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On-chip evaluation of voltage fluctuations and fault occurrence induced by Si backside EM injection

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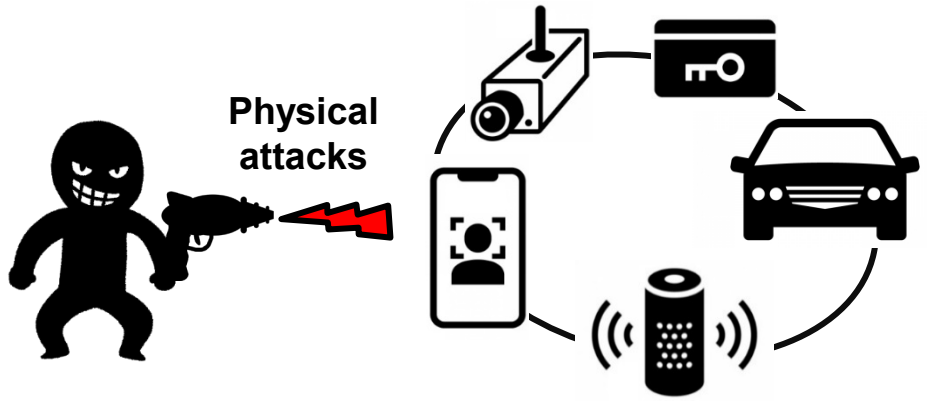
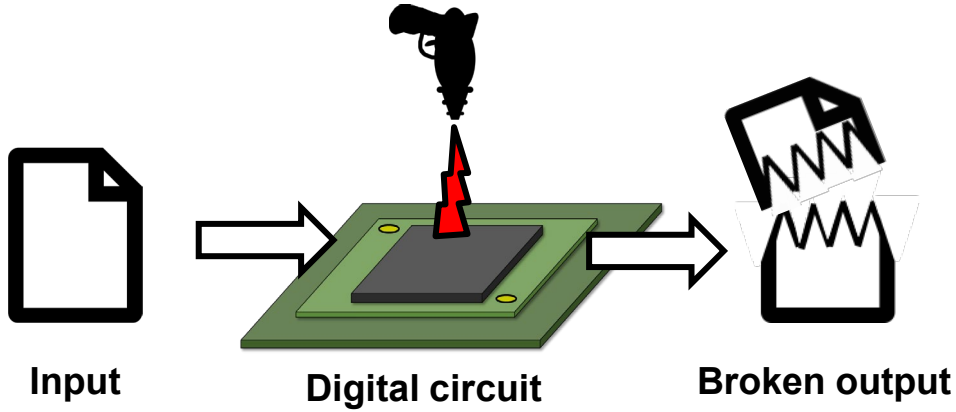
Threats of fault injection

- Security of semiconductor devices
  - ✓ Physical attack threats

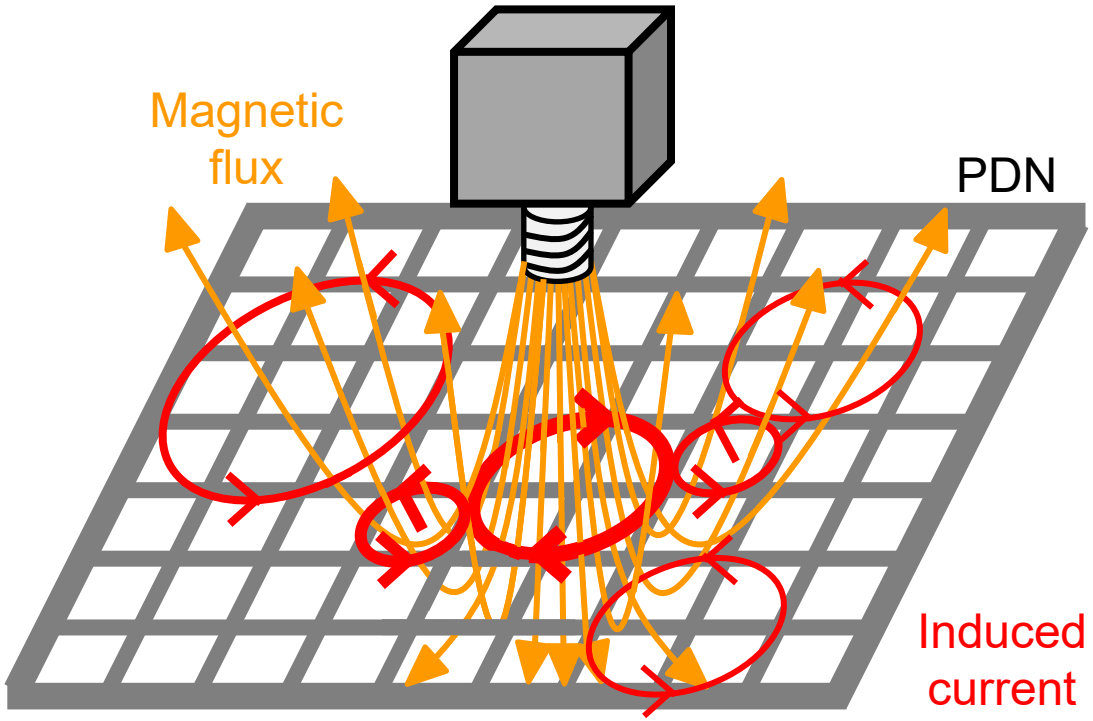


- Fault injection
  - ✓ Disturbance injection induces malfunction in the circuit operation.
    - – Laser, Voltage/Clock glitch, Body biasing, **Electromagnetic**



Electromagnetic fault injection (EMFI)

- Advantages of EMFI
  - ✓ Inexpensive and easy
  - ✓ Universal to any chip assembly technology



- Attack concept
  - ✓ Magnetic flux induces unwanted currents.

- Problems
  - ✓ The principle is not simpler as perceived from attack concepts.
  - ✓ Physical level understanding is missing.

Outline

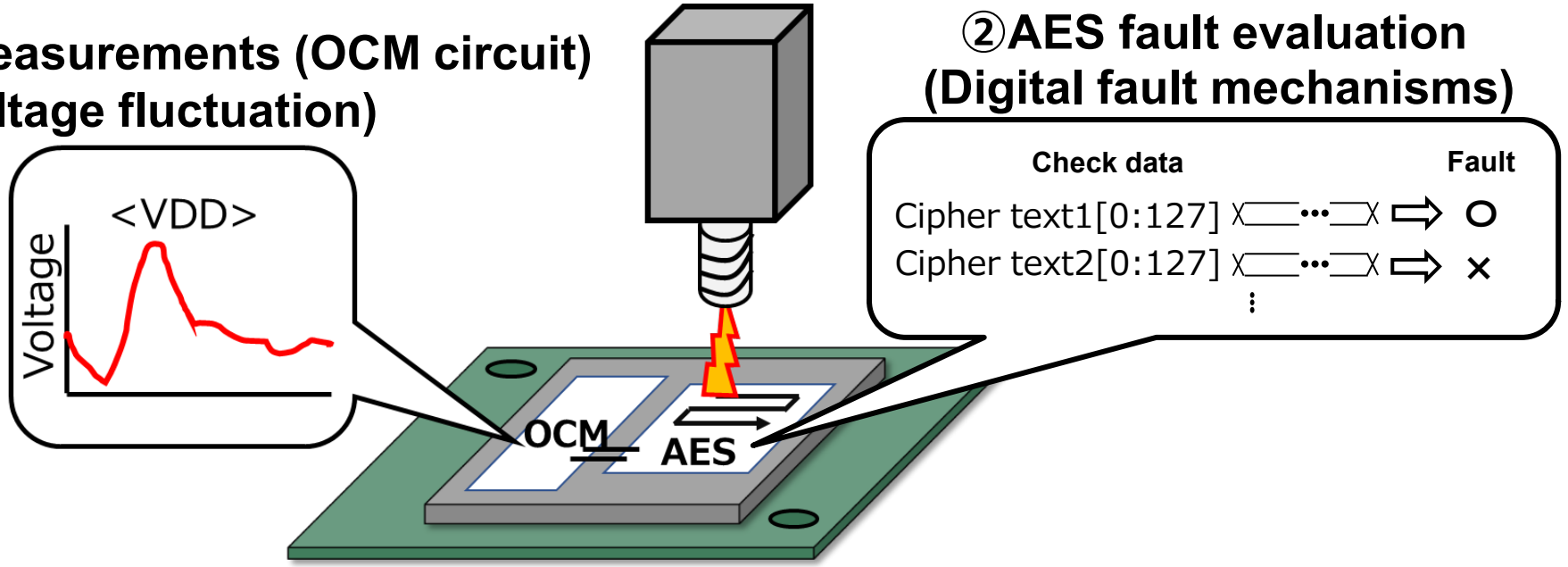
1. Background
2. Deliverables
3. Measurement and evaluation
   - On-chip voltage fluctuation
   - AES digital faults
4. EM simulation
5. Conclusion

Deliverables

- **Problems**
  - ✓ Physical mechanisms and parameters are less involved in EMFI analyses.
  - ✓ Needed more in-depth understandings from device physics
- **Contributions**
  - ✓ EMFI voltage fluctuations visualized by on-chip measurements, correlated with digital faults
  - ✓ Initial trials of EM simulation-based analysis

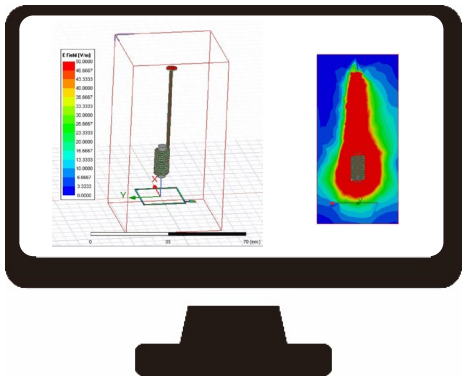
What we did…

①On-chip measurements (OCM circuit)
(Voltage fluctuation)



②AES fault evaluation
(Digital fault mechanisms)

③EM simulation
(Voltage fluctuation)



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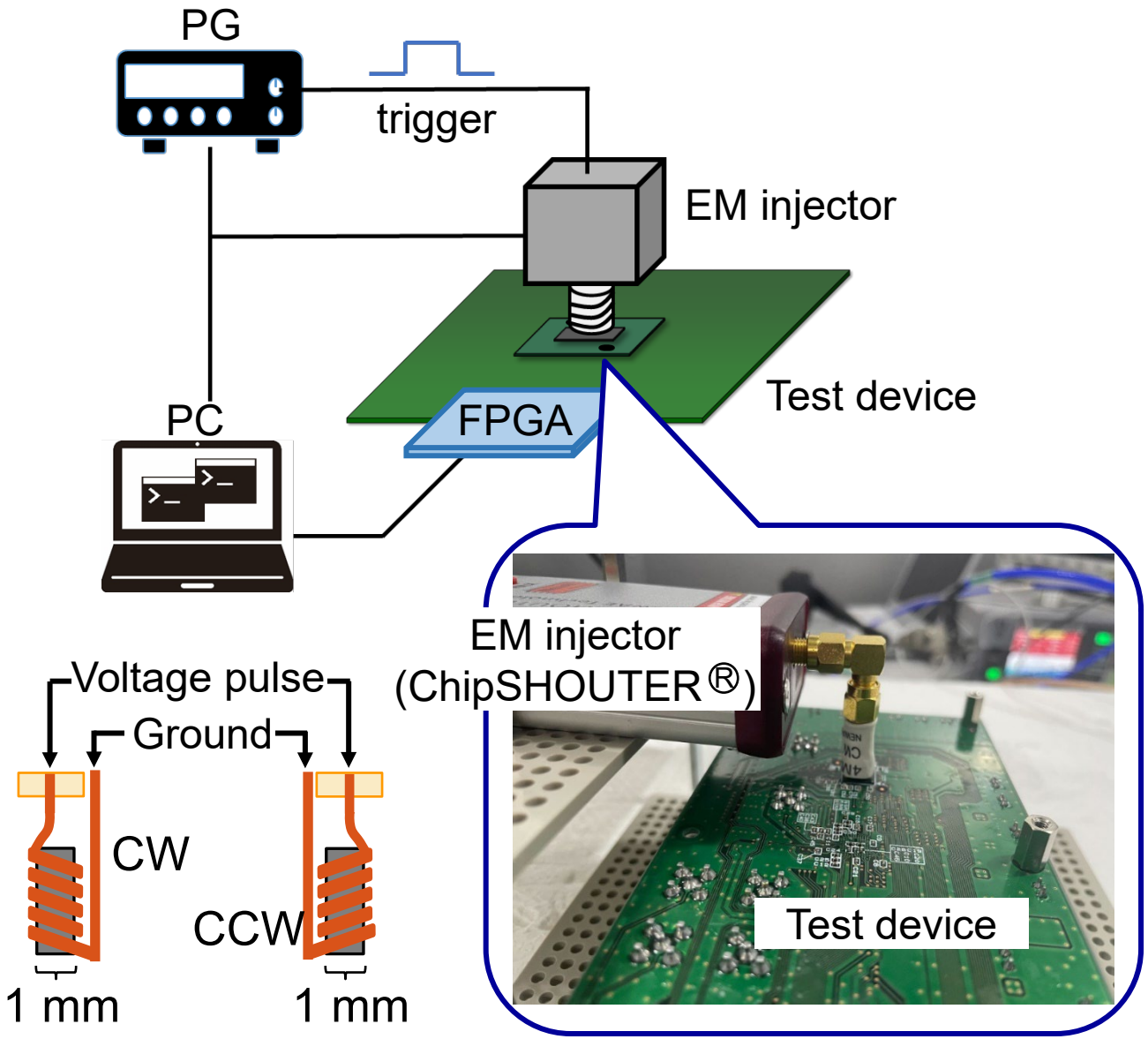
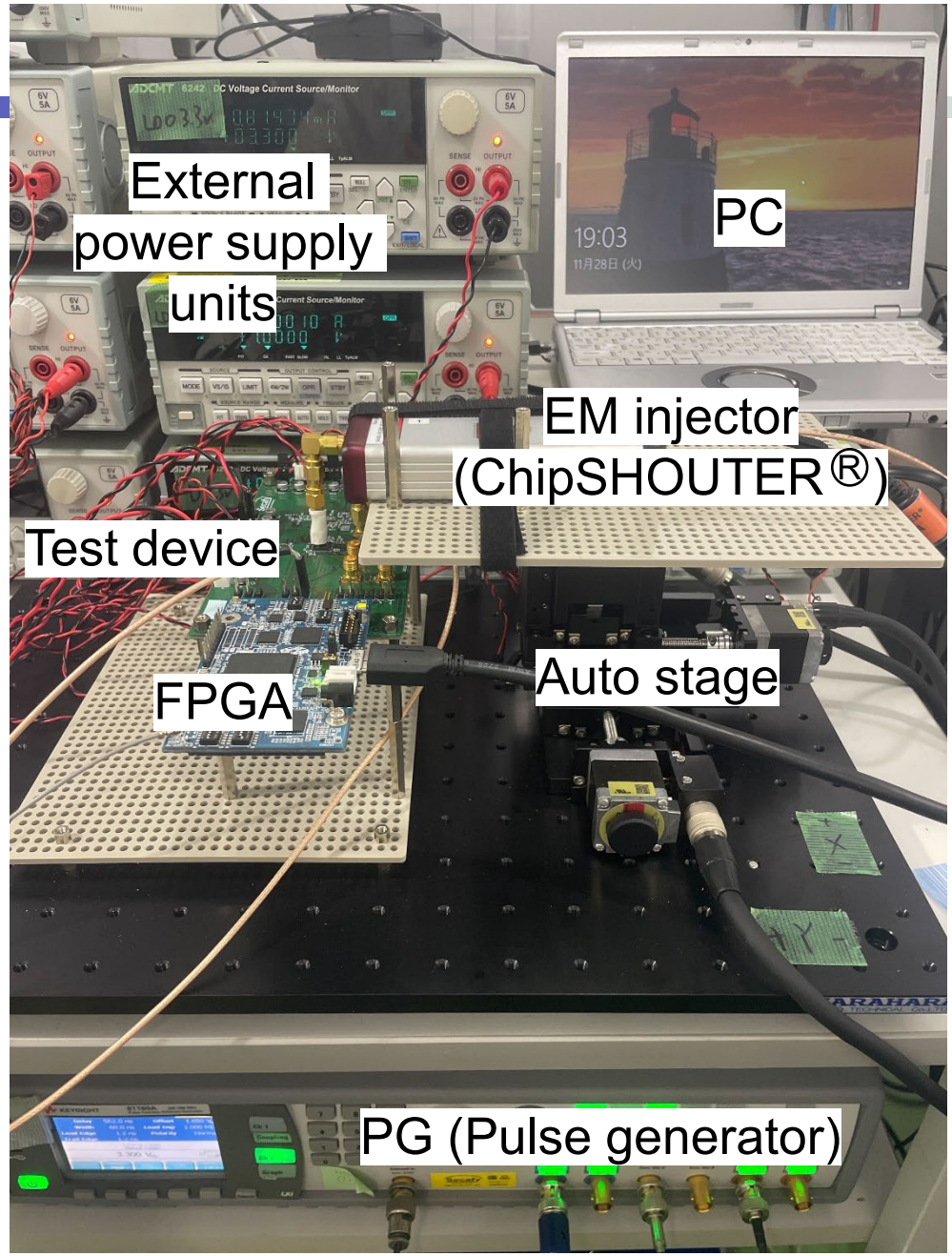
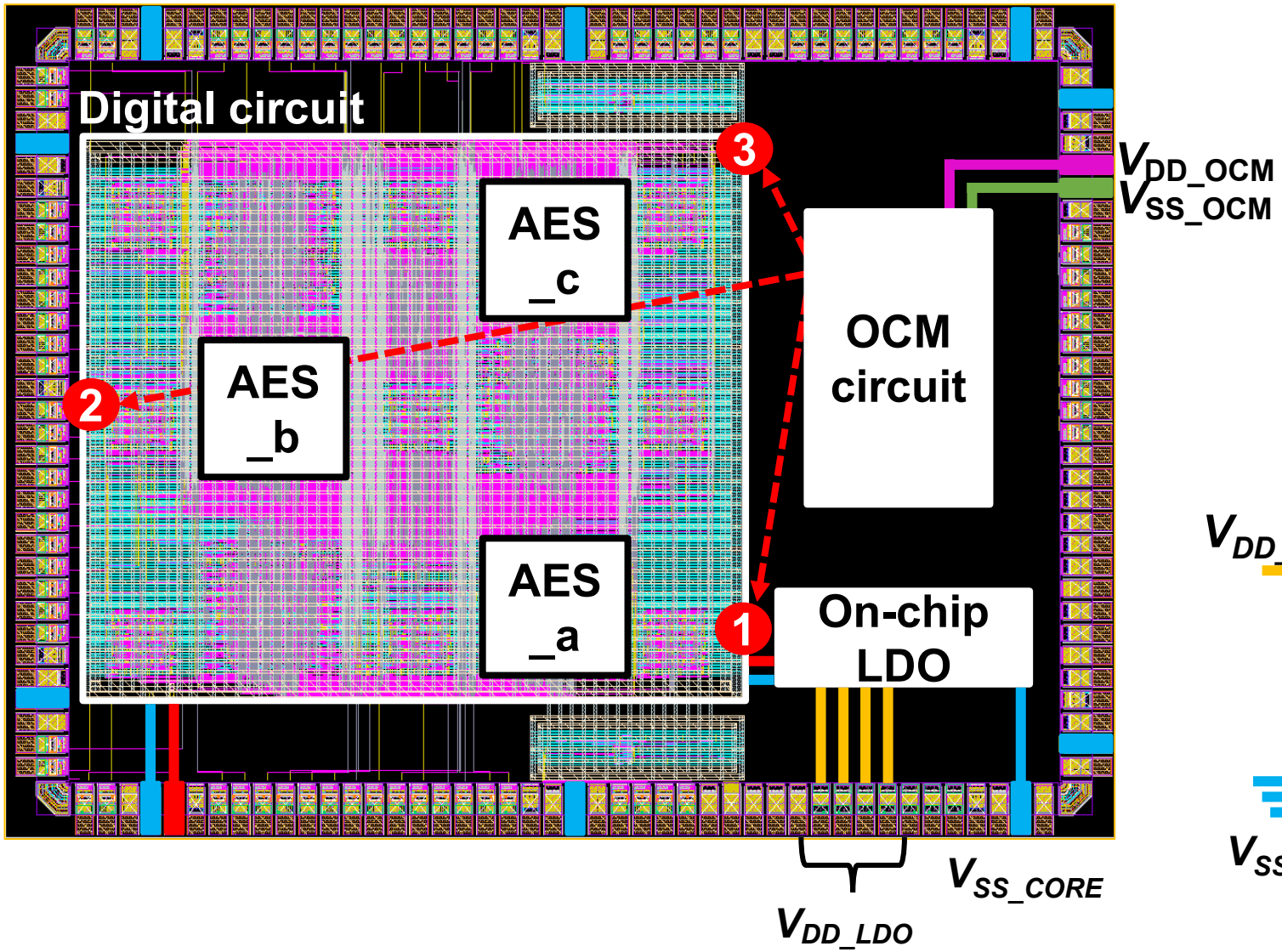
Evaluation setup

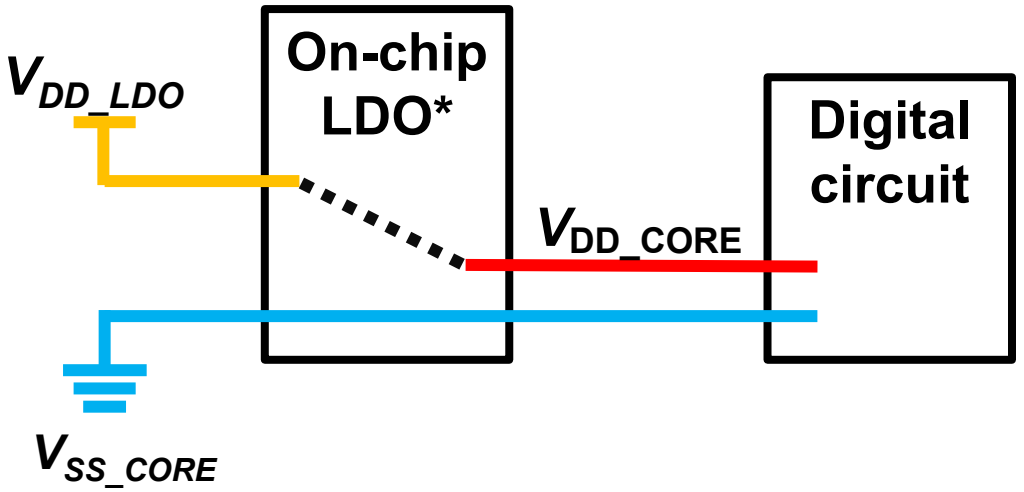




Test chip



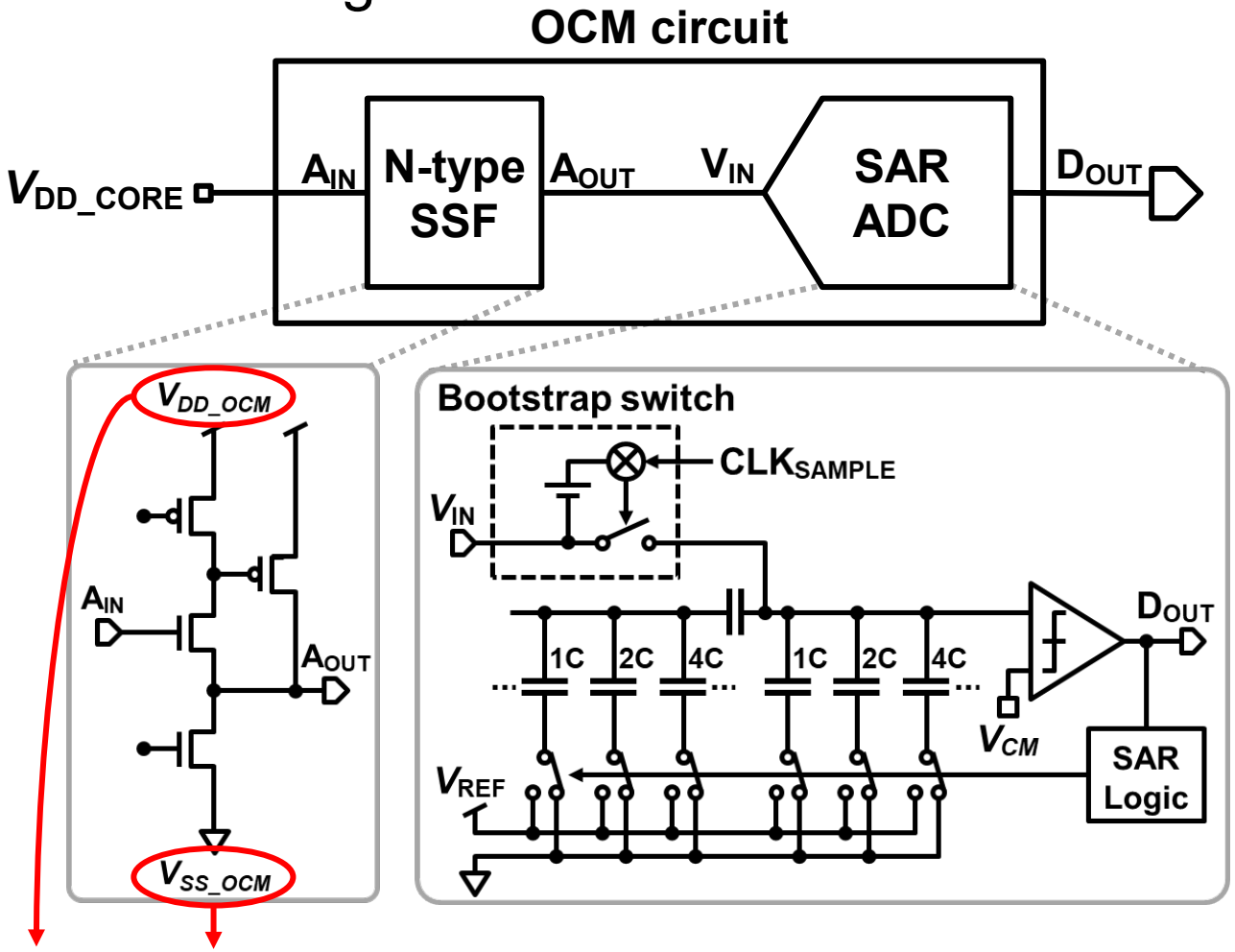
- 180 nm CMOS
- Flip-chip BGA
- Chip size : 3 mm x 4 mm



*LDO : Low drop-out voltage regulator

OCM circuits and on-chip waveforms

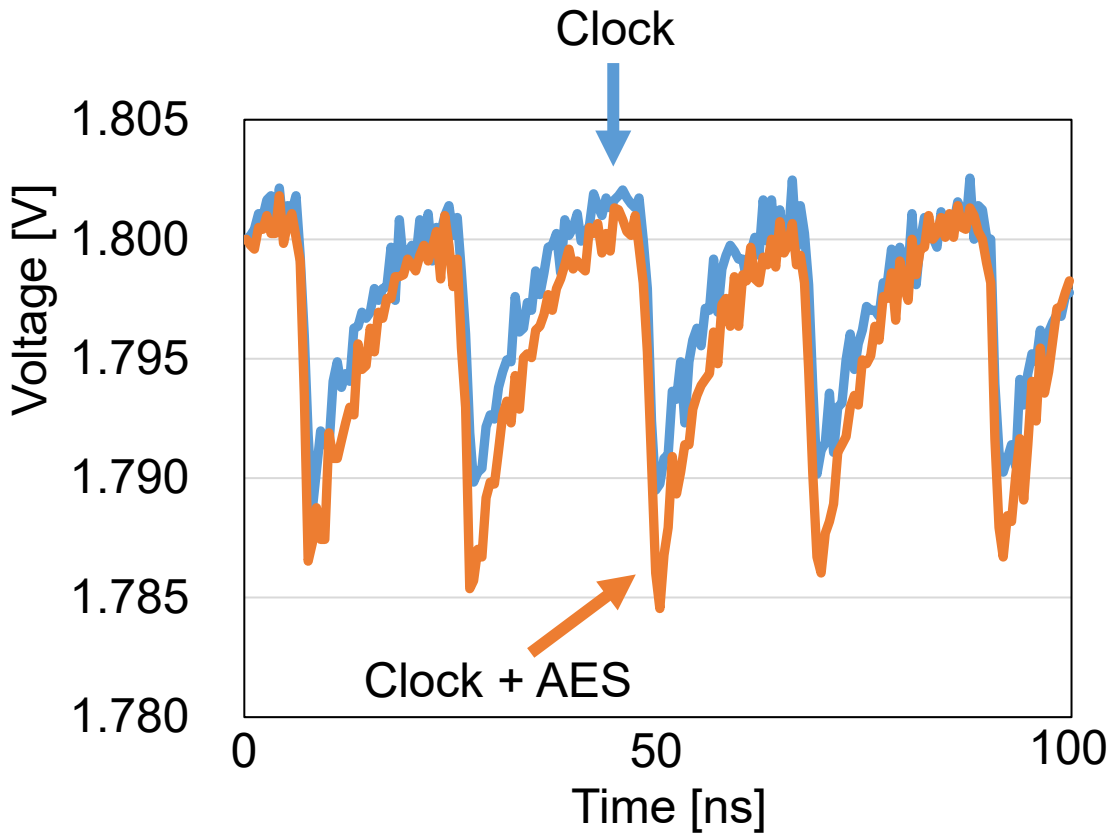
- Circuit diagrams



Isolated from digital circuit

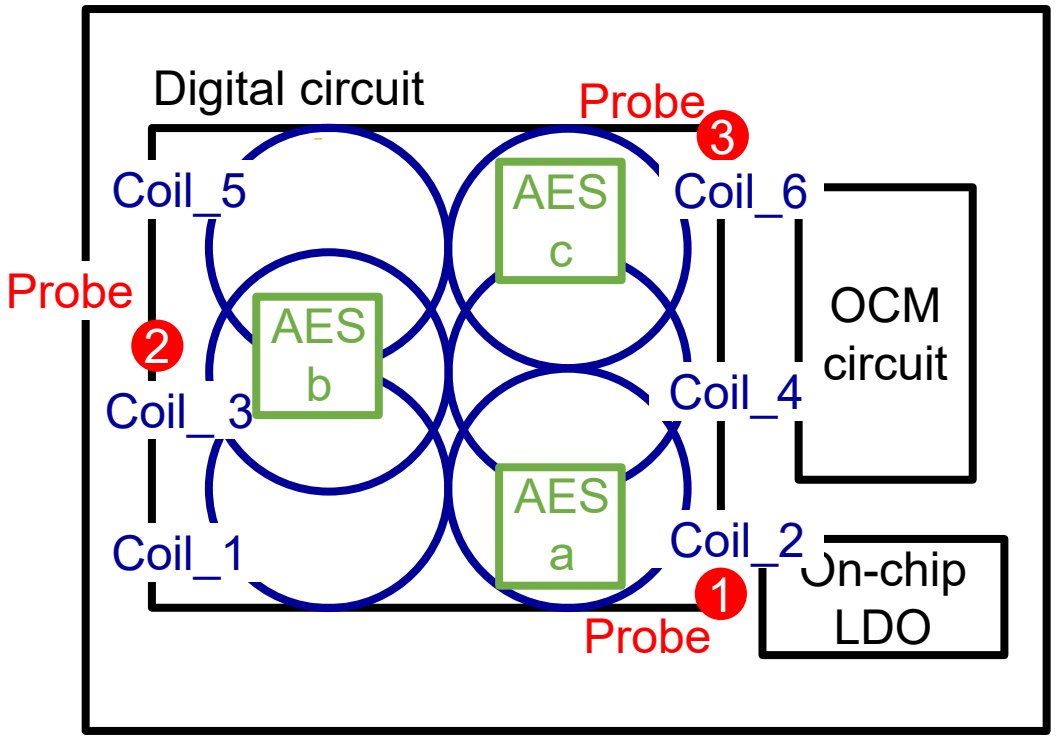
- ✓ Frequency bandwidth : 1 GHz
- ✓ Voltage resolution: 11 bit, 1 mV for 1 *V*pp

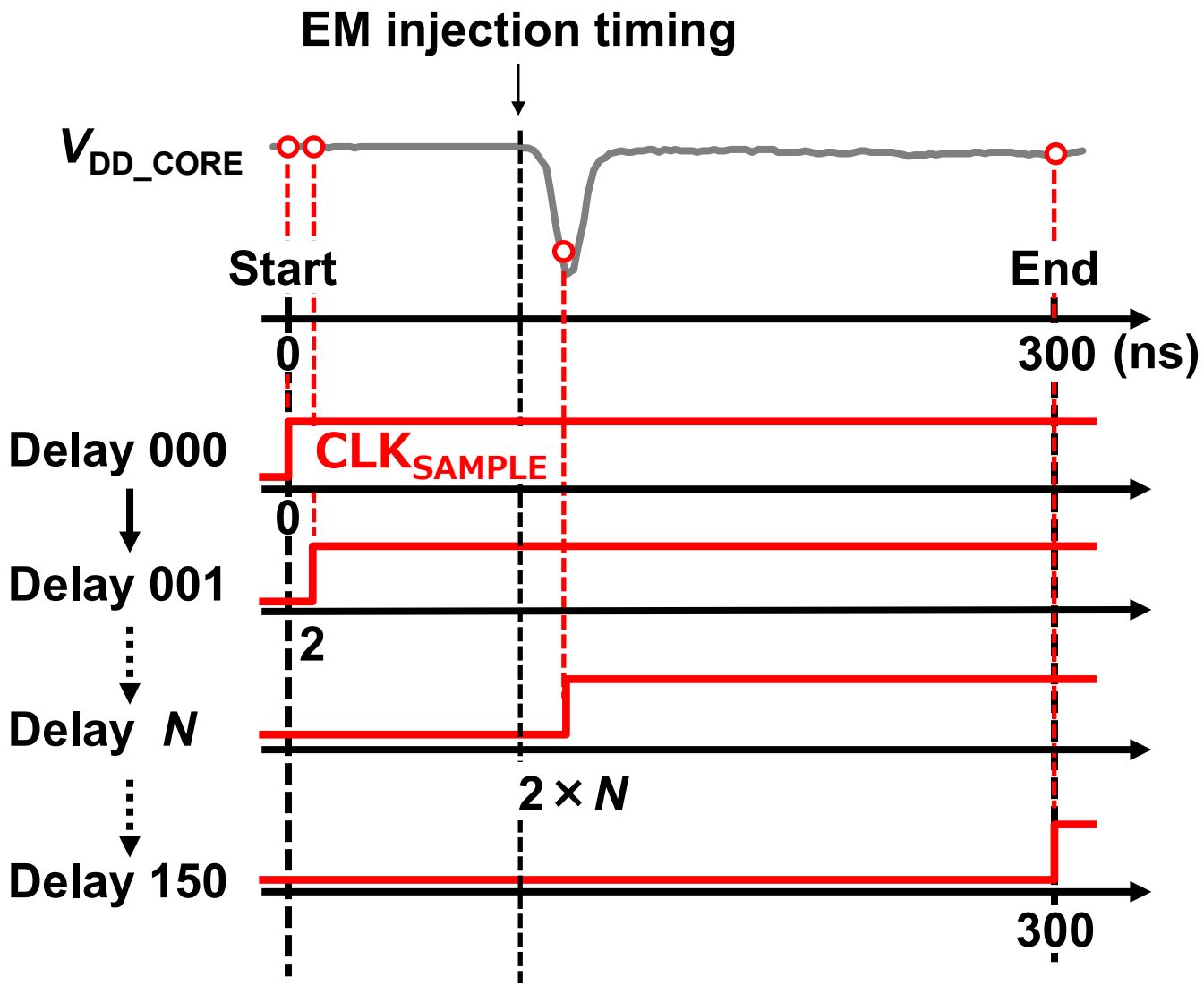
- Power noise waveforms
  - ✓ Differences due to the scale of the circuit in operation



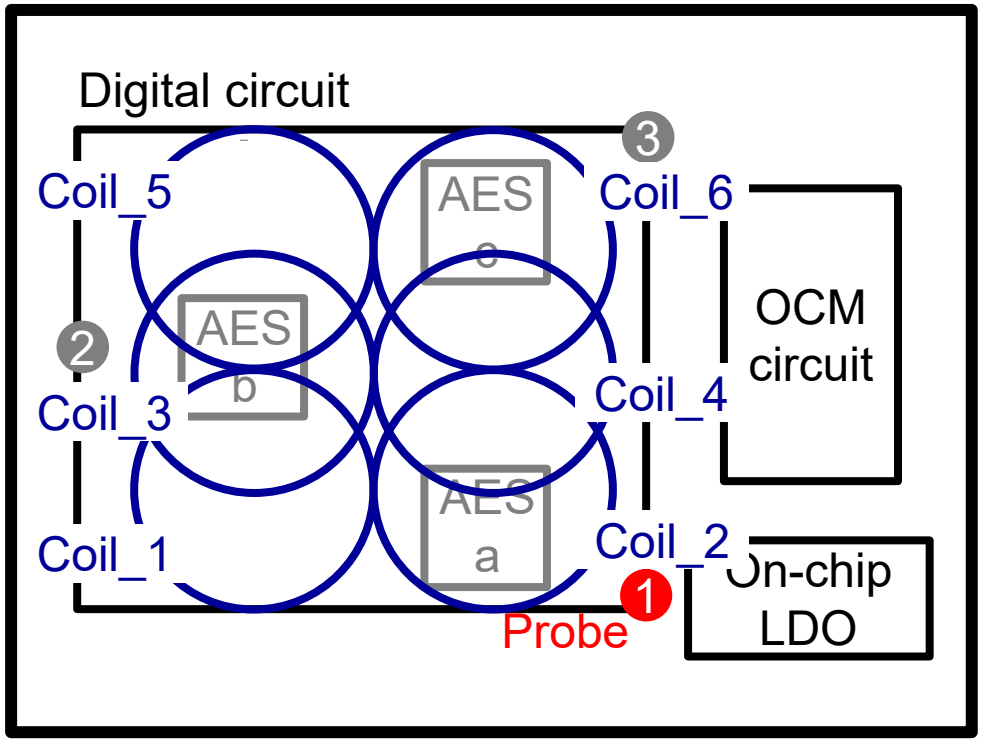
EMFI on-chip voltage measurements

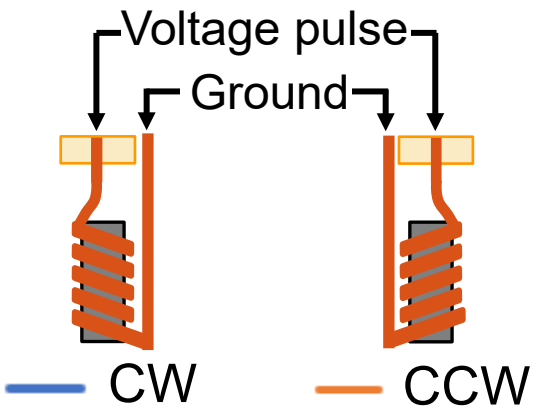
- Waveform acquisition under EMFI
- Time equivalent sampling method applied in measurement

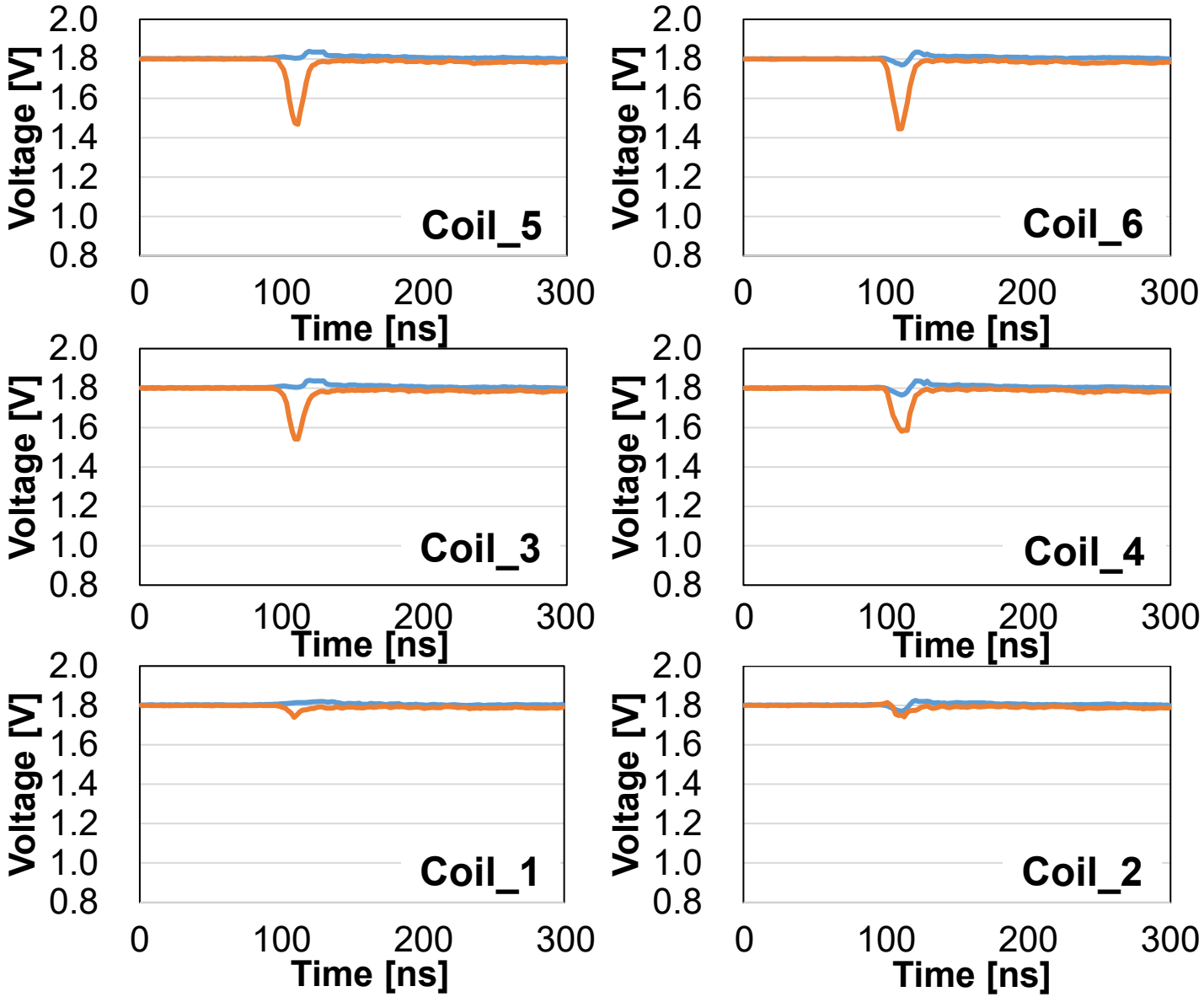




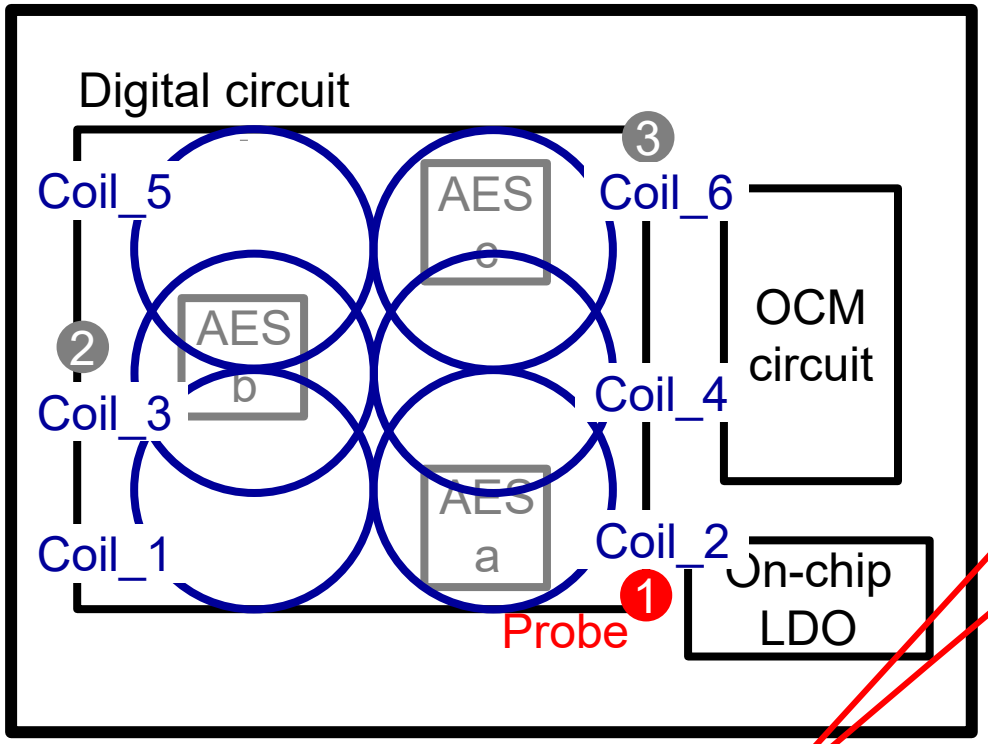
Measurement results



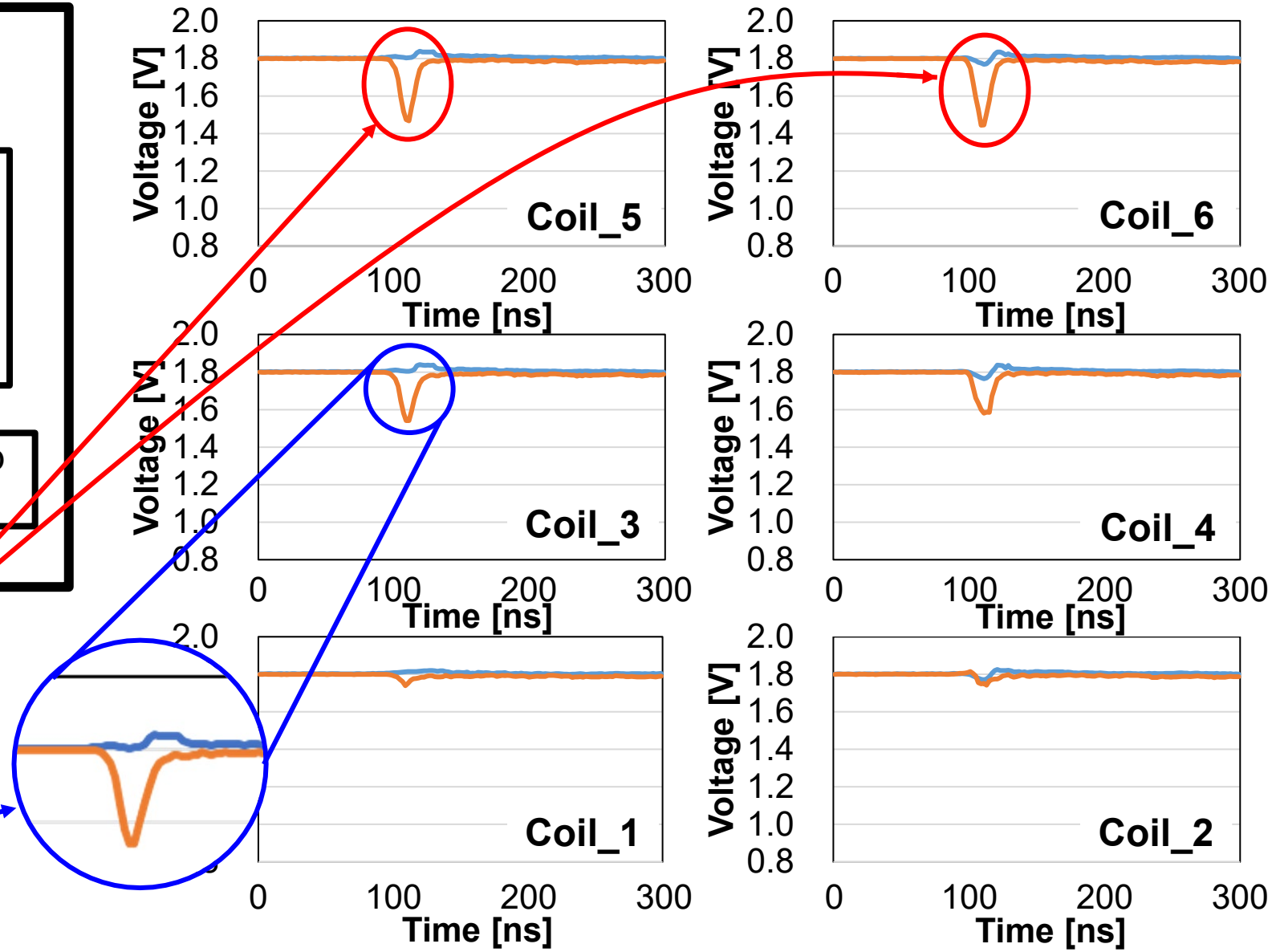




Findings from measurements



- Large drops in areas far from the coil
- Both positive and negative voltage fluctuation



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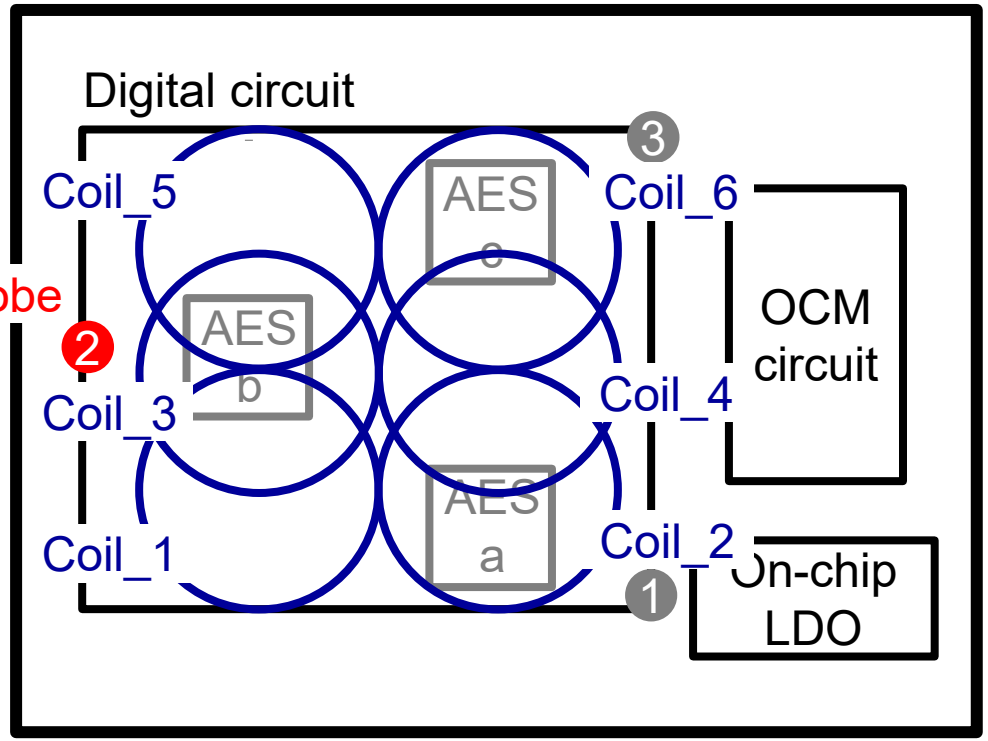
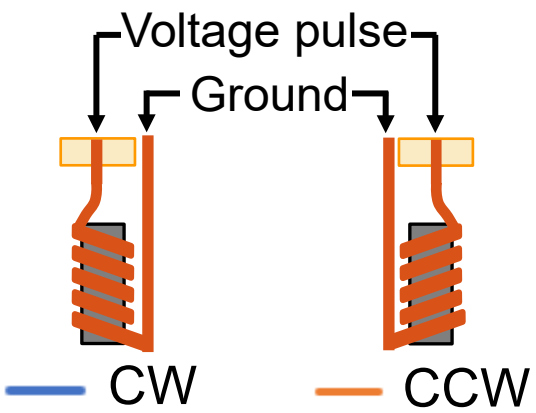
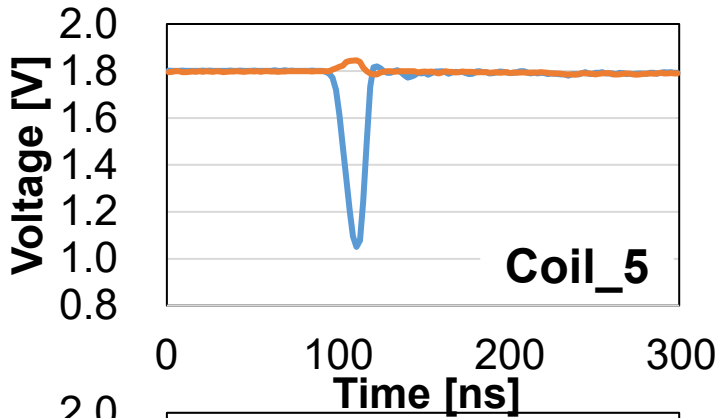
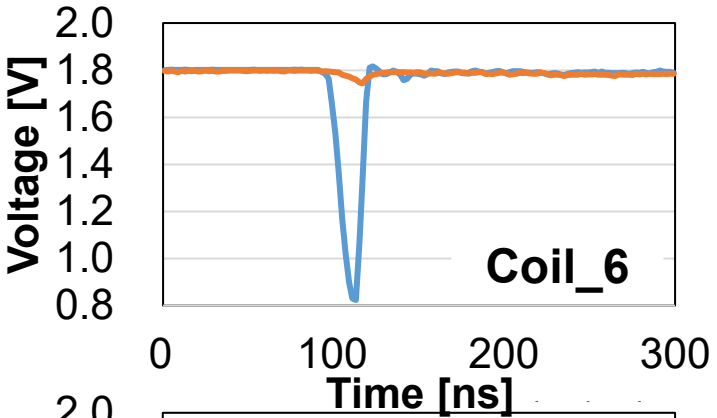
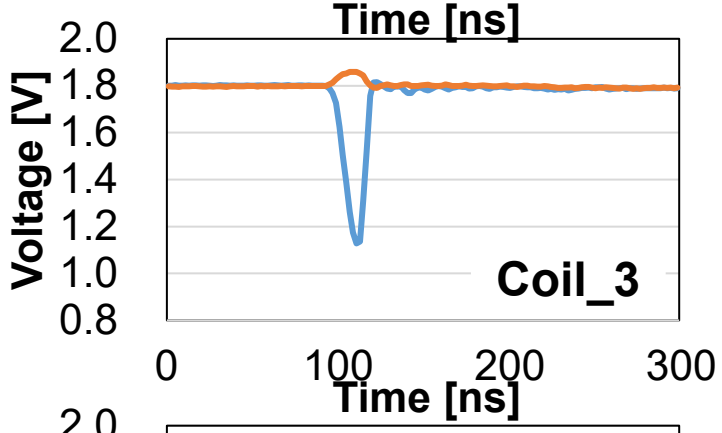
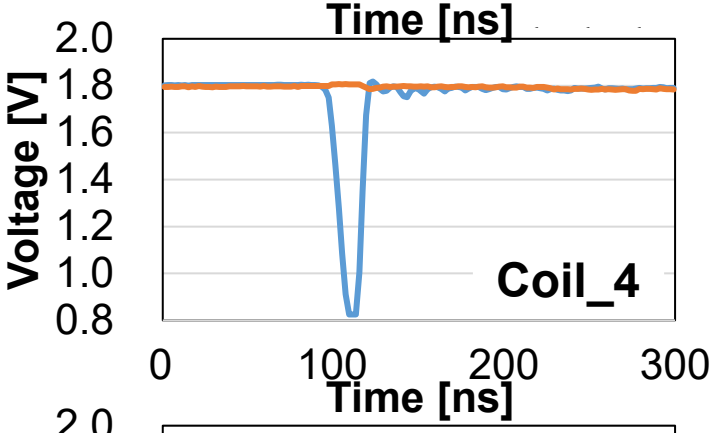


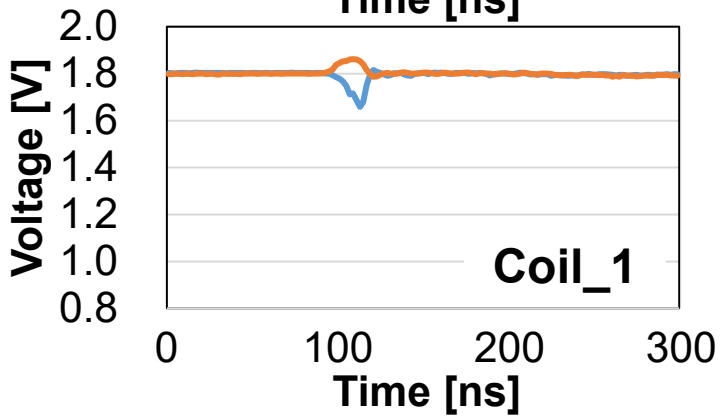


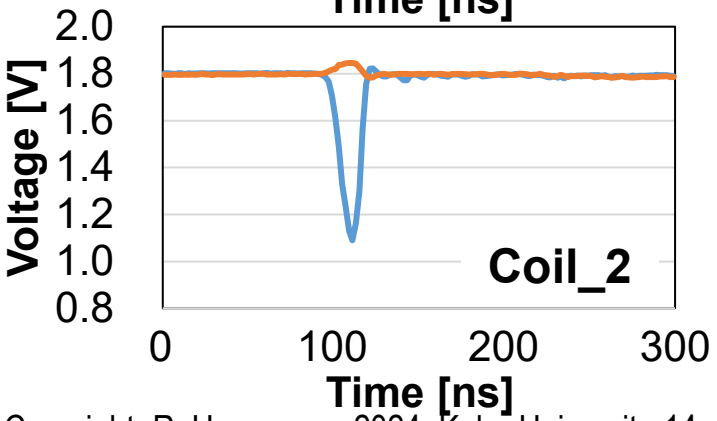




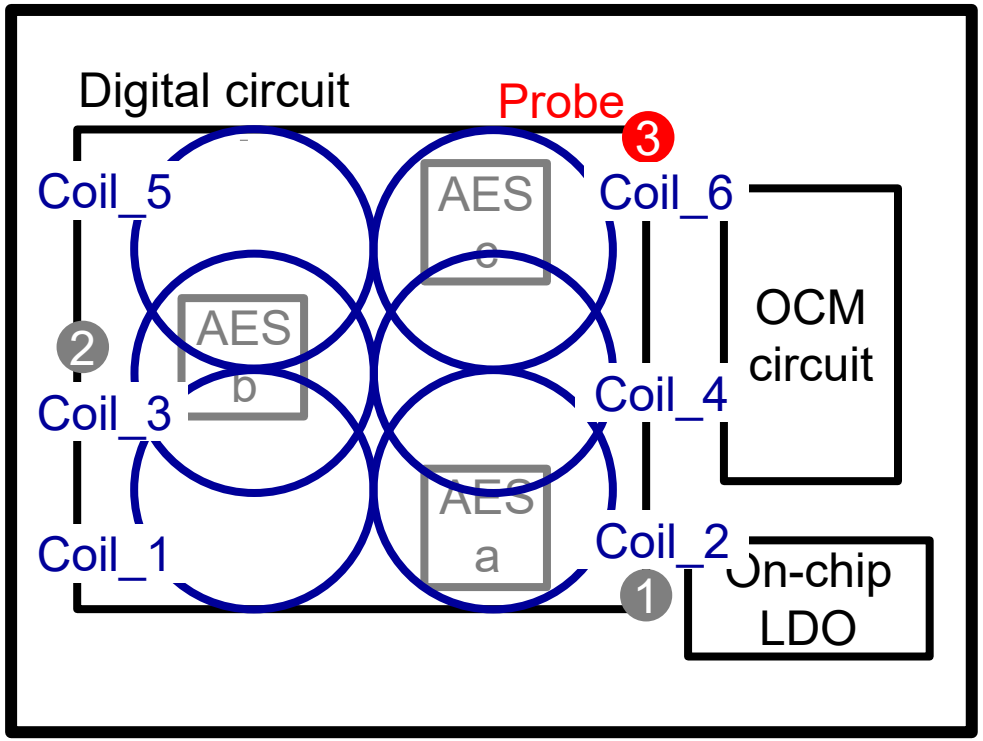


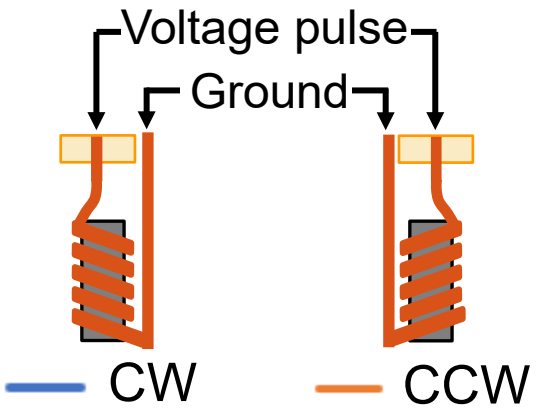


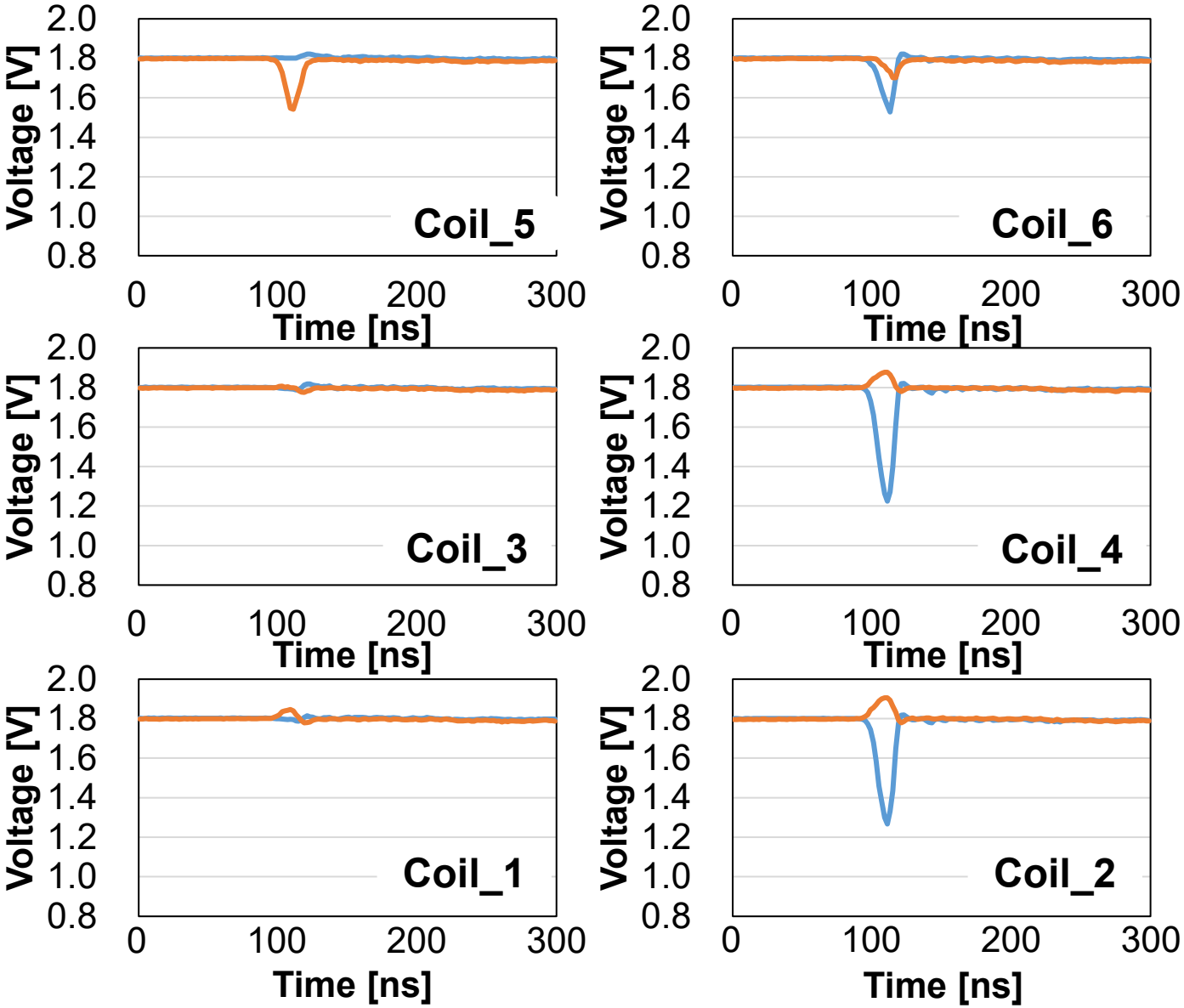




Measurement results

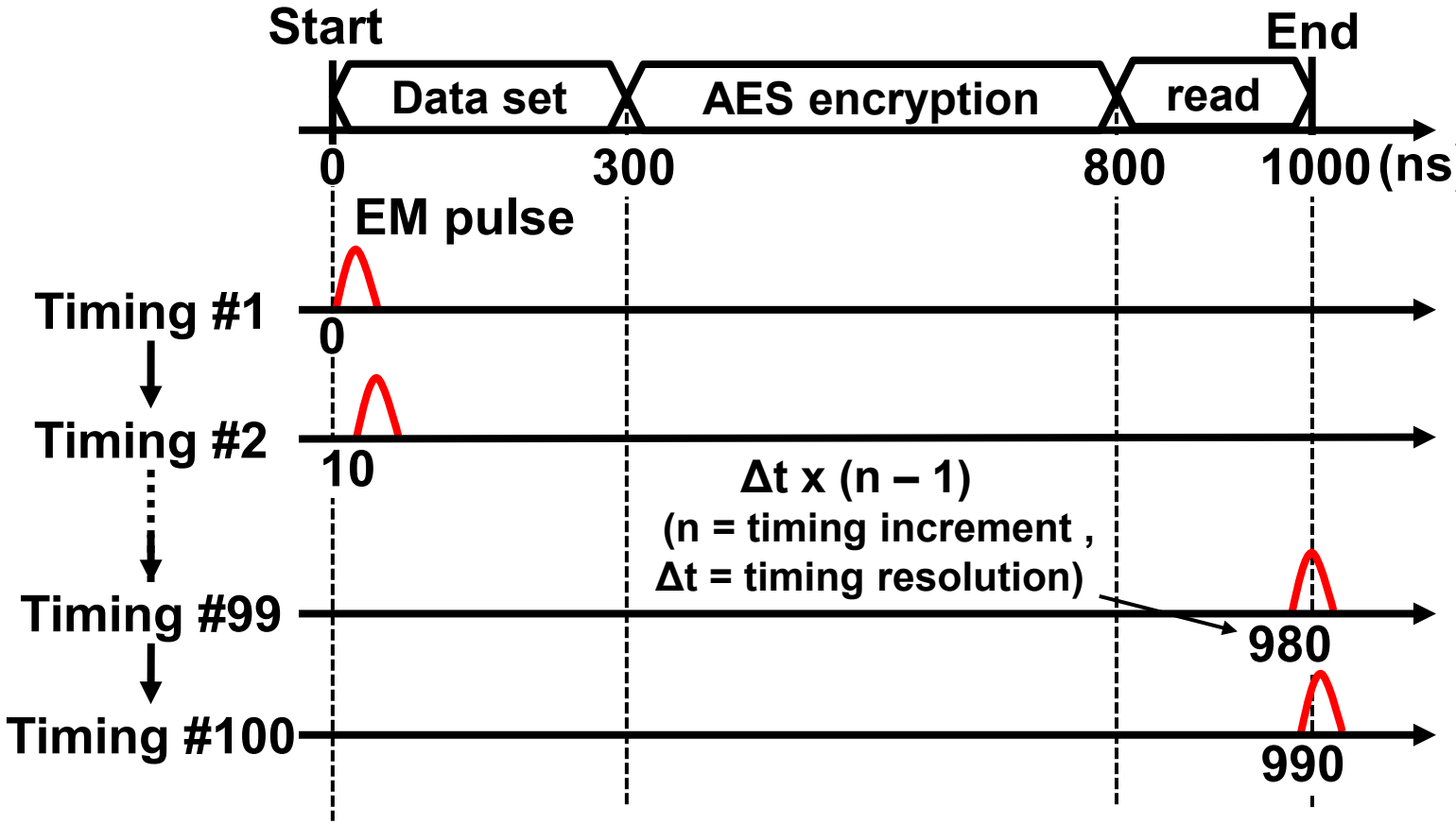


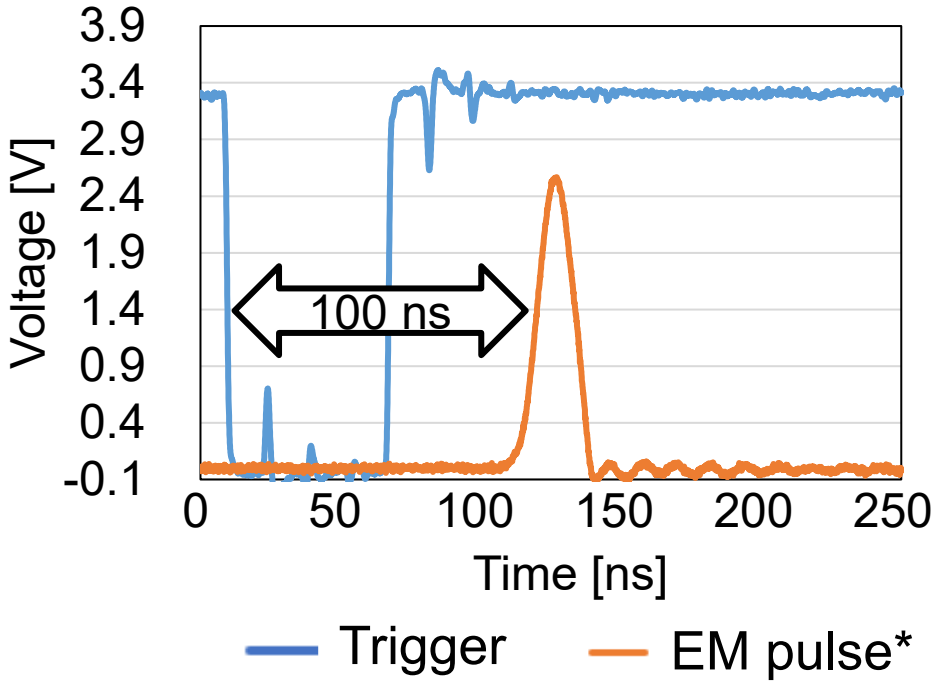




Evaluation of digital faults

- Irradiate EM pulse during digital circuit operation

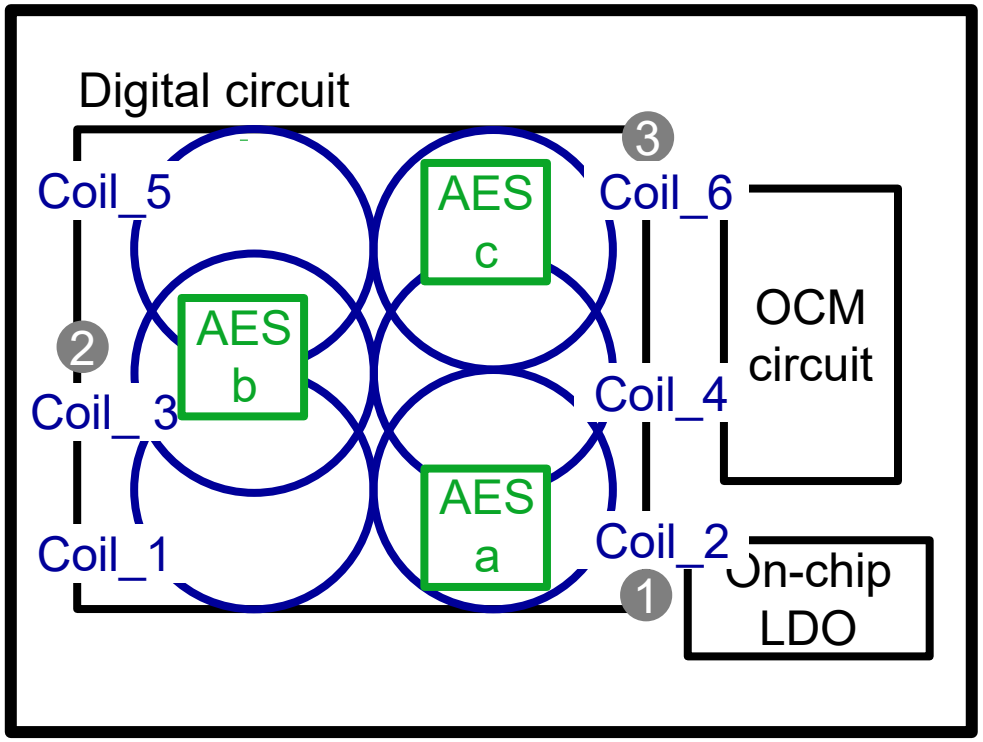




Repeat 3 time at each timing
⇒Total 300 ciphertext

*measured by EM probe

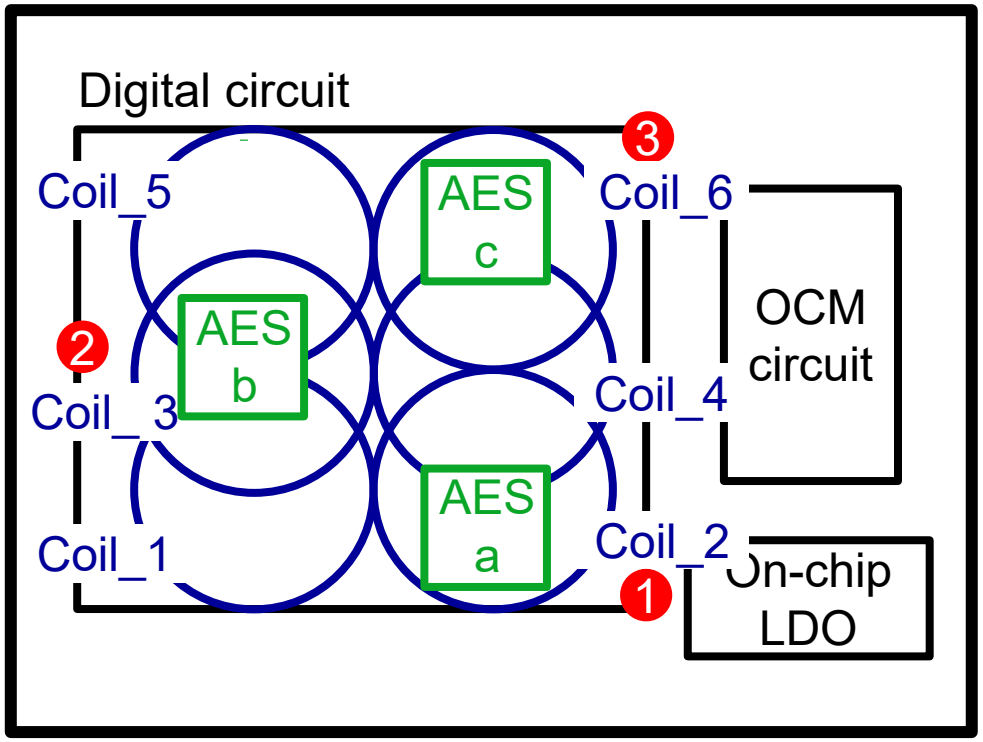
Evaluation results

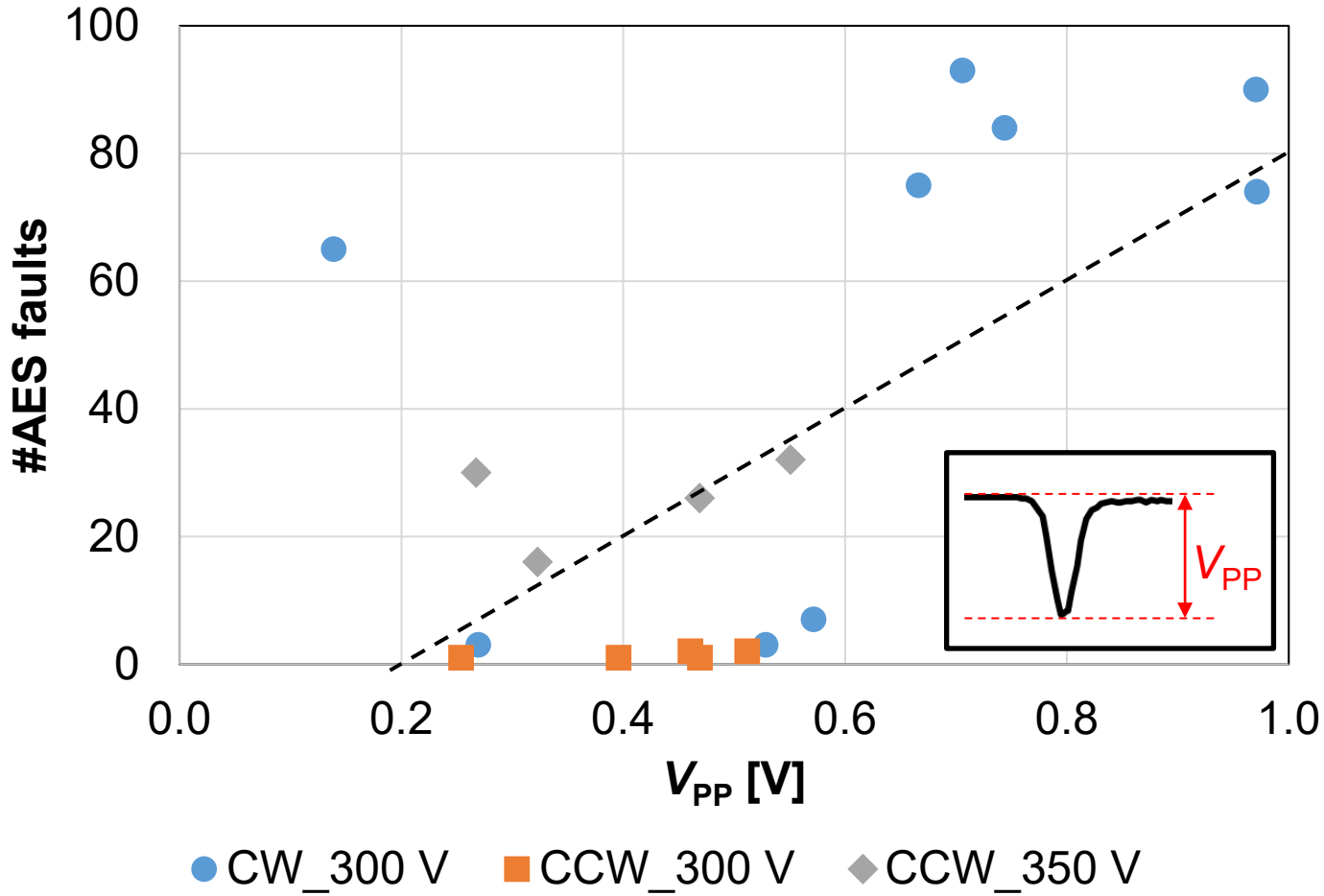


CW				CCW			
AES_c				AES_c			
Coil_5	**6**	Coil_6	3	Coil_5	1	Coil_6	3
Coil_3	1	Coil_4	**7**	Coil_3	1	Coil_4	2
Coil_1	2	Coil_2	3	Coil_1	1	Coil_2	2
AES_b				AES_b			
Coil_5	**84**	Coil_6	**74**	Coil_5	1	Coil_6	1
Coil_3	**75**	Coil_4	**90**	Coil_3	1	Coil_4	0
Coil_1	**65**	Coil_2	**93**	Coil_1	1	Coil_2	1
AES_a				AES_a			
Coil_5	**9**	Coil_6	**6**	Coil_5	2	Coil_6	1
Coil_3	3	Coil_4	**13**	Coil_3	2	Coil_4	1
Coil_1	4	Coil_2	2	Coil_1	4	Coil_2	1

- Key findings
  - ✓ # of digital faults reflect different layout positions among identical AES cores

Analysis : Voltage fluctuations and AES faults





- On-chip voltage fluctuations and AES digital faults are correlated

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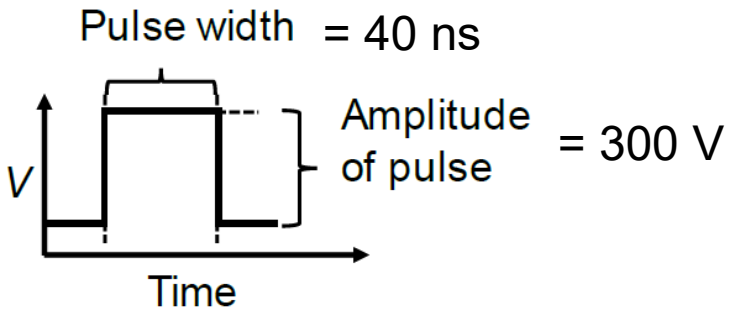
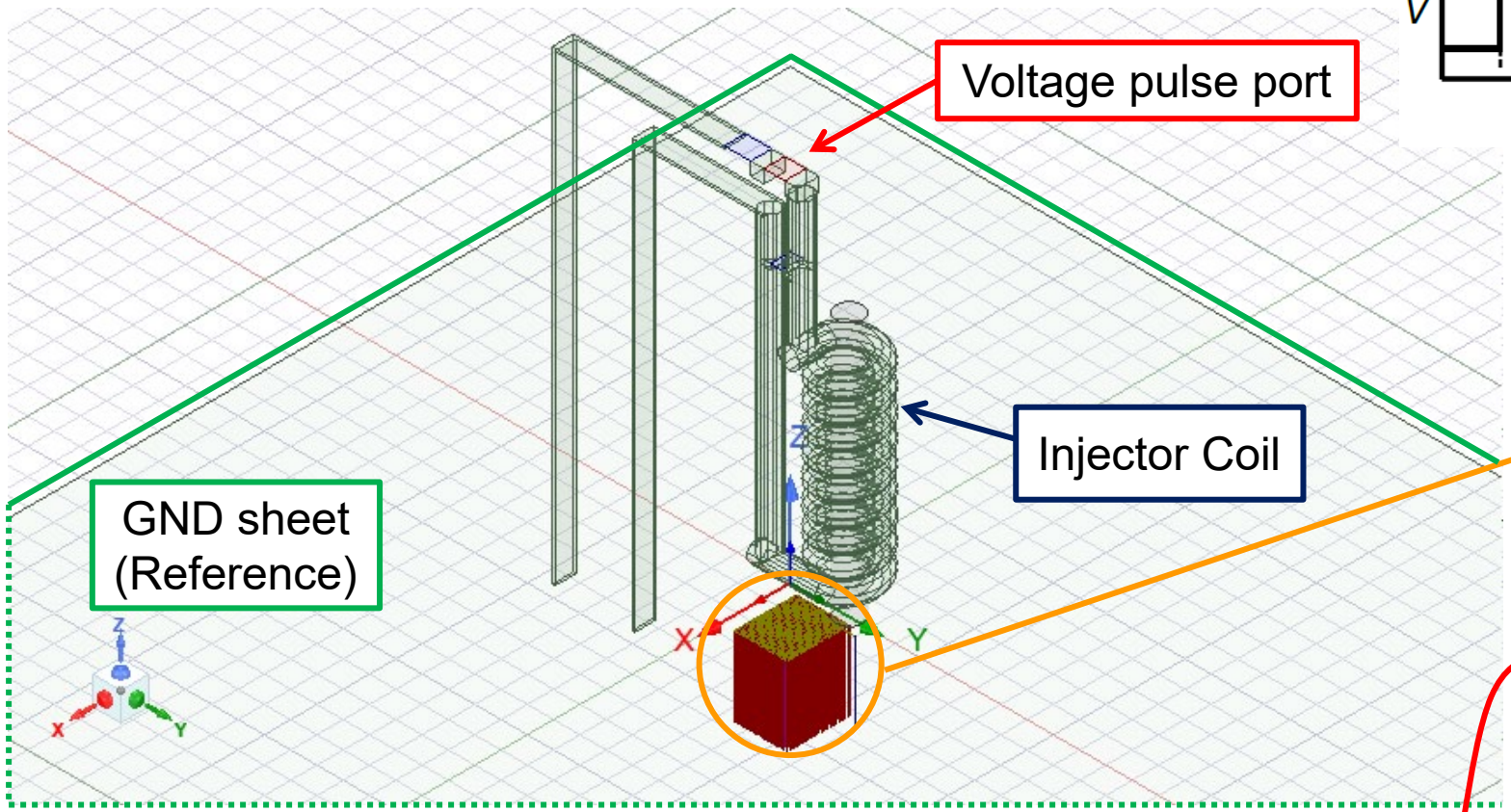
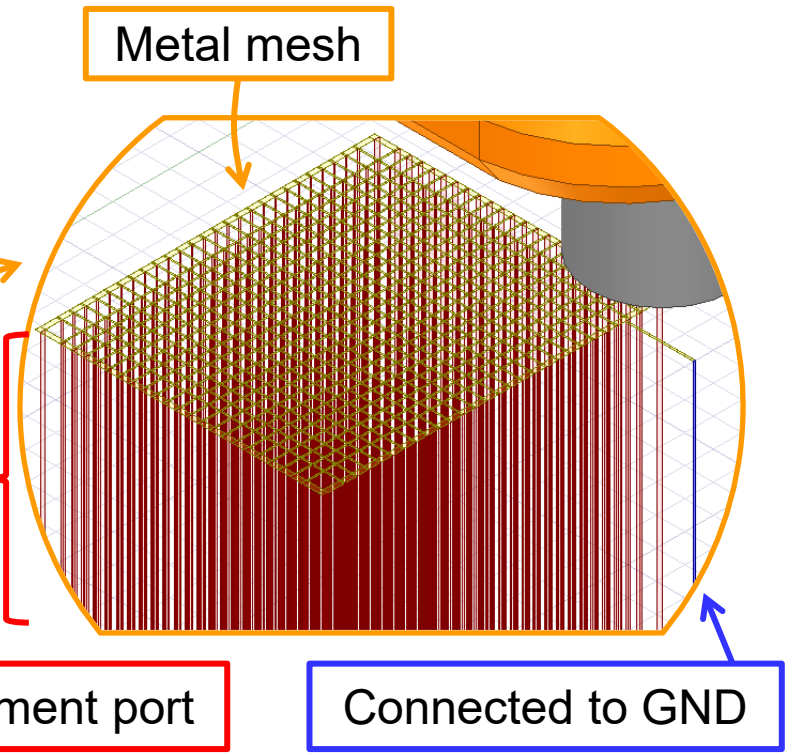
EM simulation trials

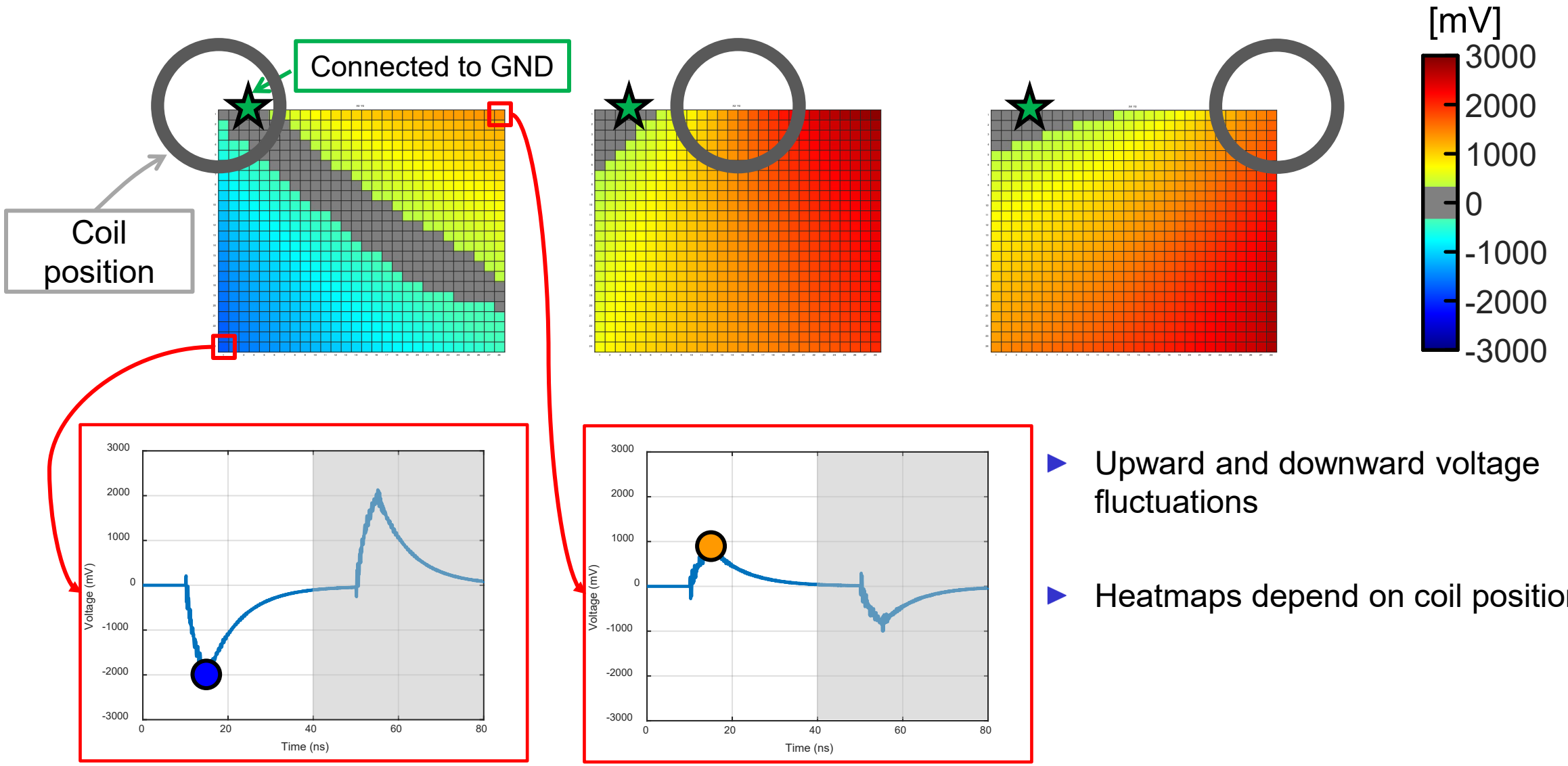
- Simulation models built for EM field solver







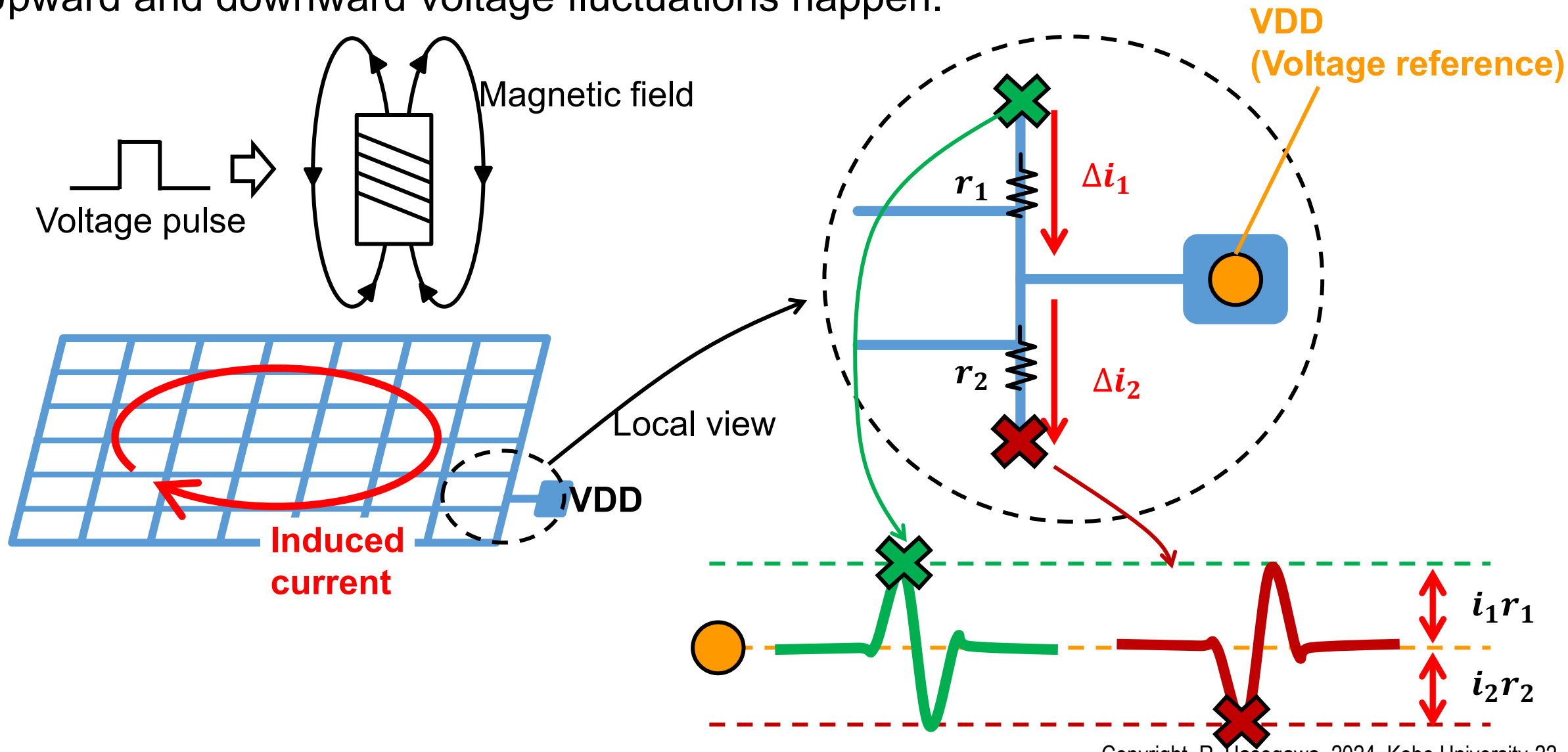
Simulation results



- Upward and downward voltage fluctuations
- Heatmaps depend on coil positions

Interpretation

- Upward and downward voltage fluctuations happen.



Conclusion

- EMFI voltage fluctuations visualized by on-chip measurements
  - ✓ Large drops in areas far from the coil
  - ✓ Both positive and negative voltage fluctuation
- Digital fault evaluation
  - ✓ On-chip voltage fluctuations and AES digital faults are correlated
- EM simulation trial
  - ✓ Positive and negative voltage fluctuations happen.

This work has been partly supported by JSPS KAKENHI Grant No. JP22H04999
and by SECOM Science and Technology Foundation