High Efficiency & Fast Charging Battery Charger Designs

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Tablet/Smartphone Battery Capacity Trend

High Battery Capacity Requires
High Efficiency & Fast Charging Battery Charger
High Capacity Battery Charging Challenges

- Long Run Time
- Fast & Efficient Charging
- Safety
Critical Charging System Considerations

• **System Instant-On** with Deeply Discharge or Dead Battery

• **Longer Run Time**
  – Highest efficiency for down-stream DC-DC converters
  – Lowest Rdson for battery discharge MOSFET

• **Fast & Efficient Charging**
  – High charge current to support high capacity battery pack
  – Low charge path resistance to minimize loss
  – Thermal Regulation to maximize charging

• **Safety Operations**:
  – Battery Safety: Temperature monitoring, Charging duration, battery over-voltage, battery short
  – IC safety: IC junction temperature, Power path MOSFETs over-current

• **Other Considerations**
  – USB2.0 and USB3.0 and boost mode OTG
NVDC Charger Topology

Non-Power Path Topology

- **System Voltage = Battery Voltage**
- System cannot power-on when battery is deeply discharged

Power Path Topology

- **System Voltage = Battery Voltage or Vsys-min**
- System **Instant-on** when battery is deeply discharged. Buck to supply system load and use Q3 to regulate battery charging
## NVDC Charger Benefits and Challenges

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**Limitations**

- Charger size and cost increases
  - All system power goes through buck converter: Need larger current rating for inductor and power FETs

**Challenges**

- Energy star
  - Light load efficiency → PFM; lower Iq
- Input Current DPM transient
  - Overloading adapter → Fast DPM transient response
bq2419x - Integrated NVDC Charger with Power Path

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

Input 3.9V – 17V

USB

D+/D- Detection (bq24190)

I2C Interface

USB On-The-Go Default USB Current

SYS: 3.4V-4.4V

4x4mm^2 QFN-24Pin Package

Integration of power path and switching MOSFETs

Up to 4A Charge Current and 6A Discharge Current

Input Current Setting

Dual battery Pack Thermistor Monitoring

Host

VREF

SDA

SCL

INT

OTG

ICE

Thermal

PAD

TS1

TS2

REGN

PGND

SYS

BAT

ILIM

REGN

USB On-The-Go

Default USB Current

Up to 4A Current Setting

Input Current Setting

Dual battery Pack Thermistor Monitoring

Texas Instruments
Fast Charging – Lowest Rdson Integrated Power Path

- First integrated 4.5A charger in the market with highest efficiency
  - 92% @ 2A and 90% @ 4A
- Low head room to extract maximum adapter current for USB Charging
- **Innovative IR Compensation** further reduces the charging time
High Efficiency / Low $R_{DS\_ON}$ is essential

- FET performance in an integrated switching converter (charger) is fundamental to the overall performance of the device
Charger Supplement Mode & Extended Battery Life

- **12 mΩ battery FET Q4** minimizes the voltage drop between battery to system and extend the **battery life time**.
- **Peak 9A discharge current** allow best system performance without input adapter, or with low power USB source.
Fast Charging 4.5A vs 2.5A

VBUS=12V, Battery Capacity = 29.6Whr

30% Longer Charge Time for 2.5A Charge Current (269 min vs. 206 min)
bq2419x vs High Resistance Power Path Charger

VBUS=4.5V, Battery Capacity = 14.8Whr

22% Longer Charge Time with Additional 80mΩ Rds_on (196 min vs. 160 min)
IR Compensation Charging Algorithm

- To speed up the charging cycle, it is best to stay in constant current mode as long as possible.

- Parasitic resistance (Rpar), including routing, connector, MOSFETs and sense resistor increases IR drop in the battery path. This forces the charger to transition from constant current to constant voltage too early and extends charge time.

- IR Compensation Algorithm senses charge current and automatically raises voltage regulation output (Vchg) to compensate for the drop based on parasitic resistance (BATCOMP) set by system designer.

- VCLAMP parameter is included to prevent output regulation from exceeding a pre-determined safe max limit.

![IR Compensation Circuit Diagram]

| IR Compensation / Thermal Regulation Control Register REG6 (default 00000011, or 03) |
|-------------------------------------|---------------------------------|----------------|
| **BIT** | **DESCRIPTION** | **NOTE** |
| IR Compensation Resistor Setting | BAT_COMP[2] | 40mΩ |
| Bit 7 | BAT_COMP[1] | 20mΩ |
| Bit 6 | BAT_COMP[0] | 10mΩ |
| Bit 5 | IR Compensation Voltage Clamp (above regulation voltage) | |
| IR Compensation Resistor Setting | VCLAMP[2] | 64mV |
| Bit 4 | VCLAMP[1] | 32mV |
| Bit 3 | VCLAMP[0] | 16mV |
| Bit 2 | Thermal Regulation Threshold | |
| Bit 1 | TREG[1] | 00 – 60°C, 01 – 80°C, 10 – 100°C, 11 – 120°C | Default: 120°C (11) |
| Bit 0 | TREG[0] | -120°C |
Fast Charging 4.5A with IR Compensation

VBUS=12V, Battery Capacity = 29.6Whr

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

• Charge current can be automatically adjusted to maintain a pre-determined max die temperature
Low Temperature – Thermal Image

- 32°C rise with charge current 4A (VBUS=9V, VBAT=3.8V)
- 12°C rise with discharge current 4A (VBAT=3.8V)
- Charger stays COOL with high charging or discharging current
Summary

• The growing capacity of battery in tablets & smartphones drive the need of **High Efficiency & Fast Charging**

• Consumer Applications require NVDC Charger with Power Path Topology to support **System Instant-On**

• High Efficiency & Fast Charging is achieved by
  – **High Power Integrated** NVDC Charger
  – **Lowest Rdson** to maximize efficiency
  – Innovative **IR Compensation** Charging Algorithm to speed up charging
  – **Adaptive Thermal Regulation** to stay cool