POWER AND THERMAL CHALLENGES IN MOBILE DEVICES

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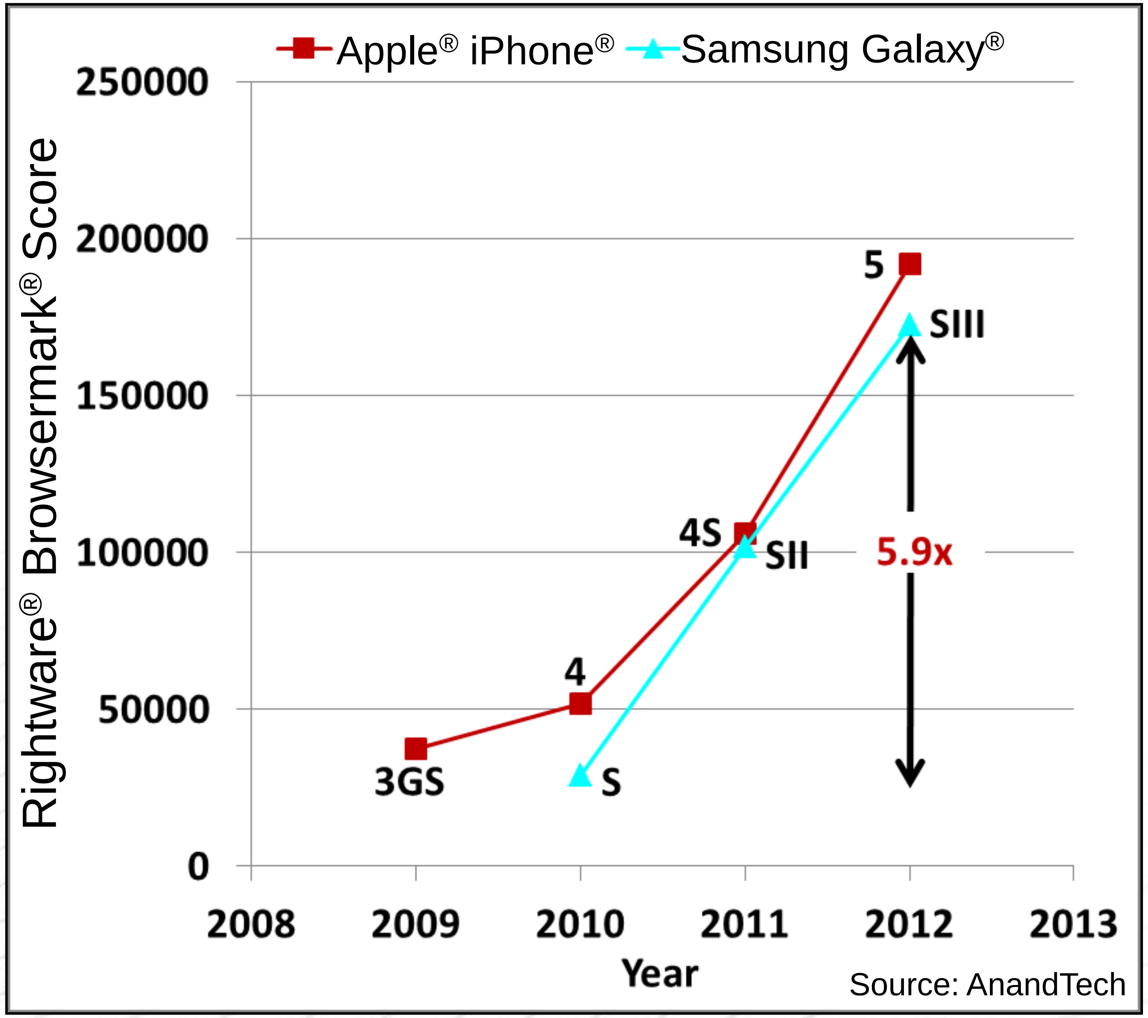
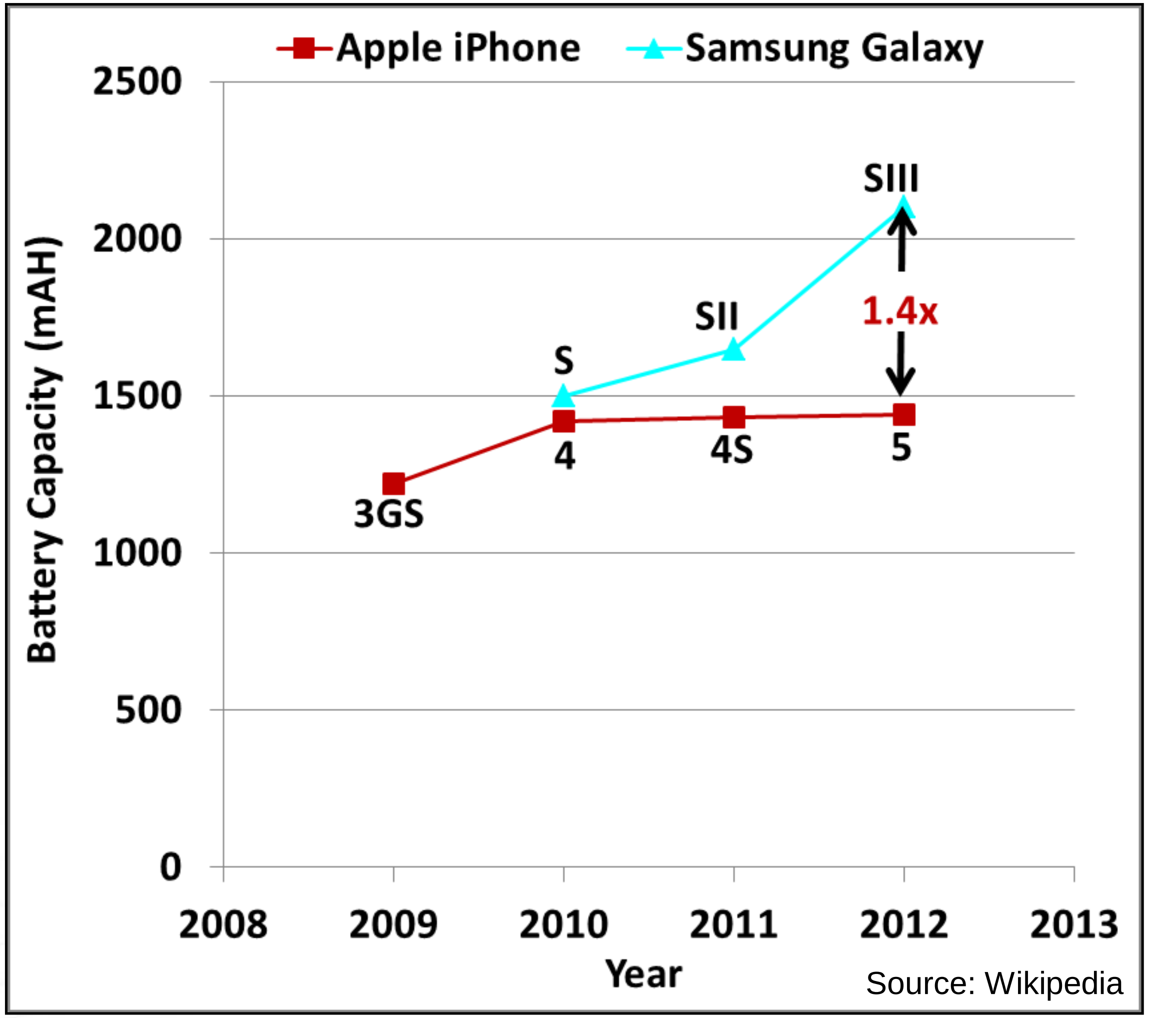
PERFORMANCE AND BATTERY CAPACITY TRENDS

- **CPU performance increase**
  - Samsung® Galaxy S → S3: **5.9x**



- **Battery capacity increase**
  - Samsung® Galaxy S → S3: **1.4x**



- **Enabled by advancements in low-power designs and power management techniques.**

INCREASING INTEGRATION OF ADVANCED FEATURE SETS

BROADCOM

AP **AP** **AP** **AP** **MODEM**
GRAPHICS **VIDEO** **ISP**

Multicore CPU + 2G/3G/4G + Multimedia SoC

RFIC
Radio Frequency IC

PMU
Power Management IC

Camera Flash
Flash

Camera
Camera
Front + Rear (Dual)

uSD
SD Card

LCD
Display

WLAN/BT/ FM
802.11a/b/g/n/ac + BT 4.0 + FM SoC

GPS/GLONASS
GPS SoC

NFC
Near-Field Communications IC

eMMC
Flash

TSC
Touchscreen Controller

Sensors
Sensors

A4WP
Wireless Charger

Sensor Hub
Sensor Fusion

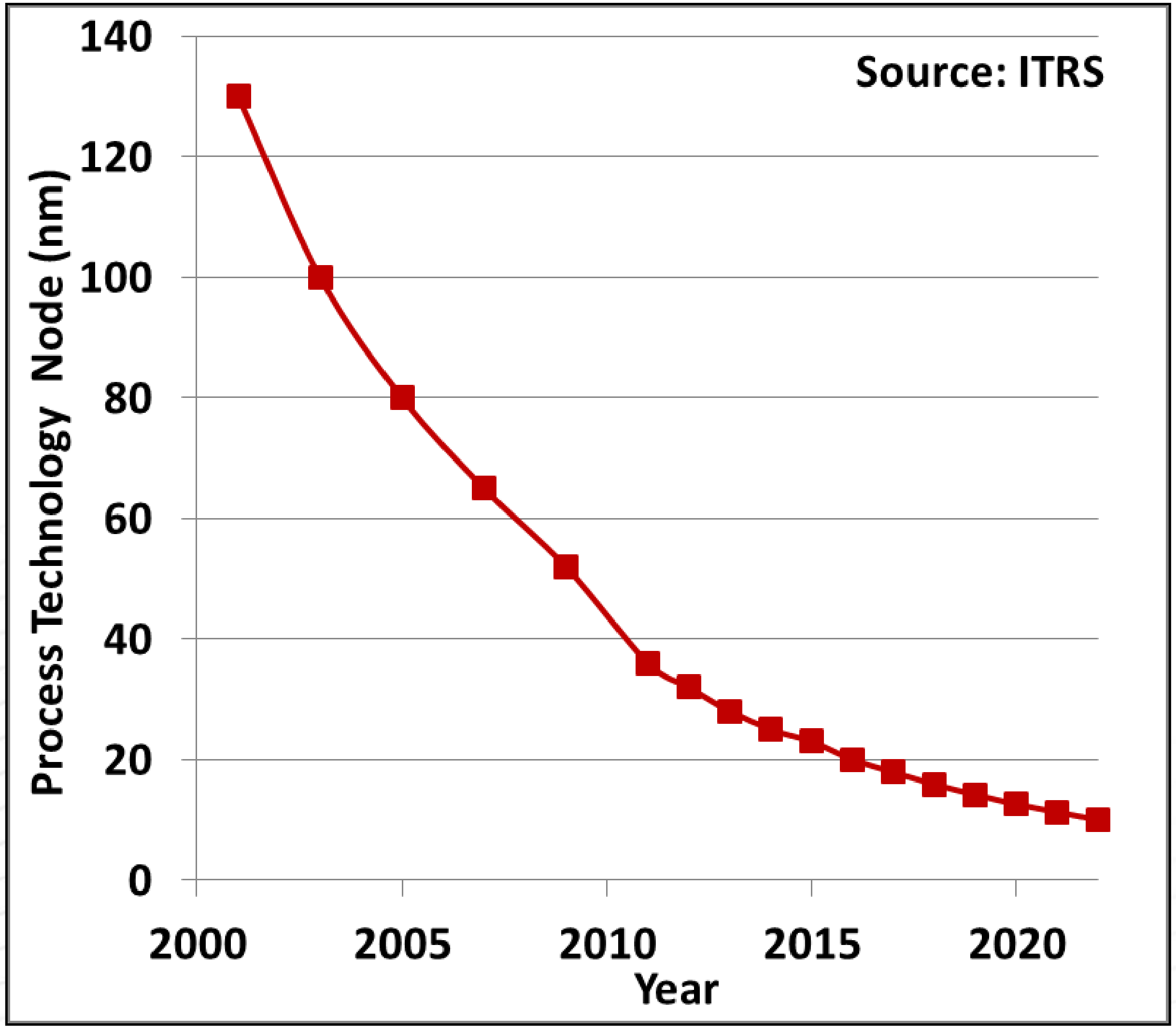
POWER AND THERMAL CHALLENGES: FIRST-CLASS DESIGN CONSTRAINTS

- **Process-variability-aware power management**
- **Thermally aware power management**
- **Thermal management**

PROCESS-VARIABILITY-AWARE POWER MANAGEMENT

SEMICONDUCTOR PROCESS NODE EVOLUTION AND VARIABILITY

- 130 nm in 2001 → 28 nm in 2013
- Driving force behind Moore's Law

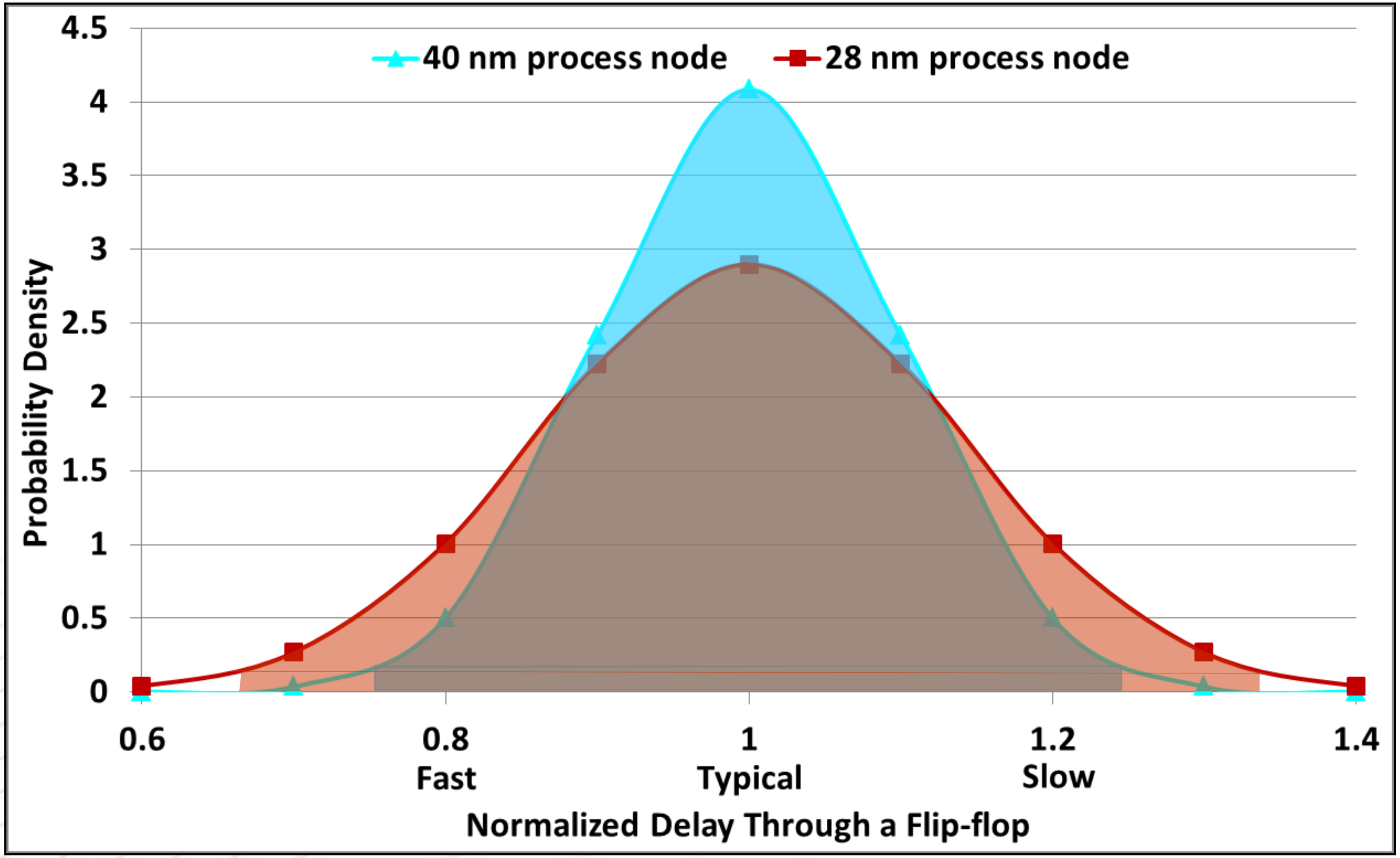


- Limitations of fabrication process
- +/- 1 molecule makes a difference

Year of Production	2013
Process Technology Node (nm)	28
Gate Oxide Thichness (nm)	1.4 (n), 1.7 (p)
Gate Oxide Thickness (# of SiO2 molecules)	2-3
% Vdd Variability	10%
% Vth Variability	42%
% Performance Variability	42%
% Total Power Variability	51%

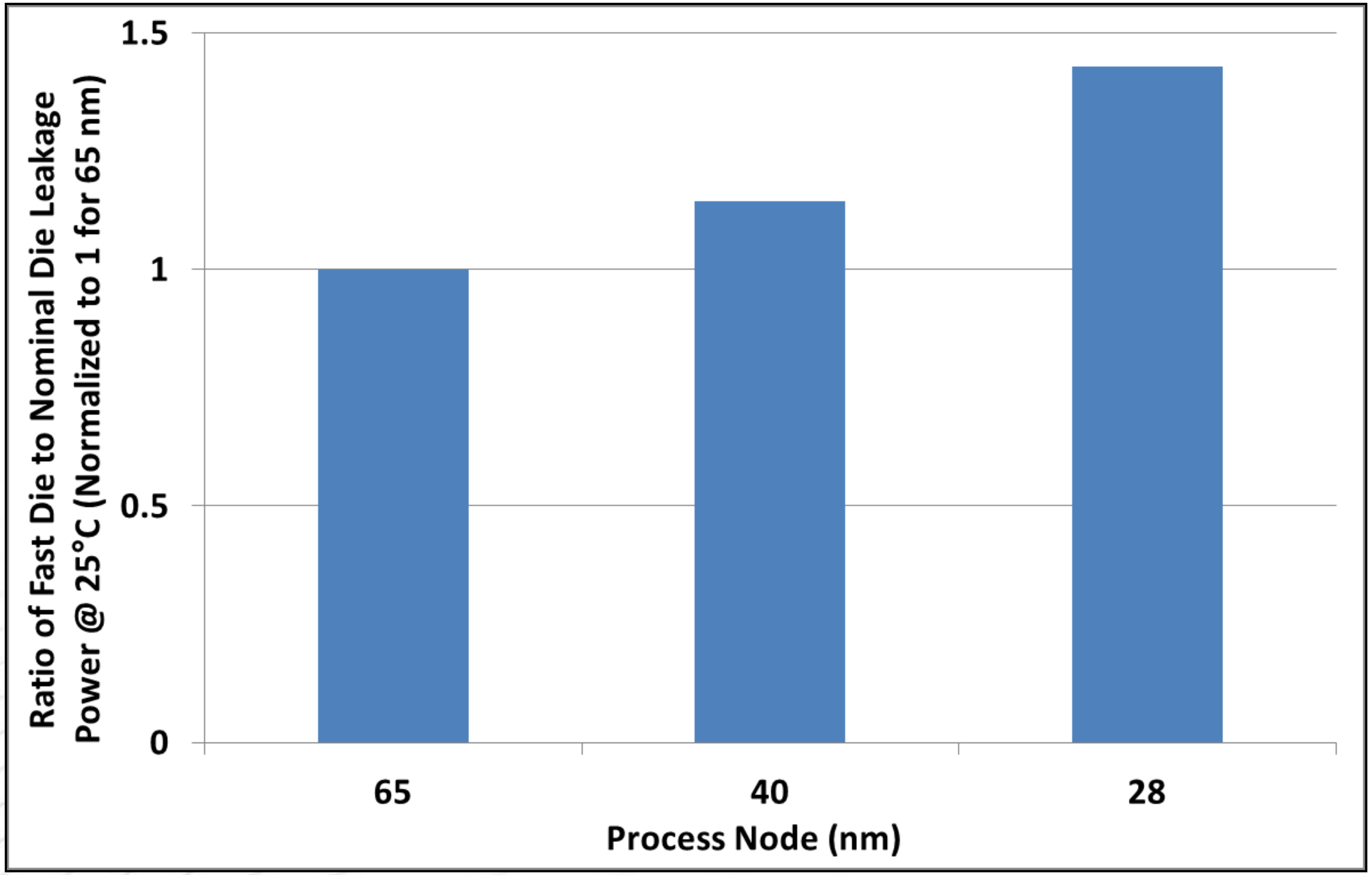
Source: ITRS

SEMICONDUCTOR DEVICE VARIABILITY



- Higher *number* of non-nominal dice
- Larger *magnitude of difference* between nominal and non-nominal dice

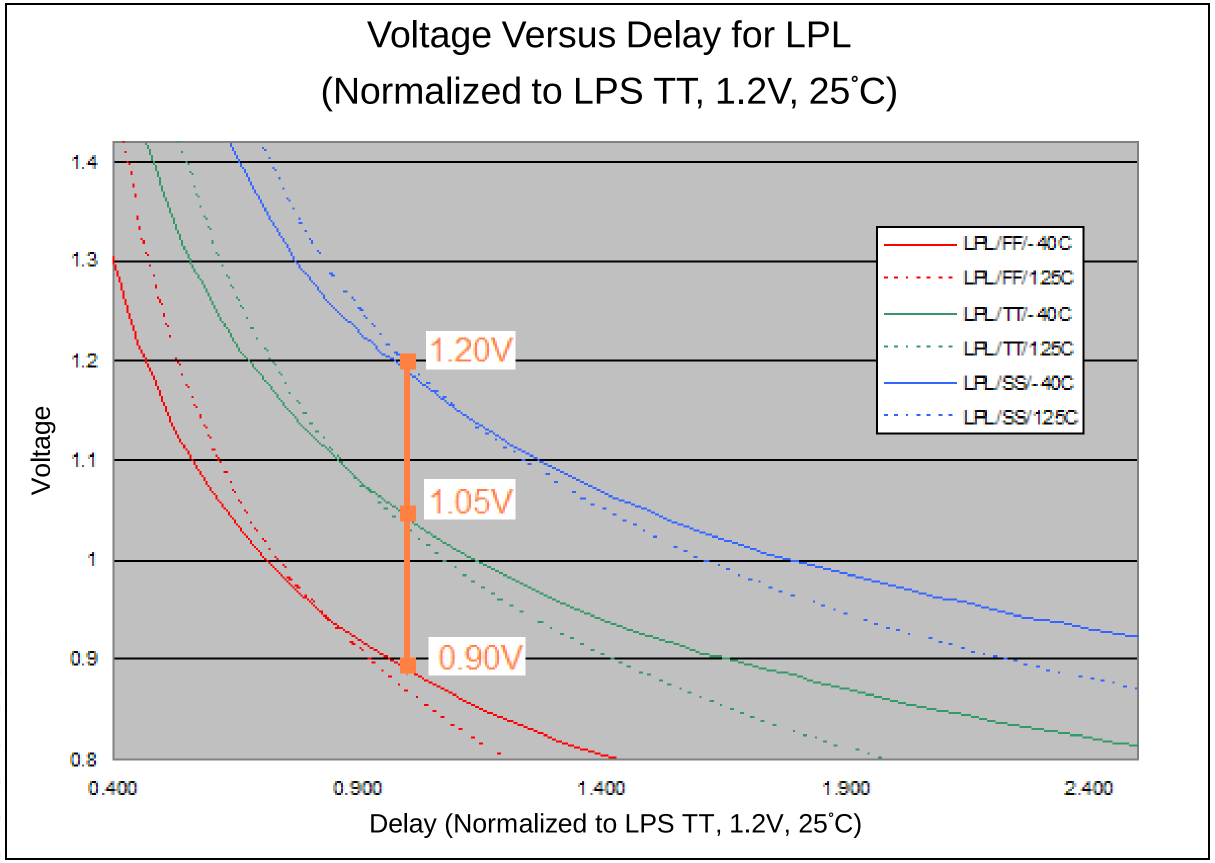
LEAKAGE POWER VARIABILITY OVER PROCESS NODES



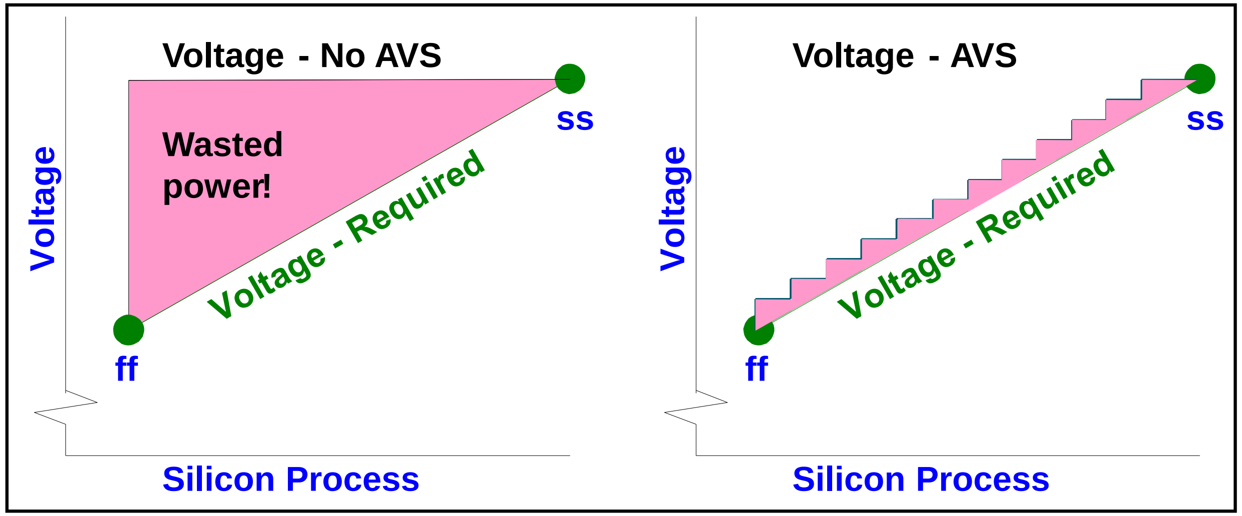
- **Similar trend but much smaller magnitude for dynamic power variability**
- **Process-variability-aware power management policies required**

ADAPTIVE VOLTAGE SCALING (AVS)

- **For same performance, different voltage requirements for fast vs. typical vs. slow dice.**



- **AVS adjusts voltage to die type.**



- **Reduces dynamic and leakage power of fast dice and nominal dice.**
- **Reduces power consumption variability between dice.**

CHALLENGE

- **Power is no longer a number but a *distribution*.**

- **Power models, estimates, and policies today are typically geared towards typical/nominal dice.**

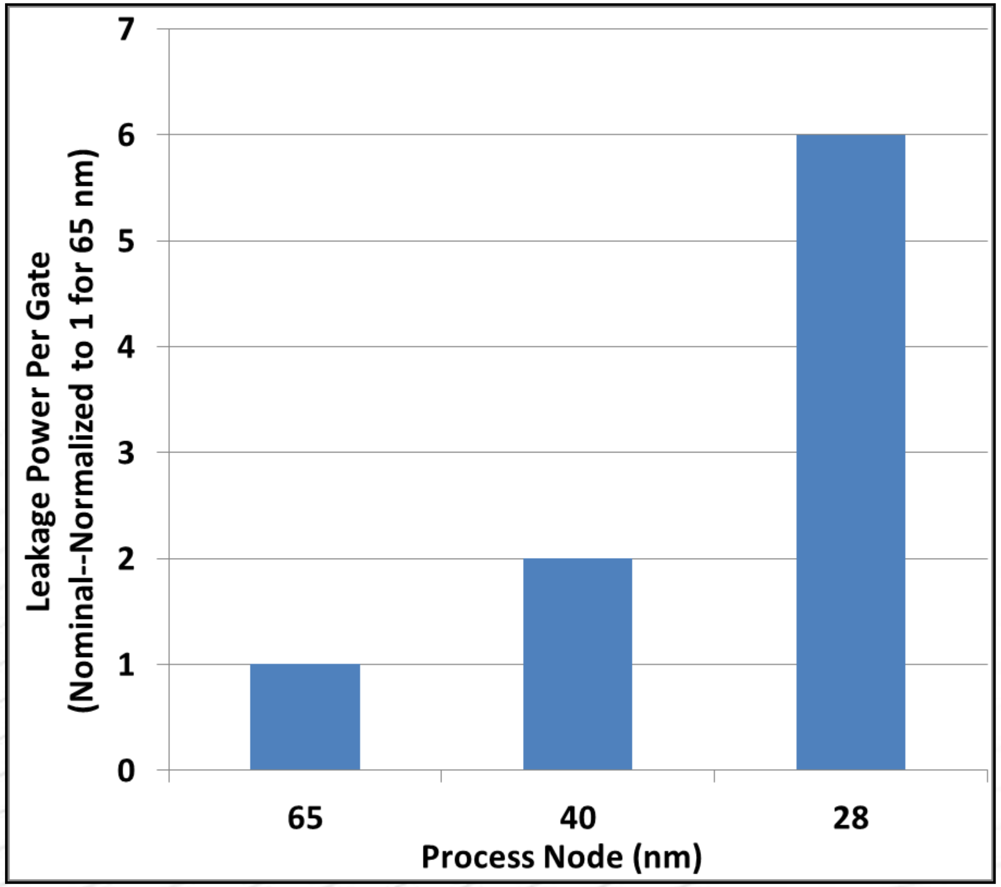
- **One-size-fits-all power management policies are increasingly insufficient.**

- **All aspects of power management need to be made *process-variability-aware.***

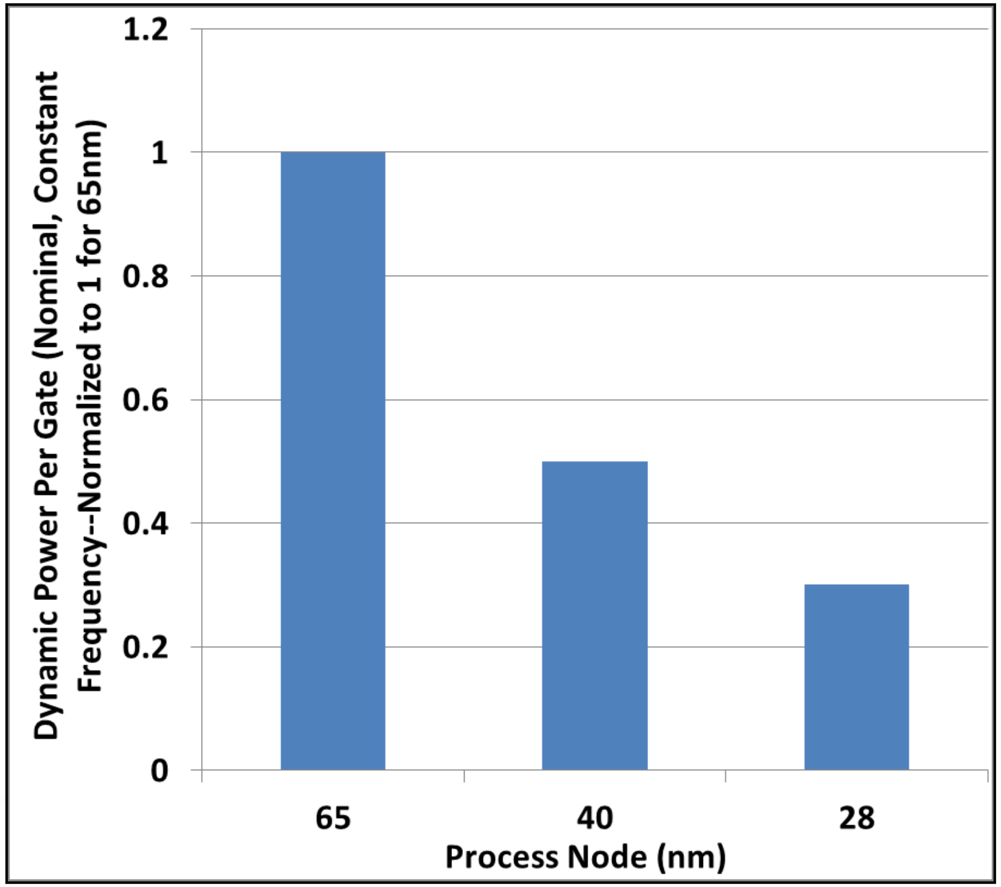
THERMALLY AWARE POWER MANAGEMENT

LEAKAGE POWER AND DYNAMIC POWER OVER PROCESS NODES

- Leakage power increases exponentially every technology generation.



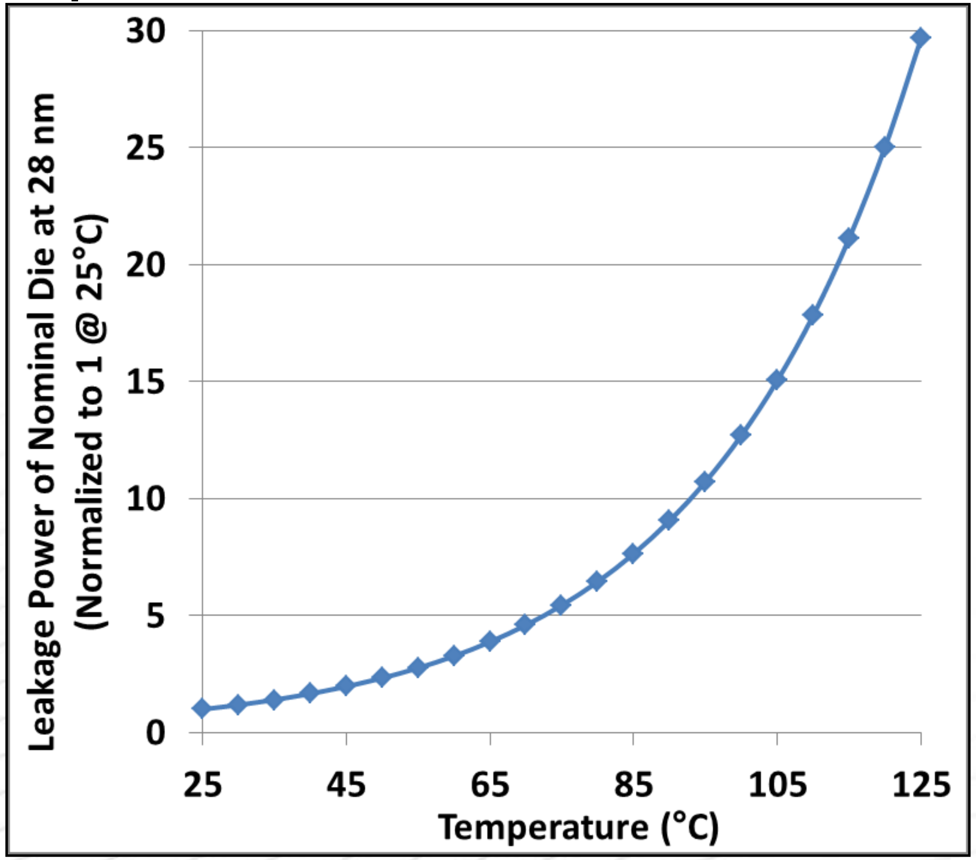
- Dynamic power per gate @ same frequency decreases every technology generation.
- Overall device dynamic power increases.



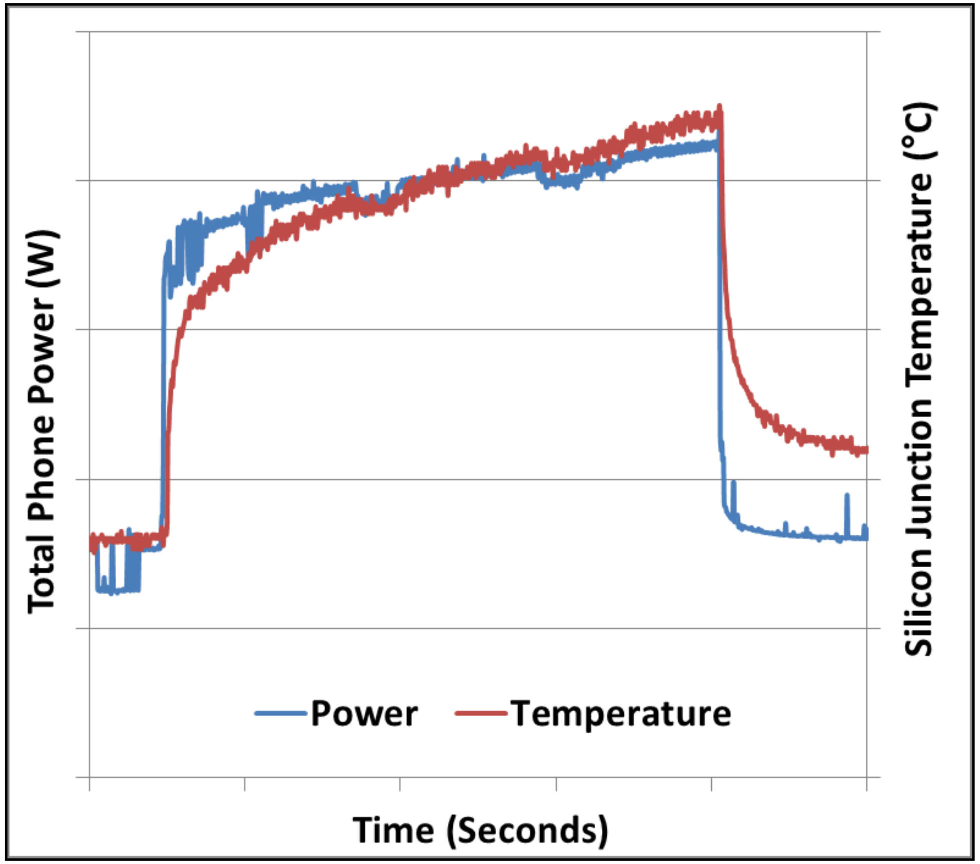
- Leakage power becoming a more dominant factor in total power dissipation.

LEAKAGE POWER VERSUS TEMPERATURE

- **Leakage power depends exponentially on temperature.**
- **It may account for 40%–50% of total power dissipation.**



- **There is a positive feedback loop between power and temperature.**
  - Power ↑ => Temperature ↑ => Power ↑

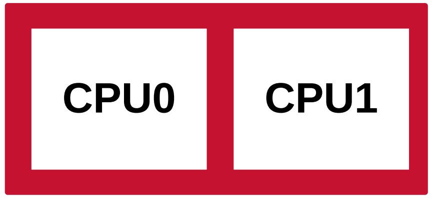


- **Temperature is a very important factor to consider in the context of power.**

DVFS VERSUS CPU HOT-PLUG

Dynamic Voltage and Frequency Scaling (DVFS)

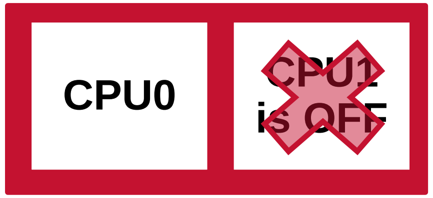
- Run at the lowest possible frequency and voltage to meet the computational requirements.
- Dynamic power has a square dependence on voltage.



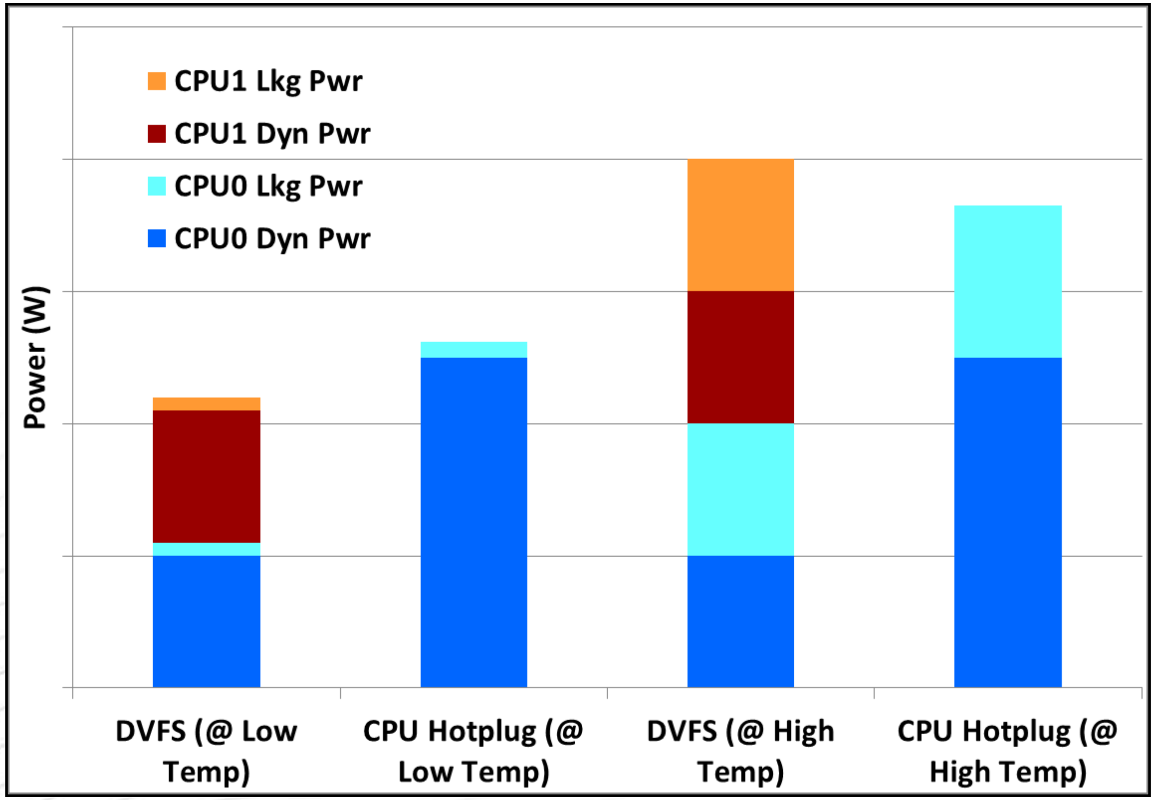
Frequency = ***F***

CPU Hot-plug

- Power the CPU cores on and off depending on the computational requirements.
- Better for leakage power.



Frequency = ***2F***



- DVFS may be better suited for low/medium temperatures where dynamic power dominates.
- CPU hot-plug may be better suited for high temperatures where leakage power may dominate.

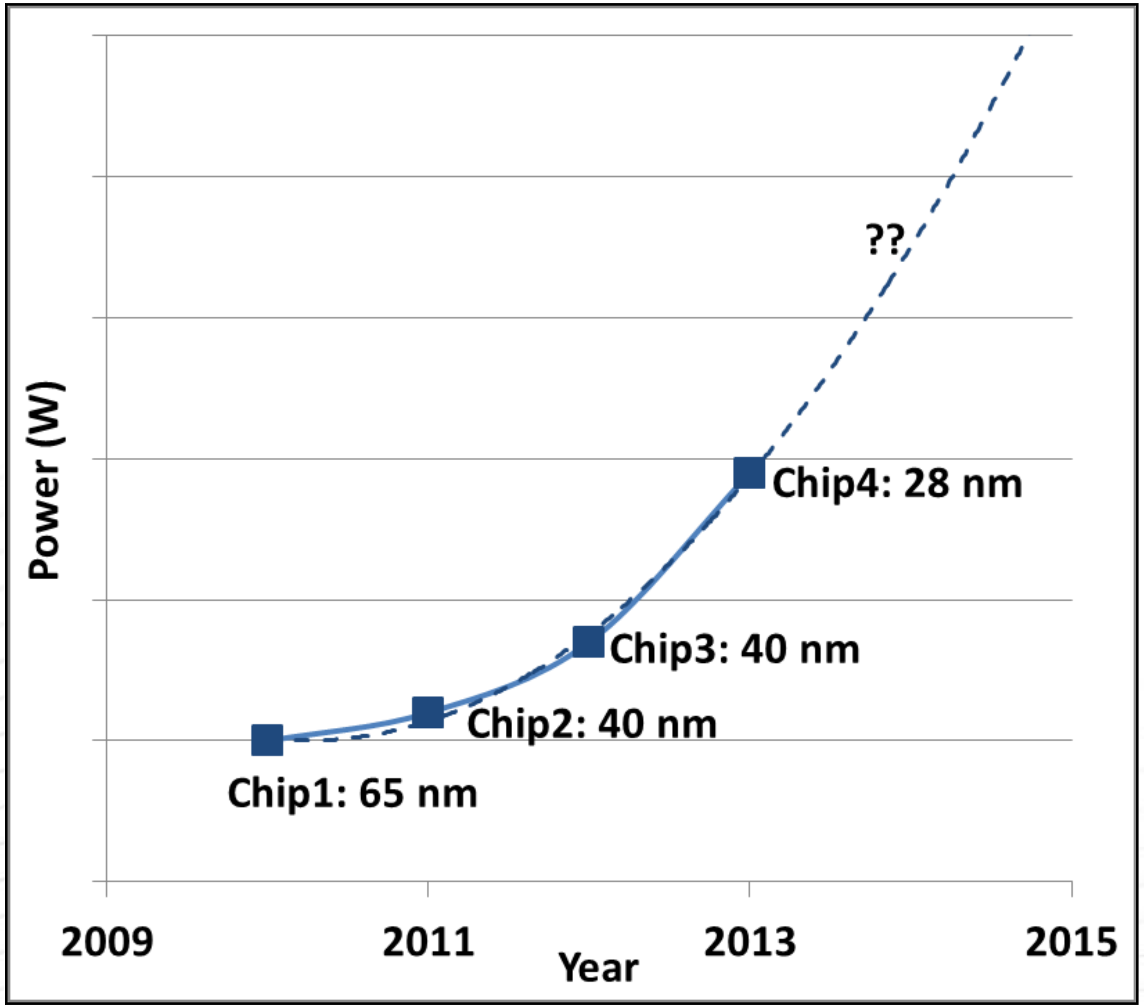
CHALLENGE

- **Leakage power is increasing as a fraction of total power dissipation at smaller technology nodes.**
- **Leakage power increases exponentially with temperature.**
- **Power models, estimates, and policies today are typically temperature agnostic.**
- **All aspects of power management need to be made *temperature-aware.***

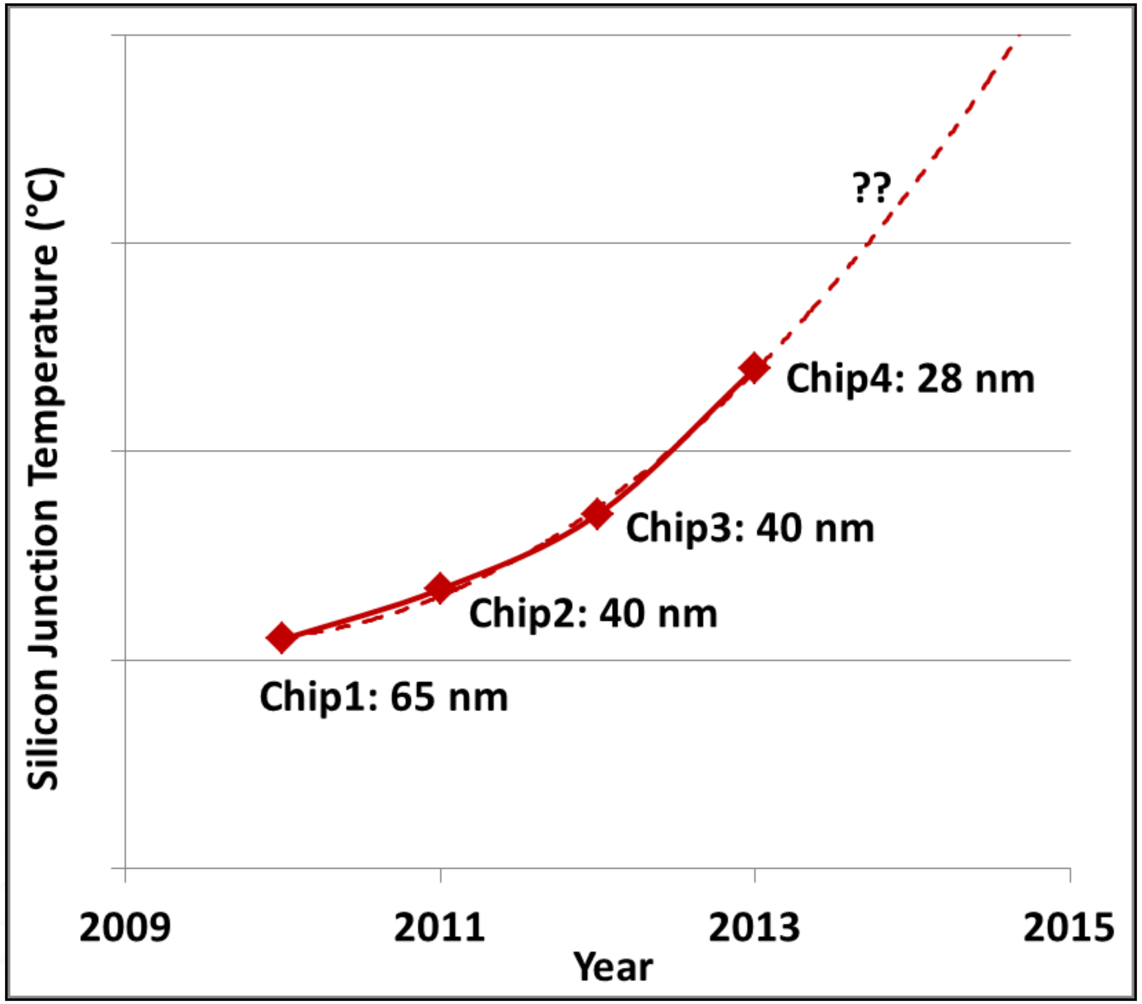
THERMAL MANAGEMENT

SMARTPHONE POWER AND TEMPERATURE EVOLUTION

- **SoC power dissipation for representative heavy usage scenario (without thermal management)**



- **Corresponding SoC silicon junction temperature (without thermal management)**

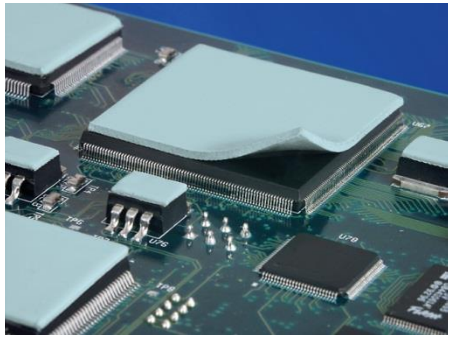


MOBILE DEVICE THERMAL CONSTRAINTS

- **Thermal limits are not changing.**
  - Phone skin temperature (front and rear) < ~40°C – 45°C
  - Silicon die temperature < ~125°C (Discrete), ~105°C (PoP)
  - DRAM temperature < ~105°C
  - eMMC temperature < ~85°C
  - Battery temperature during charging < ~45°C
  - Battery temperature during discharging < ~60°C
- **Active cooling mechanisms used in PCs/laptops are not feasible for mobile devices.**
  - Fans
  - Heat sinks
- **Mobile device form-factors are shrinking.**
  - Harder to dissipate heat
- **Power density is increasing with shrinking process nodes.**
  - Hot spots

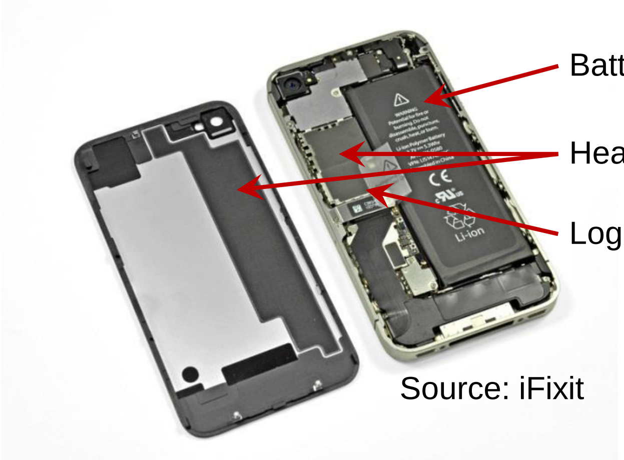
MOBILE DEVICE THERMAL DESIGN

- **Thermal Interface Materials (TIM)**
  - Thermal gap pad
  - Better thermal conduction between components and EMI shield/chassis
  - Through-thickness heat conduction



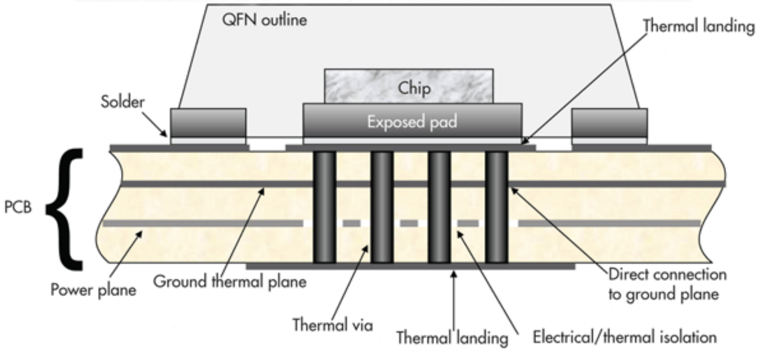
Source: Bergquist Company

- **Heat spreaders**
  - Distribute heat evenly and prevent hotspots.
  - Made of graphite/graphene, copper, or aluminum.
  - Provide lateral heat conduction.



Source: iFixit

- **Thermal vias**
  - Conduct heat away from SoC to PCB ground plane.
  - Distribute heat through the PCB.



Source: Electronic Design

Provide limited improvements and are relatively expensive.

Need for thermal management for mobile devices

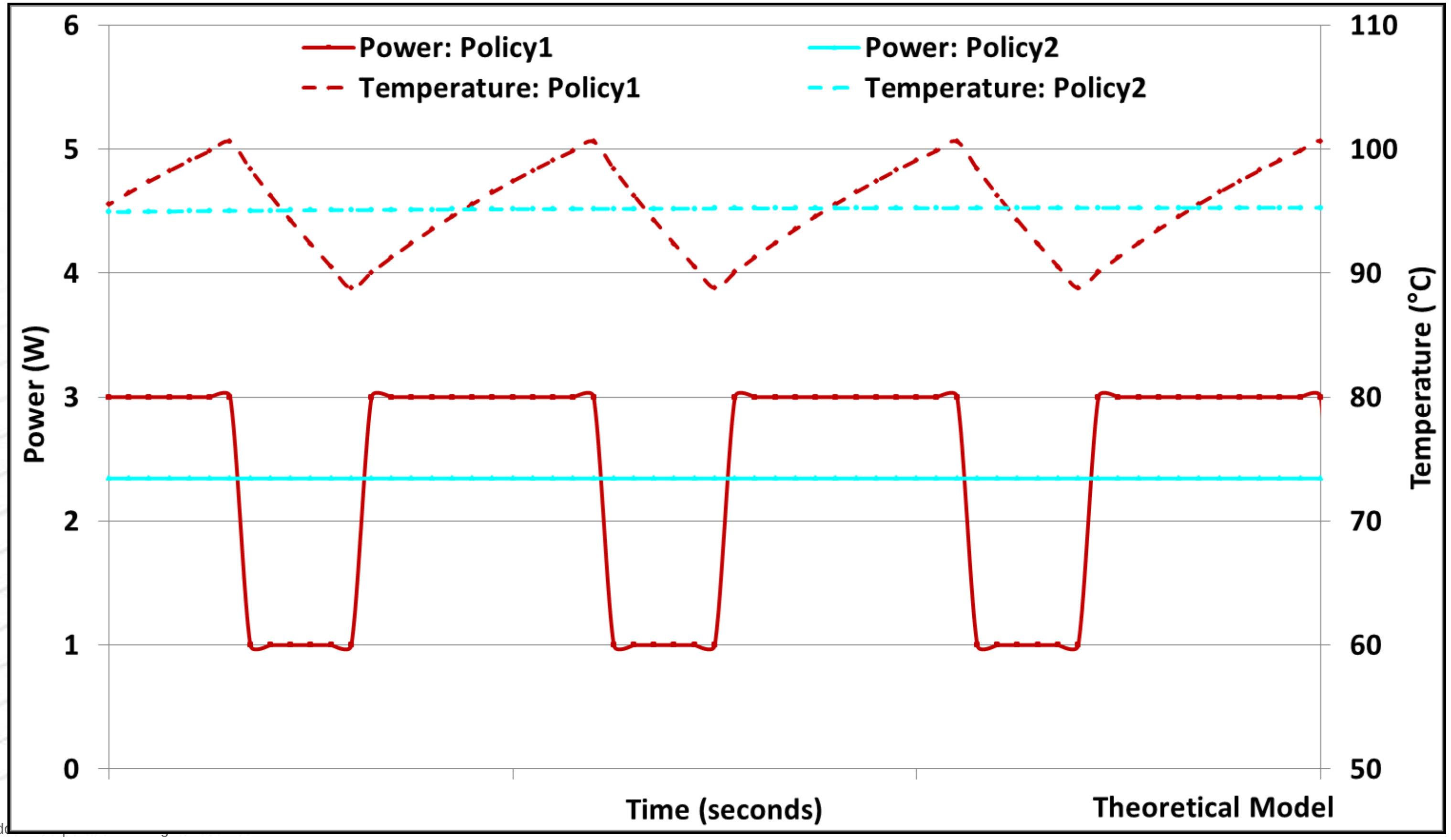
THERMAL THROTTLING

Thermal Policy 1

- Allow 3W power until 100°C (maximum limit).
- Throttle to 1W until 90°C.
- Average power = 2.3W.

Thermal Policy 2

- Allow only 2.3W power above 90°C.
- Device temperature reached = 95°C.
- 5°C thermal headroom compared to Policy 1.
- Achieves smoother application performance.



CHALLENGE

- **With increasing integration of advanced functionality, mobile device power consumption is rapidly increasing.**
  - Therefore, temperature is also rapidly increasing.
- **Thermal constraints are constant.**
- **Temperature, even more so than power, is fast becoming a fundamental design bottleneck.**
- **Ad hoc thermal throttling will significantly degrade performance.**
- **Smart thermal management algorithms are required that can effectively trade-off:**
  - Performance
  - Power
  - Temperature
  - User experience

SUMMARY

- **Huge advances have been made in low-power design and power management techniques, enabling the mobile revolution.**
- **Significant challenges remain in the areas of power and thermal.**
- **Three such challenges from a semiconductor company point-of-view include:**
  - Process-variability-aware power management.
  - Thermally aware power management.
  - Thermal management.
- **Broadcom mobile chipsets today feature multiple such advanced technologies.**
- **Broadcom is actively pursuing research and development in each of these areas.**

Thank You

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