Battery Charging Technology

May 2015
Speaker: John Hsiao
Agenda

➢ Li-ion battery cell Characteristics and Charging algorithm
➢ Linear and Switching Charger
➢ Dynamic Power Path Management
➢ Turbo boost and NVDC charger analysis
➢ Fast charging / USB Type C/PD
➢ Wireless Charging
Li-ion battery cell
Characteristics and Charging algorithm
Rechargeable Battery Options

- **Lead Acid**
  - ↑ 100 years of fine service!
  - ↓ Heavy, low energy density, toxic materials

- **NiCd**
  - ↑ High cycle count, low cost
  - ↓ Toxic heavy metal, low energy density

- **NiMH**
  - ↑ Improvement in capacity over NiCd
  - ↓ High self-discharge

- **Lithium Ion / Polymer**
  - ↑ High Energy density, low self-discharge
  - ↓ Cost, external electronics required for battery management
18650 Li-Ion Cell Capacity Development Trend

• 18650: Cylindrical, 65mm length, 18mm diameter
• 8% yearly capacity increase over last 15 years
• Capacity increase has been delayed from 2010

Li-Ion Battery Tutorial, Florida battery seminar
Li-Ion 18650 Discharge at Various Temperatures

- Organic electrolyte makes internal resistance of Li-Ion battery more temperature dependent than other batteries.

**Charge Conditions:** Constant voltage/constant current, 4.2 V, 1190 mA (max.), 2 hours, 20°C.

**Discharge Conditions:** Constant current 1700mA

Self-heating Effect Lowers the Internal Impedance
Effect of Impedance Increase on Runtime

- Change of no-load capacity during 100 cycles < 1%
- Also, after 100 cycles, impedance doubles
- Double impedance results in 7% decrease in runtime
Charge Voltage Affects Battery Service Life

- The higher the voltage, the higher the initial capacity
- Overcharging shortens battery cycle life

Source: “Factors that affect cycle-life and possible degradation mechanisms of a Li-Ion cell based on LiCoO₂,” Journal of Power Sources 111 (2002) 130-136
If battery sits on the shelf too long, capacity will decrease
Degradation accelerates at higher temperatures and voltages
Depending on chemistry, there are specific recommendations for best storage conditions

Source: M. Broussely et al at Journal of Power Sources 97-98 (2001)
• Charge Current: Limited to 1C rate to prevent overheating that can accelerate degradation

• Some new cells can handle higher-rate

Source: “Factors that affect cycle-life and possible degradation mechanisms of a Li-Ion cell based on LiCoO₂,” Journal of Power Sources 111 (2002) 130-136
Li-Ion CC-CV Charge Curve

Charge Characteristics
Measurement temperature: 20°C
Charge: CC-CV: 2.1A-4.2V (3hrs.cut)

Charge time (min.)

Cell voltage
“CC”

“CV”
capacity

Current (mA)
0 500 1000 1500 2000 2500

Capacity (mAh)
0 500 1000 1500 2000 2500

Texas Instruments
Linear and Switching Charger
Host and Standalone charger
Linear or Switch-Mode Charger…

- Same type of decision as whether to use an LDO or a DC/DC converter
  - Low current, simplest solution → Linear Charger
  - High current, high efficiency → Switch-Mode Charger

- General Guideline ~ 1A and higher should use switching charger… or, if you need to maximize charge rate from a current-limited USB port
Charging from a Current-Limited Source

- USB port limited to 500mA
- But… w/ Switching charger, can charge > 500 mA

- 500-mA Current Limit
- 40% more charge current with switcher
- Full use of USB Power
- Shorter charging time
- Higher efficiency, lower temperature

\[
I_{CHG} = \text{?} \\
V_{IN} + \text{Charge Controller} \\
V_{BAT}
\]

\[
I_{CHG_{sw}} = \frac{V_{IN}}{V_{BAT}} \cdot \eta \cdot 500\text{mA}
\]
Standalone Charger

- Standalone charger:
  - HW controlled - **No system controller (MCU)**
  - Set critical parameters with resistors or pullup/pulldowns
  - Fixed functionality
Host – Controlled Charger

Charger setting based on which battery pack (2S/3S/4S) was connected.
Dynamic Power Path Management
Some possible concerns / issues:
- What happens when battery is very low?
- What happens if battery is missing or defective?
- If system is operating, how can charger determine if battery current has reached a termination level?
Power Path Management

- Power supplied from adapter through Q1; Charge current controlled by Q2
- Separates charge current path from system current path; No interaction between charge current and system current
- Ideal topology when powering system and charging battery simultaneously is a requirement
Adaptor supplies power to both SYSTEM and battery charger switching regulator through Q1 and Q2 ACFET when both adaptor and battery on the system.
Battery supplies power to SYSTEM through Q3 BATFET when only battery on the system.
Without Dynamic power path management

Could we use adaptor power rating < Max system power + Max charging power?

Non-DPM function charger solution. As charging current in constant current charging and system current increased, total input current reach adaptor maximum power limit results system voltage crashed.
With Dynamic power path management

- Lower power rating adaptor can be used with DPPM function

With Dynamic Power Management control scheme, charging current reduced when total input current reached $I(DPM)$ threshold. Battery charger regulate input current in constant by dynamic adjust charging current.
Turbo boost and NVDC charger analysis
• Use existing input DPM loop to support turbo mode
• Charger change from buck mode to boost mode when system current is higher than adapter max allowed current
- Use existing input DPM loop
- System load voltage equal to battery voltage
# Turbo Boost vs. NVDC

- Assume 40W adapter, peak power 62W. Average system power 15W, 2S battery

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<thead>
<tr>
<th></th>
<th>Turbo Boost</th>
<th>NVDC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum VBUS</td>
<td>19.5V</td>
<td>6-8.4V (2S); 9-12.6V (3S)</td>
<td>Low voltage rating MOSFET with lower Rdson</td>
</tr>
<tr>
<td>Efficiency@charge/discharge</td>
<td>93%</td>
<td>91%</td>
<td>2% higher and 1.9W saving in Turbo Boost charger</td>
</tr>
<tr>
<td>DC-DC efficiency</td>
<td>Lower</td>
<td>Higher</td>
<td></td>
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<td>External FETs</td>
<td>Lower current rating (3-4A)</td>
<td>Double current rating (6-8A for 45W)</td>
<td>May find a reasonable size with 7A</td>
</tr>
<tr>
<td>Inductor</td>
<td>Yes, 1-2ms delay</td>
<td>Yes, instant without delay</td>
<td>Turbo Boost: Overload adapter by 1-2ms</td>
</tr>
<tr>
<td>Inductor size</td>
<td>4.2A, 2.2uH 5.2x5.5x2mm (Vishay IHLP2020BZ)</td>
<td>6.5/8A, 2.2uH 6.5x6.9x2.4/3mm (Vishay IHLP2525BD/CZ)</td>
<td></td>
</tr>
<tr>
<td>Total size and cost</td>
<td>Charger: Smaller L and FET DC-DC: Larger size and lower efficiency</td>
<td>Charger: Larger L and FET DC-DC: Smaller inductor and higher efficiency</td>
<td>Turbo boost solution has smaller size and lower cost</td>
</tr>
<tr>
<td>Limitation</td>
<td>Adapter overloading</td>
<td>NOT attractive &gt;=65W</td>
<td></td>
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</tbody>
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[Texas Instruments logo]
Fast charging / USB Type C/PD
Fast Charging

Handshaking is achieved between charger and adapter

5V2A (default) →
9V or 12V2A after MaxCharge™ Handshake

Application Processor

MaxCharge™ Master

Charger bq25890

AC Adapter

MaxCharge™ Slave

AC-DC

1S

12C

D+

D-

VBUS

GND

Micro USB Connector

VFB

D+

D-

VBUS

GND

Texas Instruments
Fast Charging - Current Pulse Control on VBUS

Handshaking is achieved between charger and adapter through VBUS current change

5V (default) → 7V / 9V / 12V after Handshake

Application Processor

Micro USB Connector

High Voltage Adapter

Charger bq25890/2

Handshake Master

1S

5V (default) → 7V / 9V / 12V after Handshake
IRComp to Reduce CV Time

Goal:
VREG = 4.2V + IR (R = Rdson + Rsense + Trace resistance)

- Speed up the charge cycle by compensating the battery pack parasitic resistance (IR compensation).
Fast Charging with IR Compensation

VBUS = 12V, Battery Capacity = 29.6Whr

17% Longer Charge Time without IR Compensation (234 min vs. 200 min)

- Improved IR Compensation Configurations
  - Resistance range
  - Safe Voltage Clamp range
Why USB Type C?

- Smaller size → same size connector as uB
- Richer content → 3.1, DP, TB
- Higher power → 100W
- Better user experience → Flippable, no more host and device specific cable and connector
- More customization with standardized mechanical dimensions
Type C Connection
## Power Supply Options

Table 2-1 Summary of power supply options

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>Nominal Voltage</th>
<th>Maximum Current</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USB 2.0</strong></td>
<td>5 V</td>
<td>500 mA</td>
<td>Default Current, based on definitions in the base specifications</td>
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<tr>
<td><strong>USB 3.1</strong></td>
<td>5 V</td>
<td>900 mA</td>
<td></td>
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<tr>
<td><strong>USB BC 1.2</strong></td>
<td>5 V</td>
<td>Up to 1.5 A</td>
<td>Legacy charging</td>
</tr>
<tr>
<td><strong>USB Type-C Current @ 1.5 A</strong></td>
<td>5 V</td>
<td>1.5 A</td>
<td>Supports higher power devices</td>
</tr>
<tr>
<td><strong>USB Type-C Current @ 3.0 A</strong></td>
<td>5 V</td>
<td>3 A</td>
<td>Supports higher power devices</td>
</tr>
<tr>
<td><strong>USB PD</strong></td>
<td>Configurable up to 20 V</td>
<td>Configurable up to 5 A</td>
<td>Directional control and power level management</td>
</tr>
</tbody>
</table>
Wireless Charging
Factors Affecting Coupling Efficiency

- **Coil Geometry**
  - Distance (z) between coils
  - Ratio of diameters ($D_2 / D$) of the two coils \( \rightarrow \text{ideally } D_2 = D \)
  - Physical orientation

- **Quality factor**
  - Ratio of inductance to resistance
  - Geometric mean of two Q factors

- **Near field allows TX to “see” RX**

- **Good Efficiency when coils displacement is less than coil diameter** (\(z << D\))
Factors Affecting Coupling Efficiency

Good efficiency

Bad efficiency

Power efficiency

Optimal operating distance

Factors affecting coupling efficiency:
- 40% at 1 diameter
- 1% at 2.5 diameter
- 0.1% at 4 diameters
- 0.01% at 6 diameters

Axial distance $z / D$
bq50k + bq51K: Qi-Compliant Solution

Wireless Transmitter

Wireless Receiver

TX Controller

RX COIL

TX COIL

Rectifier

Voltage Regulation

Linear Controller

RX Communication & Control

COMM DRV

Portable Device (System Load up to 5W)

V_{OUT}

5V @ 1A

To System

I_{PRI}

I_{SEC}

I_{FEEDBACK}

R_{SENSE}

Power

Communication / Feedback

Communication / Feedback

Texas Instruments
Communication – How it works...

TX Coil current or voltage can be measured and demodulated to decode data from RX.

Control processor on RX side will apply load pulses for signaling back to TX.
Switching Frequency Variation

- System operates near resonance for improved efficiency.
- Power control by changing the frequency, moving along the resonance curve.
- Modulation using the power transfer coils establishes the communications.
- Feedback is transferred to the primary as error.
Where To Start
Selection Tools – Choosing the Right Fit

Battery Chargers Selection Tool
A powerful tool that will help to select exactly the right product to suit your customers needs in a user friendly and highly efficient way.

TI.com Parameter Searches
Enter the parametric answers to the questions in this presentation into the easy-to-use search section and pick from a number of suitable devices with quick and easy links to data-sheets, pricing and more.
Design Tools

PowerLab™ Power Reference Design Library
The PowerLab™ library includes an interactive and powerful search engine for design engineers looking for a proven and tested solution to their power-supply requirements. This interactive search tool allows engineers to find designs by application, topology, input type, input voltage or output voltage.

Features
• Extensive collection of tested power-management reference designs
• Hundreds of power-management designs for a wide range of applications and power-conversion topologies
• Reference designs include both isolated and non-isolated designs for lighting, telecommunication, computing, consumer electronics and more

For more information, visit: www.ti.com/powerlab

WEBENCH System Power Architect w/Hot Swap & Isolated
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Quickly compare performance across multiple parameters for complete systems:
• Designer Series—Single-circuit design tools
• Architect Series—Advanced hierarchical design tools
• Unique Design Features—Vasulator and Optimizer Dai

www.ti.com/webench

The Power Stage Designer™ Tool 2.1 helps you design the power stage of the most commonly used switch mode power supplies. This tool is a great assistance for getting a deeper understanding of voltages and current flows inside converters. This new revised Power Stage Designer™ Tool 2.1 also offers you the ease of automatically transferring all given parameters directly into WEBENCH® and PowerLab™.
Wireless and Low Power Charging

- **bq25570**
  - Boost Charger + Buck
  - Ultra Low IQ

- **Bq25504/5**
  - Boost Charger
  - Ultra low IQ

- **TPS62736**
  - 330na Ultra Low Iq DC-DC Buck
  - High efficiency

- **bq2423x**
  - 0.5A, 28V input max
  - Power path,

- **Bq24040/45,50**
  - 0.8A, 30V input max
  - 24050 : D+/D-
  - 24045 : 4.35V Vbatreg

- **bq5105xB**
  - Direct Li-Ion charger
  - 4.2V or 4.35V opt

- **bq52013B**
  - 5V, Output, 1A
  - 20V input max
  - Wireless Power supply

- **bq25060**
  - 1A, 30V input max
  - Power path,

- **Bq24090/95**
  - 1A, 12V input max
  - 24095 : 4.35V Vbatreg

- **Bq24157/8**
  - 1.25A, 20V input max
  - USB OTG: 5V, 200mA

- **bq24140**
  - 1.5A, Dual input, OTG

- **bq24187**
  - 2A, 30V input
  - OTG

- **bq2407x**
  - 1.5 A, 28V input
  - Power path

- **bq24156A**
  - 1.5A, 20V input max
  - USB500ma

- **bq2426x**
  - 3A, 30V input max
  - OTG: 1A out Power path

- **bq24270**
  - 1.5A, 20V input
  - Power path

- **bq2425x**
  - 2.0A, 20V input max
  - USB2.0, 3.0
  - BC1.2 certified
  - Auto detect setting for 100/500/900ma USB
  - CDP/DCP detect
  - Power path

- **bq24231x/5x**
  - OVP and OCP

- **bq24090/95**
  - 1A, 30V input max
  - Power path,

- **bq24231x/5x**
  - OVP and OCP

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  - OVP and OCP
High Power Chargers

1-3 Cells with iFET

bq24170/1/2
- 4A iFET, 20V, 1-3 Cell
- 2.5A iFET, bq24133
- Standalone
- 3.5x5.5 QFN-24

1-7 Cells Standalone Li-Ion Supercap, and Solar Charger

bq24610/6/7/8
- 30V, 1-6 Cells
- 600kHz; >10A
- DPM, PowerPath
- Standalone
- 4x4 QFN-24
- JEITA: bq24616
- 4.75V Vin, bq24618

bq24630/20
- 1-7 Cell LiFePO4
- 300kHz; >10A
- DPM, PowerPath
- Standalone
- 4x4 QFN-24

bq24640
- SuperCap, Li-Ion
- 600kHz;
- iFET up to 4A
- 3.5x4.5 QFN-20

bq24130
- Solar Charger
- MPPT
- 600kHz; 0.2A-10A
- Standalone
- 3.5x3.5 QFN-16

1-4 Cells SMBus Charger

bq24707A
- 28V, 1-4 Cells
- DPM, 750kHz
- 3.5x3.5 QFN-20

bq24735/25A
- 28V, 1-4 Cells
- Turbo Boost (735)
- DPM, 750kHz
- N-FETs Selector
- 3.5x3.5 QFN-20

bq24760
- 28V, 1-4 Cells
- 6A iFET
- Turbo Boost
- DPM, 750kHz
- 5x5 QFN-40

bq24715
- Ultrabook
- NVDC-1, 800kHz
- 28V, 2-3 Cells
- N-FET PowerPath
- 3.5x3.5 QFN-20
- pin-pin bq24725

bq24190/1/2/3
- 20V, 1-Cell; I2C
- NVDC-1, USB2.0/3.0
- 4.5A iFET, 1.5MHz
- 1.3A OTG (bq24190/2)
- 12mΩ Rdson BATFET
- IR compensation
- 4x4 QFN-24

bq24295/6/7
- 5V, 1-Cell; I2C
- NVDC-1, USB2.0/3.0
- 3A iFET, 1.5A OTG
- P2P w/bq2419x

bq2410x/12x
- 20V, 1-3 Cells
- 1.5A iFET, 1.1MHz
- 3.5x4.5 QFN-20

bq200x
- NiMH/NiCd charger
- Lead Acid Charger

Released
Development
Q & A
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Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

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