Battery Charging and Chemistry Detection with the MSP430

Neal Brenner
MSP430 FAE North America
Texas Instruments
Agenda

- Battery Charging Basics
- Li-Ion Charging
- NiMH Charging
- Chemistry Detection
- Hardware and Software Overview
- Demo
## Battery Chemistries

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Alkaline</th>
<th>Ni-Cad</th>
<th>NiMH</th>
<th>Li-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rechargeable</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Memory Effect</td>
<td>N/A</td>
<td>Large</td>
<td>Small</td>
<td>None</td>
</tr>
<tr>
<td>Self Discharge</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Current Output</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capacity</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

- Li-Ion is potentially dangerous to charge
- Ni-Cad is very environmentally unfriendly
Battery Charging Basics

• Battery Capacity is expressed in mAh
• Charge rate is expressed in terms of C
• \( C = \text{Battery Capacity} / 1 \text{ hour} \)
• Example: 2500mAh battery
  - \( C = 2.5A \)
  - \( 2C = 5A \)
  - \( C/2 = 1.25A \)
  - \( C/10 = 250mA \)
  - Etc.

• A battery charged at 1C should charge in ~1 hour, at C/2 in ~2 hours
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Li-Ion Charging Stages

• Pre-Charge (Conditioning)
  ▪ If battery voltage < 2.5V
  ▪ Constant current of C/10

• Fast Charge
  ▪ Constant current of 1C
  ▪ While battery voltage in between 2.5V and 4.1V

• Constant Voltage Charge
  ▪ Constant voltage at 4.1V

• Termination
  ▪ When current drops below C/10
Li-Ion Charging

Pre-Charge  Fast Charge  Constant Voltage

4.1V  ~C  Battery Voltage

2.5V  ~C  Charge Current

Vstart  ~C/10  Termination

Time

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NiMH Charging Stages

• Pre-Charge (Conditioning)
  ▪ If battery voltage < 0.9V
  ▪ Constant Current of C/10

• Charge
  ▪ Constant current of C/2 - 1C
  ▪ When battery voltage > 0.9V

• Termination
  ▪ 3 different methods

• Trickle Charge
  ▪ After termination constant current of C/20 to maintain charge
NiMH Charging

- Conditioning
  - ~C/2 - C
  - ~C/8

- Trickle
  - ~1.2 - 1.4 V

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NiMH Charge Termination

• 3 Methods
  - $-\Delta V/\Delta t$ (primary)
  - $\Delta T/\Delta t$ (secondary)
  - Timer (secondary)

• Use all 3 for robust charge termination

• $\Delta T/\Delta t$
  - Look for sharp increase in battery temperature over ambient or absolute safety temperature

• Timer
  - Set timer for appropriate charge time + 10% to 20% (to account for inefficiencies)
  - Example: if charging at C/2, set timer for 2 hours + 12 to 24 minutes
-\( \Delta V/\Delta t \) Termination

- Look for battery voltage dip
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About Chemistries Detection

• Different battery chemistries have different internal impedances
• These impedances change over temperature, charge state, and life of the battery
• Goal: only charge the battery if it is definitely a NiMH (or NiCad)
• Never attempt to charge different chemistries (Alkaline, Lithium, etc.)
• NiMH has lowest impedance of all AA battery chemistries

• Impedance = $R_{\text{Bat}} = \frac{V_{\text{Bat(Closed)}} - V_{\text{Bat(Open)}}}{I_{\text{Bat(Closed)}}}$
Open Loop Voltage

- $I_{\text{Bat}} = 0\, \text{mA}$
- $V_{\text{sense}} = 0\, \text{V}$
- $V_{\text{Bat}} = V_{\text{In}}$
Closed Loop Voltage

- $I_{\text{Bat}} < 150\text{mA}$

- $V_{\text{sense}} = G \cdot I_{\text{Bat}} \cdot R_{\text{Sense}}$

- $V_{\text{Bat}} = V_{\text{In}} - (I_{\text{Bat}} \cdot R_{\text{Sense}})$
Impedance Calculation

- \( V_{\text{Bat(Closed)}} = V_{\text{In}} - \left( \frac{V_{\text{sense}}}{G} \right) \)

- \( I_{\text{Bat(Closed)}} = \frac{V_{\text{sense}}}{(G \cdot R_{\text{Sense}})} \)

- \( R_{\text{Bat}} = \frac{V_{\text{Bat(Closed)}} - V_{\text{Bat(Open)}}}{I_{\text{Bat(Closed)}}} \)
How to Identify a NiMH AA Battery

• We use the battery’s impedance calculation along with its open circuit voltage (estimate of its charge state) to determine whether it is a NiMH battery.

• This method will sometimes fail to identify very old NiMH batteries correctly:
  ▪ Impedance increases over the life of a battery.

• Conditioning charge of 150mA for some time often allows NiMH to recover to low impedance.

• Example Impedance cutoffs for AA batteries

<table>
<thead>
<tr>
<th>Voltage</th>
<th>1.5V</th>
<th>1.2V</th>
<th>0.9V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutoff Impedance</td>
<td>100mOhm</td>
<td>150mOhm</td>
<td>200mOhm</td>
</tr>
</tbody>
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Battery Charge Circuitry

[Diagram showing a battery charge circuit with labeled components: 5V-6V, PWM, Op Amp, ADC, and a battery.]
Software Overview

Main Program
- Initialize Clocks, ADC, Op Amps, Pins, Variables, and TimerB
  - Test Chemistry(Battery 1)
  - Test Chemistry(Battery 2)
  - Charge()

Test Chemistry
- Measure open circuit voltage
- Apply 150mA
- Measure closed circuit voltage and current
- Calculate impedance, determine chemistry
- Battery is NiMH?
  - Yes: Set battery to charge
  - No: Set battery to no charge
  - Return

Charge
- Determine battery charge state
- Start and regulate appropriate charge current
- Test termination
- Update LEDs, send status
  - No: Set battery to no charge
  - Yes: Set battery to charge
  - Return
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Demo

• Impedance Demo
• NiMH Charging Demo
Summary

• Li-ion and NiMH batteries can be charged using the analog and digital control capabilities of the MSP430
• Non-Rechargeable batteries can be detected by measuring their open circuit voltage and impedance
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