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Accurate and Efficient Crosstalk Analysis by Full-wave Computations and System Identification

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VOLVO CHALMERS provinn. Modelon VINNOVA

Presentation outline

- Motivation
- Method
- Results
- Summary

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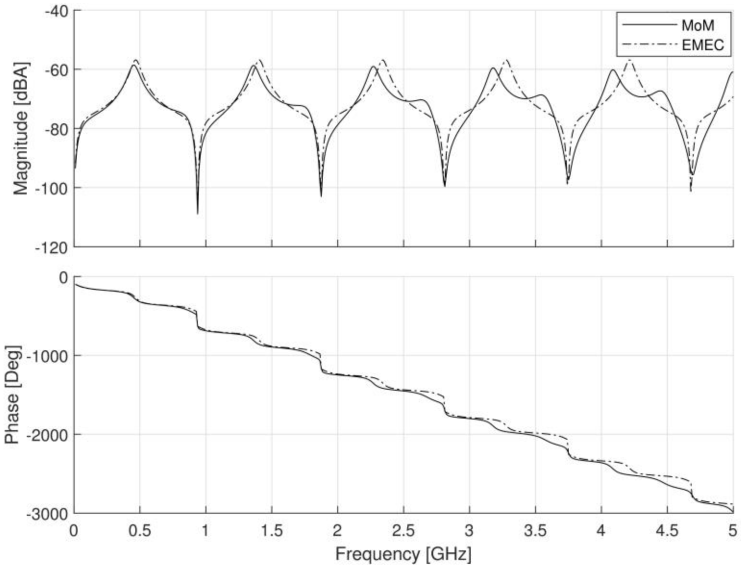
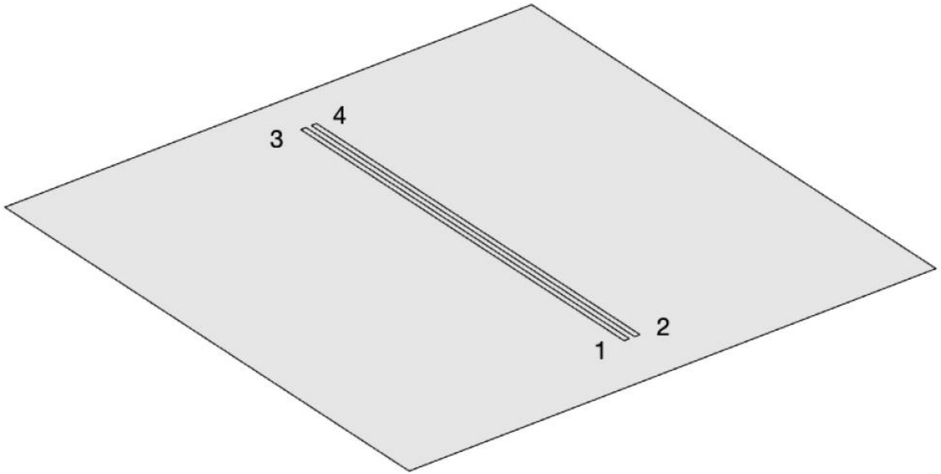
Motivation

- Transmission line theory not suitable for high frequencies





Motivation

- Transmission line theory not suitable for high frequencies
- Full-wave solvers are computationally expensive (time, memory etc)
  - Infeasible to analyze many cases, or large systems of components
  - Reduction of the computational expense is needed!
  - We want to maintain the higher level of accuracy.
  - Reduced-order models can be used!

Motivation

- Transmission line theory not suitable for high frequencies
- Full-wave solvers are computationally expensive (time, memory etc)
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  - Reduction of the computational expense is needed!
  - Want to maintain the higher level of accuracy.
  - Reduced-order models can be used!
- Reduced-order models are effective and cheap
  - Estimated from data
  - Possible to use data from full-wave solvers or measurements for estimation
  - Can give good models from small amount of data
  - Gives physical insights to the system

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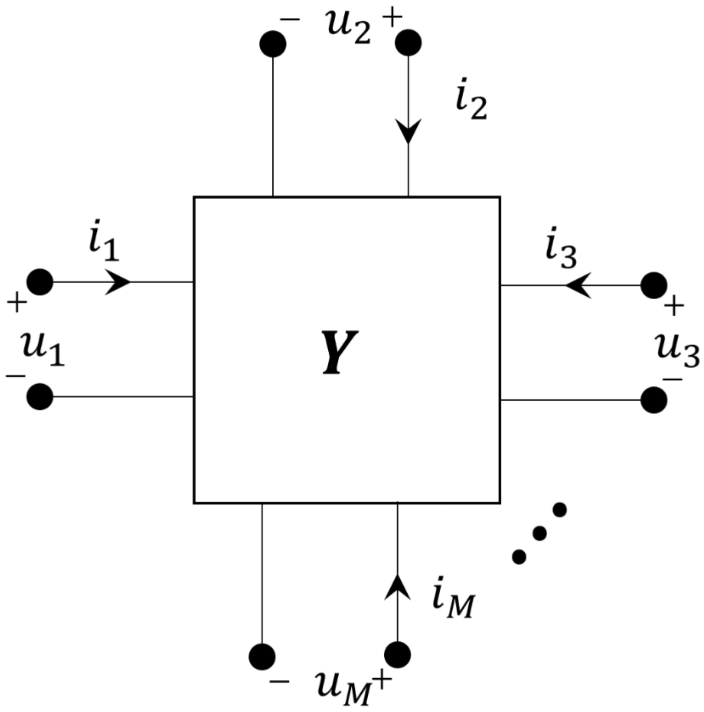
Modeling of physical problem

Y-parameters



Modeling of physical problem

Y-parameters

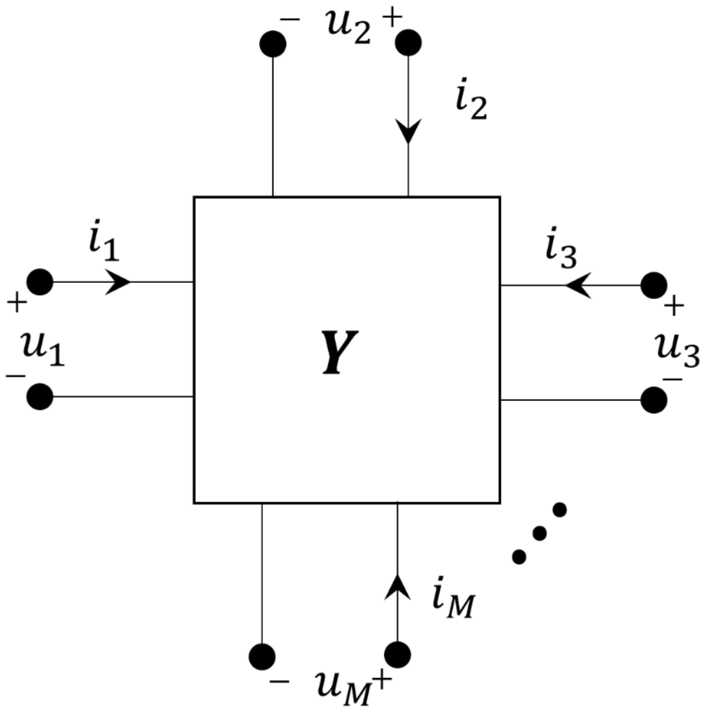
- Relates voltages to the currents as:

$$\mathbf{i} = \mathbf{Y}\mathbf{u},$$

where

$$\mathbf{i}, \mathbf{u} \in \mathbb{C}^{M \times 1}$$

$$\mathbf{Y} \in \mathbb{C}^{M \times M}$$

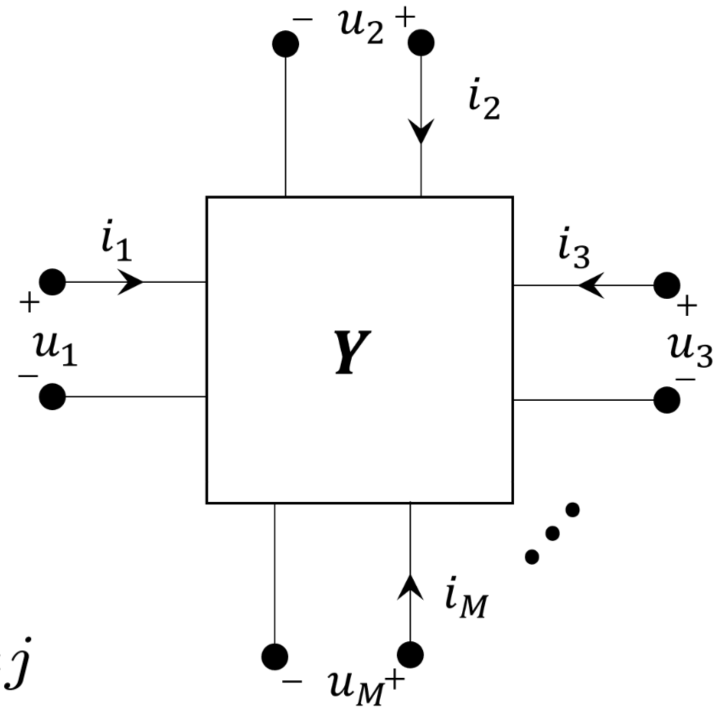


Modeling of physical problem

Obtaining the Y-parameters:

1. Apply a voltage to port j, with other ports short circuited.
2. Solve for the resulting currents i_i.
3. Compute column j by:

$$[\mathbf{Y}]_{i,j} = \left.\frac{i_i}{u_j}\right|_{u_k=0 \text{ for } k\neq j}$$



Modeling of physical problem

Z-parameters

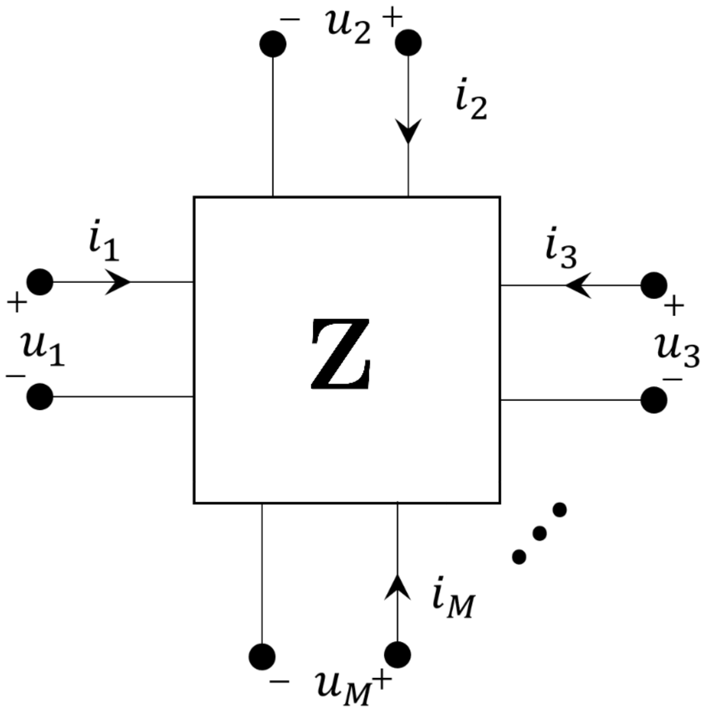
- Relates currents to the voltages as:

$$\mathbf{u} = \mathbf{Z}\mathbf{i},$$

- Relates to Y-parameters as

$$\mathbf{Z} = \mathbf{Y}^{-1}$$

- Good for interfacing components



Modeling of physical problem

S-parameters

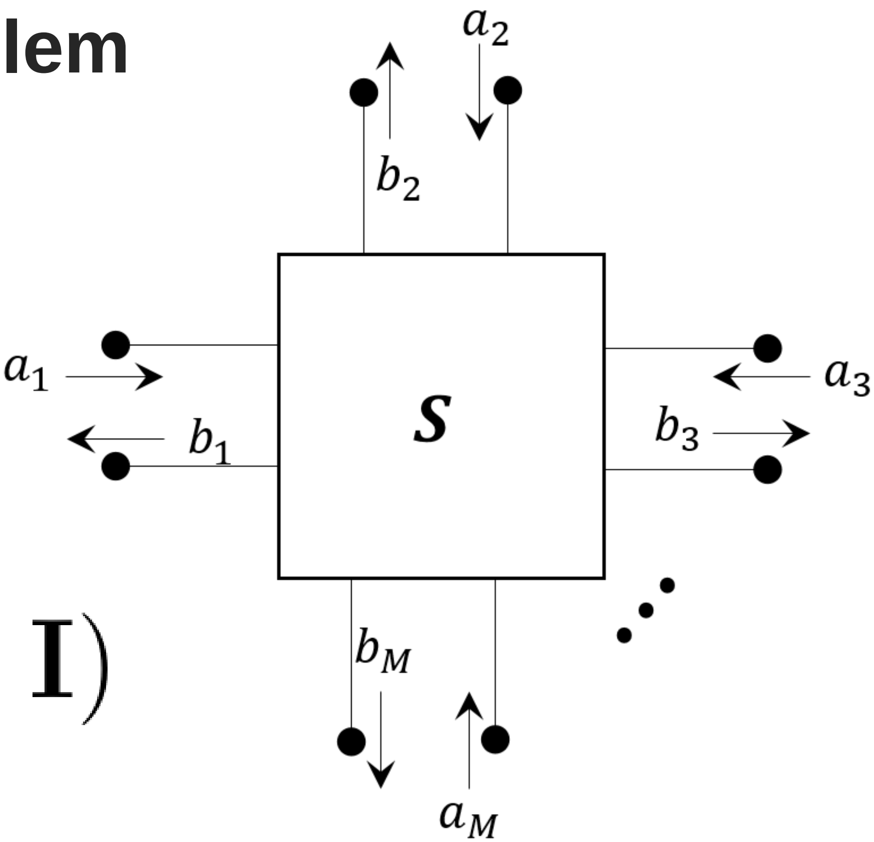
- Relates outgoing and ingoing power waves as:

$$\mathbf{b} = \mathbf{S}\mathbf{a},$$

- Relates to Z-parameters as

$$\mathbf{S} = (\hat{\mathbf{Z}} + \mathbf{I})^{-1}(\hat{\mathbf{Z}} - \mathbf{I})$$

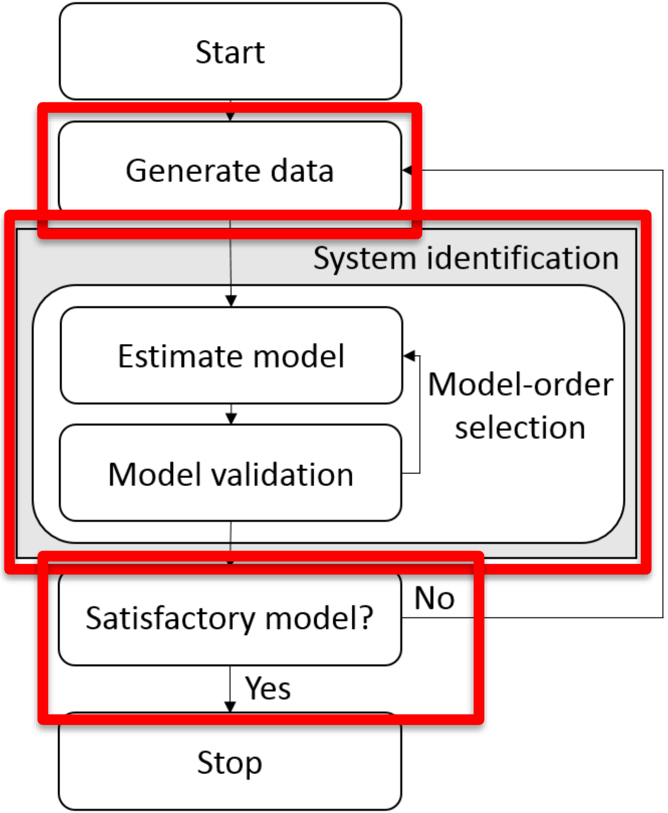
- Commonly used in measurements



Method overview

The proposed estimation process

- Data generation
- System identification
  - Model-order selection
    - Iterative estimation and validation
- Decision of satisfaction
  - Stop or expansion of data sets



Data generation

- Measurement or simulation data can be used
- We use an in-house method of moments solver
  - Solves the EFIE on metallic surfaces

$$-\frac{j}{\omega\mu_0}\left[\hat{\mathbf{n}}(\mathbf{r}) \times \mathbf{E}^i(\mathbf{r})\right] =$$
$$= \hat{\mathbf{n}}(\mathbf{r}) \times \iint_S \left[1 + \frac{1}{k_0^2}\nabla\nabla\cdot\right] \mathbf{J}(\mathbf{r}')G(\mathbf{r},\mathbf{r}')\,\mathrm{d}\mathbf{r}'$$

System identification

State-space representation of linear system

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{i}(t),$$
$$\mathbf{u}(t) = \mathbf{C}\mathbf{x}(t) + \mathbf{D}\mathbf{i}(t).$$

State-space parameters are related to transfer function as

$$\mathbf{Z}(s) = \mathbf{C}(s\mathbf{I} - \mathbf{A})^{-1}\mathbf{B} + \mathbf{D}.$$

Freedom in choosing the model-order (number of internal states)

System identification

We use a two-step estimation

- Initial estimate using FSID
- Initial estimate is refined with regards to the weighted cost function:

$$\sum_{k=1}^{K} ||\mathbf{C}(\mathrm{j}\omega_k \mathbf{I} - \mathbf{A})^{-1}\mathbf{B} + \mathbf{D} - \mathbf{Z}_k||^2_{\mathbf{W}_k},$$

- BCD-iterations:
  1. Estimate B, D, while A, C are kept fixed.
  2. Estimate C, D, while A, B are kept fixed.

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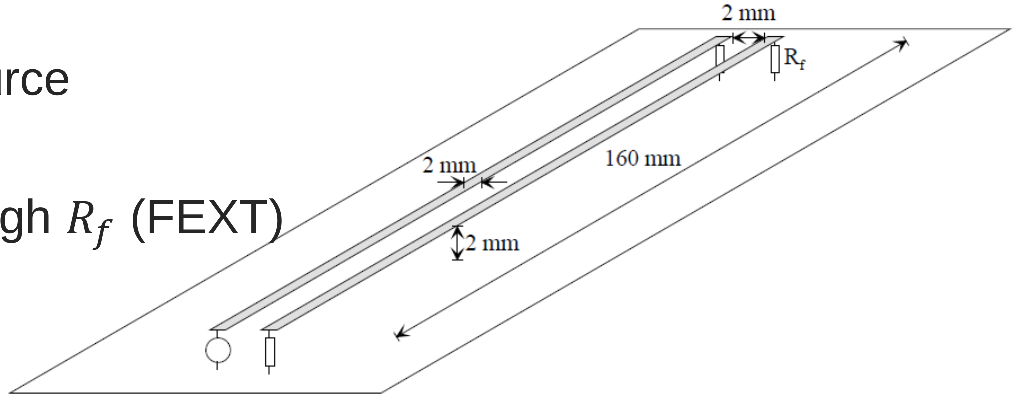
Test case 1: Parallel lines SISO (1x1)

Two parallel strips above infinite metallic ground plane

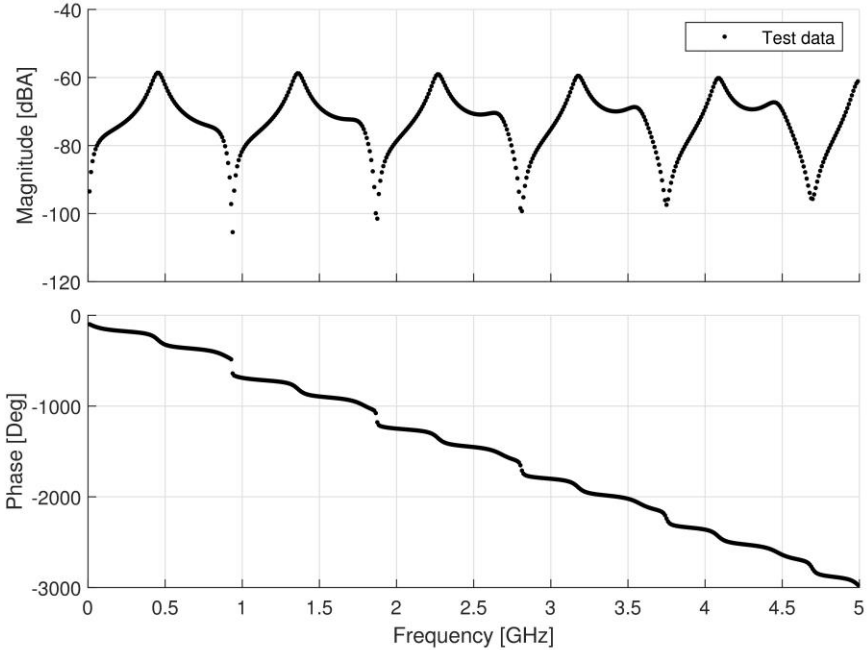
- Excited by sinusoidal voltage source
- Terminated by 1 kΩ resistors
- Quantity of interest: current through R_f (FEXT)



Test case 1: Data sets

Test data set

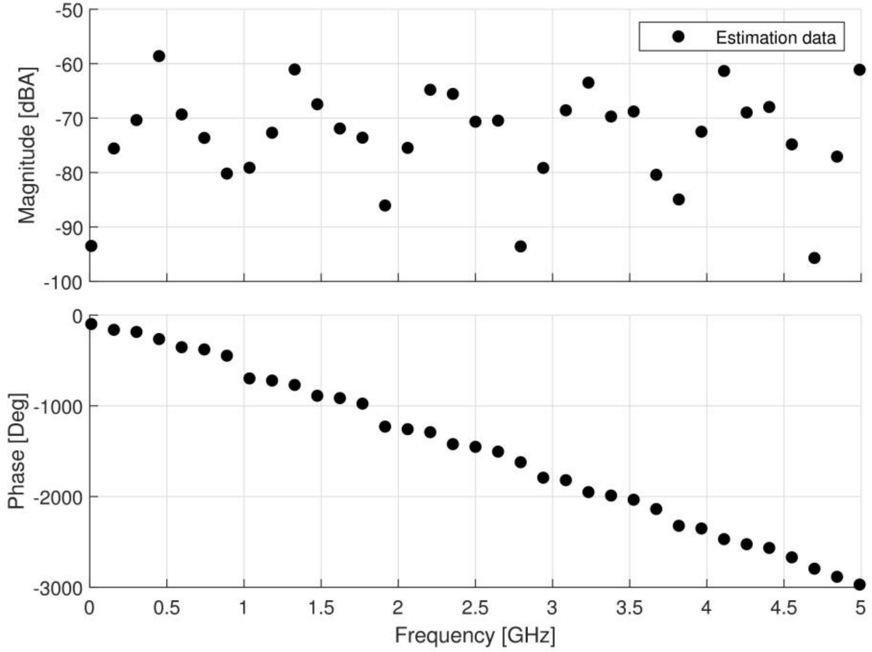
- 512 data points
- Uniformly distributed
- Range from 10 MHz to 5 GHz
- Fully resolves frequency response



Test case 1: Data sets

Estimation data set

- 35 uniformly spaced samples
- Range from 10 MHz to 5 GHz
- Can be expanded if needed



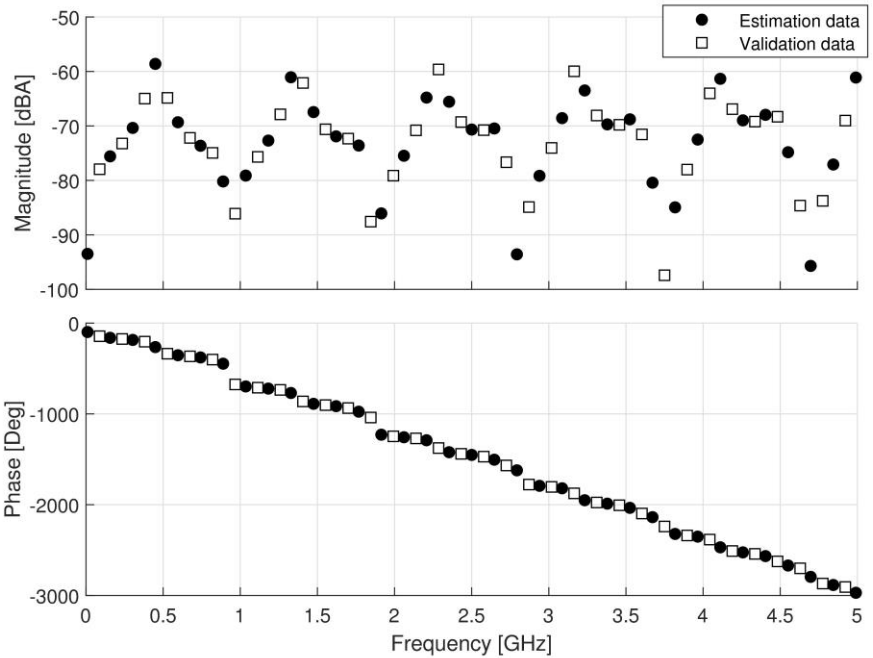
Test case 1: Data sets

Estimation data set

- 35 uniformly spaced samples
- Range from 10 MHz to 5 GHz
- Can be expanded if needed

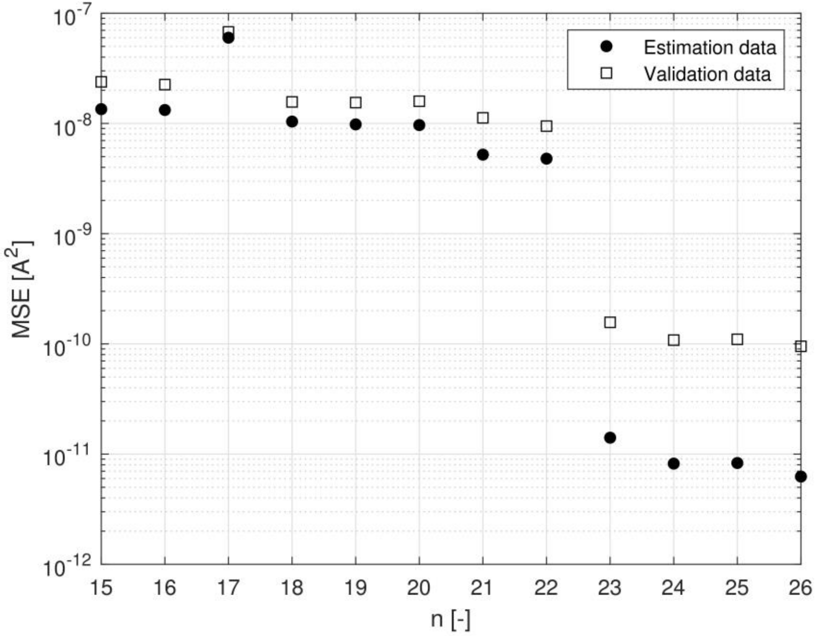
Validation data set

- 34 uniformly spaced samples
- Centered between estimation samples



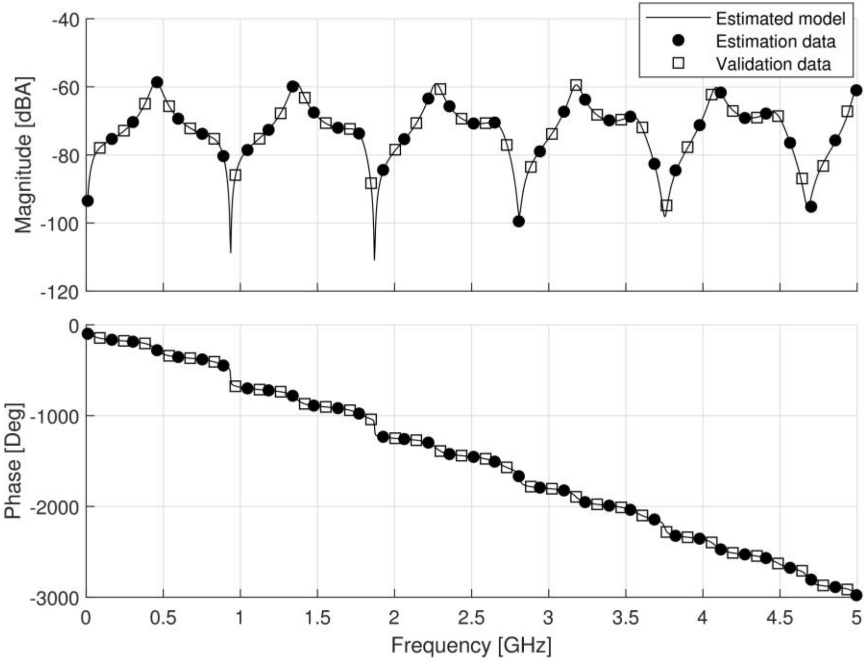
Test case 1: Model order selection

- Model orders ranging from 15 to 26
- Sharp decrease in MSE at order 23
- Same decrease in both estimation and validation data
    - No noise – No overfitting!



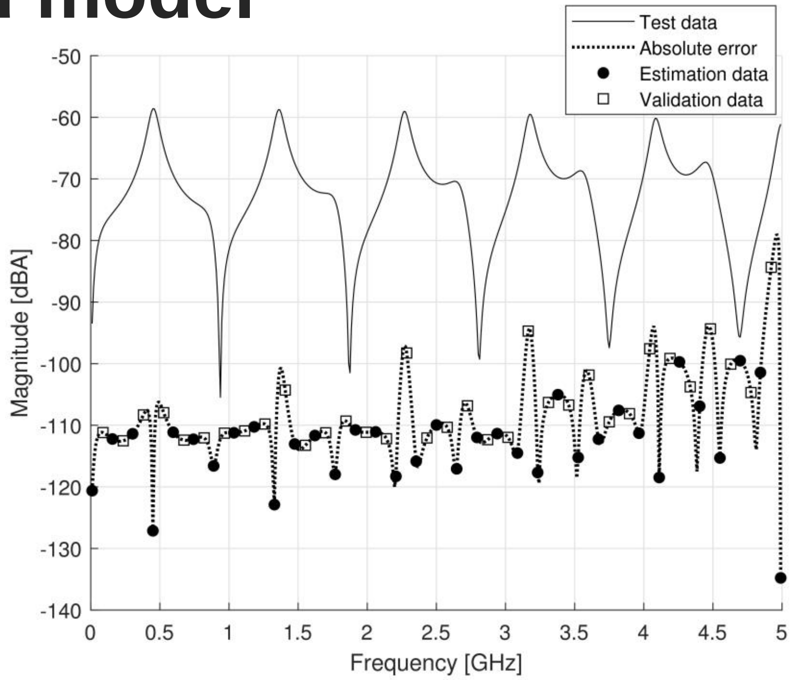
Test case 1: The estimated model

- Chosen model compares well against both estimation and validation data



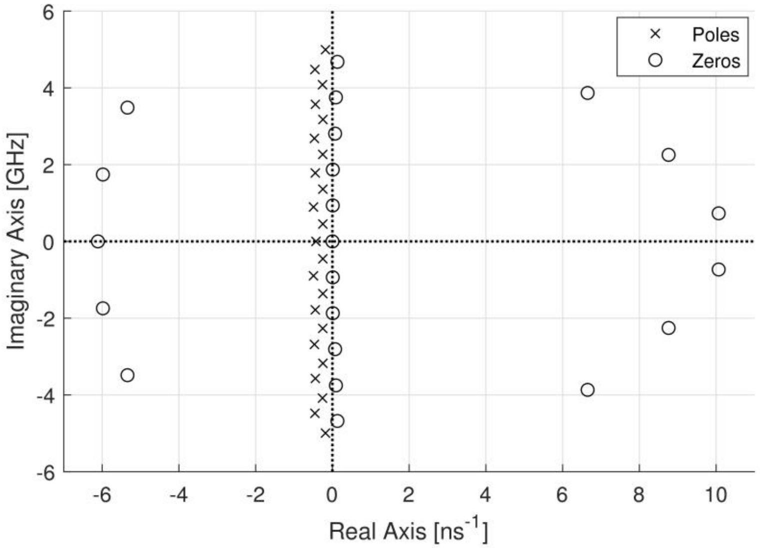
Test case 1: The estimated model

- Chosen model compares well against both estimation and validation data
- The model compares well with the test data over the whole interval
  - Effects from truncation of pole-zero expansion at high frequencies
  - Validation data points well positioned



Test case 1: The estimated model

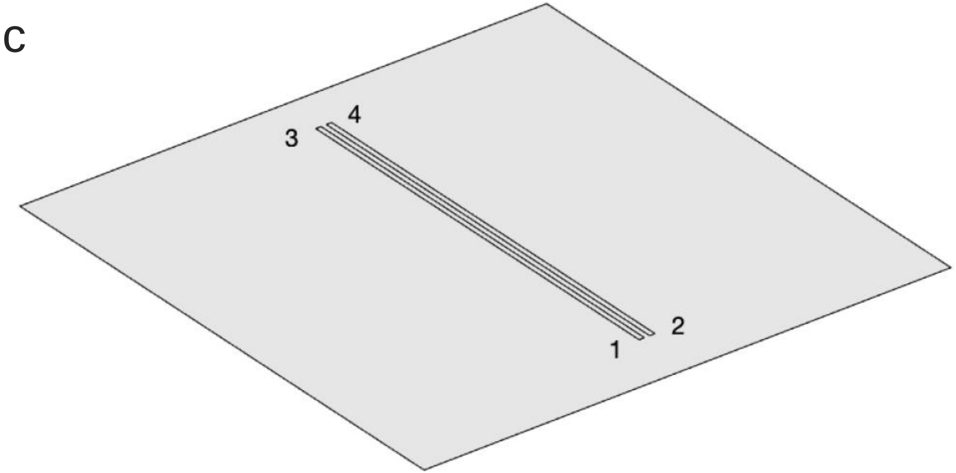
- Chosen model compares well against both estimation and validation data
- The model also compares well with the test data, over whole interval
  - Effects from truncation of pole-zero expansion at high frequencies
  - Validation data points well positioned
- Additionally, model poles and zeros can give insight to the physical problem!



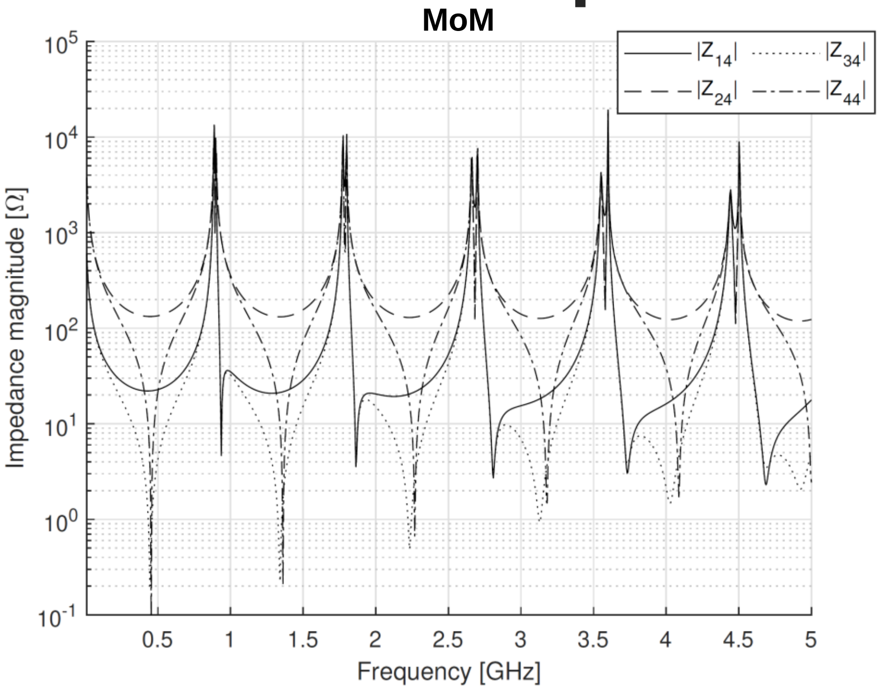
Test case 2: Parallel strips MIMO (4x4)

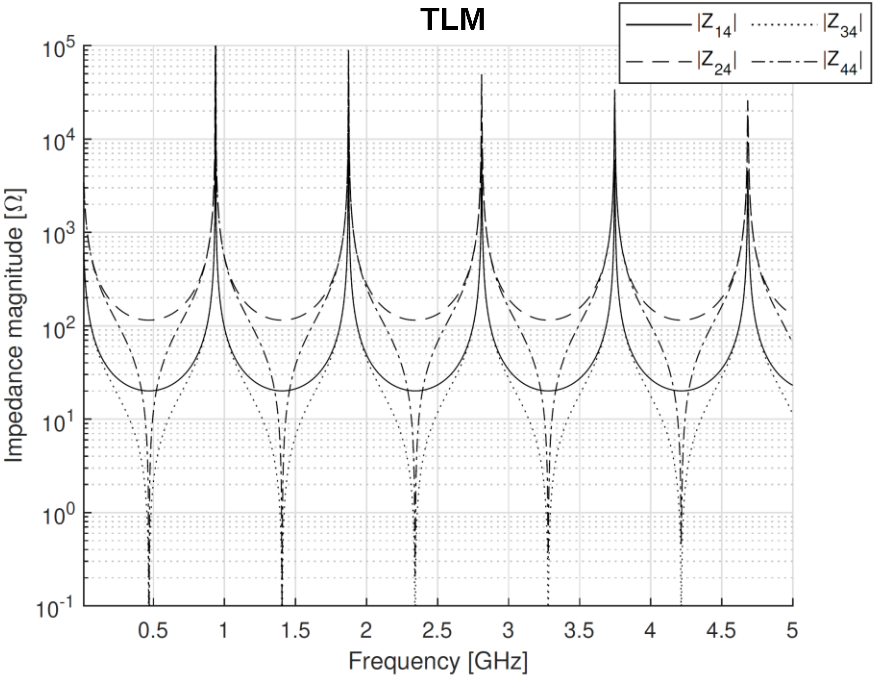
Two parallel strips above infinite metallic ground plane

- 4 ports
- Quantity of interest: 4x4 impedance matrix
- Gives entire system response!

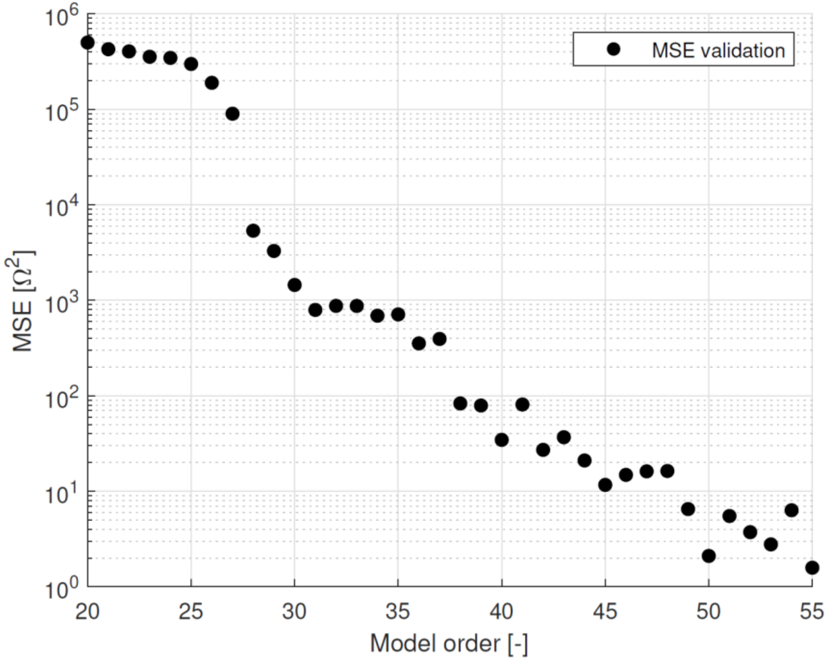


Test case 2: Z-parameters

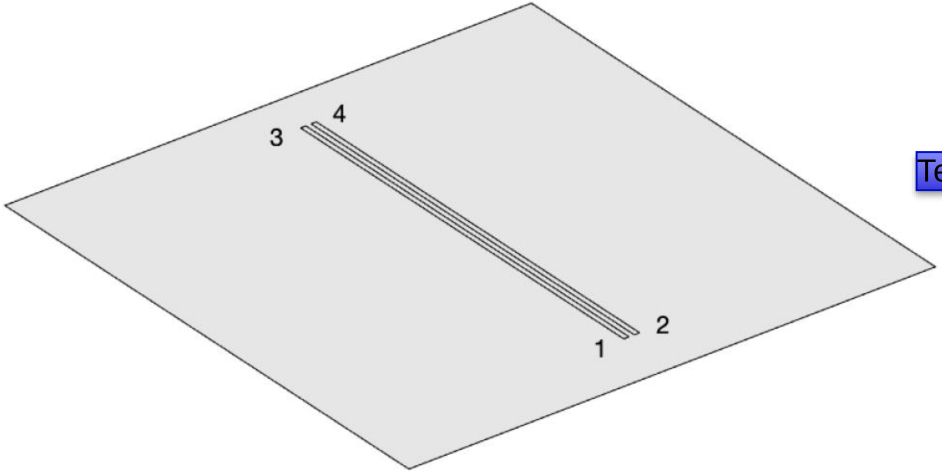




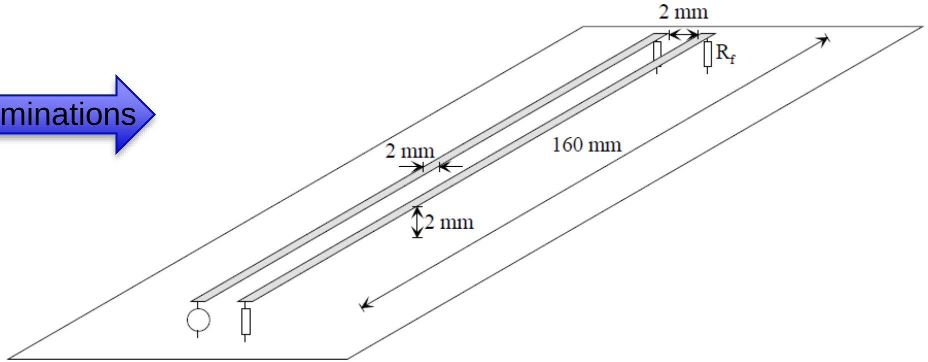
Test case 2: Model order selection



Test case 2: Model with terminations



Terminations



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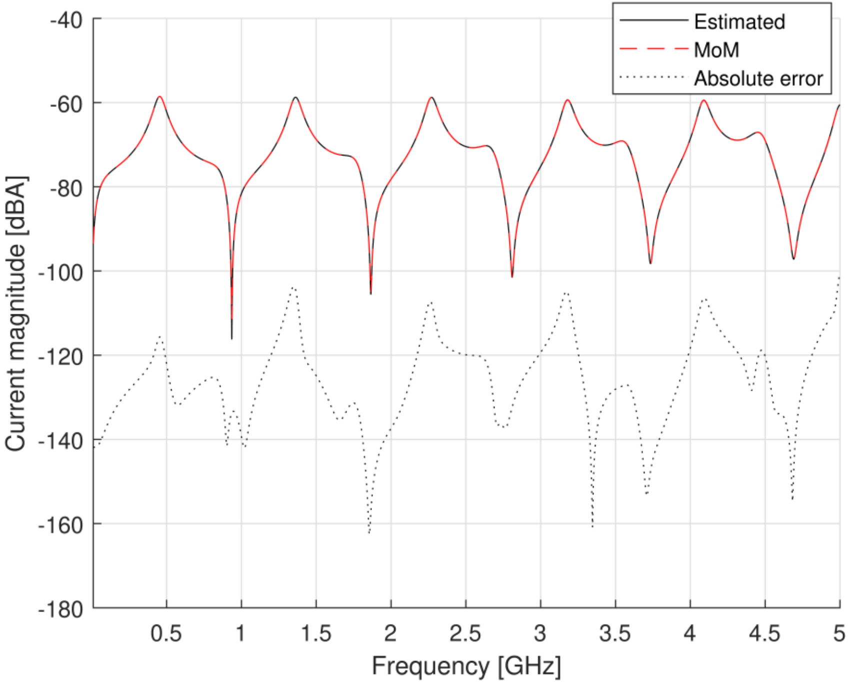
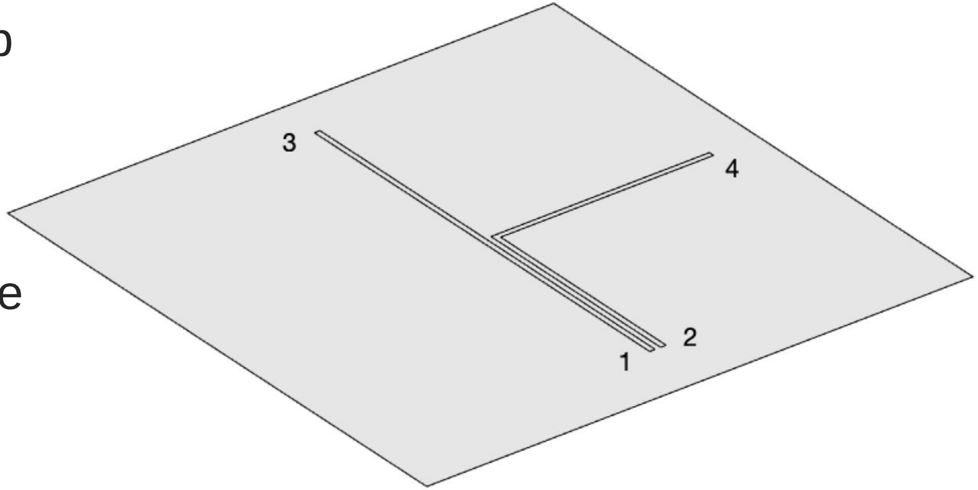


Test case 3: L-shaped strip MIMO (4x4)

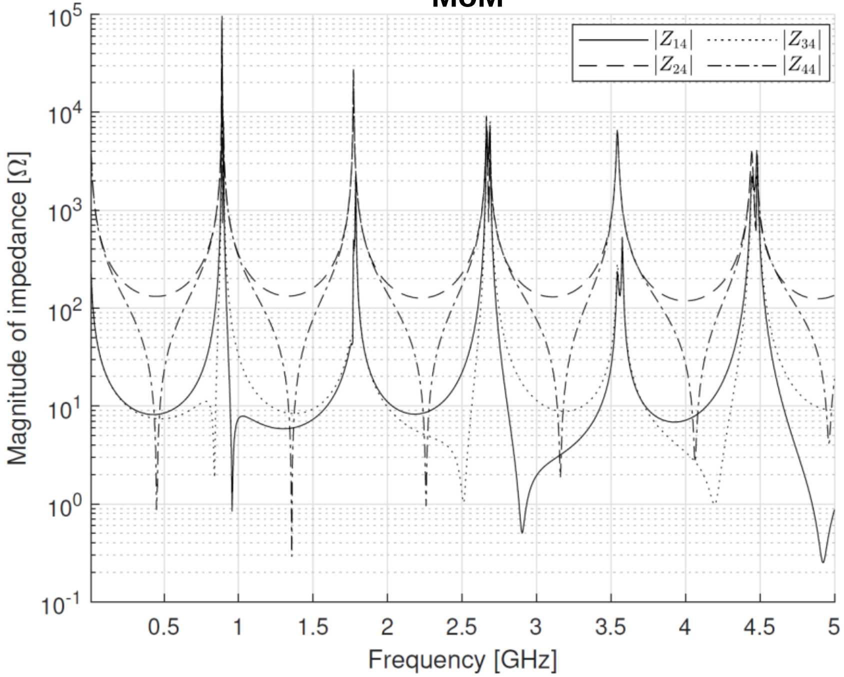
One straight strip and a L-shaped strip above infinite metallic ground plane

- Complicated to analyze using transmission line theory
- Quantity of interest: 4x4 impedance matrix

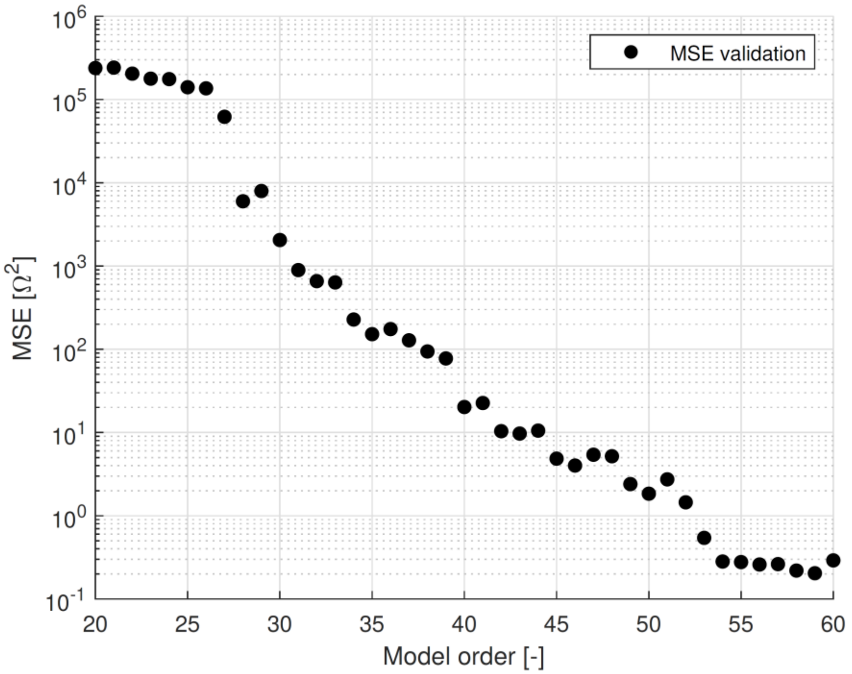


Test case 3: Z-parameters

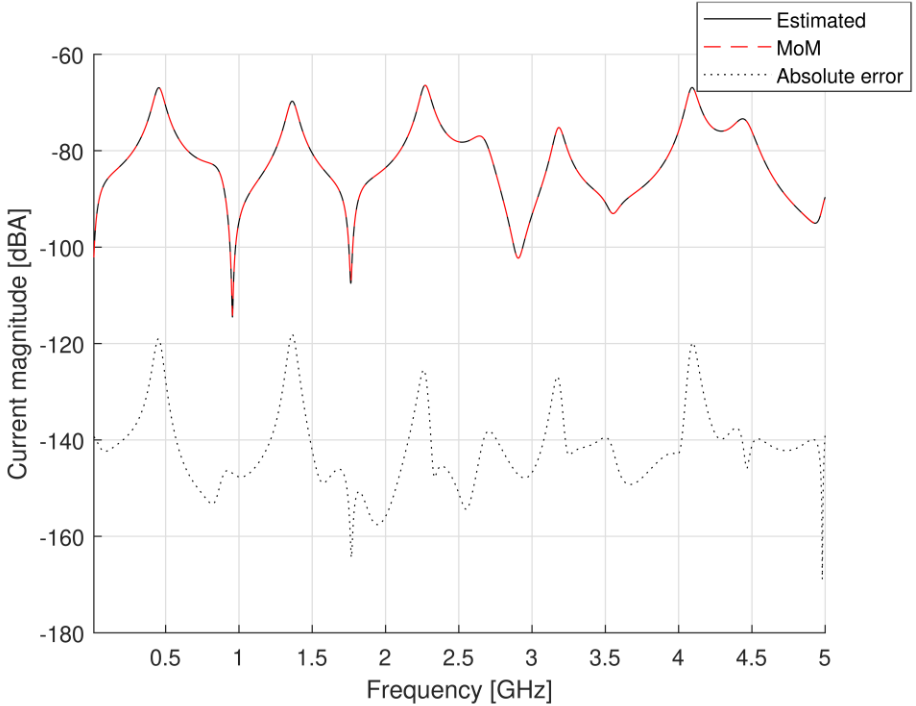
MoM



Test case 3: Model order selection



Test case 3: Model with terminations



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Summary

- The proposed estimation framework gives excellent results for the studied test cases
- Flexible system representation using Z, Y or S-parameters
- Few samples needed even for a wide frequency range
- The produced state-space model allow fast evaluation of the frequency response over the whole frequency range
- The component model can be simulated separately, or as part of a system simulation

Thank you for listening!