Efficient Characterization of Interference Propagation in Multilayered Substrates with Multiple-Stage Open Discontinuities

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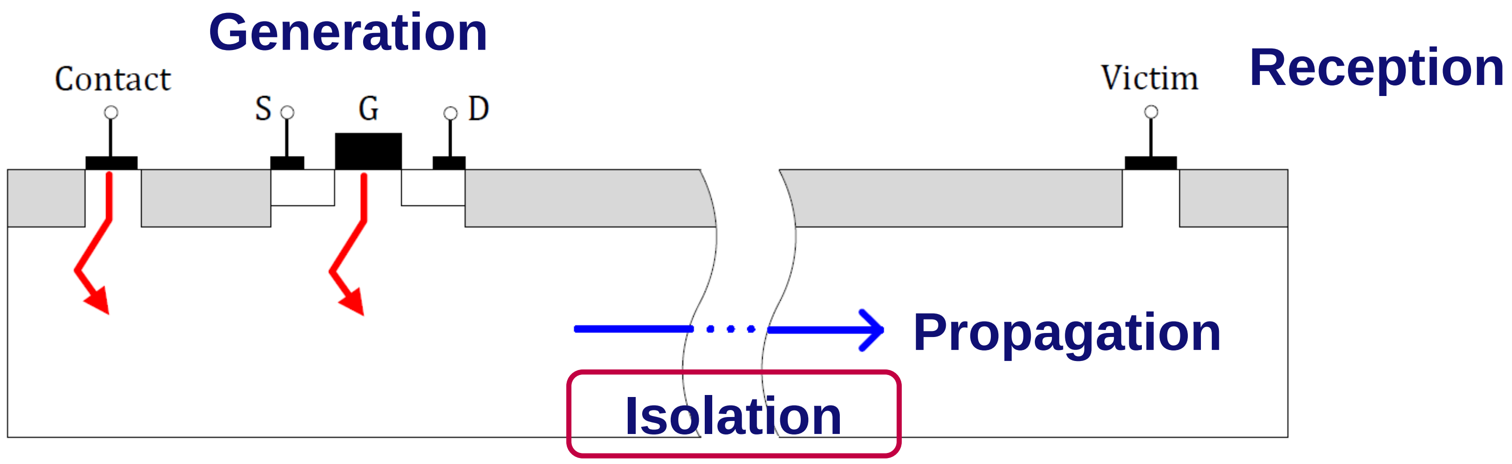
Where innovation starts

Outline

- Introduction
- EM characterization of IC substrates
- Substrate discontinuities
- Efficient modeling approach
- Study case: triple-well
- Study case: filled trench
- Conclusions

Introduction

- High-performance ICs include noisy digital or power circuitry together with sensitive analog systems
- EMC prediction at early design stages is highly convenient
- Evaluate the impact of substrate technology choices



Introduction

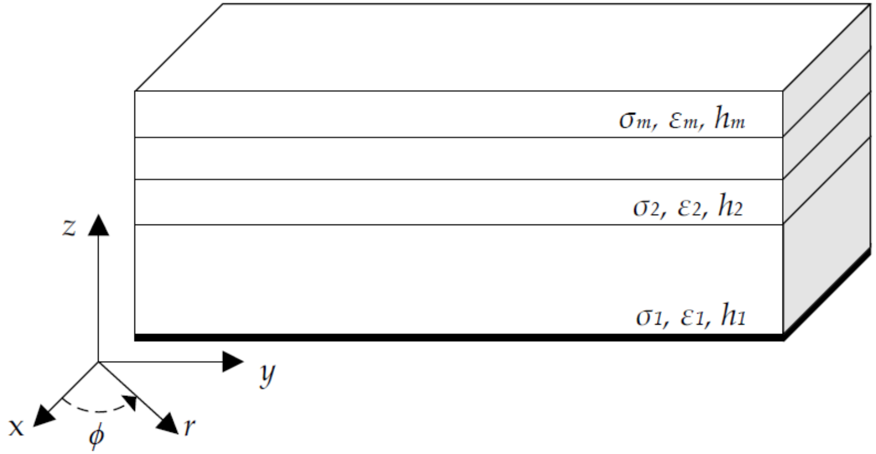
Source reduction
(low impedance paths)
- Guard rings
- Substrate contacts

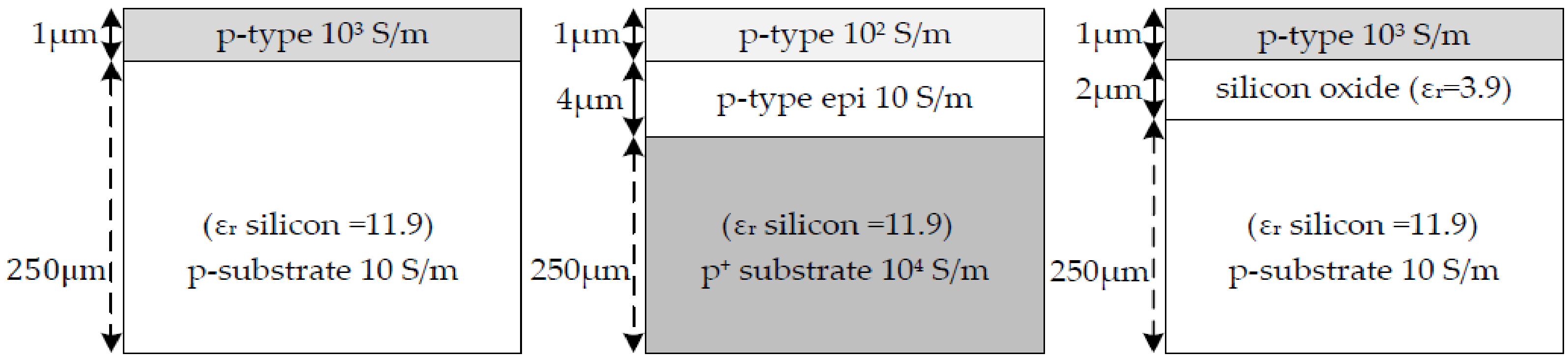
Interference blocking
(charge-free sections)
- SiO_2 trenches
- Buried oxide layers
- Reverse-biased junctions

- **On-chip isolation structures**
- **Keep interference away from sensitive nodes**
- **Characterization by means of simulations, experimental tests or lumped-element models + extraction tools**

EM Characterization of IC Substrates

- **Propagative description of interference coupling**
- **Multilayered open lossy dielectric radial waveguides**





(a) Lightly Doped **(b) Heavily Doped** **(c) Silicon on Insulator**

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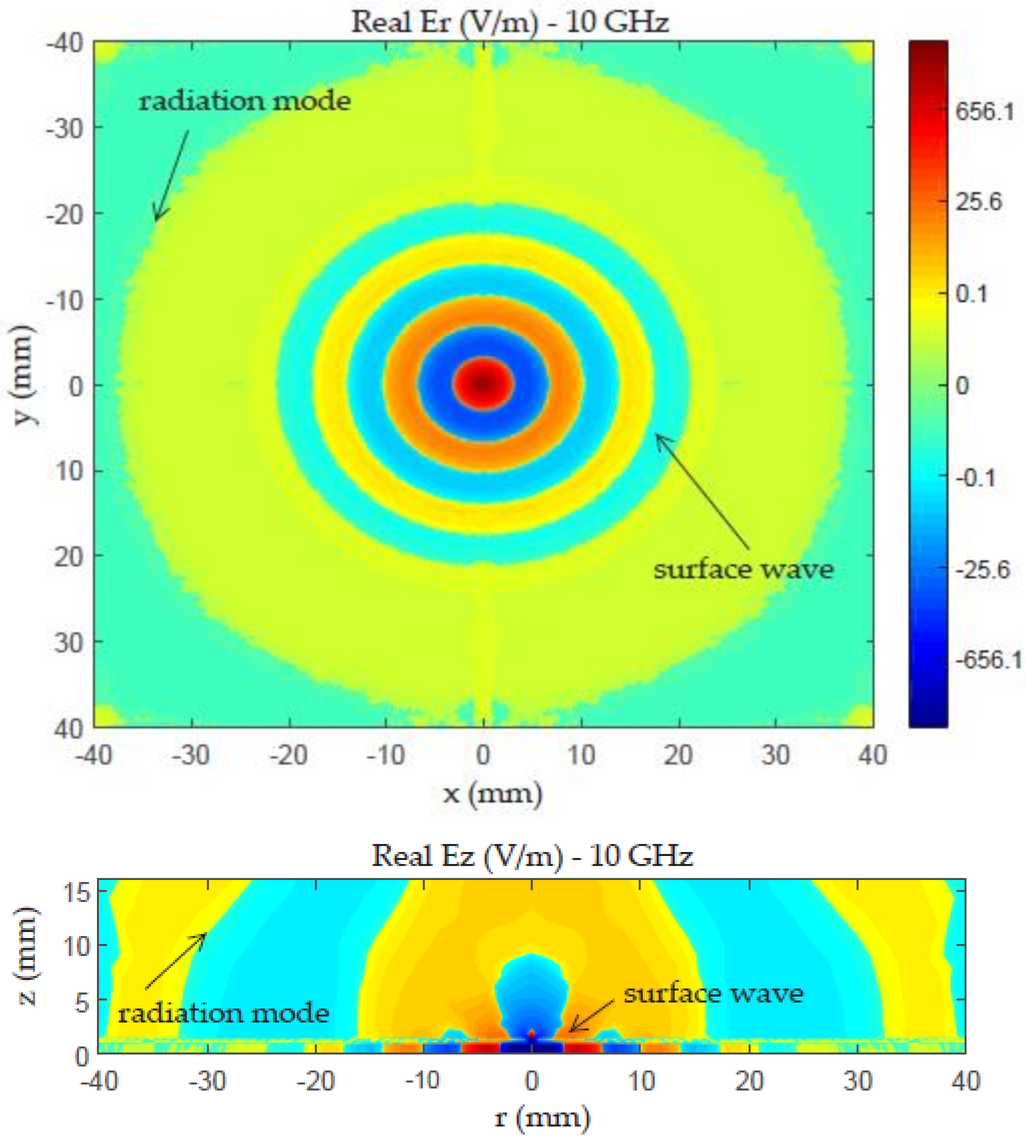
EM Characterization of IC Substrates

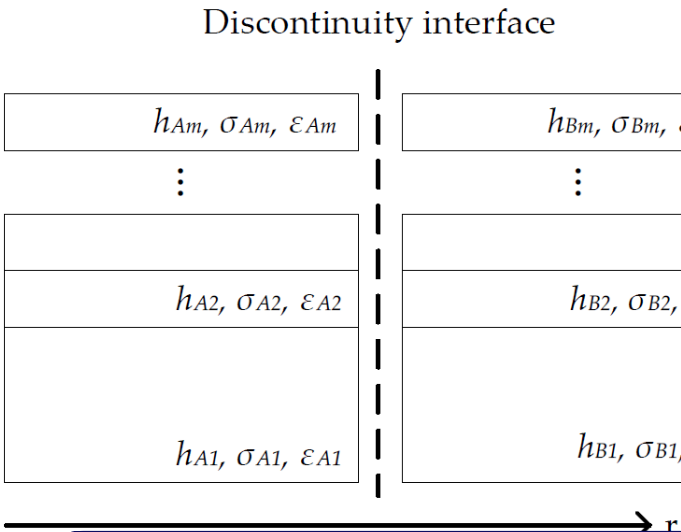


- **Two types of propagation modes**
  - **Discrete (surface waves)**
  - **Continuous (radiation m.)**
    - **Propagative**
    - **Evanescent**

Dominant modes are determined by the parameters of the top active layer

Substrates Discontinuities

- **Different cascaded doping profiles**
- **Model of one-stage discontinuity:**
  - **Continuity of tangential fields**
  - **Orthogonality**



$$\mathbf{E}_A = a_{A1}\mathbf{e}_{A1} + \sum_{i=1}^{\infty} a_{A1}\rho_{Ai\_A1}\mathbf{e}_{Ai} + \int_{\mathcal{D}} a_{A1}\rho_{A\_A1}(k_r)\mathbf{e}_A(k_r)\,\mathrm{d}k_r$$

$$\mathbf{E}_B = \sum_{j=1}^{\infty} a_{Bj}\mathbf{e}_{Bj} + \int_{\mathcal{D}} a_B(k_r)\mathbf{e}_B(k_r)\,\mathrm{d}k_r$$

Excitation **Discrete** **Radiation**

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Substrates Discontinuities

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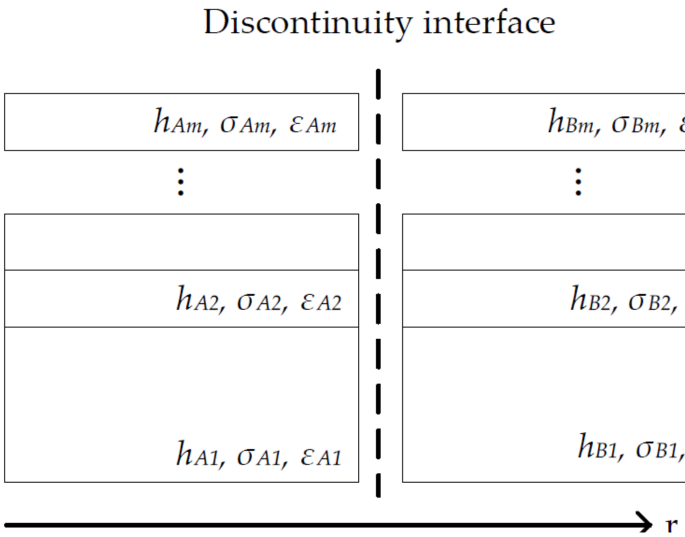

$$\mathbf{E}_A = a_{A1}\mathbf{e}_{A1} + \sum_{i=1}^{\infty} a_{A1}\boxed{\rho_{Ai\_A1}}\mathbf{e}_{Ai} + \int_{\mathcal{D}} a_{A1}\boxed{\rho_{A\_A1}(k_r)}\mathbf{e}_A(k_r)\,\mathrm{d}k_r$$

$$\mathbf{E}_B = \sum_{j=1}^{\infty} \boxed{a_{Bj}}\mathbf{e}_{Bj} + \int_{\mathcal{D}} \boxed{a_B(k_r)}\mathbf{e}_B(k_r)\,\mathrm{d}k_r$$

Mode conversion

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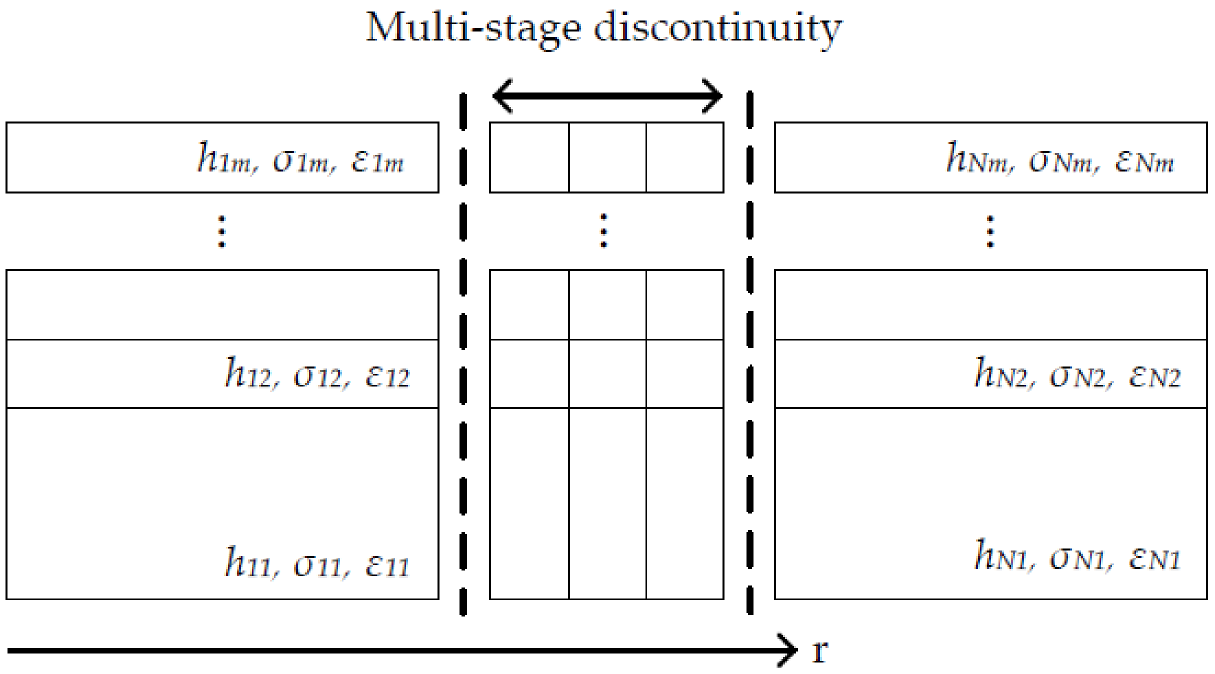
Substrates Discontinuities

- **Multi-stage substrate discontinuities**



Efficient modeling approach

Drawbacks	Proposed approach
- *Large and complex system of equations*	- *Smart mode selection (greater contribution to transfer function)*
- *Discretization of continuous spectrum*	- *Bounded sections: few discrete modes*
- *Truncation of number of equations and modes considered*	- *Unbounded section: spectral components with better matching*

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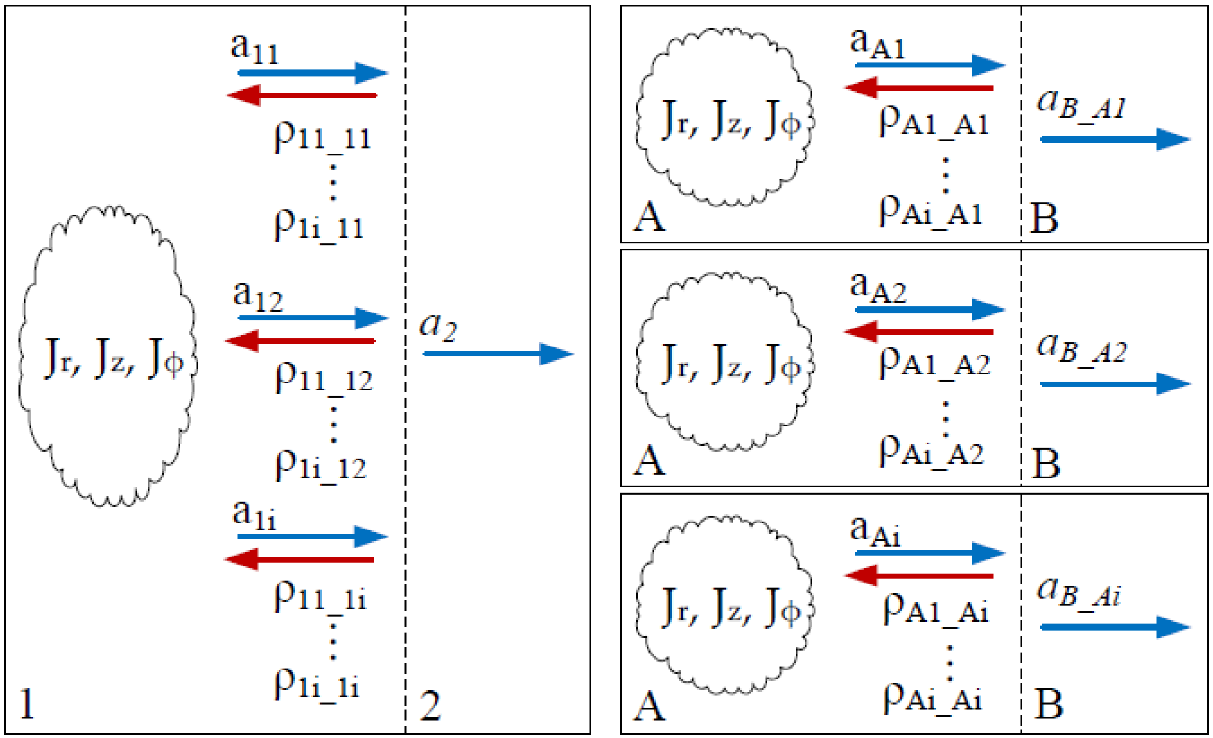
Efficient modeling approach

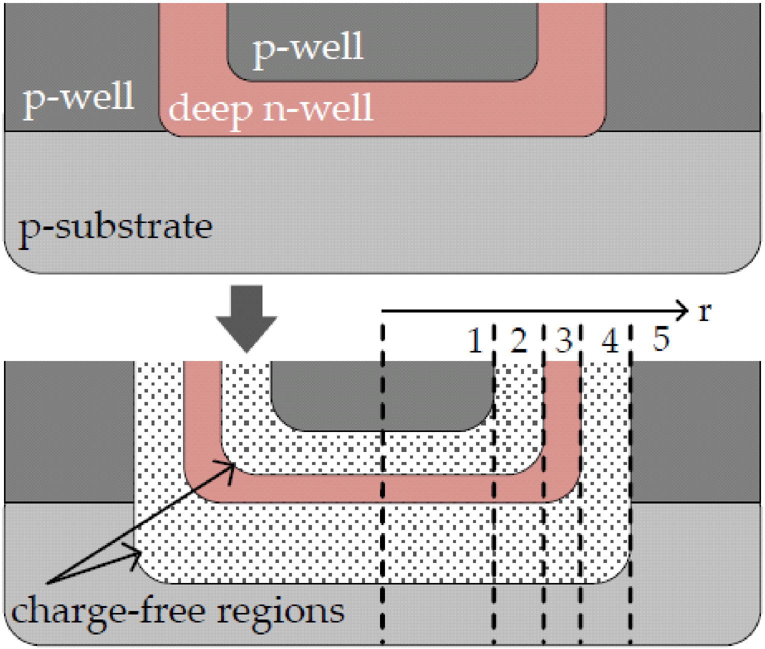
- **Goal: describe each sections with few modes**



- **Isolate the section**
- **Select spectral component:**
  - **Known source**
  - **Arbitrary source**

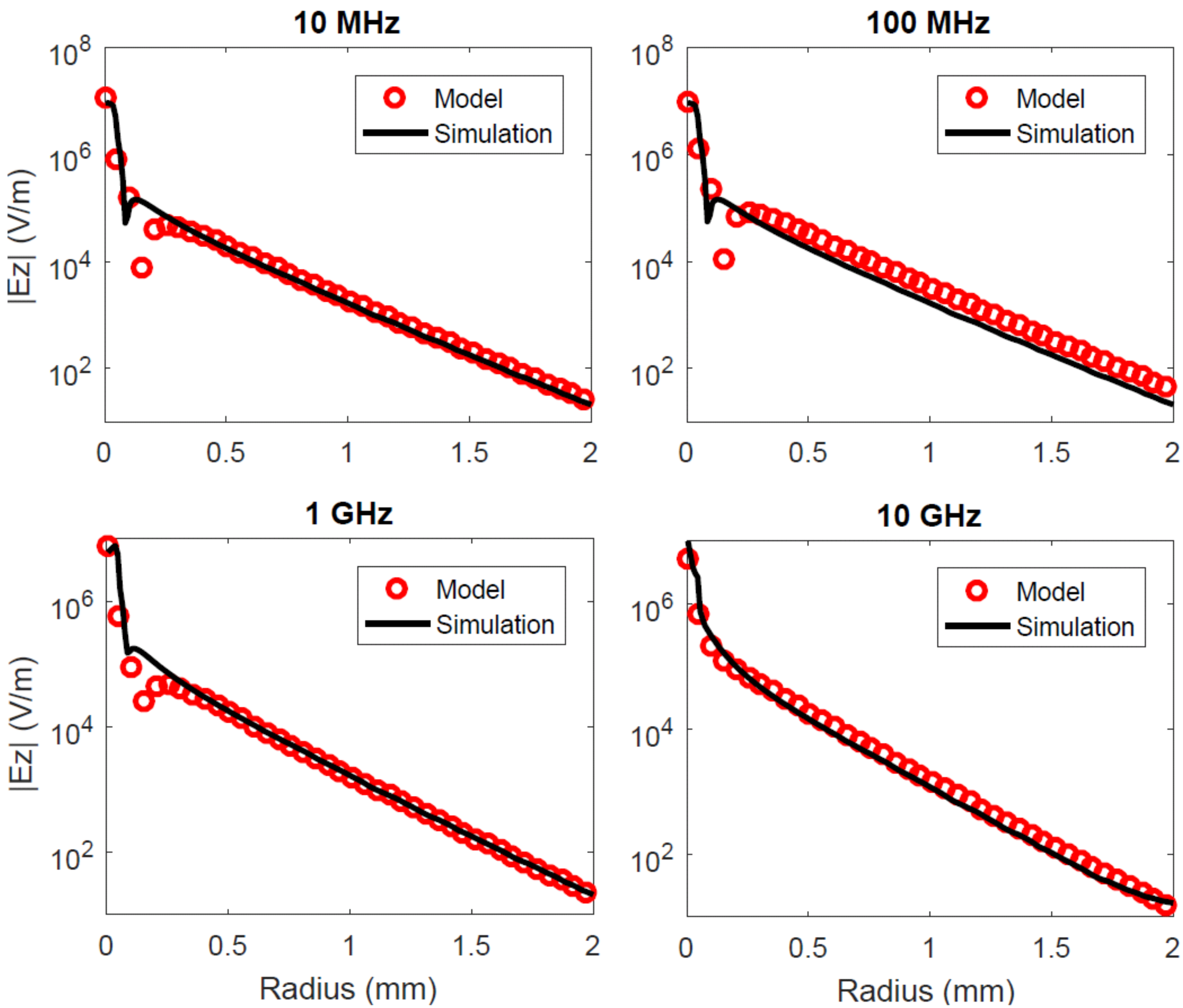
Study Case: triple well

- Triple-well: 2 consecutive reverse-biased junctions
- Characterized with 5 sections
- Each section is characterized with either 2 or 3 modes
- Computation time was 12 minutes for 100 freq. points



- Results are compared to full-wave simulations (CST)

Study Case: triple well

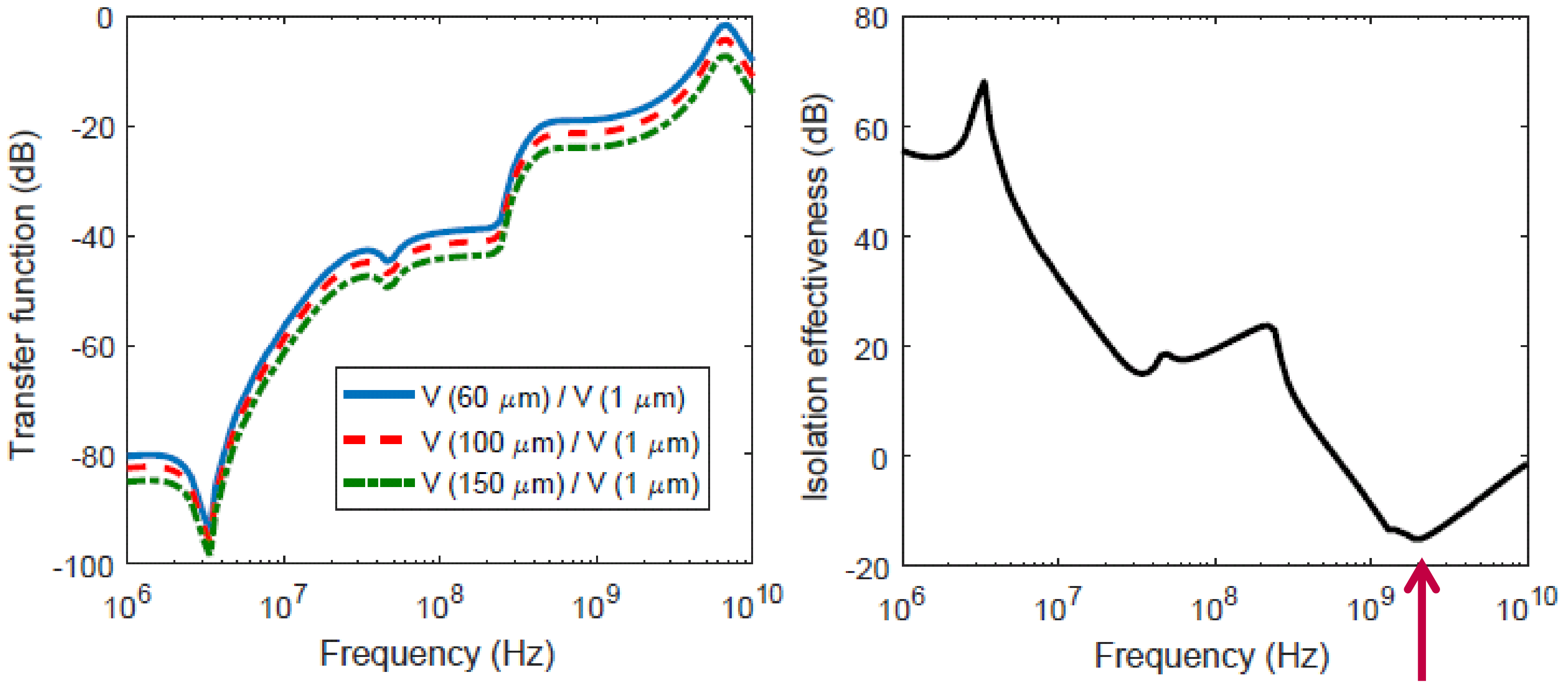


Simulation time was 3 hours for 5 freq. points

Transitory effects due to destructive mode interaction

Study Case: triple well

- **Transfer function vs. Isolation effectiveness**



Interference enhancement due to mode conversion

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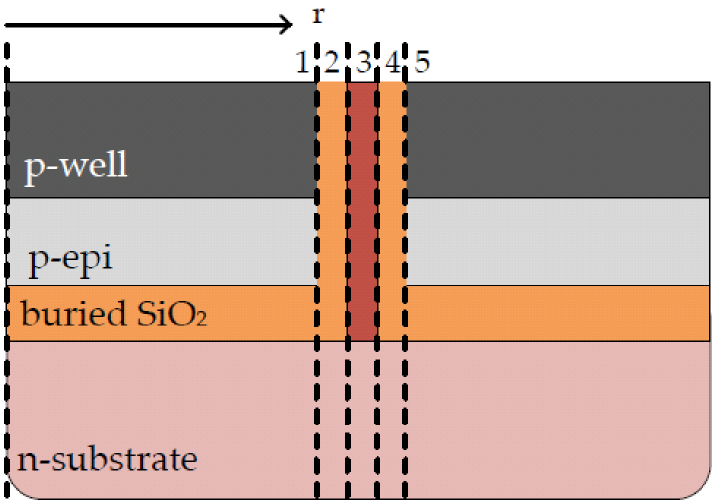
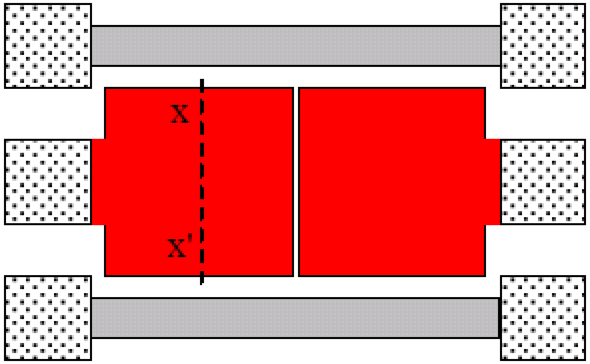
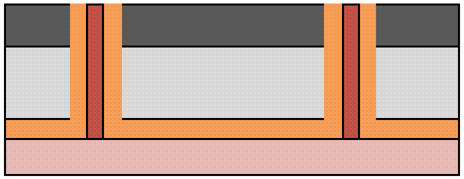
Study Case: filled trench

- **Characterized with 5 sections**
- **Test structure in 0.13 um SOI technology, embedded in a Ground-Signal-Ground structure**
- **Two 200 x 200 islands surrounded by Deep Trench Isolation**



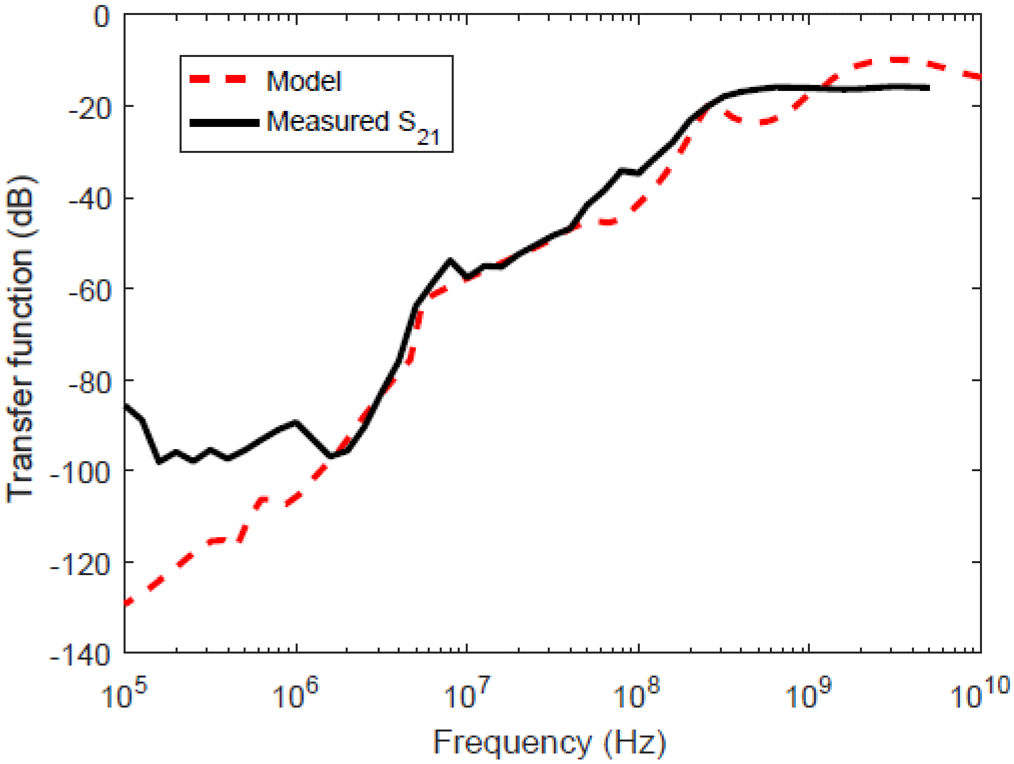




cross-section xx'

Study Case: filled trench

Transfer function vs measured S21



Computation time was 8 min. for 100 freq. points

Noise floor below 1 MHz

Radially symmetric structures are equivalent

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Conclusions

- EM modeling approach based on modal analysis
- Provides early and fast estimation of isolation effectiveness
- Smart mode selection enables a significant simplification of the system of equations
- Results show that effects derived from mode conversion are present even at few MHz (transitory isolation peaks and interference enhancement)
- Results obtained with radially symmetric structures can be extrapolated to other topologies

Thank you for your attention