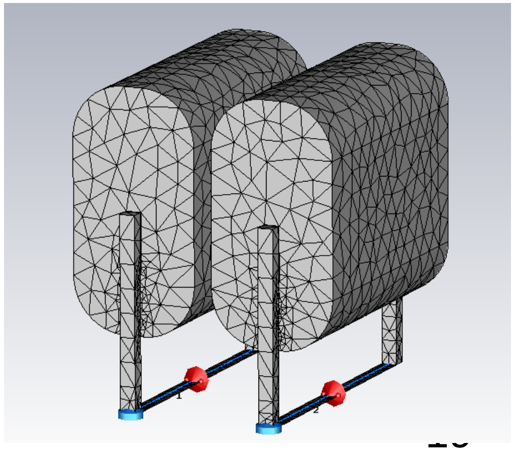
Fullwave to Circuit models

- Predicting influence of component placement by integrating fields into an equivalent circuit simulator.









Mutual Coupling Effects

- Mutual inductive coupling between passive components:
  - Inductors
  - Capacitors
    - Presented at APEMC 2016, Shenzen

      “Enhanced Circuit Simulation using Mutual Coupling Parameters obtained via 3D Field Extraction”
  - Inductor and Capacitor
    - Presented at EMC Europe 2016, Wroclaw

      “Optimizing Capacitor Placement in EMI-Filter”
- Active
  - Transistors → passive components

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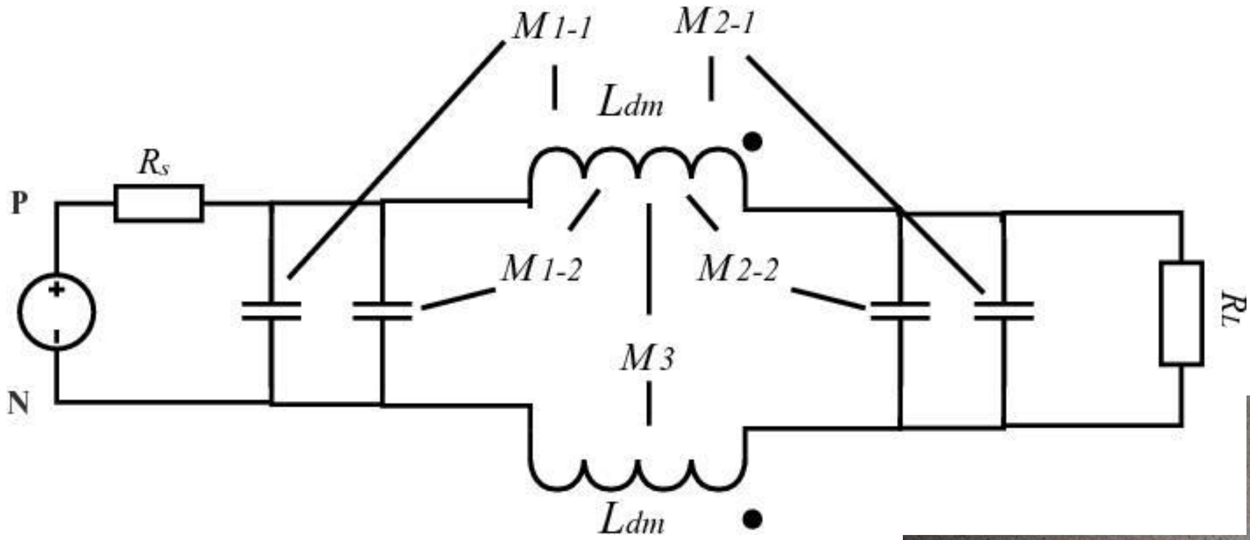
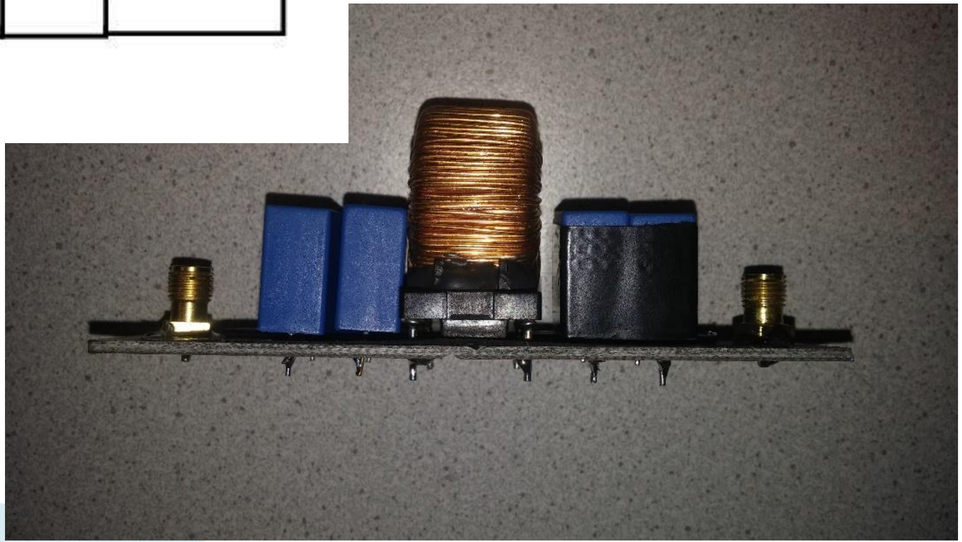
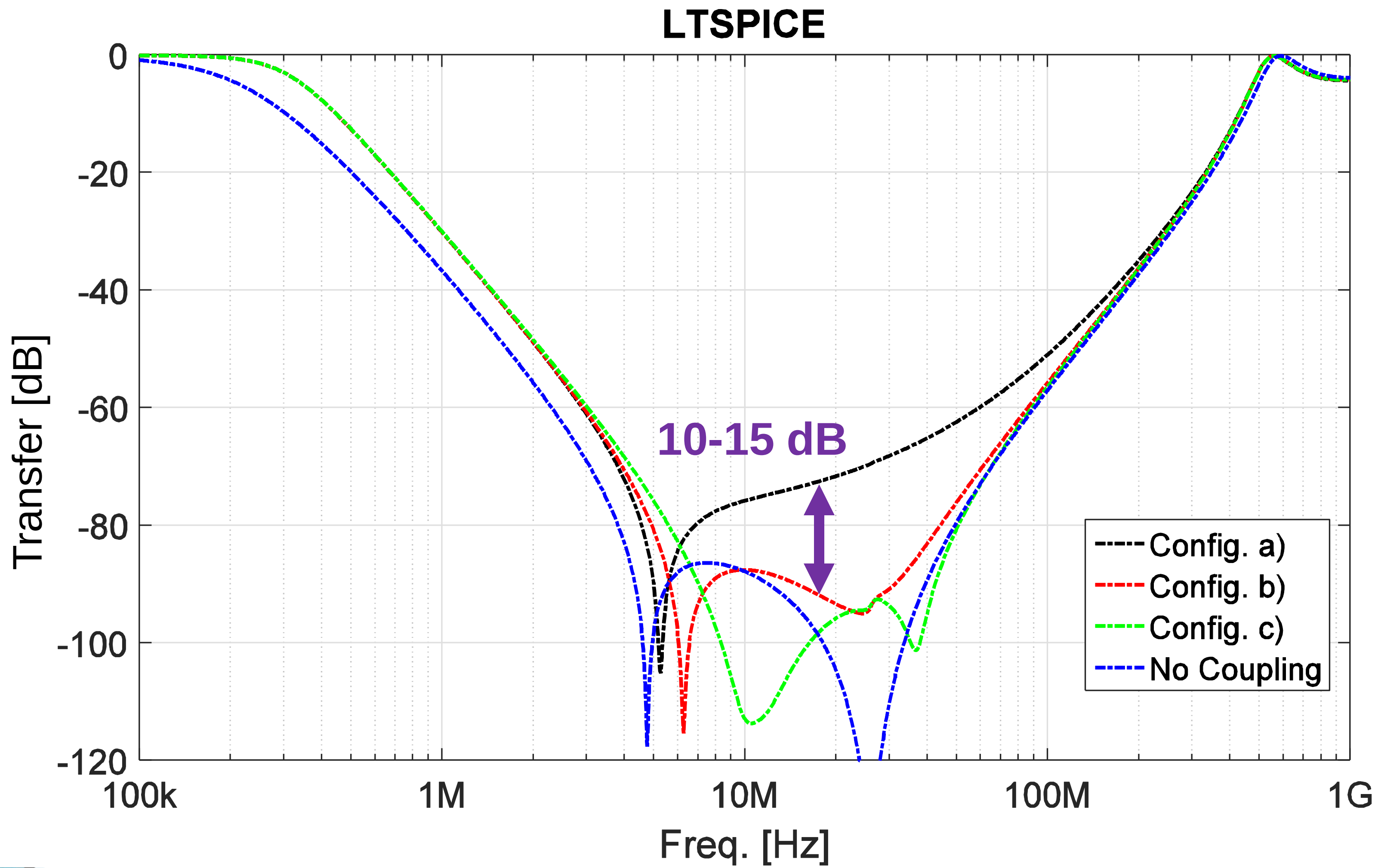
Filters

- Multiple configurations were Simulated with LTSPICE
  - 1. Induced currents are in phase
  - 2. induced current are out of phase (opposite, thus cancel)

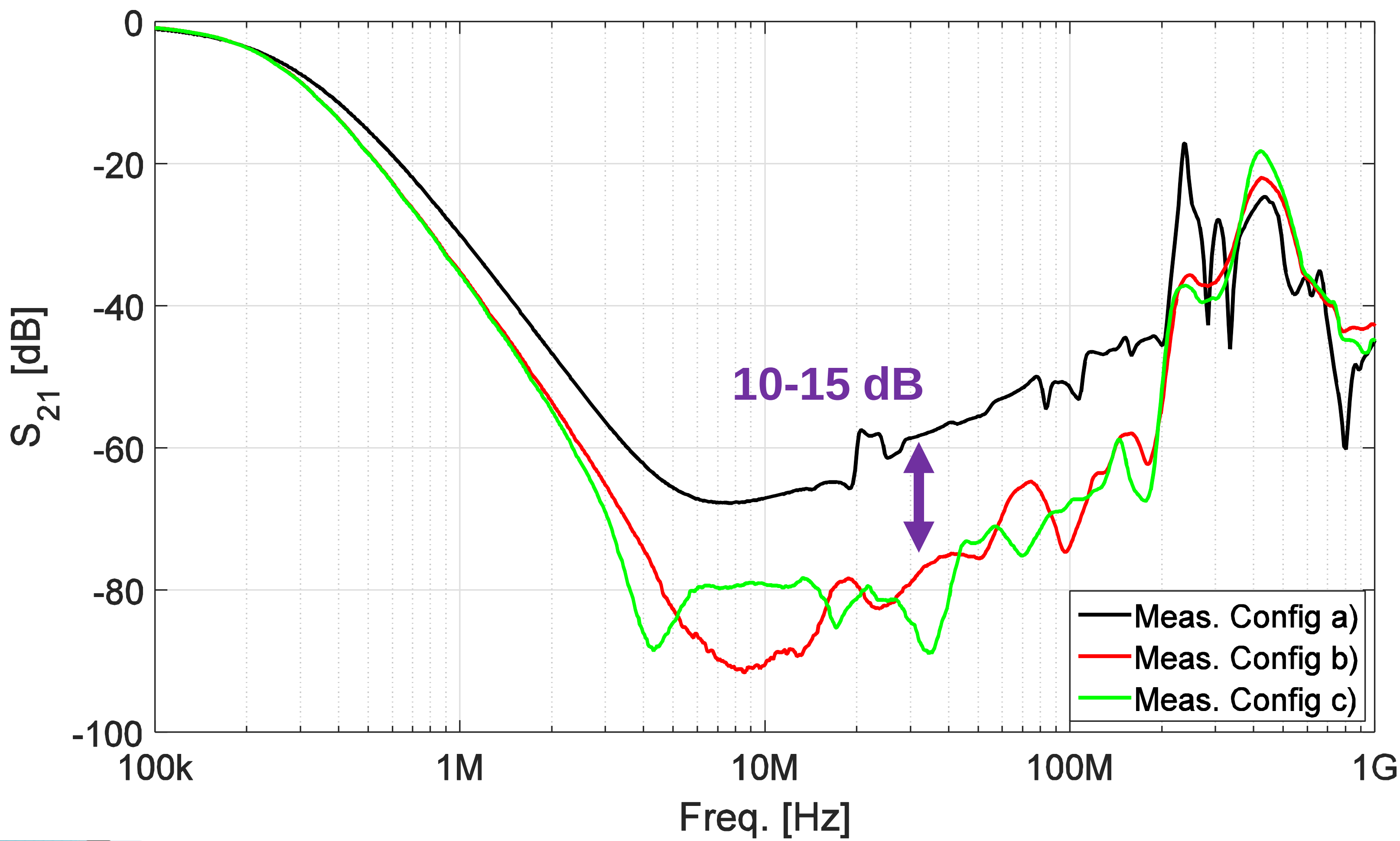




LTSPICE - Prediction



Result



0
-20
-40
-60
-80
-100
S_{21} [dB]
100k
1M
10M
100M
1G
Freq. [Hz]
10-15 dB
Meas. Config a)
Meas. Config b)
Meas. Config c)

Conclusion

- Including Mutual coupling in **circuit simulator** can predict optimized placement of components

- **One step closer to easier design of Complex Systems over a broader frequency band!**

The End

- Questions?

Inductor to Capacitor

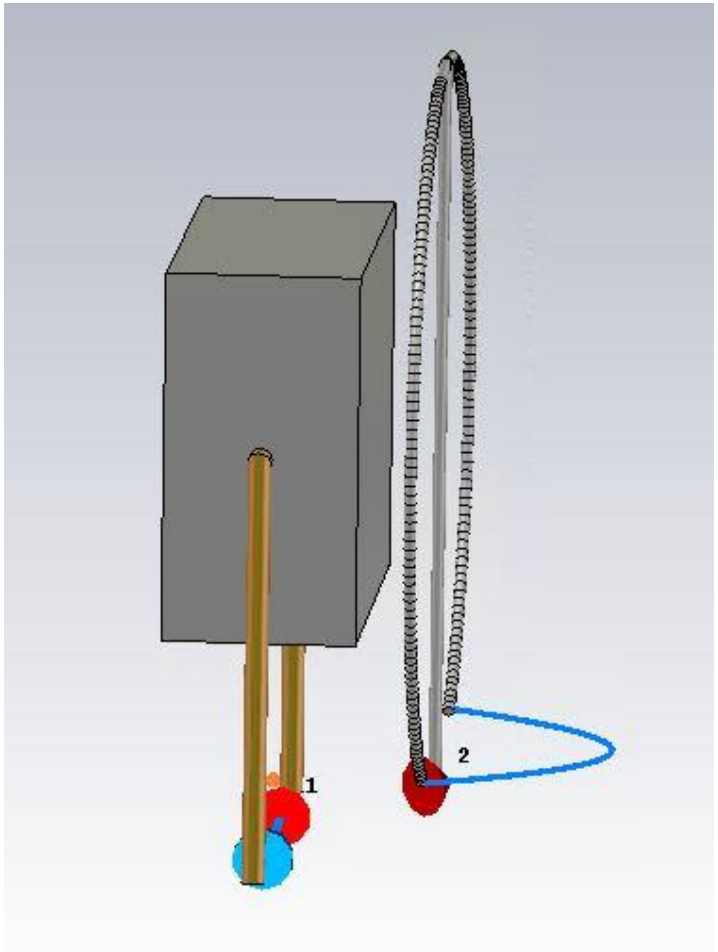
- Mutual coupling between an inductor and parallel capacitors

Inductor to Capacitor

- Simplified Capacitor
  - PEC
  - Lumped Element
  - ESL determined by dimensions
  - Discrete port

- Simplified Inductor
  - PEC
  - Discrete port

$$M = \left|\frac{2 \cdot Z_0 \cdot S_{21}}{(1 - S_{22} + S_{22}S_{11} - S_{11} - S_{21}^2)}\right| \cdot \frac{1}{(2 \cdot \pi \cdot f)}$$

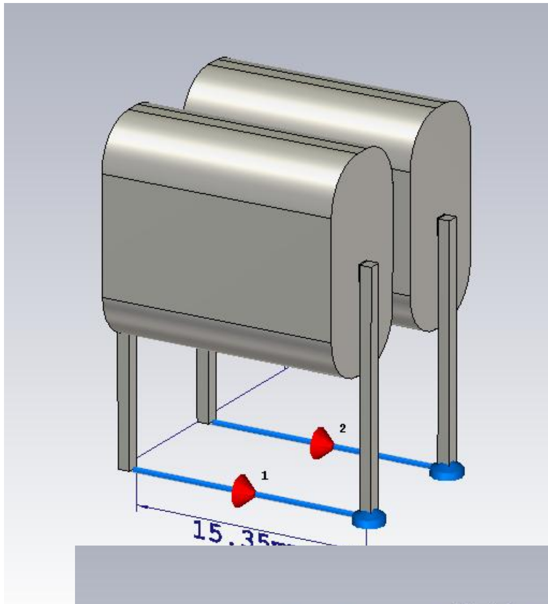


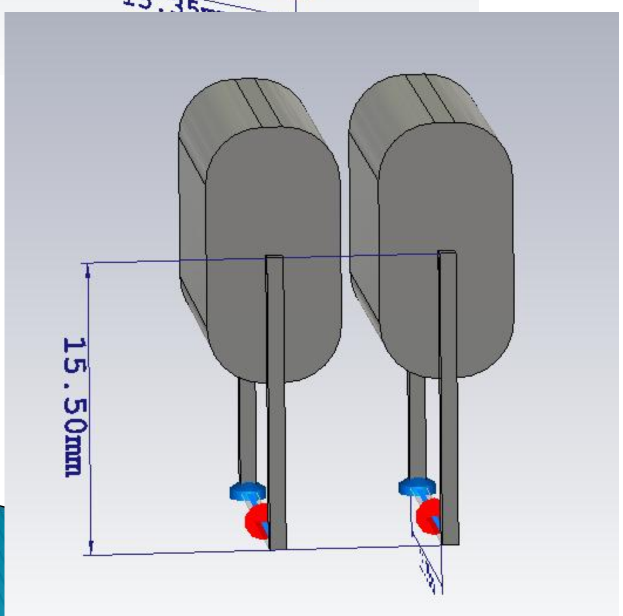
Capacitors

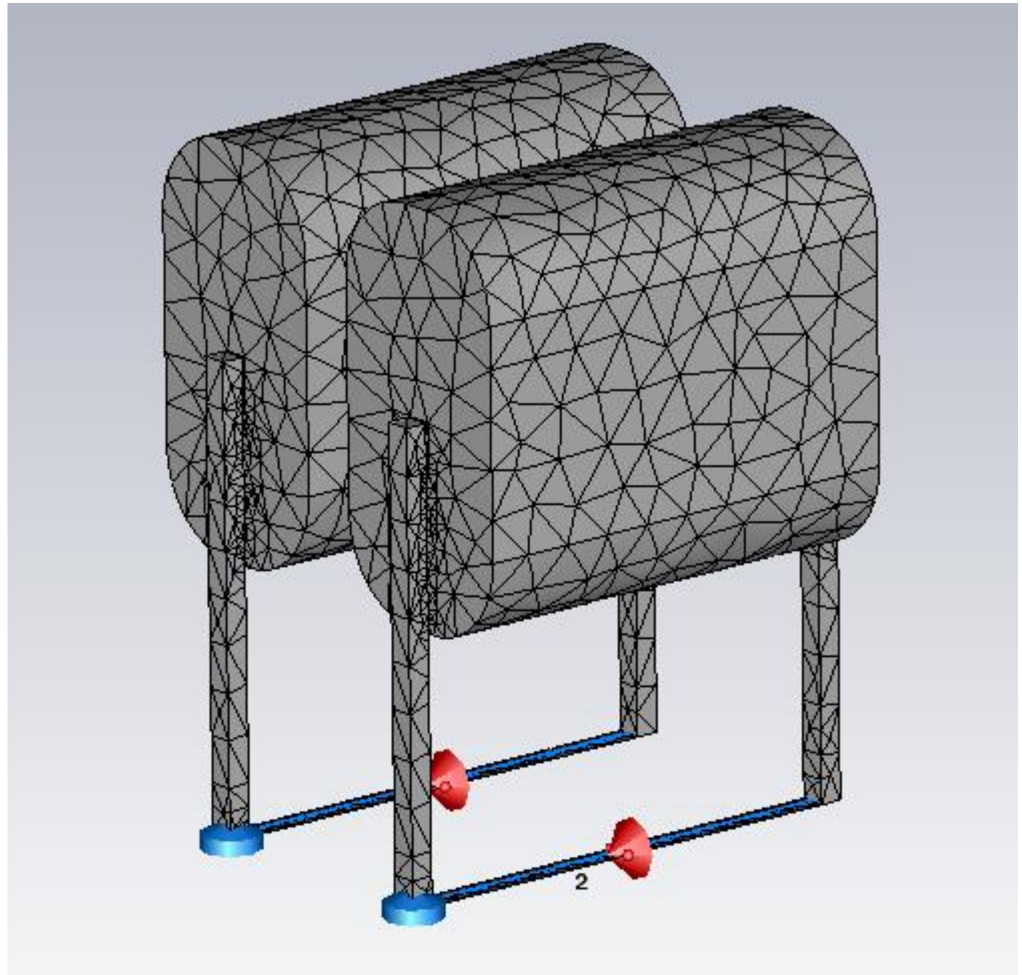
- Mutual coupling between two parallel capacitors

Capacitors

$$M = 25 \cdot \frac{|S_{21}|}{2\pi f}$$

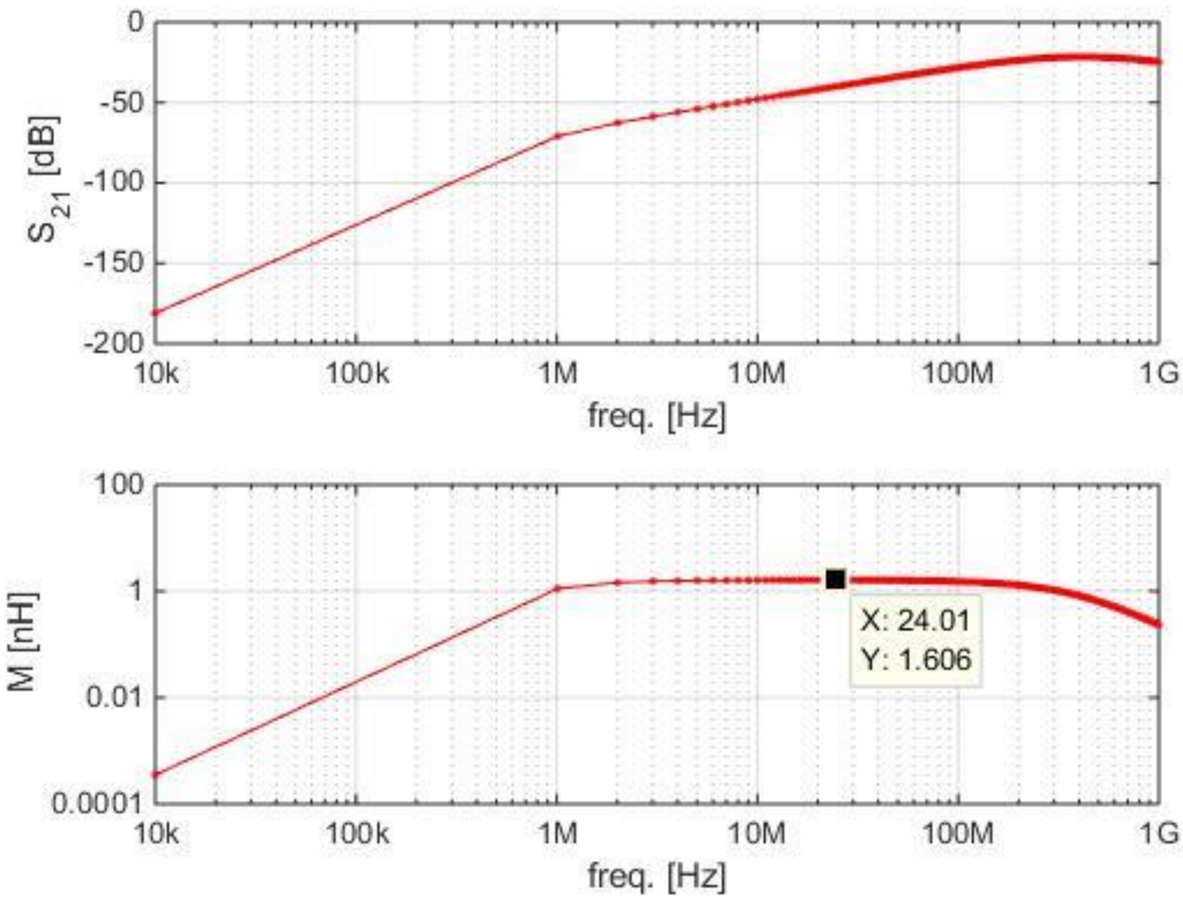






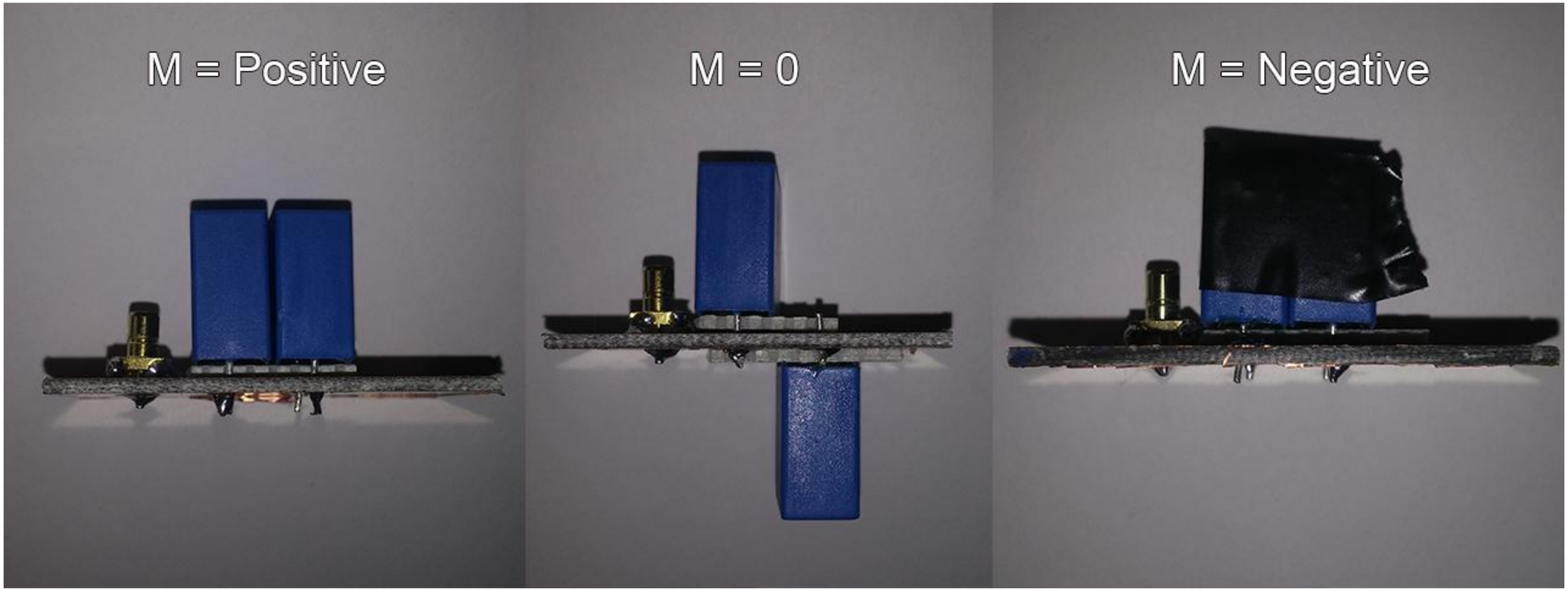
Capacitors

$$M = 25 \cdot \frac{|S_{21}|}{2\pi f} \approx 1.6\,nH$$

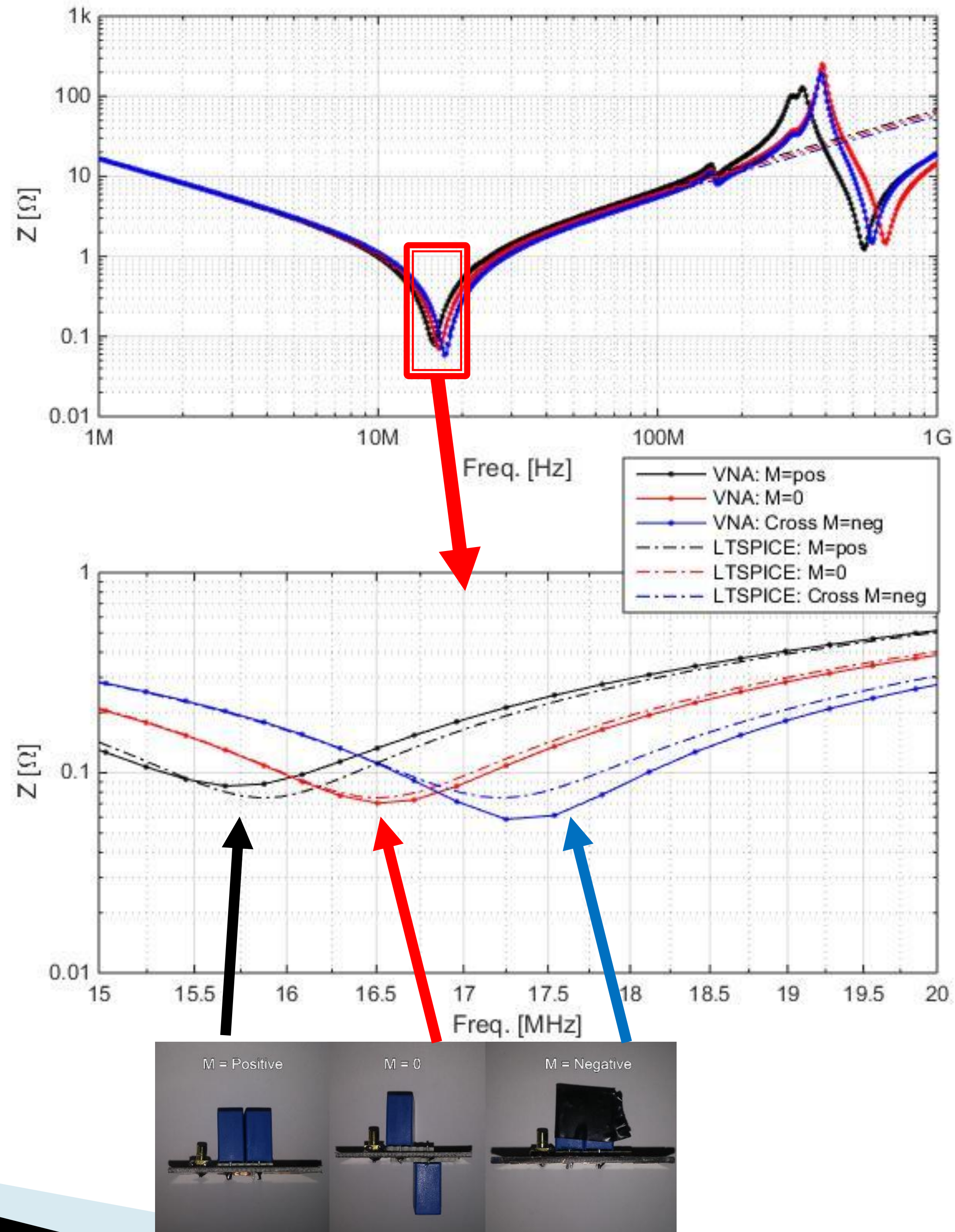


Measurement: Setup

Multiple configurations were Simulated with LTSPICE



Results



Shift in resonance peak approx. 1 MHz