EMC + SIPI Virtual IBIS Summit

Fast PDN Impedance Prediction Using Deep Learning

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Speaker Introduction

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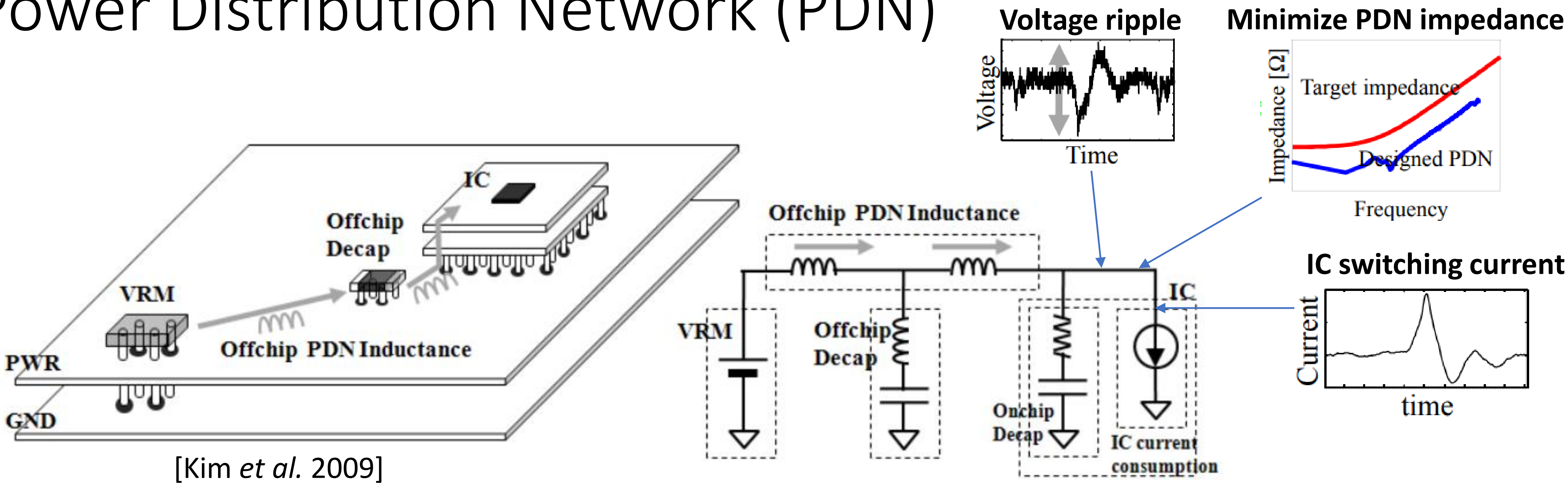
Power Distribution Network (PDN)

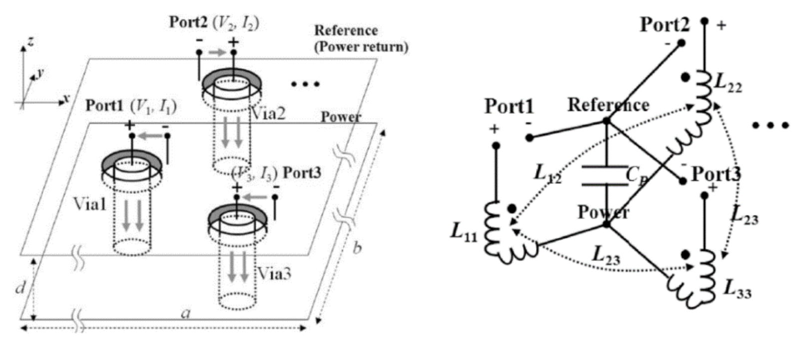


[Kim *et al.* 2009]

- PDN design is important to reduce voltage supply noise caused by IC switching current and ensure power integrity for IC
- Decoupling capacitors (decaps) are utilized to reduce PDN impedance so as to reduce voltage ripples

PDN Impedance Modeling

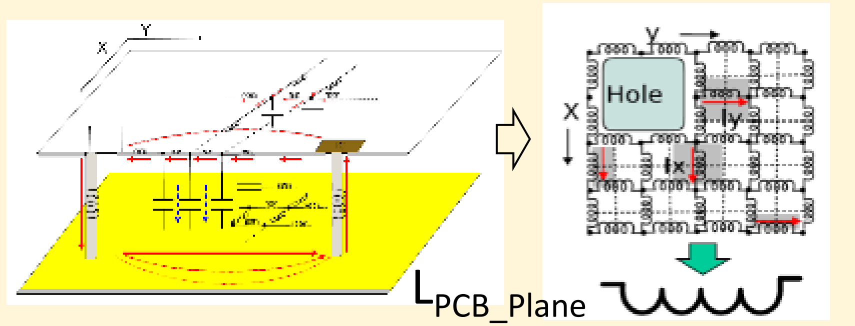
Cavity model [Kim *et al.* 2010]



$$L_{ij} = \frac{\mu d}{ab} \sum_{m=0} \sum_{n=0} \frac{\varepsilon_m^2 \varepsilon_n^2}{k_{mn}^2} f(x_i, y_i, x_j, y_j) \Big|_{(m,n)\neq(0,0)}$$

- Cavity model: can only handle rectangle power plane shapes

Plane-Pair PEEC (PPP) Model [Wei *et al.* 2016]

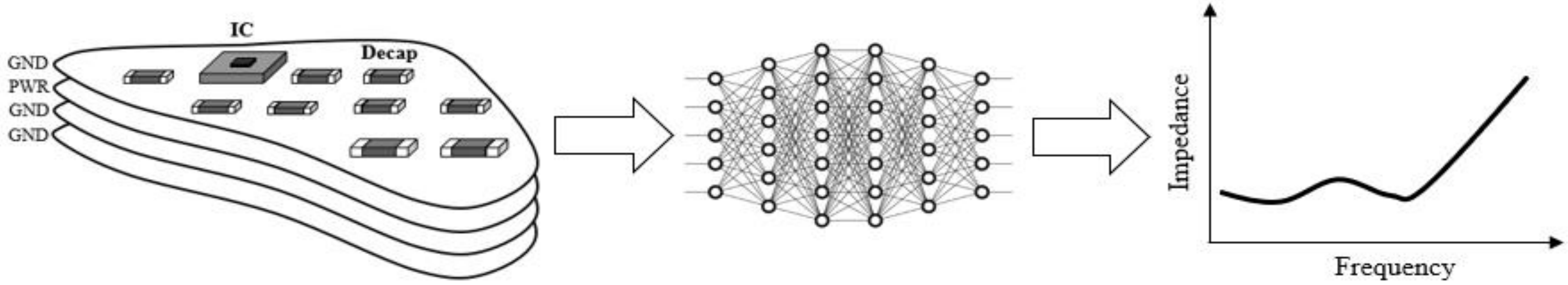


Equivalent circuit for power net area fill

- PPP: Relatively time-consuming

A fast calculation approach for multi-layer PDN with irregular board shapes is desired!!!

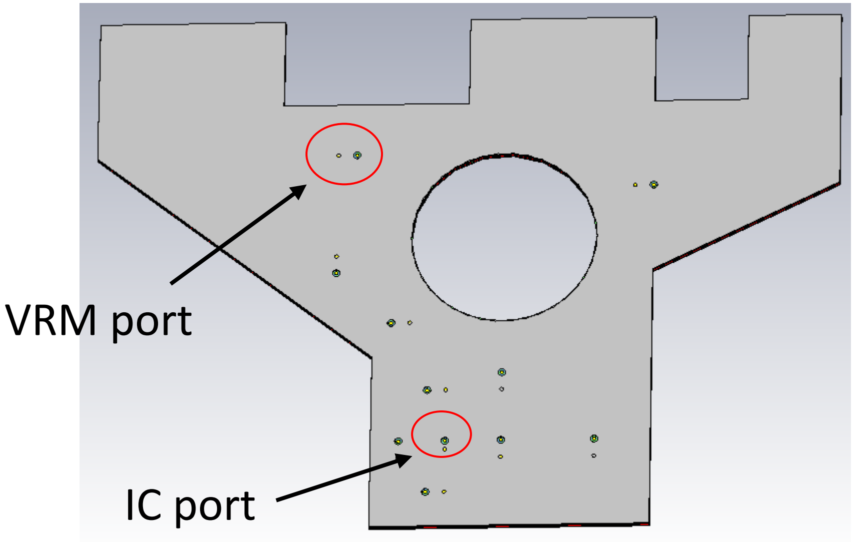
Objective: Deep Learning for PDN Impedance Prediction

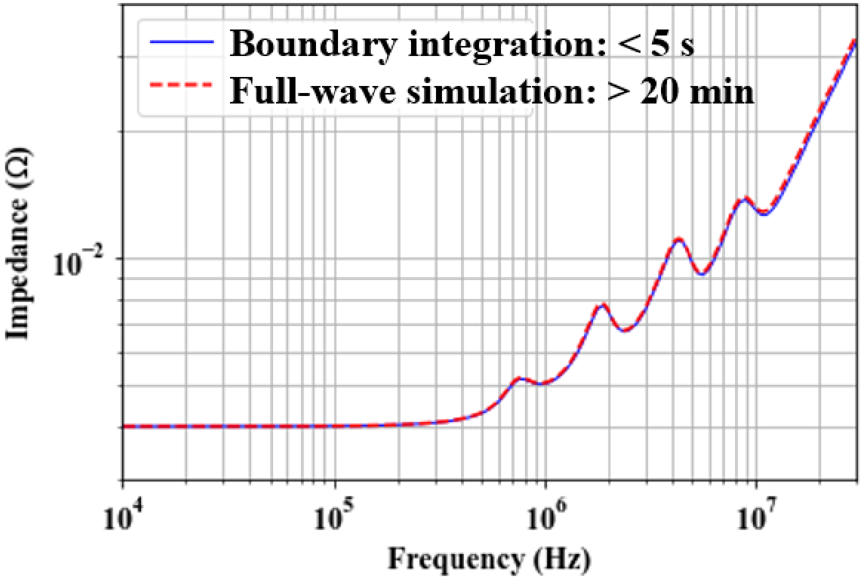


Train a deep learning model that can predict the PDN impedance given any:

- Board shapes
- Stackup
- IC location
- Decap placement

Boundary Integration for PDN Impedance Calculation



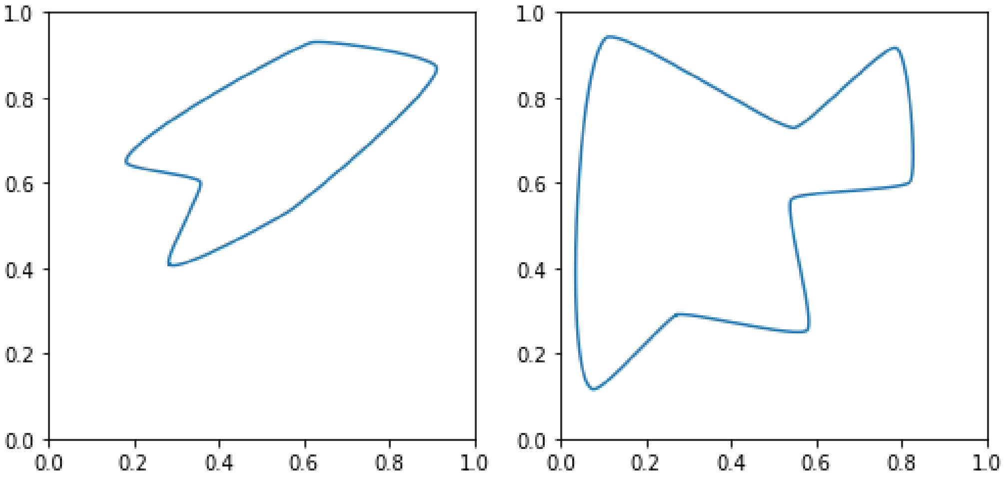


- A boundary integration method is adopted to calculate PDN impedance for arbitrary shape and stackup from DC to AC
- The boundary integration method is much faster than full-wave simulations

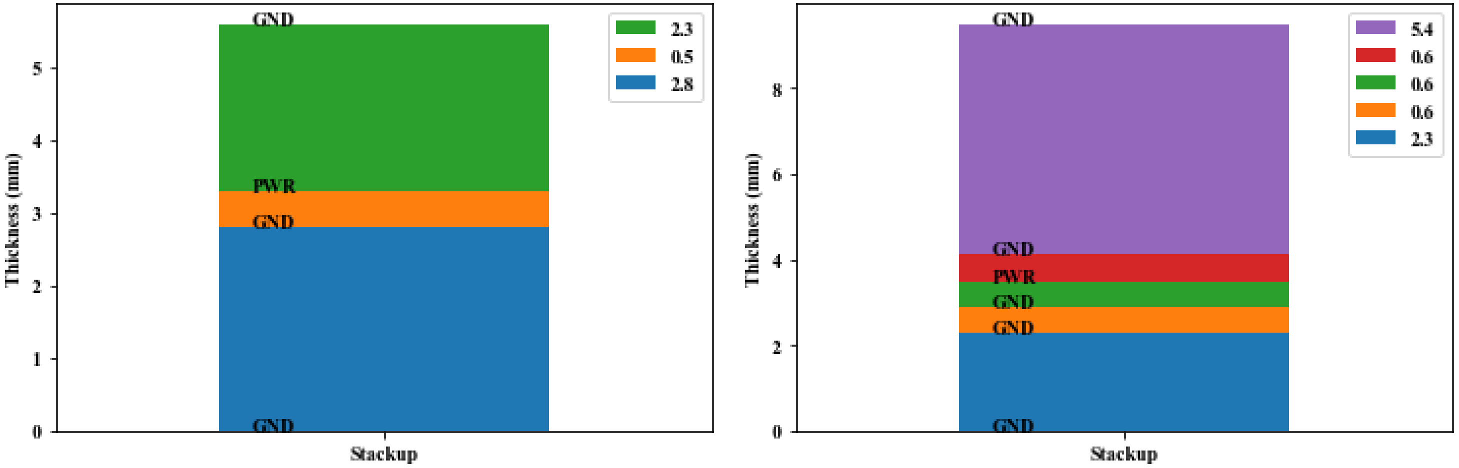
- L. Zhang, J. Juang, Z. Kiguradze, B. Pu, S. Jin, S. Wu, Z. Yang, and C. Hwang, "Efficient DC and AC Impedance Calculation for Arbitrary-shape and Multi-layer PDN Using Boundary Integration," *IEEE Trans. Electromagn. Compat.*, to be submitted.
- M. Friedrich and M. Leone, "Boundary-Element Method for the Calculation of Port Inductances in Parallel-Plane Structures," *IEEE Trans. Electromagn. Compat.*, vol. 56, no. 6, pp. 1439-1447, Dec. 2014.

Generate Random Shape & Stackup

Generate random 2D shape



Generate random stackup



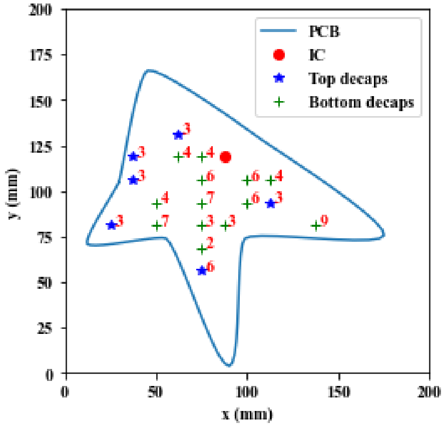
- https://stackoverflow.com/questions/50731785/create-random-shape-contour-using-matplotlib
- L. Zhang, J. Juang, Z. Kiguradze, B. Pu, S. Jin, S. Wu, Z. Yang, and C. Hwang, "Fast PDN Impedance Prediction Using Deep Learning," *International Journal of Numerical Modeling: Electronic Networks, Devices and Fields*, accepted with minor revision.

Decap Library

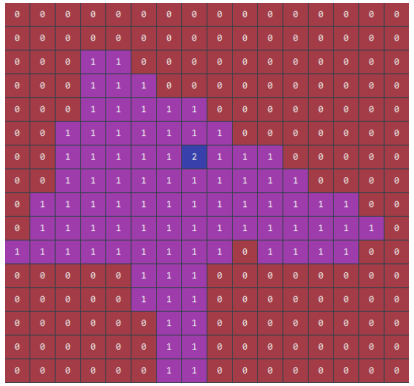
Type #	Decap Parameters				
	Capacitance (uF)	ESL (nH)	ESR (mΩ)	Serial number (Murata)	Size
1	0.1	0.19	34.7	GRM033C80J104KE84	0201
2	0.47	0.18	18.3	GRM033R60J474KE90	0201
3	1	0.22	15.2	GRM155B31C105KA12	0402
4	2.2	0.20	7.2	GRM155C70J225KE11	0402
5	4.7	0.28	7.1	GRM185C81A475KE11	0603
6	10	0.26	5.2	GRM188R61A106KAAL	0603
7	22	0.27	4.0	GRM188B30J226MEA0	0603
8	47	0.15	2.9	GRM219D80E476ME44	0805
9	220	0.41	1.9	GRM31CR60J227ME11	1206
10	330	0.46	1.2	GRM32EC80E337ME05	1210

Matrix Representation

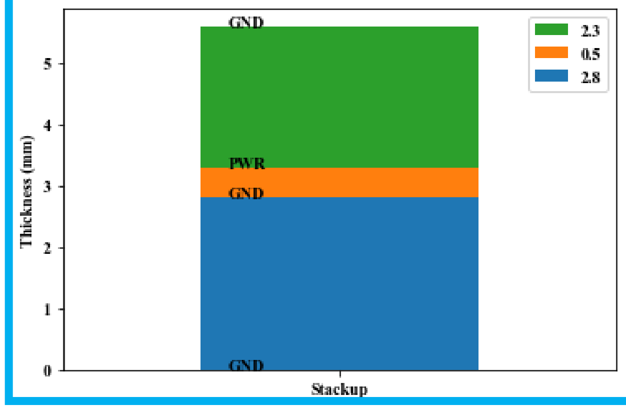
Board contour



Board shape + IC location



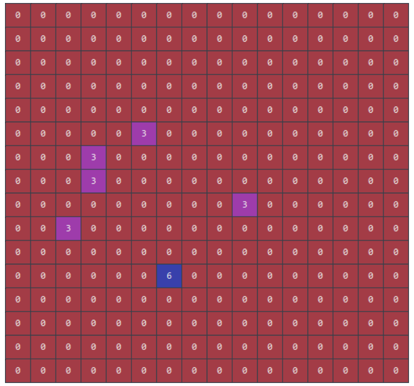
Stackup



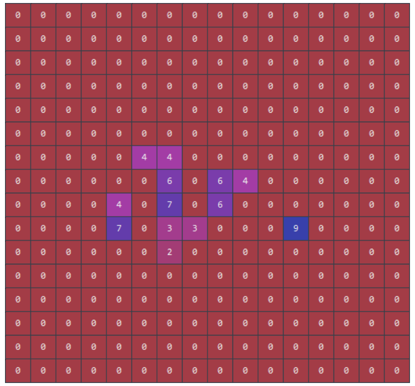
1D matrix

Layer type (1 for GND, 2 for PWR)									Dielectric thickness (unit: mm)							
1	2	1	1	0	0	0	0	0	2.3	0.5	2.8	0	0	0	0	0

Top decaps



Bottom decaps

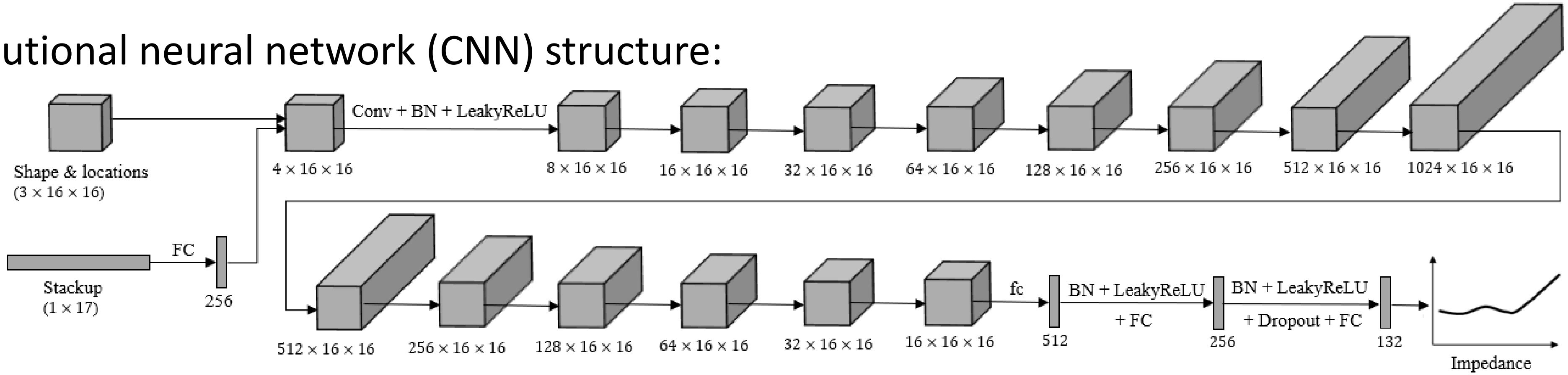


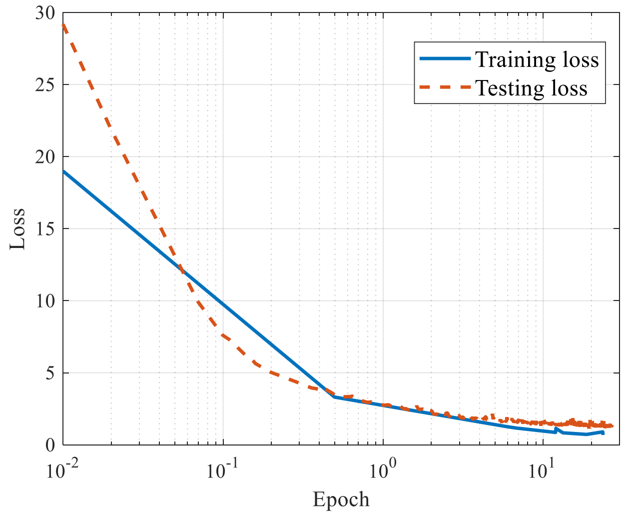
- Board information: 16×16 matrices
- Stackup (4~9 layers): 1×17 matrix
- Maximum size: 200mm×200mm; number of decap locations: 20
- IC and decap locations are generated randomly
- One unit contains one horizontal decap

L. Zhang, *et al.*, *International Journal of Numerical Modeling: Electronic Networks, Devices and Fields*, accepted with minor revision.

CNN Training

Convolutional neural network (CNN) structure:





- 1.3 million board data are generated, 10,000 used for testing
- Output: dB value is used
- Loss function: root mean square error (RMSE)
- Learning rate: 0.0001; Adam optimizer; batch size 128
- Training time: 80 hours (1 NVIDIA Tesla K80 GPU)

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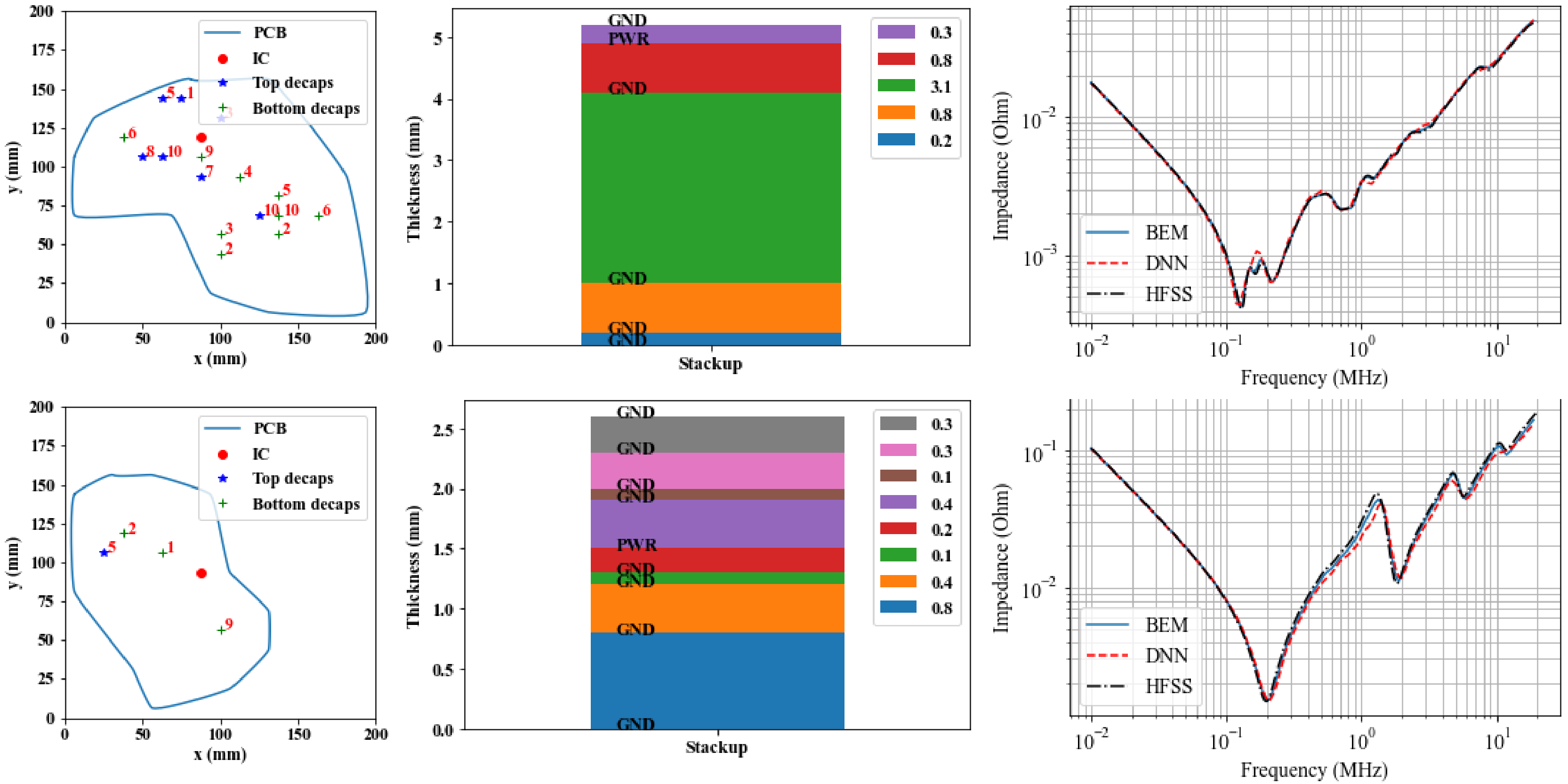
Test Trained Model



- RMSE for the testing data is just around 1dB
- Two testing cases are randomly picked and plotted here

Methods	Case #1	Case #2
Full-wave	35 min	40 min
BEM	10 s	30 s
DNN	**0.1 s**	**0.1 s**

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Summary

- A deep learning model is developed to fast predict the PDN impedance for arbitrarily-shaped power plane and arbitrary stackup
- The trained model can predict PDN impedance within 0.1s with a tolerable accuracy

- Code link on GitHub: https://github.com/lingzhang0319/PDN-Impedance-Prediction-Using-Deep-Learning/tree/master

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