Optimized Mobile System Power

"Exact Power @ Exact Time"

PWRSoC 2016
Session 8: Granular Power

Tong H. Kim
Principal System Power Architect
Samsung Electronics Corp/System LSI
Contents

- Mobile System Contents & Teardown
- System Power and Connectivity
- Power Delivery and Si Technology Trends
- System Power Management & Sequencing
- Putting it altogether!
Typical Smart Phone System Contents

- **Apps Processor**
  - 14nm Quad-Core
- **Graphics Processor**
  - Capable of 4K @ 60fps

- **Power Management**
  - PFM/PWM
  - Multi-Phase
  - Thin and Tiny

- **Cellular (LTE-A)**
- **WiFi (802.11abgn)**
- **BLE-4.1**
- **GNSS (Quad mode)**

- **Storage**
  - eMMC
  - UFS
  - DDR

- **Connectivity**
  - Cellular (LTE-A)
  - WiFi (802.11abgn)
  - BLE-4.1
  - GNSS (Quad mode)

- **Display**
  - AMOLED
  - 5.7” QHD (2560x1440)
  - RES = 3.7M-pixels

- **AP/GPU**
  - Apps Processor
  - 14nm Quad-Core
  - Graphics Processor
  - Capable of 4K @ 60fps

- **uBIO, CIS**
- **PMIC**
  - Power Management
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SEC/System LSI
### Typical Wearable System Contents

**Storage**
- UFS - 4GB
- DDR - 768MB

**Connectivity**
- WiFi (802.11bgn)
- BLE-4.2
- NFC, MST, GPS
- Glonass

**Display**
- AMOLED - 1.3” Always-ON
  - 360x360 @ 278ppi

**AP/GPU**
- Apps Processor
  - 14nm 2x-Core @ 1GHz
- Capable of 4K @ 60fps

**uBIO**
- BIO Processor
  - Accelerometer
  - Gyro, Barometer
  - HRM, Ambient Light
- uBIO Processor
  - Accelerometer
  - Gyro, Barometer
  - HRM, Ambient Light

**PMIC**
- Power Management
  - PFM/PWM
  - Thin and Tiny

**Battery Management**
- WPC Inductive
- Battery Management
  - WPC Inductive

**Power Management**
- PFM/PWM
- Thin and Tiny

**Power Management**
- PFM/PWM
- Thin and Tiny

**Battery Management**
- WPC Inductive
- Battery Management
  - WPC Inductive
Galaxy S7-Edge Teardown

Galaxy S7-Edge Platform Front-Side

- SK Hynix H9KNNTUMU-BRNMH 4 GB LPDDR4 SDRAM layered over the Qualcomm MSM8996 Snapdragon 820
- Samsung KLUBG41CE 32 GB MLC Universal Flash Storage 2.0
- Avago AFEM-9040 Multiband Multimode Module
- Murata FAJ15 Front End Module
- Qorvo QM78064 high band RF Fusion Module and QM63001A diversity receive module
- Qualcomm WCD9335 Audio Codec
- Maxim MAX77854 PMIC and MAX9850A REV2 audio amplifier

Galaxy S7-Edge Platform Back-Side

- Murata KM5D17074 Wi-Fi module
- NXP 67T05 NFC Controller
- IDT P9221 Wireless Power Receiver (likely an iteration of IDT P9220)
- Qualcomm PM8996 and PM8004 PMICs
- Qualcomm QFE3100 Envelope Tracker
- Qualcomm WTR4905 and WTR3925 RF Transceivers
- Samsung C3 image processor and Samsung S2MC0202 PMIC

* Courtesy of iFixit
Typical Mobile Device System Power

Mobile System Device Ingredients

- OLED PMIC
- SoC PMIC
- UFS PMIC
- Camera PMIC
- Audio Codec
- SPK AMP
- Interface BMS-IC
- MFC IC

Mobile System Power Device Connectivity

- SOC
- SOC PMIC
- Type-C
- mUSB
- Charger Fuel-Gauge
- Self Discharger
- WPT
- UFS PMIC
- UFS/eMMC
- mSSD
- Camera
- Display
- LCD
- OLED
- LCD PMIC
- OLED PMIC

SEC/System LSI
Silicon Technology Trend Setters

1985
- 5.0V
- CMOS
- Gate level power analysis
- RTL power analysis
- Gate level power optimization
- Power gating
- Power intent specs
- High-K gate dielectric
- FinFETs
- Ultra-Low Voltage
- 2.5D & 3D designs
- System-level Power Modeling

1995
- 3.3V

2005
- 2.5V
- 1.8V
- 1.2V

2015
- 0.6V
- 0.35V?

* Courtesy of DAC 2016
### Power Delivery Requirements

Not $\eta_{\text{PEAK}}$, not even $\eta_{\text{MAX}}$, but \textbf{W-I-D-E-S-T $\eta_{\text{HIGH}}(\%)$ Wins!}

**Higher Power Requirement $\rightarrow$ Complex Power Delivery and Management**

<table>
<thead>
<tr>
<th>Component</th>
<th>Power Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Charger</td>
<td>• ISP Core-DVS</td>
</tr>
<tr>
<td>CAM/SNS Power</td>
<td>• Avg. PWR Track</td>
</tr>
<tr>
<td>Modem/RF Power</td>
<td>• ENV. Tracking</td>
</tr>
<tr>
<td>Storage Power</td>
<td>• Dyn. Lane CTRL</td>
</tr>
<tr>
<td>Display Power</td>
<td>• Panel PWR DVS</td>
</tr>
<tr>
<td>GPU Power</td>
<td>• On-Fly On/Off</td>
</tr>
<tr>
<td>CPU Power</td>
<td>• DVFS</td>
</tr>
<tr>
<td></td>
<td>• Power Gating</td>
</tr>
<tr>
<td></td>
<td>• CL-DVFS</td>
</tr>
<tr>
<td></td>
<td>• Power Gating</td>
</tr>
<tr>
<td></td>
<td>• Auto-CLK</td>
</tr>
</tbody>
</table>

---

\[ \eta(\%) \]

\[ \eta_{\text{MIN}} \rightarrow \eta_{\text{PEAK}} \rightarrow \eta_{\text{MAX}} \]

\[ P(\text{W}) \]

\[ P_{\text{MIN}} \rightarrow P_{\text{MAX}} \]

**User Interface**
- ERM
- LRA
- RAM

**USB Interface**
- Adaptive Charging

**SEC/System LSI**
System Power Saving Techniques

Multi-Φ BUCK

Adaptive Volt. Position

APT Technology

Average Power Tracking
: Discretely stepped $V_{\text{SUPPLY}}$

ET Technology

Envelope Tracking
: Cont. Modulated $V_{\text{SUPPLY}}$

Cascaded Sub-Regulation

$V_{\text{BATT}} = 3.7\text{V}$

$V_{0,\text{BUCK}} = 1.2\text{V@1A}$

$V_{O1} = 1.1\text{V}$

$V_{O2} = 1.0\text{V}$

$V_{O3} = 0.95\text{V}$

$V_{O4} = 0.9\text{V}$

$> 50\%$ Increase

Max. $P_{\text{SAV}} = 25\%$

Max. $P_{\text{SAV}} = 35\%$
Typical Mobile SoC Power Sequencing

- **Input Power**
  - 1-S Li-ion **BATT**
  - **V_{BUS}** &/or **V_{SYS}**

- **PMIC Enabler**
  - Discrete On/Off
  - **I\(^2\)C**

- **VR Sequencer**
  - Integrated SEQ
  - By-pass via **I\(^2\)C**

- **PMIC COM-Link**
  - Interrupts via **I\(^2\)C**
**System Power Management Technology**

- **THERM_THROT:** Active Thermal Throttling
  - Skin Temperature Consideration
  - System Thermal Throttling
  - CPU & Device Thermal Throttling

- **SMPL:** Sudden Momentarily Power Loss
  - Dynamic $f_{CLK}$ Throttling to LFM for System Stability

- **$P_{MAX}$:** Maximum Power

- **$P_{LIM}$:** Power Limiting

- **ACPI:** Advanced Configuration & Power Interface
  - G-State: G0 ~ G4 // S-State: S0 ~ S4
  - C-State: C0 ~ C6 // P-State: P0 ~ $P_n$, $P_m$
  - D-State: D0 ~ D4

- **APM:** Android Power Management
Mobile System Power trends increase in Complexity
→ Expect more features/performance with longer battery life

Advances in System Power Delivery
→ New advanced technologies for higher and flatter efficiency

System Power Management
→ System Power Delivery must be controlled
→ Aging ACPI and APM...

Intelligent System Power Management???
Thank you
Backup
## Packaging Technology

<table>
<thead>
<tr>
<th>Package Solution</th>
<th>WB_FBGA</th>
<th>QFN_ELP</th>
<th>FC-FBGA (CUF/MUF mini)</th>
<th>WLP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PKG Cost</strong></td>
<td>★★★</td>
<td>★★★</td>
<td>★</td>
<td>★★★★☆☆</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>★★★★★</td>
<td>★★★★★</td>
<td>★★★★☆☆</td>
<td>★★★★★</td>
</tr>
<tr>
<td><strong>PKG size</strong></td>
<td>★★★★★</td>
<td>★★★☆☆</td>
<td>★★★☆☆</td>
<td>★★★★★</td>
</tr>
<tr>
<td><strong>(Degree of Freedom)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Remark**       | - Popular Packaging Method  
- PKG size limit ; > 3.0x3.0mm²  
(Die-size Independent)  
- Limitation of Array-type Pad configuration. | - Popular Packaging Method  
- Quality issue  
(PKG crack Issue due to CTE Gap (LF/EMC/EPOXY))  
- Limitation of Array-type Pad configuration. | - Popular Packaging Method  
- Cost addition (PCB & Bump) | - PKG size = Chip size  
- Complicated Process  
(WF level EDS/Test Issue (Vertical probing ) Ball pitch & Chip size is estimated.  
Only outsource site. |
Multi-Phase SMPS for Wide Efficiency Curvature

**Conditions:**
- $V_{IN} = 3.8\, \text{V}$, $V_{OUT} = 0.9\, \text{V}$
- $L = 0.47\, \mu\text{H}$, $C_{IN} = 10\, \mu\text{F}$, $C_{OUT} = 66\, \mu\text{F}$

9A, 3-Φ BUCK: $\eta(\%)_{\text{MAX}} = 89\%$

**Bridge Shedding**

**Phase Shedding**

Power-TR Size X Phase

9A, 3-Φ BUCK: $\eta(\%)_{\text{MAX}} = 89\%$
SYS_P_{SAV} Technique: Adaptive Volt Positioning

AVP Explained

- **i_{load}**: Load current
  - **Sleep**: Active
  - **V_{MAX}**: Maximum voltage
  - **V_{MIN}**: Minimum voltage
  - **V_{OUT,BUCK} w/o AVP**: Output voltage without AVP
  - **V_{OUT, BUCK} with AVP**: Output voltage with AVP
  - **0.5x(V_{MAX} - V_{MIN})**: Low V_{OUT}, High I_{OUT}

AVP Results

- **P \approx 3W**
- **P \approx 2.85W**
- **\downarrow 5%**

- **0.985V**: Light Load
- **0.950V**: Heavy Load

- **I_{load}**: Load current

w/o AVP

with AVP
SYS_P\textsubscript{SAV} Technique: Cascaded Sub-Regulation

**Low Dropout Regulator**
- \( \eta = 27.0\% \)
- \( V_{\text{BATT}} = 3.7V \)
- \( V_{\text{OUT}} = 1.0V \)
- \( I_{\text{OUT}} = 1A \)

**Cascaded Sub-REG BUCK+LDO**
- \( \eta = 0.67 \sim 82\% \)
- \( V_{\text{BATT}} = 3.7V \)
- \( V_{\text{OUT}} \) increases by \( >50\% \)

**BUCK**
- \( \eta = 90\% \)
- \( V_{\text{BATT}} = 3.7V \)
- \( V_{\text{OUT}} = 1V \)
- \( I_{\text{OUT}} = 1A \)
SYS_\text{P}_{\text{SAV}} \text{ Technique: APT & ET for RF}

APT & ET Introduction

- PA’s power consumption is at the peak during smart phone wireless transmission.
- Average Power Tracking and/or Envelope Tracking techniques are used to increase energy efficiency.

Average Power Tracking

- PA’s supply voltage is discretely stepped in order to save power

Envelope Tracking

- PA’s supply voltage is continuously modulated to match envelope to save power

APT Technology

- **Average Power Tracking**: Discretely stepped \( V_{\text{SUPPLY}} \)
- **Envelope Tracking**: Continuously modulated \( V_{\text{SUPPLY}} \)

Max. \( P_{\text{SAV}} = 25\% \)

Max. \( P_{\text{SAV}} = 35\% \)

APT-PMIC Block Diag.