Hierarchical Power Distribution and Power Management Scheme for a Single Chip Mobile Processor

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Outline

- A single chip implementation for cellular
- Hierarchical power domain
- Power line implementation
- Low noise power switch controller
- Partial power off & operation scene
  - Scenes of mobile phone usage & leakage current
- EDA Supports
- Summary
3G Multi-Media Cellular Phone System

- HPA
- RFIC

Baseband Processor
- GSM
- W-CDMA

Application Processor
- Multi-Media Accelerator

Single Chip
- BB
- AP-SYS
- AP-RT

GSM
W-CDMA
Chip Overview

<table>
<thead>
<tr>
<th>Die size</th>
<th>11.15mm x 11.15mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>90nm LP</td>
</tr>
<tr>
<td></td>
<td>8M(7Cu+1Al)</td>
</tr>
<tr>
<td></td>
<td>CMOS dual-Vth</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>1.2V(internal),</td>
</tr>
<tr>
<td></td>
<td>1.8/2.5/3.3V(I/O)</td>
</tr>
<tr>
<td># of TRs, gate,</td>
<td>181M TRs,</td>
</tr>
<tr>
<td>memory</td>
<td>13.5M Gate</td>
</tr>
<tr>
<td></td>
<td>20.2 Mbit mem</td>
</tr>
</tbody>
</table>
One Chip Integration

- Performance: UP
  - Wide data transfer throughput
- Chip cost: DOWN
- Mounting area: DOWN
  - Share common peripherals
- Dynamic power consumption: DOWN
  - Low-load for inter-domain signals
- Static power consumption: UP?
  - Leakage current of unused domain
# Reduction of Leakage Current

<table>
<thead>
<tr>
<th>ISSCC98</th>
<th>ISSCC02</th>
<th>ISSCC04</th>
<th>ISSCC06</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="ISSCC98 Diagram" /></td>
<td><img src="image" alt="ISSCC02 Diagram" /></td>
<td><img src="image" alt="ISSCC04 Diagram" /></td>
<td><img src="image" alt="ISSCC06 Diagram" /></td>
</tr>
<tr>
<td>0.25μm</td>
<td>0.18μm</td>
<td>0.13μm</td>
<td>0.09μm</td>
</tr>
<tr>
<td>CPU</td>
<td>CPU + SRAM</td>
<td>CPU + SRAM + IP’s</td>
<td>3 CPU + Systems</td>
</tr>
<tr>
<td>@ Clock stop</td>
<td>@ Power-off</td>
<td>@ data retention</td>
<td>@ active</td>
</tr>
<tr>
<td>Back-bias</td>
<td>U-standby (Logic off)</td>
<td>R-standby (Data retention)</td>
<td>Hierarchical Power domain</td>
</tr>
</tbody>
</table>
Power Domains

- 20 power domains for partial power-off
- CPD (Common power domain) for repeater etc.
  - B* domains for BB, A* domains for AP

Chip Floorplan

- W-CDMA
- AP-Misc
- AP-RT
- Camera
- 3D G
- MPEG
- AP-SYS
- CPU
- Media
- RAM
- Sound

Power Domains

- BW2
- BA2
- A2
- C5
- CPD
- A1A
- A1R
- A4U1
- BG1

20 power domains for partial power-off
CPD (Common power domain) for repeater etc.
- B* domains for BB, A* domains for AP
Hierarchical Structure of Power Domain

- Minimize \( \mu \) I/O cells for avoiding floating signal
- Taking account for functional dependency of activation
- One-by-one power on to avoid rush current

Application part

- C5 (System controller, PAD controller)
- CPD (Repeaters, CK buffers, BKUP FFs)
- LCDC
- VRAM
- Reg
- PLL for Application part
- Mobile Video Interface
- Mem control. Serial I/Os
- SYS-CPU
- RT-CPU

Baseband part

- Mem Control. RAM, DMA
- PLL for Baseband part
- BB-CPU
- WCDMA
- GSM
- DFT
- WCDMA
- GSM
Common power-domain implementation

- Global Clock Buffer
- Repeater
- Backup latches

CPD: Common Power Domain
Power switch and power line implementation

Power line implementation

- VSSM_P Dw
  - local
  - VSSM_P De
  - VSSM_CP D
  - global
  - VDD
  - VSS

Power switch (PSW) implementation

- PSW (thick Tox MOS)
- (thin Tox MOS)
- VDD
- VSS
- VSSM_P Dw
- VSSM_P De

1/4000 leakage @ 1MG

Power switch and power line implementation

PSW for CPD
Power switch controllers

PSW for PD x
CPD

Power switch
Power switch and power line implementation
**Power switch controller**

**Improvement:**
- Timer circuit (VLSI ’02)
- Dynamic comparator to accurately detect 90% of VCC (this work)

**Effect:**
- Easy process migration
- Small area overhead (~1/2)

**Components:**
- Dynamic comparator
- Control Logic & FSM
- RSFF
- VCC
- Vref
- CLK
- CTL

**Features:**
- Low slew-rate driving
- Power switches
Simulated waveforms

Worst rush-current conditions

- 3.9-µs recovery time and 53.8-mA rush current at 1 MG under worst rush-current conditions
Measured rush current

Power switch ON

Worst case with TEG, REQ, ACK

1 V/div 2 µs/div
VDD-VSS

2.6 mV/div 2 µs/div
Voltage drop

Measurement point

This domain is powered ON

Negligible rush current

VDD-VSS

1 V/div 5 µs/div

3.6 mV/div 5 µs/div
### Implementation Results

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Power domains</td>
<td>20 domains</td>
</tr>
<tr>
<td># of Islands for CPD</td>
<td>19 islands</td>
</tr>
<tr>
<td>(Repeaters, CK buffers, BKUP FFs)</td>
<td></td>
</tr>
<tr>
<td># of Repeaters in CPD domain</td>
<td>3100 cells</td>
</tr>
<tr>
<td># of Clock buffers in CPD domain</td>
<td>1600 cells</td>
</tr>
<tr>
<td># of Backup FFs in CPD domain</td>
<td>2300 cells</td>
</tr>
<tr>
<td># of μIOs (isolation cell)</td>
<td>20000 cells</td>
</tr>
<tr>
<td>Total area of power switch</td>
<td>4.2 mm²</td>
</tr>
<tr>
<td>Power switch area ratio in the chip</td>
<td>3.4 %</td>
</tr>
<tr>
<td>Power-off -&gt; power-on time (one-by-one on)</td>
<td>&lt;100μSec</td>
</tr>
</tbody>
</table>
Leakage Current in Usage Scenes (1)

Video telephony

<table>
<thead>
<tr>
<th>Baseband part</th>
<th>Control</th>
<th>On</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-CDMA</td>
<td></td>
<td>On</td>
</tr>
<tr>
<td>GSM</td>
<td></td>
<td>On / Off</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application part</th>
<th>System-domain</th>
<th>On</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realtime-domain</td>
<td></td>
<td>On</td>
</tr>
</tbody>
</table>

| Measured Leakage Current (@ Room Temp, 1.2V) | 849 μA |

Power on

Power off
## Leakage Current in Usage Scenes (2)

### Telephony (W-CDMA)

<table>
<thead>
<tr>
<th>Component</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseband part</strong></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>ON</td>
</tr>
<tr>
<td>W-CDMA</td>
<td>ON</td>
</tr>
<tr>
<td><strong>Application part</strong></td>
<td></td>
</tr>
<tr>
<td>System-domain</td>
<td>ON</td>
</tr>
<tr>
<td>Realtime-domain</td>
<td>OFF</td>
</tr>
<tr>
<td><strong>Measured Leakage Current</strong></td>
<td></td>
</tr>
<tr>
<td>(@ Room Temp, 1.2V)</td>
<td>407 μA</td>
</tr>
</tbody>
</table>

![Diagram with power on/off indicators]

- Power on
- Power off
Leakage Current in Usage Scenes (3)

Waiting for Calling

<table>
<thead>
<tr>
<th>Baseband part</th>
<th>Control</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-CDMA</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>GSM</td>
<td>OFF</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application part</th>
<th>System-domain</th>
<th>OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realtime-domain</td>
<td></td>
<td>OFF</td>
</tr>
</tbody>
</table>

| Measured Leakage Current (@ Room Temp, 1.2V) | 299 μA |

Power on

Power off
Leakage Current in Usage Scenes (4)

Power off (I/O fixed)

<table>
<thead>
<tr>
<th>Baseband part</th>
<th>Control</th>
<th>OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-CDMA</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>GSM</td>
<td>OFF</td>
<td></td>
</tr>
<tr>
<td>Application part</td>
<td>System-domain</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>Realtime-domain</td>
<td>OFF</td>
</tr>
<tr>
<td>Measured Leakage Current (@ Room Temp, 1.2V)</td>
<td>7 μA</td>
<td></td>
</tr>
</tbody>
</table>
EDA supports

- Power-off gate-level simulation
  - Set X to all FFs in power-off domain
- Transistor level leakage path checker
  - Check leakage path through well connect etc.
- μIO (isolation cell) insertion tool
- Inter-power-domain isolation checker
- DFT insertion considering power domains
- IR drop calculation considering power switch
Summary

- A single chip for 3G cellular phone integrates 3 CPUs and many IPs.
- 20 power domains allows the partial power off to reduce the leakage in active-mode.
- Partial power off regarding the cellular phone scene.
  - Waiting for calling = 299μA
  - Power-off (I/O fixed) = 7μA
- New power-switch control enabled 3.9-μs recovery time with 53.8-mA rush current at 1 MG.