1208 LPD

Low-Power Design for 16-bit Devices
Objectives

When you finish this class you will know:

- What low-power features are available on 16-bit PIC® MCUs
- Design best practices for low-power applications
- Power Consumption of PIC24F MCUs
Agenda

- Power-Saving Feature Overview
- Peripheral Power Consumption and Power Reduction Tips
- Other Power Reduction Tips
- Power Reduction Demo
- Case Study – Benchmark Data
- Summary
Power-Saving Features
Power-Saving Features

- Sleep, Idle, and Doze Modes
- Clock Switching
- Peripheral Module Disable (PMD) Bits
- Selectable Secondary Oscillator
  - Higher Gain or Lower Power
- Deep Sleep Mode

New
Power-Saving Modes

- **Normal Mode**: 4 mA @ 4 MIPS
- **Sleep Mode**: 3.5 μA
- **Idle Mode**: 0.8 mA @ 4 MIPS
- **Doze Mode (1:4 ratio)**: 2 mA @ 1 MIPS

Average Current 0.25 mA
## Power-Saving Modes

<table>
<thead>
<tr>
<th></th>
<th>Deep Sleep</th>
<th>Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td>&lt;1 uA-1 uA</td>
<td>3.5 uA</td>
</tr>
<tr>
<td><strong>Peripherals</strong></td>
<td>INT1, DSWDT &amp; RTCC</td>
<td>RTCC, INTx, WDT, ADC, Timer 1 and Comparators</td>
</tr>
<tr>
<td><strong>RAM Retention</strong></td>
<td>All Reset</td>
<td>All Retained</td>
</tr>
<tr>
<td><strong>SFR Retention</strong></td>
<td>I/O States, RTCC and DSSEMAx Only</td>
<td>All Retained</td>
</tr>
<tr>
<td><strong>Wake-up</strong></td>
<td>POR, MCLR, INT1, DSWDT, and RTCC</td>
<td>Many Options</td>
</tr>
</tbody>
</table>
Peripheral Power Consumption and Power Reduction Tips
Peripheral Power Consumption

- ADC and Comparators
- Serial Communication
- Flash Modification
- RTCC and Timers
Analog Peripherals
ADC Power Consumption

0.65 mA to 0.90 mA

AVDD and AVSS require 0.5 mA higher current

Discharged after conversion completion

16 word result buffer allows for longer sleep periods

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Comparator Power Consumption

- **20 uA Base Current**
  - Input level variation adds ~20 uA
  - High frequency adds ~20 uA-100 uA
  - Enabling output adds 0 uA to 0.5 mA

- **Comparator Voltage Reference**
  - 65 uA Typical
Analog Peripheral Tips

- Choose external references ($V_{REF+/-}$ and $C_{xIN+/-}$) over internal references ($AV_{DD}/AV_{SS}$ and $CV_{REF}$)

- Fast sample and disable ADC
  - 50% less ADC power (0.7 mA typ)

- Utilize 16 word deep buffer for Sleep mode conversions
Serial Communication Peripherals
Serial Communications
Power Consumption

- Enabling module adds no current
- Faster speeds more current

- UART
  - Lowest power serial
  - Baud has minimal effect

<table>
<thead>
<tr>
<th>Constant TX/RX</th>
<th>4 MIPS</th>
<th>200 μA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 MIPS</td>
<td>300 μA</td>
</tr>
</tbody>
</table>
I²C™ Power Consumption

- **Module current**
  - 50-200 uA – based on speed

- **System current**
  - Dependent on pull-up value and data sent

\[
3.3 \div 4.7 \, k\Omega = 0.7 \, mA \\
0.7 \, mA \times 2 \, \text{lines} = 1.4 \, mA \\
\text{Typical Data} = 50\% \, \text{active} \\
1.4 \, mA \times 50\% = 0.7 \, mA
\]

<table>
<thead>
<tr>
<th>1 MHz I²C, 4.7k pull-ups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
</tr>
<tr>
<td>System</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
SPI Power Consumption

- Highest power serial protocol
- Slave is lower power
SPI Power Consumption

- Power vs. Speed is non linear – utilize to save average power

Not Linear: 2x speed is only 20% more current!

2.65 mA to run 8 MHz SPI
Serial Communications
Peripheral Tips

- Fast infrequent transmissions instead of slow constant transmissions
- \( I^2C^{\text{TM}} \)
  - Use larger resistors for pull ups

Transmit 1’s instead of 0’s!
Serial Communications
Peripheral Tips

- SPI
  - Master uses more current than slave
  - Don’t constantly transmit at high speeds
  - Low-impedance I/O
    - 3 high-speed lines!
Flash Operations
Flash Operations
Power Consumption

- Flash reads are high power
- Flash changes suspend CPU and enable FRC

![Graph showing power consumption for Flash Operations]

- Expensive Flash reading
- Less than normal operating current
RTCC Power Consumption

- SOSC current determines power requirements

<table>
<thead>
<tr>
<th>Sleep w/o RTCC</th>
<th>4 uA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep w/ RTCC</td>
<td>7.5 uA</td>
</tr>
</tbody>
</table>

- Negligible for dynamic power
Timer Power Consumption

<table>
<thead>
<tr>
<th>Source Speed</th>
<th>Timer Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 kHz</td>
<td>1 uA</td>
</tr>
<tr>
<td>16 MHz</td>
<td>150 uA</td>
</tr>
</tbody>
</table>

Internal clock uses less current than external.

Depends on clock speed NOT on prescaler setting.
Other Power Reduction Tips
Tips and Tricks

- Hardware tips
  - Voltage regulators
  - Circuit design and I/O best practices

- Firmware tips
  - Clock speed best practices
Hardware Tips
Internal Regulator

- **Suspend mode**
  - Regulator removes power from Flash to decrease $I_{PD}$
  - VREGS (RCON<8>)

<table>
<thead>
<tr>
<th>3.3V &amp; 25°C</th>
<th>$I_{PD}$</th>
<th>Wake-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disabled</td>
<td>45 µA</td>
<td>10 µS</td>
</tr>
<tr>
<td>Enabled</td>
<td>5 µA</td>
<td>190 µS / 10 µS</td>
</tr>
</tbody>
</table>
**Hardware Tips**

**Internal Regulator**

- **Tracking mode**
  - Regulator output follows VDD input when below LVD levels

![Graph showing tracking mode](image)

- Brown-out Reset
- Tracking mode entered
- Without Tracking mode
**Hardware Tips**

**Regulator Disabled**

- **Maximum Power Savings with 3V Coin Cell**

<table>
<thead>
<tr>
<th>$V_{DD}$</th>
<th>$V_{DDCORE}$</th>
<th>$I_{PD}$</th>
<th>$V_{REG}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3V</td>
<td>2.5V</td>
<td>3.5 uA</td>
<td>On</td>
</tr>
<tr>
<td>3.3V</td>
<td>2.5V</td>
<td>0.3 uA</td>
<td>Off</td>
</tr>
<tr>
<td>3.3V</td>
<td>2.0V</td>
<td>0.2 uA</td>
<td>Off</td>
</tr>
</tbody>
</table>

**Diagram:**
- VDD
- GPIO
- DISVREG
- PIC24FJ64GA004
- ~2.3V
- $V_{DDCORE}$
- VSS
- 3.0V Coin Cell

**Graph:**
- Voltage vs. Time
- Voltage drops below 2.3V when 3.0V Coin Cell is off.
Hardware Tips
Regulator Disabled

- Maximum Power Savings with AA batteries

<table>
<thead>
<tr>
<th>V_DD</th>
<th>V_DDCCORE</th>
<th>IDD</th>
<th>VREG</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3V</td>
<td>2.5V</td>
<td>3.6 mA</td>
<td>On</td>
</tr>
<tr>
<td>3.3V</td>
<td>2.0V</td>
<td>2.2 mA</td>
<td>Off</td>
</tr>
</tbody>
</table>

![Diagram]

- Alkaline Batteries
- LDO
- 2.0 V
- V_DD
- GPIO
- DISVREG
- PIC24FJ64GA004
- V_DDCCORE
- VSS
## Hardware Tips – I/O

<table>
<thead>
<tr>
<th>Floating Pin Table of Pain</th>
<th>Bad Case</th>
<th>Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Floating Pin</td>
<td>35 uA</td>
<td>0.5 mA</td>
</tr>
<tr>
<td>2 Floating Pins</td>
<td>65 uA</td>
<td>1 mA</td>
</tr>
<tr>
<td>10 Floating Pins</td>
<td>305 uA</td>
<td>5 mA</td>
</tr>
</tbody>
</table>

- No floating input pins
- Drive unused GPIO as outputs
- Pull up or pull down
- Keep impedances low
Firmware Tips – General

- Turn off unnecessary modules before entering Sleep
  - Important for modules which may remain active in sleep mode
- Utilize Idle and Doze mode any time operation is non-critical
  - Idle Mode – 80% less power
  - Doze Mode – 35-70% less power
Firmware Tips – General

- RAM and SFR accesses require more power than NOPs
- Insert NOPs into non-critical sections to reduce average power

High Power: 19.1 mA
while(!_T1IF) i++;

Low Power: 16.4 mA
while(!_T1IF){
    i++;
    Nop();
    Nop();
    Nop();
    Nop();
    Nop();
}
Firmware Tips – Clocks

- **Clock Switching**
  - Use 32 kHz LPRC, SOSC, or FRCDIV for non-critical sections

- **Running 8 MHz FRC** Uses 350 uA to 450 uA

- **Timers**
  - Use internal timer if possible – external requires more current
Firmware Tips – Clocks

- Utilize PMD at High Speed

[Diagram showing PMD Bits connected to UART, ADC, SPI, and PMP]
Firmware Tips – Clocks

- Run faster
- 32 MHz + Sleep vs. 8 MHz constant
- Higher speeds are more efficient

![Graph showing Idd at 3.3V, 25°C with two lines representing different frequencies.
- High Speed: 0.3 mA/MHz
- Low Speed: 0.5 mA/MHz]
### Peripheral Power Summary

<table>
<thead>
<tr>
<th>Dynamic Power</th>
<th>IDD Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU (8 MHz)</td>
<td>3.8 mA</td>
</tr>
<tr>
<td>ADC</td>
<td>1.0 mA</td>
</tr>
<tr>
<td>UART</td>
<td>0.2 mA</td>
</tr>
<tr>
<td>SPI (4 MHz)</td>
<td>0.7 mA</td>
</tr>
<tr>
<td>I²C™ (System)</td>
<td>1.0 mA</td>
</tr>
<tr>
<td>Flash Read</td>
<td>2.1 mA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Static Power</th>
<th>IPD Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>3.5 uA</td>
</tr>
<tr>
<td>ADC</td>
<td>785.0 uA</td>
</tr>
<tr>
<td>Comparator</td>
<td>20.0 uA</td>
</tr>
<tr>
<td>RTCC (+SOSC)</td>
<td>4.0 uA</td>
</tr>
<tr>
<td>Timer (31 kHz)</td>
<td>1.0 uA</td>
</tr>
<tr>
<td>WDT</td>
<td>3.0 uA</td>
</tr>
</tbody>
</table>

*Watch out for these!*
Demo of Tips Described
Case Study
Benchmark Data
Summary

Today We Covered:

- 16-bit Power-Saving Features
- Peripheral Power Consumption Data
- Power Reduction Techniques
- Case Study – Power Comparison and Benchmark Data
Development Tools

- Explorer 16 with PIC24FJ256GA110 PIM

- Graphics PICtail™ Plus Daughter Board
Additional Resources

- Data Sheets
  - PIC24FJ64GA004 Data Sheet (DS39881)
  - PIC24FJ256GA110 Data Sheet (DS39905)

- MASTERS/RTC Classes
  - 1206 GSS (MASTERS)
  - 203 PRC and 204 ADV (RTCs)
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