Battery Management for Smart Phone & Tablet Applications

April, 2012
Agenda:

• BMS Overview
• Fuel Gauging
• Charger
Battery Management Components

Single Cell (1SxP)

- **System Host**: TPS65xxx
- **SMPS**: TPS6xxx
- **Chemical Fuse**: Protection
- **Sense Resistor**: Temp Sensing
- **Pack+ & Pack-**: Cell Balancing
- **Charger IC**: bq2416x, bq24140, bq2415xA, bq2417x, bq24133
- **Gas Gauge IC**: bq27541
- **AFE IC**: Gas Gauge/Battery Mgr (TPS65xxx)
- **Protector**: bq2946x
- **Ac Adapter or USB**: DC+ & DC-

Charge Mgmt
Charge control into battery from an external source

Or bq28z560 (= gauge + protector)

Monitor & report battery operational status and predict battery capacity under all conditions.

Protection from abuse

Gas Gauge/Battery Mgr
Monitor & report battery operational status and predict battery capacity under all conditions.

DC+ & DC-

V_CELL1

**System Rails**
Fuel Gauging
Battery Fuel Gauging: Increasing expectations

- bars
- percent
- Time-to-Empty

42% remaining

1:27 hr remaining
What is Fuel Gauging Technology?

Fuel Gauging = technology to predict battery capacity under all system active and inactive conditions.

Its key benefit is dramatic extended RUN TIME!

The Gas Gauge IC autonomously calculate and report:

- Remaining Battery **capacity** information
  - Percentage
  - time to empty/full
  - milliamp-hours
  - Watt-hours
  - talk time, idle time, etc.

- Battery **health** and **safety** diagnostics information
  - State of Health,
  - Full Charge Capacity, temperature

Run Time 6:27

63%
Fuel Gauging Made Simple

**Impedance Track™**
Directly measures effect of discharge rate, temp, age and other factors by learning cell impedance

Calculates effect on remaining capacity and full charge capacity

No factory learning cycles needed

No host algorithms or calculations

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**Integrated Gauging Methods:**
- Voltage Measurement
  - Affected by impedance (T, age,..)
  - Imprecise under load conditions
- Integrating current over time (coulomb counting).
  - Affected by impedance
  - Affected by Self discharge
  - Standby current
  - Age
  - Must have full to empty learning cycles
  - Must develop cell models that will vary with cell maker
  - Can count the charge leaving the battery, but won’t know remaining charge without complex models
  - Models will become less accurate with age

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Available capacity: How is this known?

Design capacity
Full charge capacity
Residual capacity
## Discrete Fuel Gauge vs Integrated Components

<table>
<thead>
<tr>
<th>Item</th>
<th>TI Impedance Track Gauge Advantage</th>
<th>Integrated coulomb counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remaining Capacity</td>
<td>Automatically Computed</td>
<td>Requires host side algorithm and extensive battery modeling</td>
</tr>
<tr>
<td>Run Time to Empty</td>
<td>Automatically Computed</td>
<td>Requires host side algorithm</td>
</tr>
<tr>
<td>Compensation for current</td>
<td>Automatically Computed from battery impedance</td>
<td>Generally not known</td>
</tr>
<tr>
<td>Compensation for temperature</td>
<td>Automatically Computed from impedance temperature model</td>
<td>Generally not known</td>
</tr>
<tr>
<td>Compensation for age</td>
<td>Automatically Computed from battery impedance</td>
<td>Generally not known. Can be estimated by cycle count, but not effective, especially for removable battery</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Constant learning of impedance can achieve 1% accuracy</td>
<td>Varies with age of cell, manufacturer of cell, etc…</td>
</tr>
<tr>
<td>Run Time</td>
<td>Extended run time due to varying shutdown voltage with remaining capacity</td>
<td>Generally no effect on run time</td>
</tr>
</tbody>
</table>

*TI Confidential - NDA Restrictions*
How is it Implemented?

- The fuel gauge solution is located either in the **battery pack** or in the **host system**.
## Gauge Implementation Comparison

<table>
<thead>
<tr>
<th></th>
<th>Pack-side Gauge</th>
<th>System-side Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pack</td>
<td><strong>Intelligent</strong> Battery Pack</td>
<td>Generic Battery Pack</td>
</tr>
<tr>
<td>Integration</td>
<td>Integrated Authentication (SHA-1)</td>
<td>Integrated interrupt and GPIO to notify host; No host polling is needed</td>
</tr>
<tr>
<td>Gauging Initialization</td>
<td>Gauge is always “in-sync” with the battery. Provides instant gauging information on battery insertion.</td>
<td>Gauge is initialized during system power up</td>
</tr>
<tr>
<td>Development Effort</td>
<td>System OEM outsources design to pack makers – pack maker designs/ configures gauge</td>
<td>System OEM must understand battery characteristics to configure gauge</td>
</tr>
</tbody>
</table>
**Advantages**

- Battery Pack Manufacturers Develop ALL the gauging algorithms
- System accommodates Different Battery Chemistries
- All Monitoring and Protection contained within Battery Pack
- Scalable for different number of Cells

**Disadvantages**

- Higher Cost of Battery Pack - additional electronics
Battery Management - System Side Gas Gauge

**Advantages**
- Lower Battery Pack Costs
- Scalable for different number of Cells
- Easier for Field updates

**Disadvantages**
- OEM’s have to develop ALL the gauging algorithms
- OEM’s has to understand different Battery Chemistries
- Schedule impact if OEM does NOT have process to accommodate for different battery chemistries
- More complicated manufacturing process

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Texas Instruments Products
bq27541

Pack Side Single Cell Li-Ion Battery Fuel Gauge

Features
- HDQ or I2C Communication
- Patented Impedance Track™ next generation gauging algorithm
- Accurate & complete battery fuel gauge
- Battery lifetime datalog
- CPU-based IC reports remaining battery capacity, time-to-empty, voltage, current and temperature
- Calculates remaining capacity compensated for discharge rate, temperature, and cell age
- Pack side implementation
- Chip enable pin to shut down fuel gauge
- 2.5mm x 4mm

Applications
- PDAs and Smart Phones
- MP3 and Multimedia Players
- Digital Still and Video Cameras
- UMPC, Portable Gaming

Benefits
- Provides the system ALL data needed to effectively manage the battery & extend run-time
- Reports accurate Time-to-Empty at both measured and host-requested load values
- Impedance Track™ requires no learning or conditioning cycle
- End-of-discharge voltage compensated for discharge rate and temperature
- High accuracy charge and discharge current integration with automatic offset calibration
- Automatic sleep mode

* Optional thermistor
bq27545 (new features & CSP package)

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- CPU-based IC reports remaining battery capacity, time-to-empty, voltage, current and temperature
- Calculates remaining capacity compensated for discharge rate, temperature, and cell age
- Pack side implementation
- 15-Ball NanoFree™ small CSP package 2mm x 2.6mm

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![Diagram of bq27545 IC](image-url)
bq27520-G3
System-Side Impedance Track™ Fuel Gauge with Integrated LDO

Features
- Patented Impedance Track™ battery fuel gauging technology.
- Turn Key Solution with complete CPU and battery fuel gauge firmware.
- System side implementation
- Option for host temperature write
- Interrupt driven gas gauge signaling the host on specific state of charge status of the battery
- Integrated LDO
- 15-Ball NanoFree™ small CSP package 2.61X1.96 mm²

Benefits
- Enables lower terminate voltage of system and extends run time from battery.
- No external battery algorithm and firmware development needed
- Provides flexibility in pack selection & lowers battery pack replacement cost.
- Frees Processor of housekeeping functions that are managed by Interrupt feature in Fuel Gauge.
- Eliminates requirement for external LDO
- 20% smaller total solution size compared to bq27505 which needs LDO

Applications
- Smart Phones
- E-Readers, Tablets
- Portable Medical
- Portable Gaming
- MP3 and Multimedia Players
- Digital Still and Video Cameras

 Yazf (DSBGA 15) 2.6mm x 2mm

Host System
System Host Controller

Texas Instruments
bq27425-G1
System-Side Impedance Track™ Fuel Gauge with Integrated LDO and integrated current sense resistor

Features

- Patented Impedance Track™ battery fuel gauging technology.
- Simplified configurations and feature set
  - Easy configuration options
  - Simple gauging command set
  - Factory installed chemistry ID
  - Single pack type profile
- System side implementation
- 400 KHz I2C communication
- Integrated LDO
- Integrated current sense resistor
- 15 balls WCSP 1.8mm x 2.7mm

Benefits

- Enables lower terminate voltage of system and extends run time from battery.
- No external battery algorithm and firmware development needed
- Standard 2-wire communication protocol
- Eliminates requirement for external LDO
- Fast time-to-market
- Flexibility in pack selection & lower battery pack replacement cost
- Small solution size
- No Sense R needed. Reduce overall BOM cost

Applications

- Smart Phones
- E-Readers, Tablets
- Portable Medical
- Portable Gaming
- MP3 and Multimedia Players
- Digital Still and Video Cameras

Low Cost Released

Texas Instruments
**Direct connection to Pack Voltage**
- Li ion/Polymer Pack with 1S cell
- Operational modes: Normal, Sleep and Hibernate
- Internal LDO

**Fuel Gauging**
- Ztrack for accurate gauging
- Coulomb counter using high accuracy ADC
- Accurate Cell Measurement ±5mV
- Accurate Current Measurement ±1mA

**Safety and Protection**
- Monitors individual cell voltages
- Power delivery interruption during fault condition using FET control circuitry (COUT/DOUT output)
- Protection for: Over/Under Voltage, Over Current Charging/Discharging, Short Circuit, Over Temperature
- Pre Charge mode
- Internal or external Temp measurements ±2.0°C Temperature
- SHA-1 Authentication

**Flexibility**
- I2C Communications
- The bus communication will work at 1.8V
- SBS Command Set
- Slave mode operation only
- User Configurable data settings
- JEITA/Enhanced charging
- Alert Output for priority interrupt to Host MCU
- CHG FET control output for FW control during Over charging

**APPLICATIONS**
- Tablet PC’s
- DSLR, Camcorders
- Slates
- Portable Products

**Product Family**
- bq28Z560 – I2C Comm + IT
- bqSuperPac – Int CHG/DSG FETs (Package 5mm x 4mm QFN)

**Package**
- 12pin QFN (4 x 2.5 x 1)
- bq28z560 Samples: 2Q12
- RTP: 3Q - 2012
Smart Phone/Tablet Fuel Gauge

bq3060
CEDV Gas Gauge + AFE
P-FET Drive
2S-4S
Mainstream safety;
Lifetime data
JEITA & enhanced chg
TSSOP-24 (PW)

bq28400
Pack-Side
2s CEDV Gas Gauge + AFE
20p 6.7x6.4mm TSSOP
PFET drive

bq30z55
Impedance Track
2s – 4s
N-FET Drive
Next Gen. lifetime data
Extended SBS data
JEITA & enhanced chg
TSSOP-30 (DBT)
7.8 x 6.4 x 1.2

bq27520
IT Gas Gauge
System Side
2.6x2mm CSP
Integrated 5Vin LDO
Host Interrupt

bq27z560
Pack-Side
CEDV
12p 2.5x4mm QFN
Integrated 24Vin LDO
AFE +N Fet drive

bq28z55
IT Lite Gas Gauge
System Side
12p 2.5x4mm QFN
Integrated 24Vin LDO

bq27410
IT Gas Gauge
System Side
12p 2.5x4mm QFN
Integrated 24Vin LDO

bq27541
Pack-Side
IT Gas Gauge
12p 2.5x4mm QFN
Integrated 24Vin LDO

bq27425
LOW COST
Integrated sense resistor
IT Lite Gas Gauge
System Side
12p 2.5x4mm QFN
Integrated 24Vin LDO

Production
Development

Protector Integrated
Charger
High Performance Integrated Charger Solutions

**bqCFE**
- Input OVP, OCP protection
- 30V max input voltage protection
- MSOP and QFN

**bqLinear**
- 1.5A max charge current
- Power Path management
- Multiple input support - AC, USB, Wireless, Solar
- 2x2, 3x3, QFN

**bqSwmode**
- High efficiency charge management solutions
- 3A max Charge current
- USB-OTG, USB3.0 and USB BC1.2
- Multiple Input support – AC, USB, Wireless, Solar
- WCSP and QFN packages

**bqBMU**
- Ready to use charge management solutions
- Added protection from malicious software
- Better thermal management of system design

TI's advanced gauging and charging technology combined for the state of the art fully integrated BMU solutions
Charger IC or PMIC function?

• Some PMIC may have built in charge function
• For tablet applications, larger battery requires higher charge current
• PMIC usually has low power capability (slow charge)
• Separate charge IC can offer fast charge + other features
• New PMIC for tablet applications may remove charger function for power dissipation reasons
Li-Ion Charge CC-CV Profile

- Constant Current: 20-30% charging time, 70-80% capacity
- Constant Voltage: 70-80% charging time, 20-30% capacity
Battery charging Temperature Qualification
a. 0°C to 45°C.
b.JEITA

Low-Voltage Battery Pack Charge
Pre-charge current: < 0.1C for VCELL < 3.0V

Charging Termination
In Constant Voltage Mode, Charge current < 0.1C

Charge Timer
3-5 hrs.
JEITA Charge Requirements for Single Cell Applications

Note: LiCoO₂ Type Battery Cell

- Low charge current or voltage @ low temperature
- Low charge voltage @ high temperature
Power Path Management Technologies:

- DPPM: Dynamic Power Path Management
- DPM: Dynamic Power Management
- NVDC-1 Switch-Mode DPM charger
Charging with an Active System Load (Non-DPPM)

Advantages:
Narrow System DC voltage = Battery Voltage from 3 to 4.2V

Issues:
- Operate system and charging simultaneously
- Safety Timer
- Termination
Power Path Management Battery Charge Architecture (DPPM)

- Separate charge current path from system current path
- Charge current controlled by Q2
- Powering System from adapter through Q1
- Simultaneously powering system and charging battery
- No interaction between charge current and system current
Input Current DPM Switch-Mode Battery Charger

- Maximize use of the input current
- Current sharing between system & charger
- Minimize the AC adapter size and power rating

How to avoid adapter crash if its current is NOT Known?
Input Voltage DPM Switch-Mode Battery Charger

- If $V_{IN} < V_{INDPM}$:
  - Reduce Duty Cycle $\rightarrow$ Reduce $I_{CHG}$ $\rightarrow$ Reduce $I_{IN}$
  - Allows $V_{IN}$ to recover back to $V_{INDPM}$ level
- Automatically Track Adapter’s Max Current.
- Perfect for third party adapter
Switch-Mode NVDC-1 Battery Charger
(NVDC – Narrow System Bus Voltage)
NVDC-1 Switch-Mode DPM Charger with Supplement Mode

Pre-charge: Q4 -- Linear Mode, Fast Charge: Q4 = ON
How to Maximize the Battery Run Time?

- Minimum system bus voltage: 3.4V
- Battery Cut-Off Voltage $VCUT = 3.4V + I_{load} \times RDSON$
- For $I_{load} = 3A$; $RDSON = 50m\Omega$; $VCUT = 3.55V$
- Unused battery capacity $> 25\%$ @ $VCUT = 3.55V$

LOWER $RDSON$: 10-20m$\Omega$
Tablet/Smart-Phone 1-cell Common Charging Requirements

Input power Source
- Adapter: 5V, 9V/2.5A, 12V/1.5A, 15V/1.5A
- USB2.0: 5V@100mA/500mA
- USB3.0: 5V@150mA/900mA/1.5A

System
- Instant-on with NVDC architecture
- Operate system with deeply discharged battery
- I2C communication
- OTG function
- Best Thermal performance

Battery
- 1SnP: 2000mAh, 3000mAh-10000mAh
- Charge time: 2-5 hours
- Charge current: 2-6A
- Fast charging and longest run-time
Smart Phone / Tablet Charger Roadmap

1-3 Cells and 1 - 4A
- Int FET, 4A, 1-3S
- bq24170/2
- JEITA

Switch Mode
- bq2419x
  - 1s, 20V Vin, 4.5A, 1.5Mhz,
  - I2C, OTG
  - Single input, Power path
  - USB 2.0/3.0
  - USB D+/D- detection or PSEL
  - 4x4mm QFN
  - Sampling now

Single cell < 2.5A
- Accessory Power
- bq2415x
- bq2414x
- bq2418x
- Int FET, 1.5A
- Dual Input
- USB OTG Simul Chg

Switch Mode
- bq2416x
  - 1s, 20V Vin, 2.5A, 1.5Mhz,
  - Host / StandAlone
  - Dual I/P Power path
  - USB 2.0/3.0
  - USB D+/D- detection or PSEL
  - 20V, 1.5~2.5A

Linear
- bq2427x
  - 20V, 1.5~2.5A

Single cell < 1.0A
- Single Input – Adapter or USB
- JEITA Option
- Dynamic Power Path, 1.0A, 1S

- bq2409x
- Production
MTK 6573/6575 Platform
SN111008 & bq24158/9

- Internal input current sensing and input current limiting
- Vin based DPM and bad adaptor detection
- Charge in CC and CV mode
- Automatic termination with internal safety timer
- Boost mode operation for USB OTG

Also, bq24159 = SN111008 without battery detection
So bq24159 is also a choice for MTK6573/5 customers
**bq24153A / 56A / 185 (non-Power Path)**

3MHz switch-mode charger w/ Integrated FETs & Host I²C Control

**Features**
- Synchronous 3MHz PWM controller (1uH)
- Integrated FETs for up to 1.25A or 1.5A charge rate
- Input Voltage
  - 6V or 9V operational, 20V abs max (`153A/156A`)
  - 16.5V operational, 20V abs max (`185`)
- 0.8A max charge current from USB
- High-Speed (3.4MHz) I²C interface
  - Programs input current, fast-charge/termination current, charge voltage, charge enable, safety timer, termination enable, charger status, DCOUT current limit, Input DPM level
- Built-in input current sensing and limiting
- Input dynamic power management ($V_{IN\_DPM}$)
- Thermal regulation and protection
- Package
  - 3.5 x 3.5 mm QFN-14
  - 2.2 x 2.4 mm WCSP-25

**Benefits**
- USB compliance, can use cheaper adapter
- High efficiency, small inductor (1uH)
- Small solution size
- Protects against transient and faulty inputs
- Faster charging from USB
- High level of programmability
- Small solution size
bq24160/1/2/3
Dual Input, Switch-mode Charger with Power Path Management and I²C

**Features**

- High-Efficiency Switching Mode Charger with Separate Power Path and Control
  - **Startup System from Deeply Discharged Battery or No Battery**
- V\textsubscript{IN} Based Dynamic Power Management
- Supports USB2.0 and USB3.0 Charger Applications
- D+/D- based automatic adapter detection for USB input (bq24160)
- High level of integration
  - Synchronous Fixed-Frequency **1.5MHz PWM Converter**
  - **20V input rating**, with 10.5V Over-Voltage Protection
  - Integrated power path and driver for an external PMOS
  - Integrated Input Current Sensing and Limiting (+-5%)
  - Integrated FETs for Up to **2.5A Charge Rate**
    - Up to 2.5A from IN Input
    - Up to 1.5A from USB Input
- BOOTOK output prevents bad boot condition with USB100/USB150 sources (bq24163)
- Safe and Accurate Battery Management Functions
  - **BC1.2 Compliant**
  - **1% Battery Voltage Regulation Accuracy**
  - 5% Charge Current Accuracy
  - User Programmable Maximum Input Current Limit
  - **Thermal Regulation Protection**
- I²C Interface (1.8V, 400kHz)
  - Control Charge Parameters, Timers, V\textsubscript{INDPM} threshold

**Sampling**

2.8mm x 2.8mm WCSP
Also available in 4mm x 4mm QFN package
bq24160 Power-Path Charger

- Supplies loads up to 3A, battery supplement mode for loads up to 5A or higher with external battery FET
- Integrated Powerpath Control drives PMOS for low impedance discharge path (optional)
- I_{CHG} = 2.5A MAX

20V max, OVP @ 10.5V
20V max, OVP @ 6.5V

I^2C Interface

Supplies loads up to 3A, battery supplement mode for loads up to 5A or higher with external battery FET
bq2419x 4.5A, OTG Charger Application

Support DC Adaptor, USB2.0 and USB 3.0 up to 3A

D+/D- Detection

I2C Interface

Default USB Current

Input Current Setting

Up to 4A Charge Current and 6A Discharge Current

Integration of power path and switching MOSFETs

Dual battery Pack Thermistor Monitoring
bq2419x 4.5A, OTG Charger Key Features/Differentiators

• Fast Charge
  – Up to 4A charge current to support high capability battery pack
  – Battery IR compensation reduces charge time significantly
  – I2C programmable pre-charge and charge current (64mA step) for potential customized charge profile
• Highest battery discharge efficiency with 10mΩ BATFET (Q4)
• Input voltage regulation (VDPM) to support third party adapters
• Programmable thermal regulation options to maximize charge current while fit different case temperature requirement
• USB OTG: 1.3A
• Support both adapter and USB 2.0/3.0 inputs
• Support 1S2P battery configuration with two individual thermistor temperature monitoring
• bq24195 is a 3A, OTG Charger in the same family, pin to pin.
**Features**

- High efficiency, high frequency, high integration
  - 4.5-17V input operating range
  - Integrated MOSFETs with over 90% efficiency for up to 2.5A charge current
- Internal loop compensation
- 1.6MHz frequency
- Integrated BTST Schottky diode
- Integrated power path selector
- DPM regulation loop
- Charge Management
  - 1 to 3 Li-Ion cells in series with 4.2V/cell
  - ± 0.5% voltage regulation, charge conditioning, charge status, battery temperature monitoring
  - ± 4% input current regulation
  - ± 4% charge current regulation
  - Thermal regulation

**Benefits**

- 5V, 9V, 12V and 15V Adapter
- High efficiency, no thermal issue
- Minimize external component number
- Small size inductor
- Save cost
- Reliable operation
- Save board space
- Maximize adapter current capability
- Suitable for a wide range of applications
- Maximizes battery capacity, cycle life and safety

**Applications**

- Tablet, Netbook, UMPC or MID
- Handheld Terminals
- Industrial and Medical Equipments
- Portable Equipments with up to 3 cell Li-Ion

**bq24133:** 2.5A Standalone Charger with Power Path Selector
Thanks!
Questions?