# Towards Wearout-Aware and Accelerated Self-Healing Digital Systems

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**Motivation: Wearout is a crisis!**

### Wearout Crisis

- **BEOL** - Electromigration (EM)
- **FEOL** - Negative/Positive-bias temperature instability (N/PBTI)

### Previous Solutions
- Tolerate - Design for the worst case (margins, upsizing)
- Compensate - Dynamically adapt to wearout
- Slow down the wearout - Reduce the stress
- Passive Recovery - Remove the stress, shut off the core

### This Work
- Repair Both wearout completely by introducing the notion of Accelerated & Active Recovery
- Circadian Rhythms for FULL recovery
- Demonstrate both solutions experimentally
- Introduce Accelerated & Active Recovery as a new design knob for cross-layer resilience

### Accelerated & Active Recovery

#### BTI (FEOL Wearout) active and accelerated recovery

#### EM (BEOL Wearout) active and accelerated recovery

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**Accelerated Self-Healing Results**

### BTI Measurement Results

An example where about 72.4% of wearout is recovered by accelerated self-healing techniques in only 1% of stress time (measured).

### EM Measurement Results

There is still a permanent part.

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**Cross-Layer Implementations**

### Cross-Layer Accelerated Self-Healing (CLASH) System

- System scheduler schedules the recovery proactively based on the known circadian rhythms (e.g. for mobile device applications, 12 hrs + Sleep time)

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**Publications**

- [Submitted] Healing BEOL and FEOL Wearout with Active Recovery
- [VCS’16/ICCAD] Enabling Wearout-Immune BEOL and FEOL with Active Rejuvenation
- [INTEGRATION, the VLSI Journal] “Implications of Accelerated Self-Healing as a Key Design Knob for Cross-Layer Resilience”
- [ASP-DAC’16] “Work hard, sleep well - Avoid irreversible IC wearout with proactive rejuvenation”
- [SELE’16] “MCPS: Multiple-Critical-Path Embeddable NBTI Sensors for Dynamic Wearout Management”

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**Scheduling/Load-balancing**

- System scheduler schedules the recovery proactively based on the known circadian rhythms (e.g. for mobile device applications, 12 hrs + Sleep time)

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**Embeddable Wearout Sensors**

- Track both wearout and (accelerated) recovery
- Track path reranking

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**High Temperatures**

- Heating Elements

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**Negative Voltages**

- A Charge-pump Neg. voltage generator
- Wearout-aware Power Gating

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**Full Recovery Time**

- Different sleep conditions
- 12-hour constant stress under regular operation condition (no accelerated stress)

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**A Systematic Solution**

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**Applications**

- Sleep when getting tired for FULL recovery

- Main Ideas
  - The boundary between reversible & irreversible is “soft”
  - Irreversible wearout can be recovered through acceleration
  - Frequency dependency of accelerated wearout & recovery
  - Sleep when getting tired to FULLY avoid the irreversible wearout
  - Negative “turbo” boost at the system level