Reliability and Performance Challenges of Next-Generation Smart Power Battery Management Systems for Electric Mobility

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PitchD

the PhD's pitch

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Contents:

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- Introduction to BMS
- The vertical interface
- DPI and BCI simulations
- Investigation of failure mechanisms
- Conclusion

- ❖ **Lithium-ion (Li-ion) and Lithium-Polymer (LiPo) electrochemical battery packs**
  - ✓ High energy density
  - ✓ High power capabilities

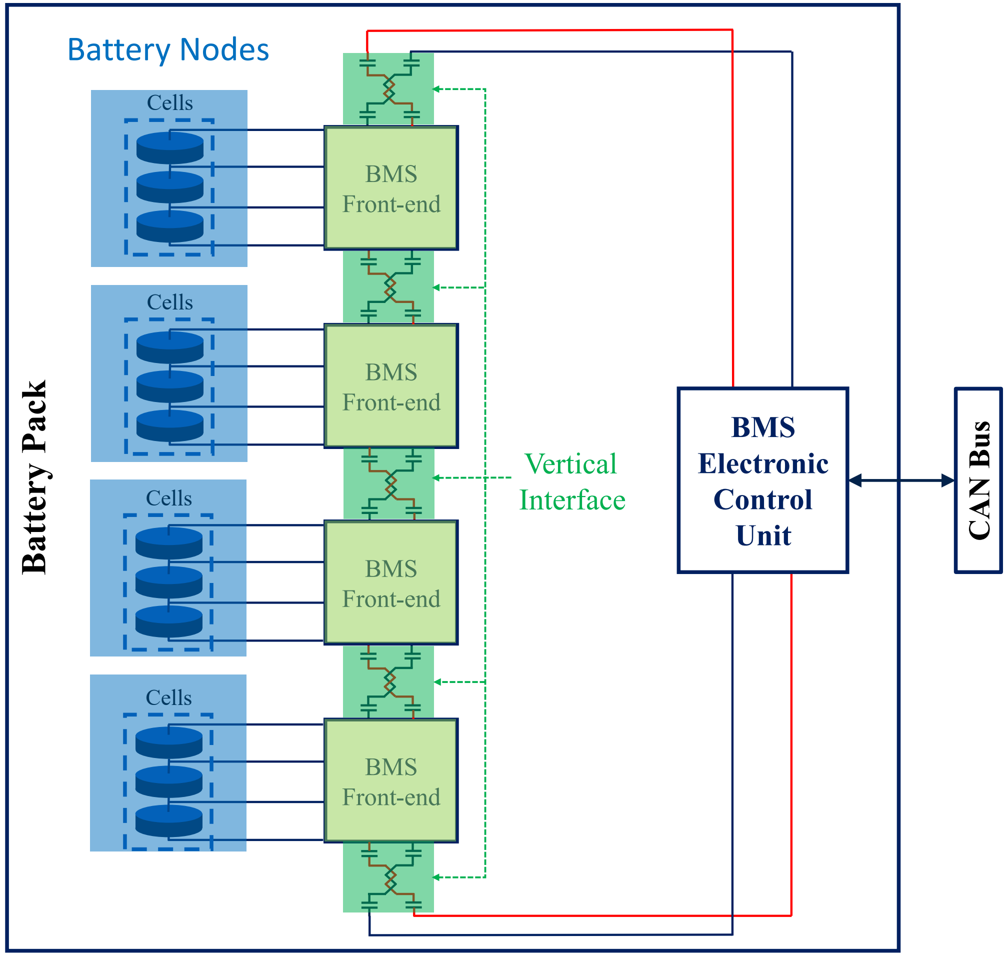
- ❖ The presence of a **Battery Management System (BMS)** is essential

✗ Under the risk of life-threatening hazards

Due to:

Electromagnetic Interface (EMI)

- ❖ The most critical EMI susceptibility issues are related to the vertical interface (VIF).



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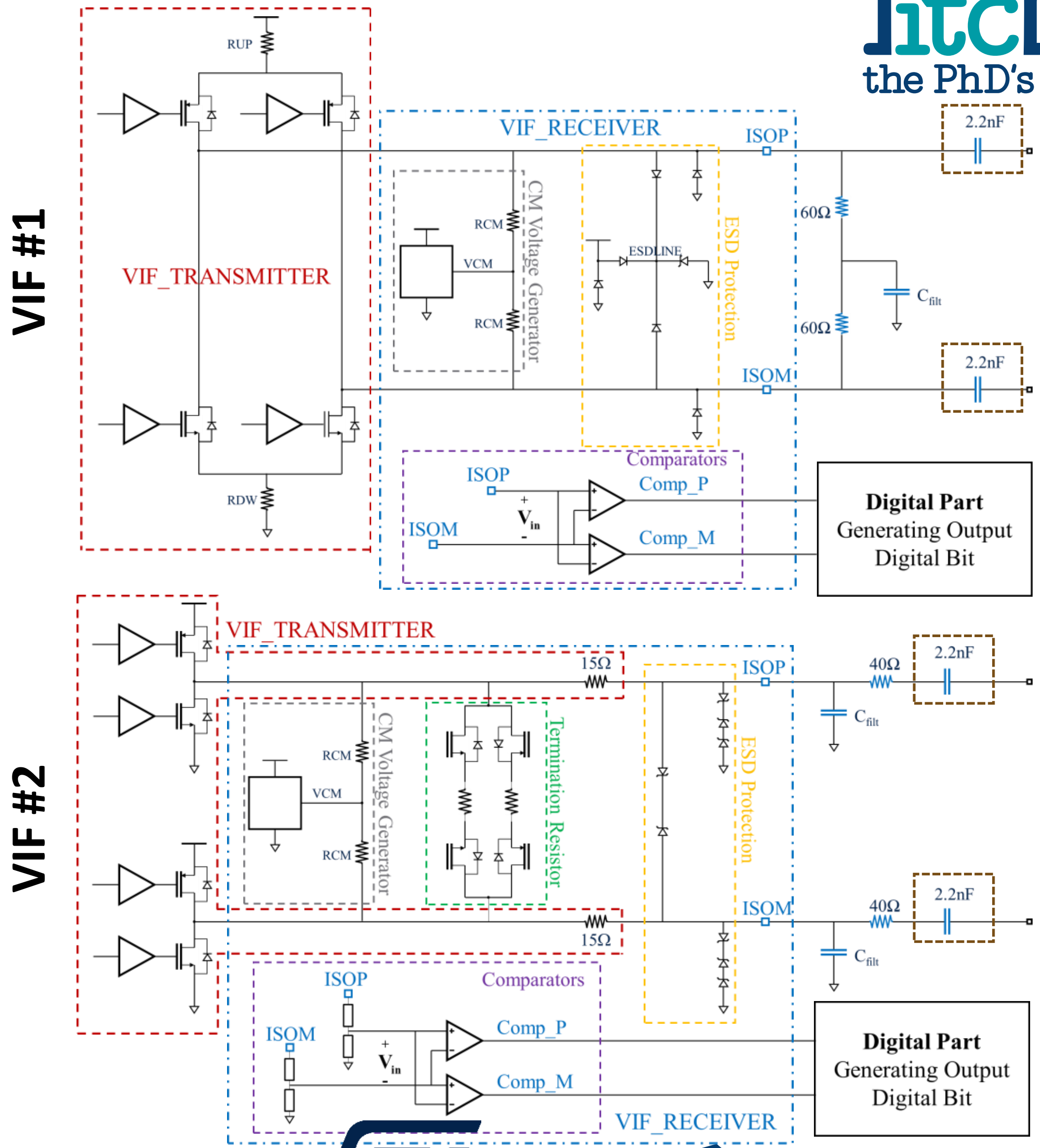
VIF working principle:

- Two different VIF structures are proposed

  The BMS VIF transceivers are comprised of:

  - ✓ Transmitter
  - ✓ ESD protection circuit
  - ✓ digital block
  - ✓ Capacitive coupling network
  - ✓ receiver
    - ✓ comparators
    - ✓ transmission resistor
    - ✓ common-mode voltage generator

- Main differences between the two structures:
  - ✓ Different CM input ranges for Comparators
  - ✓ Different threshold voltages for Comparators
  - ✓ Different overvoltage-overcurrent protections
  - ✓ Different electrostatic discharge (ESD) structures



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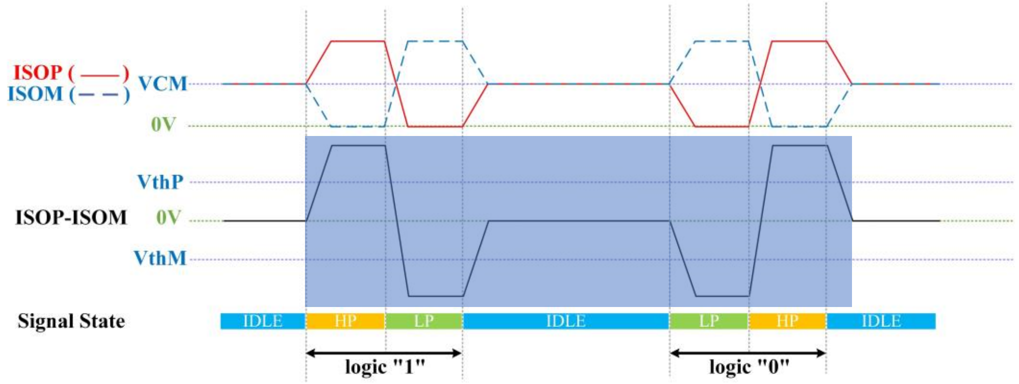
VIF working principle:

A differential, capacitively isolated, bi-directional communication at 4 Mbit/s

A proprietary protocol is adopted

- ✓ Logic "1“: a positive differential pulse followed by a negative one
- ✓ Logic "0“: a negative differential pulse followed by a positive one
- ✓ An idle time between each transmitted bit



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Evaluation of the susceptibility to EMI

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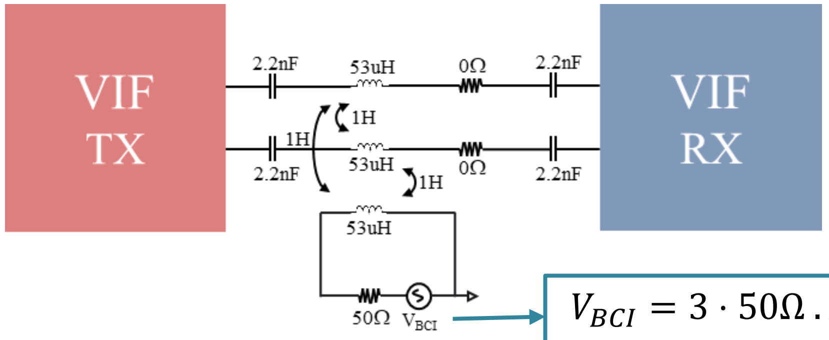
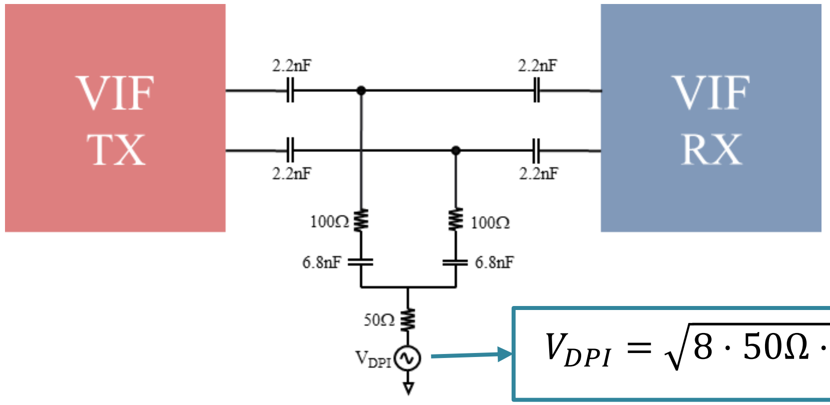
BCI



$$V_{BCI} = 3 \cdot 50\Omega \,.\, I_{BCI}$$

DPI



$$V_{DPI} = \sqrt{8 \cdot 50\Omega \cdot P_{DPI}}$$

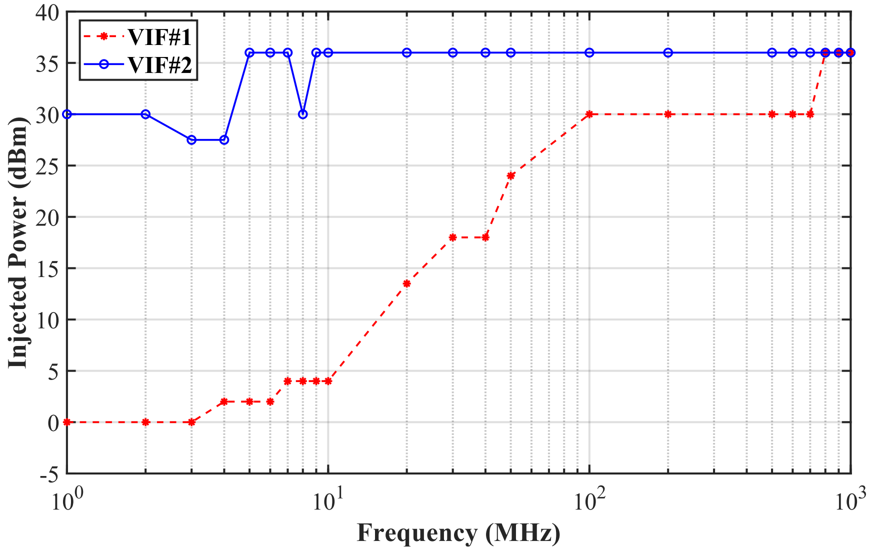
❖ DPI Simulation Procedure

Injecting a 1ms RF power → different phases at each freq → Considering the worst phase condition → 1.5 dB-step for RF power at each freq → Observing the maximum test level (36 dBm) or a failure →

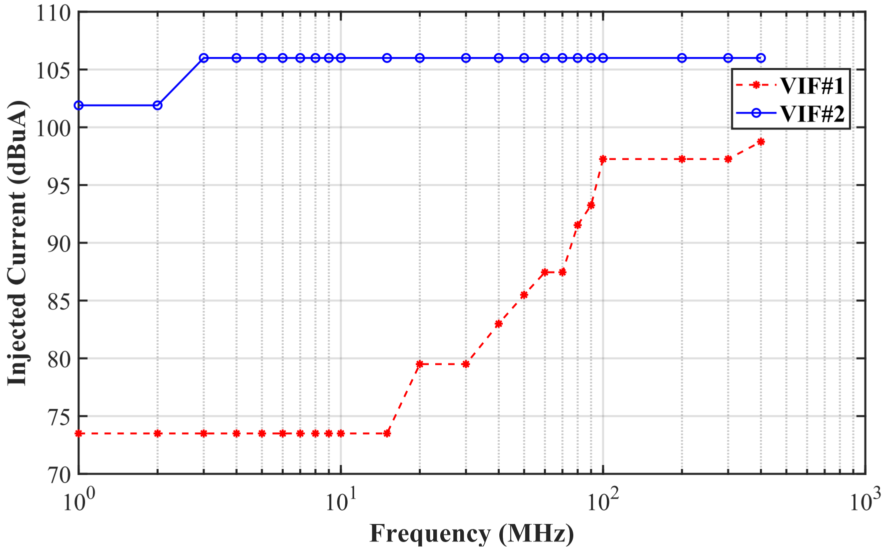
The DPI immunity level:
The minimum level of RF incident power leading to the failure

Susceptibility level to EMI

DPI Simulation Results



BCI Simulation Results



- ✓ A clear correlation between the DPI and BCI simulation results
- ✓ More susceptible to low-frequency EMI
- ✓ For VIF#1 the DPI (BCI) failure level is as low as 0 dBm (73.5 dBmA)
- ✓ For VIF#2 the DPI (BCI) failure level reaches 27.5 dBm (101.9 dBmA)

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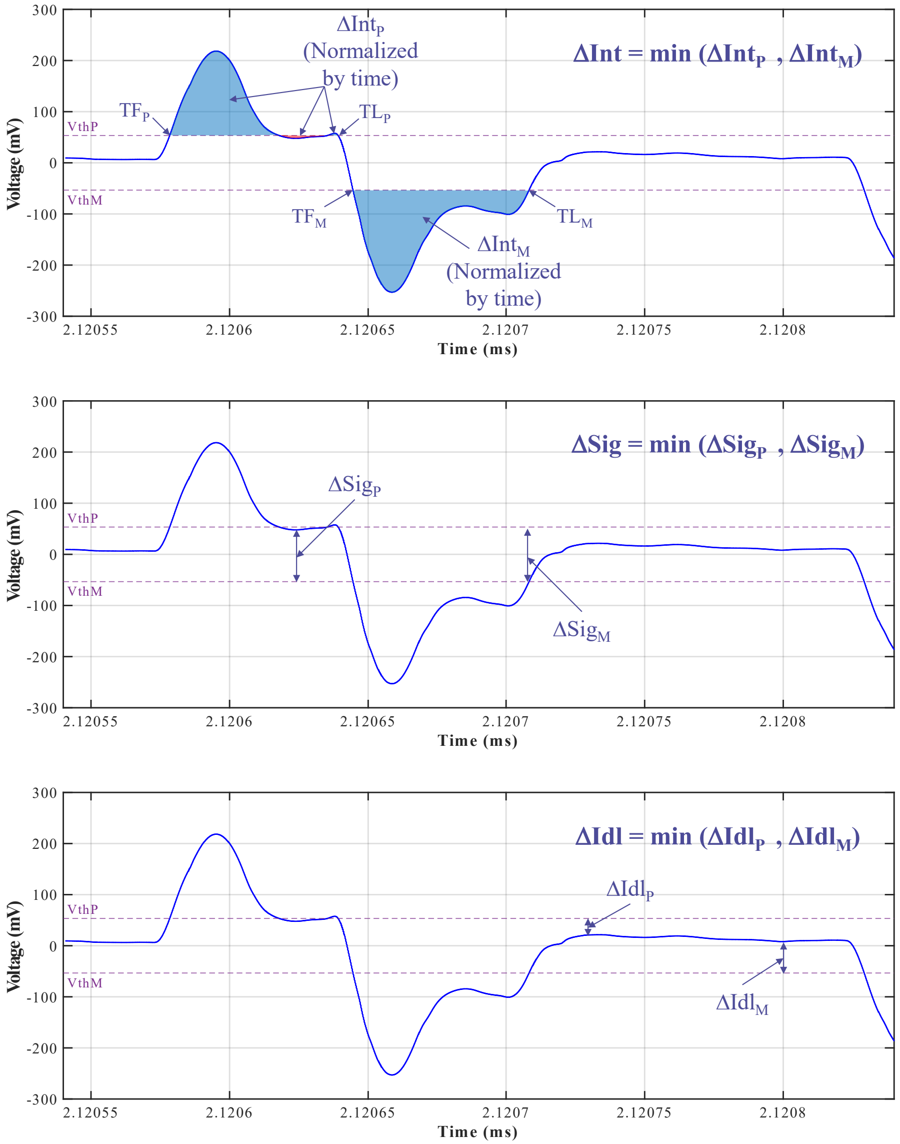

Benchmark Parameters

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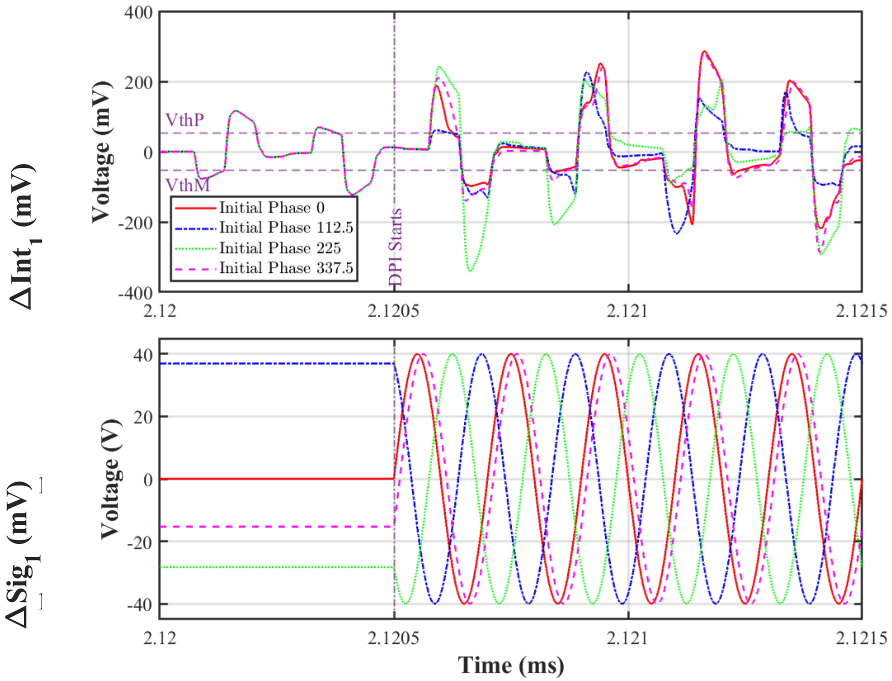
DInt: The mean value of the comparator input differential signal exceeding the threshold voltages

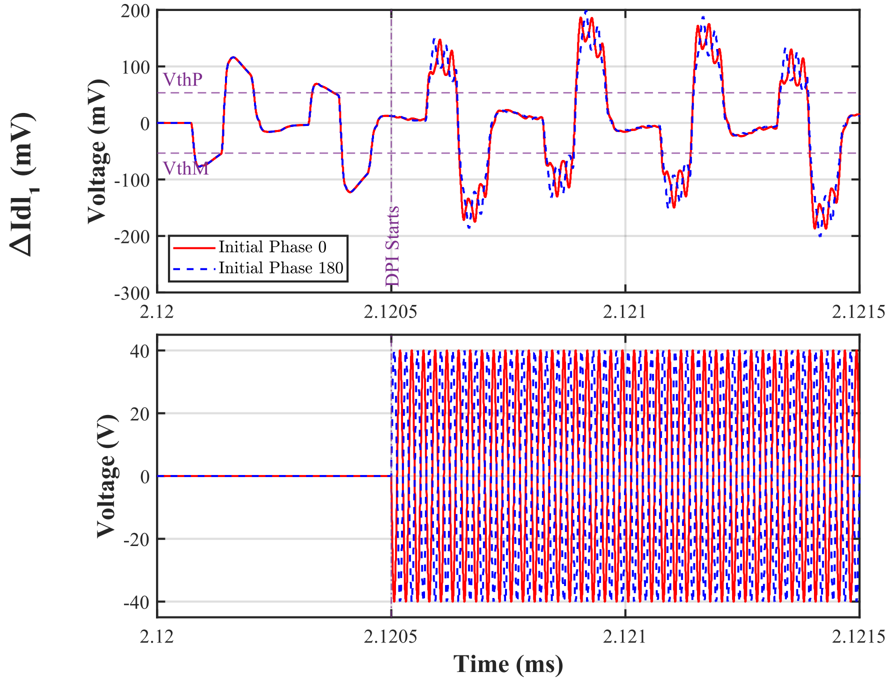
$$\Delta Int = \frac{\int_{TF}^{TL} |v_{in} - V_{th}| \; dt}{|TL - TF|}$$

DSig: The distance between VthP (VthM) and the maximum (minimum) of the signal during a low (high) pulse

DIdl: The minimum distance between the signal and the thresholds (VthM, and VthP) during the idle time

✓ the closer the parameters are to zero, the closer the transmission is to a failure condition





Phase Shifting Effect on DPI Simulation Results

Two examples of different RF signal initial phases: 5MHz, 40MHz

Based on results:

- Variation in initial phase leads to the variation in the differential signal of the comparator's inputs

Benchmark parameters for the first bit after power injection for the VIF#2

Based on results:

- Strong dependency of parameters in lower frequency on the initial phase
- No longer dependency for frequencies above 30 MHz
- In almost all cases the Dsig equals to $2V_{th}$

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Conclusion

- Imbalances in the structure and/or rectification phenomena in the ESD protections
- Conversion of common mode into differential mode interference
- Differential mode component of the received signal at the input of the comparators is corrupted by EMI
- Whenever the parameters are passed, comparators operate in a way that the output digital bit is correctly generated
- Future research are being done focusing on the mechanisms leading to CM to DM conversion

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Thank you for your attention