Detecting Latch-up Soft Failure Using an On-Die Sensor and Linux Kernel Log

Giorgi Maghlakelidze, David Pommerenke, Harald Gossner
Outline

• Why is the Soft Failure Susceptibility relevant?

• The characterization process:
  • High-level overview
  • Injection / measurement setup (hardware)
  • Automation algorithm (software)

• Detection of latch-up:
  • Use existing sub-systems to detect failure

• Moving forward: what was learned?
• Soft Failures (SF) cause device malfunction, loss of data, etc.
• Many factors affect whether fail occurs: 1) hardware 2) software 3) system state
• Failure occurrence is statistical by nature ➔ 100s of tests needed

• Benefits of SF characterization:
  • “Getting it right the first time” - less time in development
  • Less man-hours spent - automation saves time
  • Transferrable to other interfaces with little change
  • Risk management - better understanding of the system
Characterization system setup
The dev platform (DUT) in 2 parts:

**Compute module** – all main ICs (CPU, RAM, eMMC, Bluetooth, WiFi)

**Expansion board** – power, fanout (HDMI, microSD, USB3, USB-C, GPIO)

An interposer goes between the boards.

**Stress injection** directly into the data pins of active interface.

**Not** introducing SI problems (**TVS injection method** [6]).
Injection at either side of 5Ω resistor (for directionality). Coax access → UMCC connectors (surface mount snap-in coax).

ESD injection & voltage measurement

Inject

Pick-up

Inject

Pick-up

Connector side

data transfer

Joule side

Inject

Pick-up
Stress injection setup - 100ns pulse

TLP 100ns

50Ω

Z₀=50Ω

CT-1 probe

1

Current Measurement Node

Voltage Measurement Node

1k

UMCC cable

To Joule

CH_I

Atten.

Z₀=50Ω

2

To Conn.

UMCC cable

1k

5

CH_V1

Atten.

Z₀=50Ω

4

CH_V2

Atten.

Z₀=50Ω

To Conn.

UMCC cable

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TLP System and DUT initialization:

**TLP System**
- Calibrate the TLP setup
- Set SWEEP voltage & polarity
- Wait for DUT initialization
- ...

**SF Tool**
- Power cycle the DUT
- Log into the DUT via SSH
- Set DUT state (load)
- Start logging DUT status
- Connect to MCU
- Re-plug USB into DUT
### Fully Automatic USB3 characterization flow

**TLP System**

1. Adjust OSC settings
2. Wait
3. Check if firing allowed
   - no
   - yes
   - Set TLP voltage & fire
4. Prepare measured IV data
5. Is OSC clipping?
   - no
   - yes
   - Next sweep point

**SF Tool**

1. Interface file
2. Wait
3. Pulse occurred?
   - yes
   - no
4. Read injection data:
   - pulse, I, V
5. Detect SF type
6. Log data into *.csv
7. Re-plug & check USB
8. Allow TLP fire
9. End of SWEEP?
   - yes
   - no
   - Process test data produce a report

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*Note: Arrows indicate flow direction.*
Monitoring DUT power consumption

The Run-time Average Power Limit (RAPL) sub-system of the Intel Joule CPU adjusts processor power to maintain temperature targets.

RAPL reports “energy spent by the processor in micro Joules”. The sensor polled with 1 sec interval at:

\[ P_{avg} = \frac{E(t_2) - E(t_1)}{t_2 - t_1} \]

/sys/class/powercap/intel-rapl/intel-rapl:0/energy_uj
Power consumption due to Latch-up

Occurs when USB3 device is plugged in. Cannot resolve without full power cycle. Detected without needing any external instruments.
Processing characterization data

Challenge → process the results and be useful!

**Python** + big data tool **PANDAS** for **multivariate** analysis:
- Select and process the right data
- Generation of pivot charts and tables
- Pass/fail check w.r.t. likelihood thresholds

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SF Likelihood vs... :
- TLP \( V_{\text{charge}} \)
- Measured \( I_{\text{injected}} \)
- Measured \( V_{\text{injected}} \)
<table>
<thead>
<tr>
<th>Mode</th>
<th>Cat.</th>
<th>Visible</th>
<th>Interact</th>
<th>Example for USB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B</td>
<td>✔</td>
<td>✗</td>
<td>Drop in the data rate</td>
</tr>
<tr>
<td>2.1</td>
<td>B</td>
<td>✔</td>
<td>✗</td>
<td>Client re-enumerated in USB3 mode; restored by the system</td>
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<tr>
<td>2.2</td>
<td>B</td>
<td>✔</td>
<td>✔</td>
<td>Client re-enumerated in USB3 mode; GUI pop-up message appears</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>✔</td>
<td>✔</td>
<td>Client device falls back to USB2 mode</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>✔</td>
<td>✔</td>
<td>Client device disappears</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>✔</td>
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<td>Persistent power drain (latchup)</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
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<td>A</td>
<td>✗</td>
<td>✗</td>
<td>Bit errors; packets getting resent</td>
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<tr>
<td>B</td>
<td>✔</td>
<td>✗</td>
<td>Drop in data throughput; connection re-established by host</td>
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<tr>
<td>C</td>
<td>✔</td>
<td>✔</td>
<td>Stop of data transfer; re-plugging or power cycling required</td>
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<tr>
<td>D</td>
<td>✗</td>
<td>✔</td>
<td>Latch-up (power drain)</td>
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<th>Power Cycle</th>
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Conclusions

• Sometimes existing sub-systems can be used to our advantage.

• Latch-up is one of the most vicious Soft Failures for embedded and battery-powered systems.

• Automated test setups help save time and characterize DUTs for SF susceptibility
Fin.

Thank you for your time!