INTERACTIVE
DEVICE DESIGN

POWER
CONSIDERATIONS

OCT 29, 2012
Powering your device

VS

Image source: adafruit
AC ADAPTERS
Cheap power adapters: unregulated
full wave rectified + capacitor
Pros and Cons

• Cheap, simple

• Imprecise:
  – AC adapter rated 9V 200mA will deliver at least 9V when drawing up to 200mA, but could be up to 2x!
  – Voltage drops as load increases

• **Must** use a voltage regulator to protect your microcontroller!
7805 / 7803: Linear Regulators

- Maintain steady output voltage
- Act as variable resistors
- Inefficient: (current*dropped voltage) dissipated as heat
- $V_{DROP} = 2V$ for standard models
- Use low-dropout versions to get 3.3V from 5V supply!

Image source: wikipedia
Switching Power Supplies

Example: 5V 1A iPhone charger

http://www.arcfn.com/2012/05/apple-iphone-charger-teardown-quality.html
Switching Power Supplies: Intuition

- Rectify AC to high-voltage DC
- DC is switched at high speed (10s of kHz) by controller
- Chopped (square) high-voltage DC is fed into flyback transformer to get low-voltage AC, rectified and filtered
- Output can be used directly to power your microcontroller
- 5x-10x more expensive than unregulated
BATTERIES
Important Battery Concepts

• Voltage
• Power capacity
• Power capability
Voltage

• Determined by chemistry:
  – NiMh: 1.2V per cell
  – Alkaline: 1.5V per cell
  – Lead acid: 2V per cell
  – Lithium: 3V per cell
  – Li-Ion: 3.7V per cell

• **Not** constant over discharge!
Discharge Curves

Fig. 1: Discharge curves for different technologies. Note that NiCd quickly plateaus to 1.2v and has an abrupt death, while alkaline has a long, steady discharge.

http://www.geotech1.com/pages/misc/info/batteries.pdf
Power Capacity

- How much energy is stored in the battery. Based on power density of battery type and physical size of battery
- Expressed in Watt-hours (Wh). Since $W=VA$ and $V$ “constant”, usually given in Ampere-hours (Ah).
# Power Capacity

<table>
<thead>
<tr>
<th>Type</th>
<th>Typical Capacity (mAh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA Alkaline (disposable)</td>
<td>1800-2600</td>
</tr>
<tr>
<td>AAA Alkaline</td>
<td>800-1200</td>
</tr>
<tr>
<td>AA Rechargeable (NiMh)</td>
<td>800-2700</td>
</tr>
<tr>
<td>CR2032 Lithium button cell</td>
<td>190-225</td>
</tr>
<tr>
<td>9V Alkaline (disposable)</td>
<td>565</td>
</tr>
<tr>
<td>Lithium Ion / Lithium Polymer</td>
<td>Depends on size; 1000-2000</td>
</tr>
</tbody>
</table>
Power Capability

• How much current you can draw in practice.
• C-rate: rate of discharge relative to total capacity.
• 1C: current discharges entire battery in one hour
  – Ex: 1Ah 1C battery has discharge current of 1A
  – 200mAh 0.25C battery: current of 50mA
# Power Capability

<table>
<thead>
<tr>
<th>Type</th>
<th>Typical Capability for listed capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA Alkaline (disposable)</td>
<td>0.1C</td>
</tr>
<tr>
<td>AAA Alkaline</td>
<td>0.1C</td>
</tr>
<tr>
<td>AA Rechargeable (NiMh)</td>
<td>0.2C</td>
</tr>
<tr>
<td>CR2032 Lithium button cell</td>
<td>0.005C</td>
</tr>
<tr>
<td>9V Alkaline (disposable)</td>
<td>0.2C</td>
</tr>
<tr>
<td>Lithium-Ion</td>
<td>1-2C</td>
</tr>
</tbody>
</table>
Discharge: 3.0V cutoff at room temperature.
Li-Ion/ LiPo Batteries

Lithium Polymer (flat, soft)

Lithium Ion (round, assembled into packs)
Li-Ion / LiPo Batteries Advantages

• Rechargeable
• High energy capacity
• High energy capability (>1C)
• 3.7V nominal voltage per cell
  (can drive 3.3V with LDO regulator)
Li-Ion / LiPo Cautions

- Do not **charge** them above their maximum safe voltage (say 4.2V)
- Do not **discharge** them below their minimum safe voltage (say 3.0V)
- Do not **draw more current** than the battery can provide (say about 1-2C)
- Do not **charge them with more current** than the battery can take (say about 1C)
- Do not charge the batteries above or below certain **temperatures** (about 0-50 degrees C)

Source: adafruit
Incorrect Charging Procedure

http://www.youtube.com/watch?v=YCWdnjLqVWw
http://www.youtube.com/watch?v=ixlOEPnsgbl
Correct:
LiPo charger
Protection circuit

Includes charge/discharge voltage, current protections

Unprotected, “raw”

Avoid These!

Image source: adafruit
RC-type Batteries

Avoid These!
Chaining Batteries

1300mAh x 2 = 2600mAh?

7.2V? 1300mAh?
WHAT CAPACITY DO YOU NEED?
Power Budget

- Atmega 328: 5-10 mA active mode
- Typical TI LED: 20mA
- Xbee radio: 45-50mA in RX/TX
- ADXL335 MEMS
  Accelerometer: 350uA
- Servo Motor: 200mA-1A
- Beware of on-board linear voltage regulators:
  Power wasted = (\(V_{in} - V_{out}\)) * \(I_{load}\)
Towards Low-Power Designs

- $1W = 1VA$ implies two main strategies
ATmega328 Sleep Modes

- **Idle**: only some components powered down
- **Power Save**: Internal clock still going at 32 KHz
- **Power Down**: everything off
Table 9-1. Active Clock Domains and Wake-up Sources in the Different Sleep Modes.

<table>
<thead>
<tr>
<th>Sleep Mode</th>
<th>Active Clock Domains</th>
<th>Oscillators</th>
<th>Wake-up Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>clk_cpu</td>
<td>clk_FLASH</td>
<td>clk_IO</td>
</tr>
<tr>
<td>Idle</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>ADC Noise Reduction</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Power-down</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Power-save</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Standby(1)</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Extended Standby</td>
<td>X (2)</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Notes: 1. Only recommended with external crystal or resonator selected as clock source.  
2. If Timer/Counter2 is running in asynchronous mode.  
3. For INT1 and INT0, only level interrupt.
\( T_A = -40^\circ C \) to \( 85^\circ C, \ V_{CC} = 1.8V \) to \( 5.5V \) (unless otherwise noted)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Condition</th>
<th>Min.</th>
<th>Typ.(^{(2)})</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(1)})</td>
<td>Active 1 MHz, ( V_{CC} = 2V )</td>
<td>0.2</td>
<td>0.5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active 4 MHz, ( V_{CC} = 3V )</td>
<td>1.2</td>
<td>2.5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active 8 MHz, ( V_{CC} = 5V )</td>
<td>4.0</td>
<td>9</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Idle 1 MHz, ( V_{CC} = 2V )</td>
<td>0.03</td>
<td>0.15</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Idle 4 MHz, ( V_{CC} = 3V )</td>
<td>0.21</td>
<td>0.7</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Idle 8 MHz, ( V_{CC} = 5V )</td>
<td>0.9</td>
<td>2.7</td>
<td></td>
<td>mA</td>
</tr>
</tbody>
</table>

|         | Power-save mode\(^{(3)}\) | 32 kHz TOSC enabled, \( V_{CC} = 1.8V \) | 0.75 |                  |      | \( \mu A \) |
|         |                           | 32 kHz TOSC enabled, \( V_{CC} = 3V \) | 0.9  |                  |      | \( \mu A \) |

|         | Power-down mode\(^{(3)}\) | WDT enabled, \( V_{CC} = 3V \) | 3.9  | 8               |      | \( \mu A \) |
|         |                           | WDT disabled, \( V_{CC} = 3V \)  | 0.1  | 2               |      | \( \mu A \) |

Notes:
1. Values with “Minimizing Power Consumption” enabled (0xFF).
2. Typical values at 25°C. Maximum values are characterized values and not test limits in production.
3. The current consumption values include input leakage current.
Powering down microcontroller is not enough

• Also need to switch off external components (sensors, actuators, radios) – need to look at datasheet
ENERGY HARVESTING