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.

Source: AnandTech

INCREASING INTEGRATION OF ADVANCED FEATURE SETS

- **Multicore CPU + 2G/3G/4G + Multimedia SoC**
- **RFIC**
  - Radio Frequency IC
- **PMU**
  - Power Management IC
- **Camera Flash**
  - Camera
  - Front + Rear (Dual)
- **uSD**
  - SD Card
- **LCD**
  - Display
- **WLAN/BT/ FM**
  - 802.11a/b/g/n/ac + BT 4.0 + FM SoC
- **GPS/GLON ASS**
  - GPS SoC
- **NFC**
  - Near-Field Communications IC
- **TSC**
  - Touchscreen Controller
- **A4WP**
  - Wireless Charger
- **eMMC**
  - Flash
- **Sensors**
  - Sensors
- **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
- 130 nm in 2001 → 28 nm in 2013
- Driving force behind Moore’s Law
- Limitations of fabrication process
- +/- 1 molecule makes a difference

<table>
<thead>
<tr>
<th>Year of Production</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Technology Node (nm)</td>
<td>28</td>
</tr>
<tr>
<td>Gate Oxide Thickness (nm)</td>
<td>1.4 (n), 1.7 (p)</td>
</tr>
<tr>
<td>Gate Oxide Thickness (# of SiO2 molecules)</td>
<td>2-3</td>
</tr>
<tr>
<td>% Vdd Variability</td>
<td>10%</td>
</tr>
<tr>
<td>% Vth Variability</td>
<td>42%</td>
</tr>
<tr>
<td>% Performance Variability</td>
<td>42%</td>
</tr>
<tr>
<td>% Total Power Variability</td>
<td>51%</td>
</tr>
</tbody>
</table>

Source: ITRS
SEMICONDUCTOR DEVICE VARIABILITY

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

CPU Hot-plug

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

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.
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

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

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

Provide limited improvements and are relatively expensive.

Need for thermal management for mobile devices
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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