TEXAS INSTRUMENTS

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

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DESIGN CONSIDERATIONS FOR BATTERY CHARGERS TO ACHIEVE THE BEST USER EXPERIENCE

Agenda

- Charger basics.
- Stand-alone vs. host-controlled chargers.
- Power-path management.
- Charging accuracy.
- Power consumption.
- Protections.
- Input detection (D+/D–).
- On-the-go (OTG) mode.
- Additional resources to help complete your design.

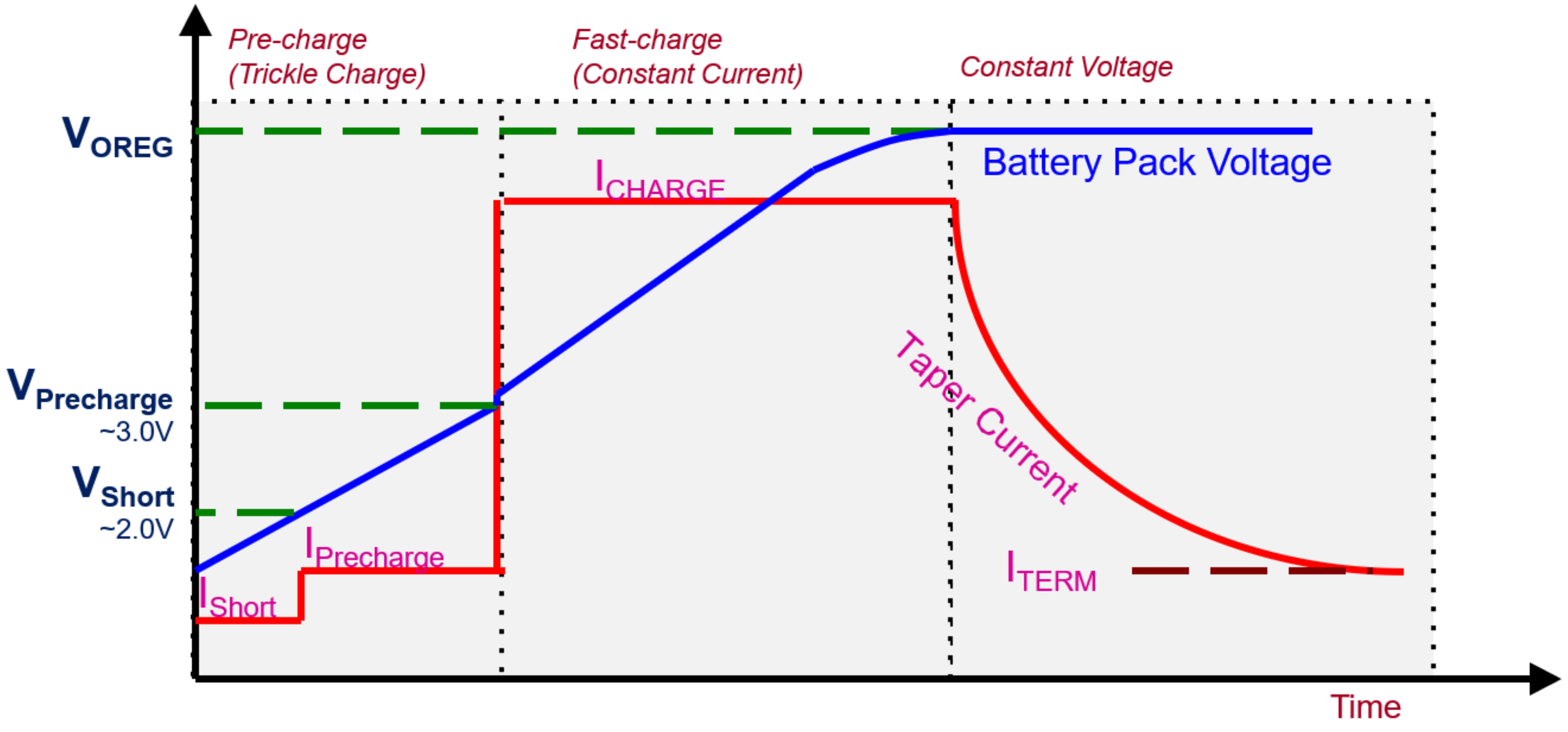
Charger basics

Charging thresholds

Charging fundamentals

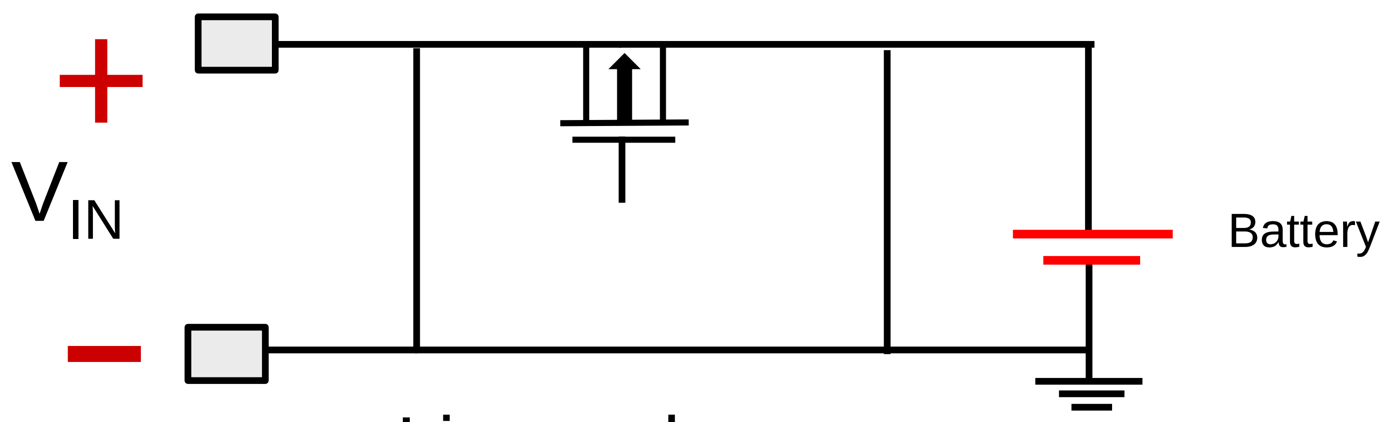
- Battery-charger IC regulates battery voltage and current.
- Chemistry and capacity determine safe charging voltages and current.
- Li-ion has distinct pre-charge, fast charge and taper regions charge.
- Follows a constant-current, constant-voltage (CC-CV) charging curve.

Typical charging profile

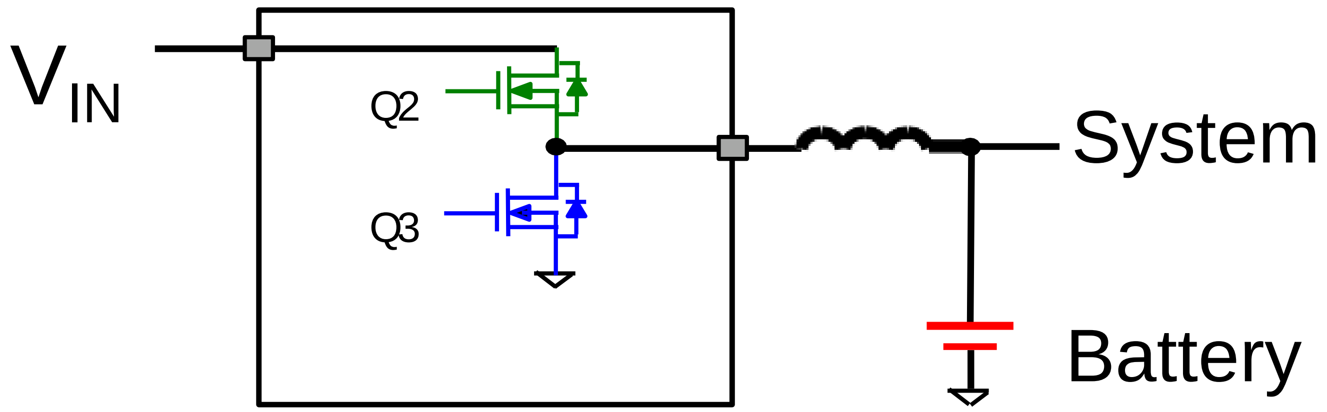


Charger topologies

Linear chargers	Switch-mode chargers
• Low charge current: <1.5 A.	• Higher charge current: >1.0 A.
• Thermal performance depends on V_{OUT}/V_{IN}.	• Good thermal performance.
• No EMI concerns.	• Switching noise dependent on layout.
• Lower efficiency.	• Higher efficiency.
• Typically lower cost.	• Typically higher cost.



Linear charger



Switching charger

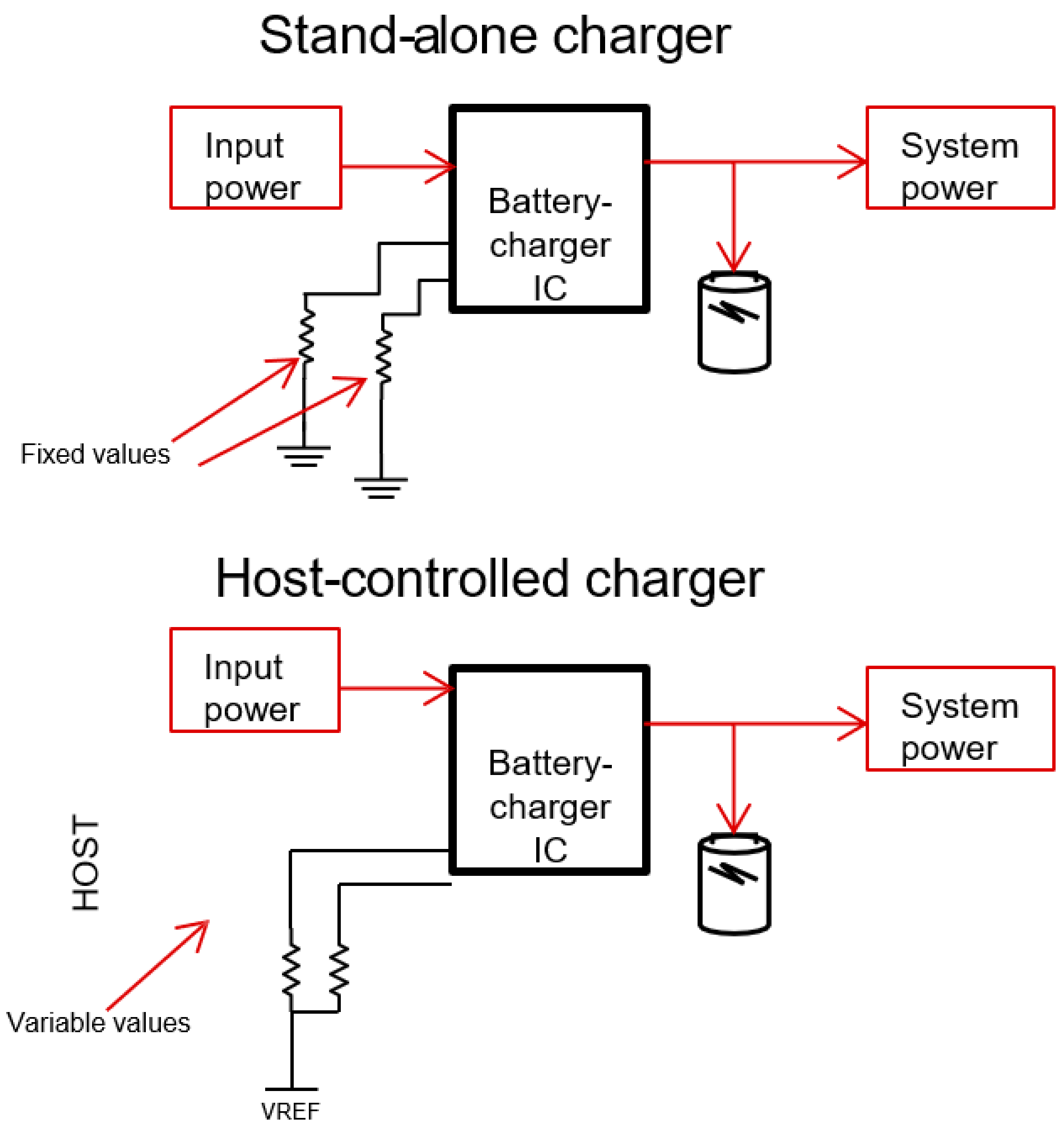
Stand-alone vs. host-controlled chargers

Stand-alone vs. I²C (host controlled)

Stand-alone vs. I²C comparison

- Stand-alone – configured by passive resistor values:
  - For straightforward applications, use our RC-settable devices.
  - Faster development time with no firmware needed.
  - Typically less options to configure; limited diagnostics.
- Host controlled (I²C):
  - Wider range of system functionality.
  - Configurable charging thresholds, TS ranges.
  - Rich status and fault reporting; interrupts.
  - ADC-enabled chargers enable continuous current, voltage, temperature monitoring.

External components



Power path and V_{INDPM}

Power-path management

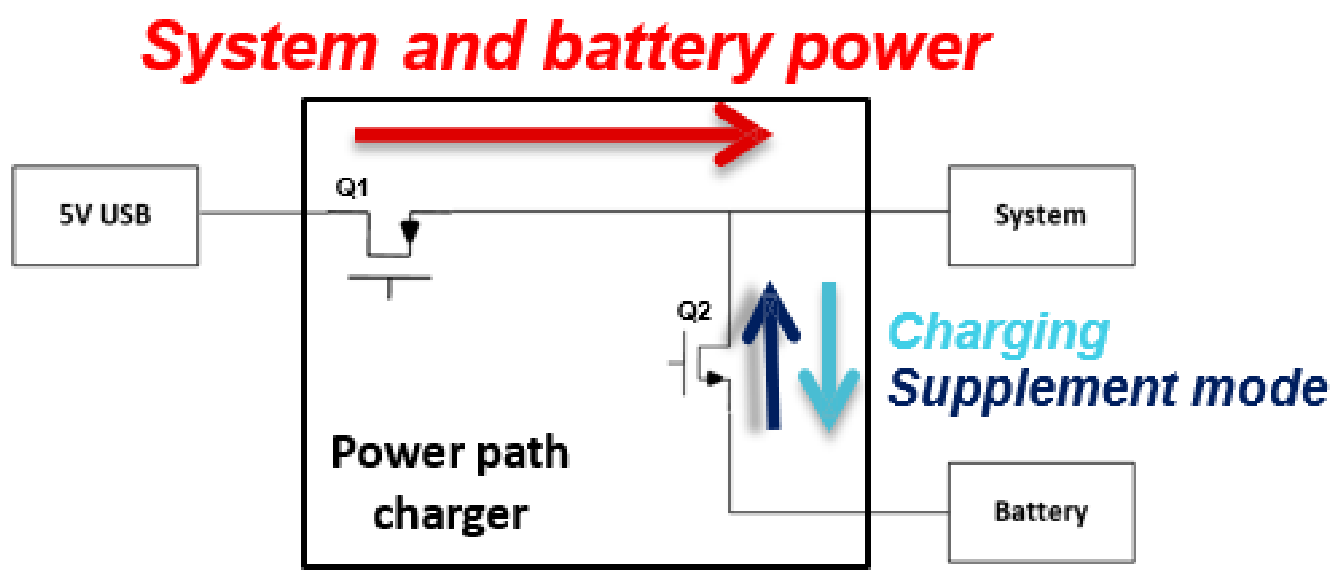
What is a power path?

- Adapter supplies power through Q1; Q2 controls charge current.
- Separates charge current path from system current path, with priority given to system current.
- Suitable topology when powering a system and charging a battery simultaneously is a requirement.
- System input enables instant system turnon when plugged in, even with a totally discharged battery, enables accurate termination as charging and system paths are different.
- Non-power-path, system and battery connected in parallel.

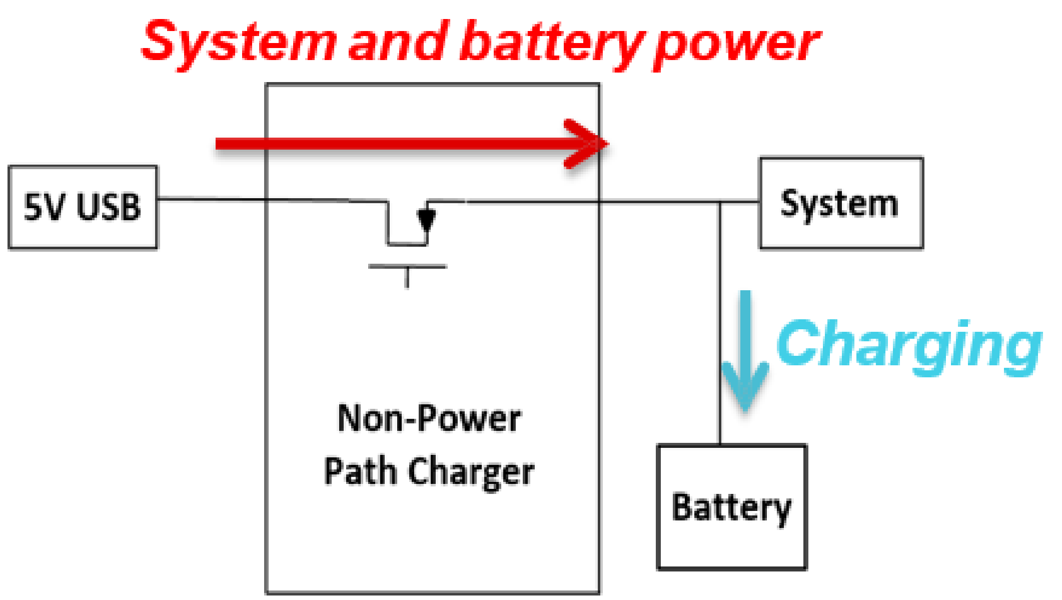
Featured products

BQ25180 | 1-A power-path 1S linear charger
BQ25170 | 800-mA non-power-path 1S linear charger
BQ25723 | 16-A power-path 1S to 4S buck-boost charger
BQ25303J | 3-A non-power-path 1S buck charger

Power-path charger



Non-power-path charger

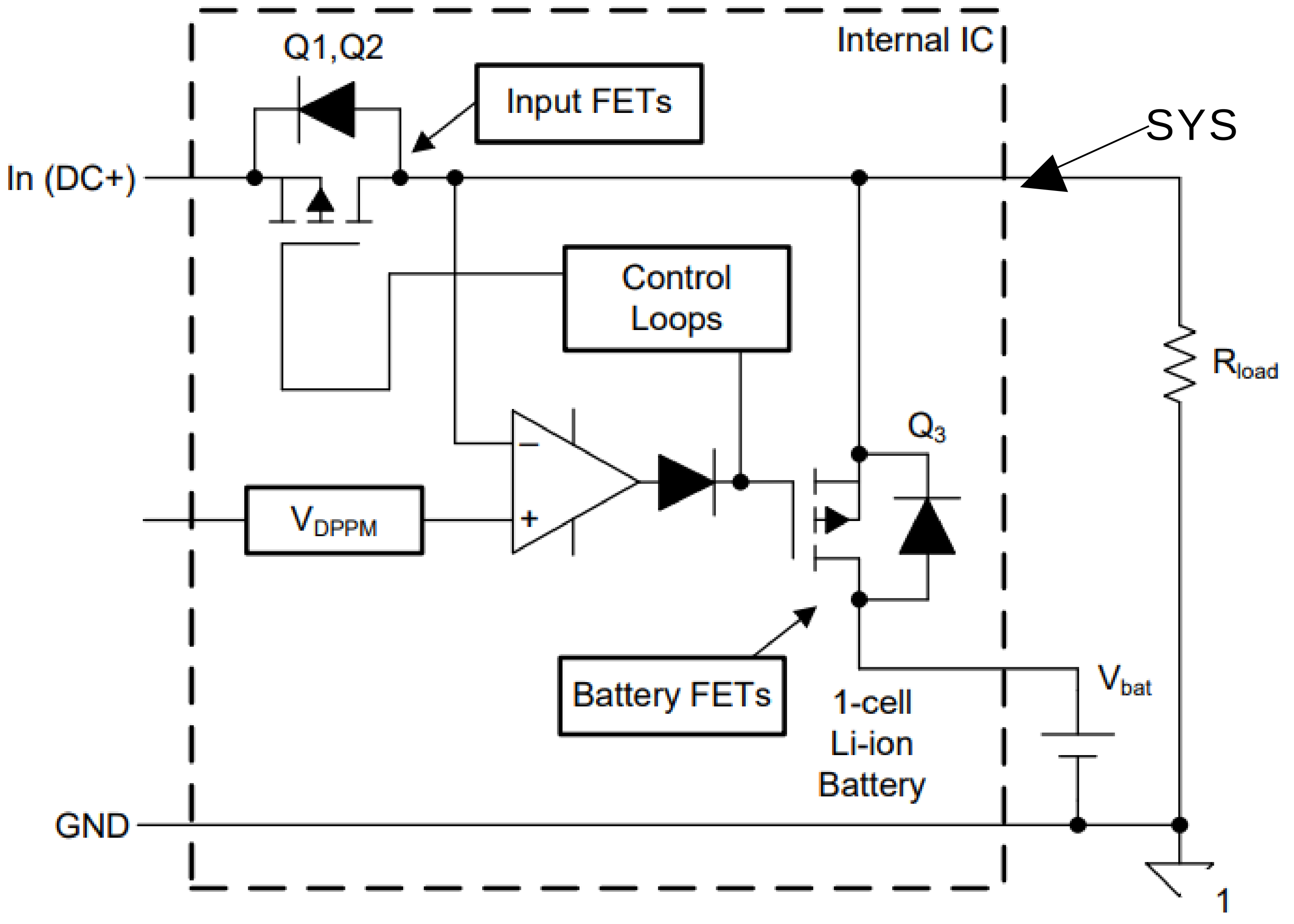


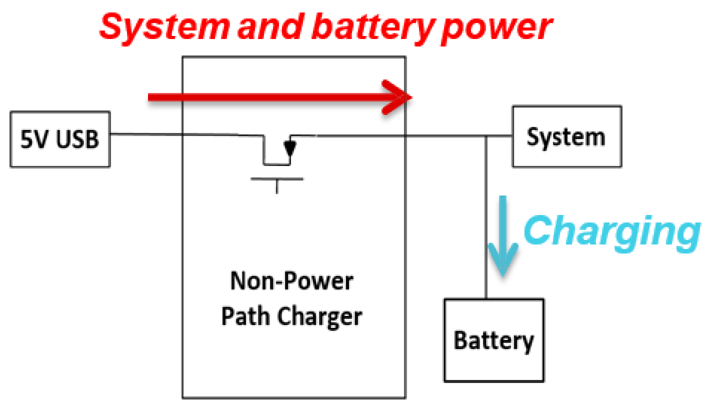
Dynamic power-path management (DPPM)

What is DPPM?

- DPPM monitors the input current, input voltage and output currents of a power-path device and automatically gives priority to the system when the adapter cannot support system and charging loads.
- The figure shows a DPPM circuit in a linear charger. The same principle applies for switching chargers.
- DPPM tries to keep SYS above a desired minimum voltage threshold to keep the system running.
- Allows for system power when the battery has been deeply discharged (Q3 off).
- Terminates current with higher accuracy than a non-power-path device where current into the battery is shared with load.

DPPM functional block diagram



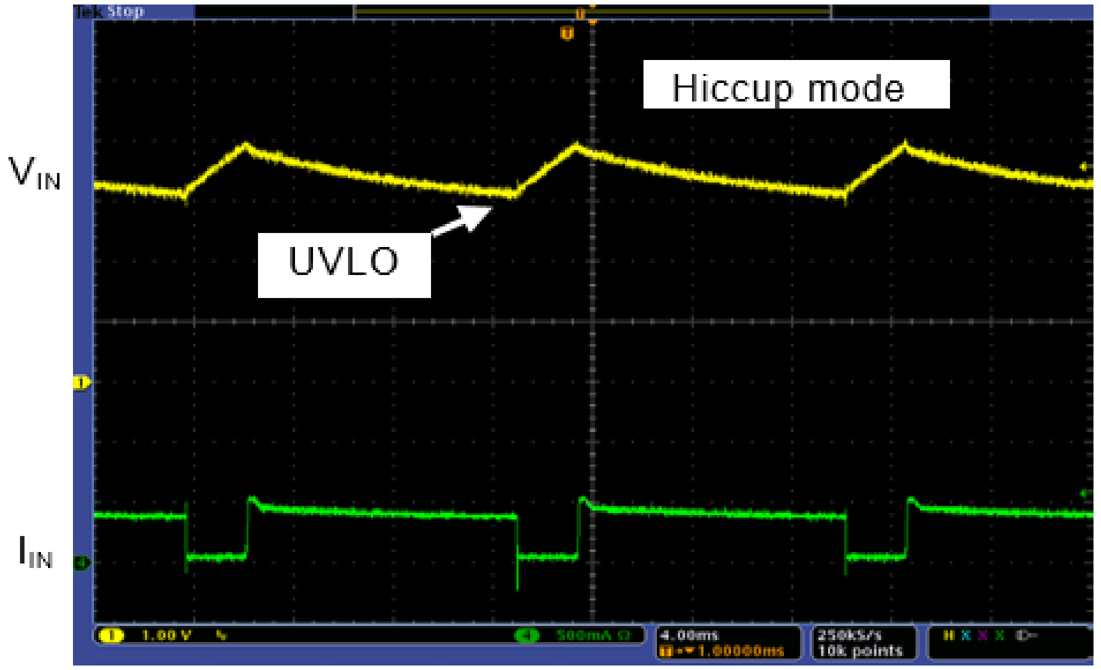


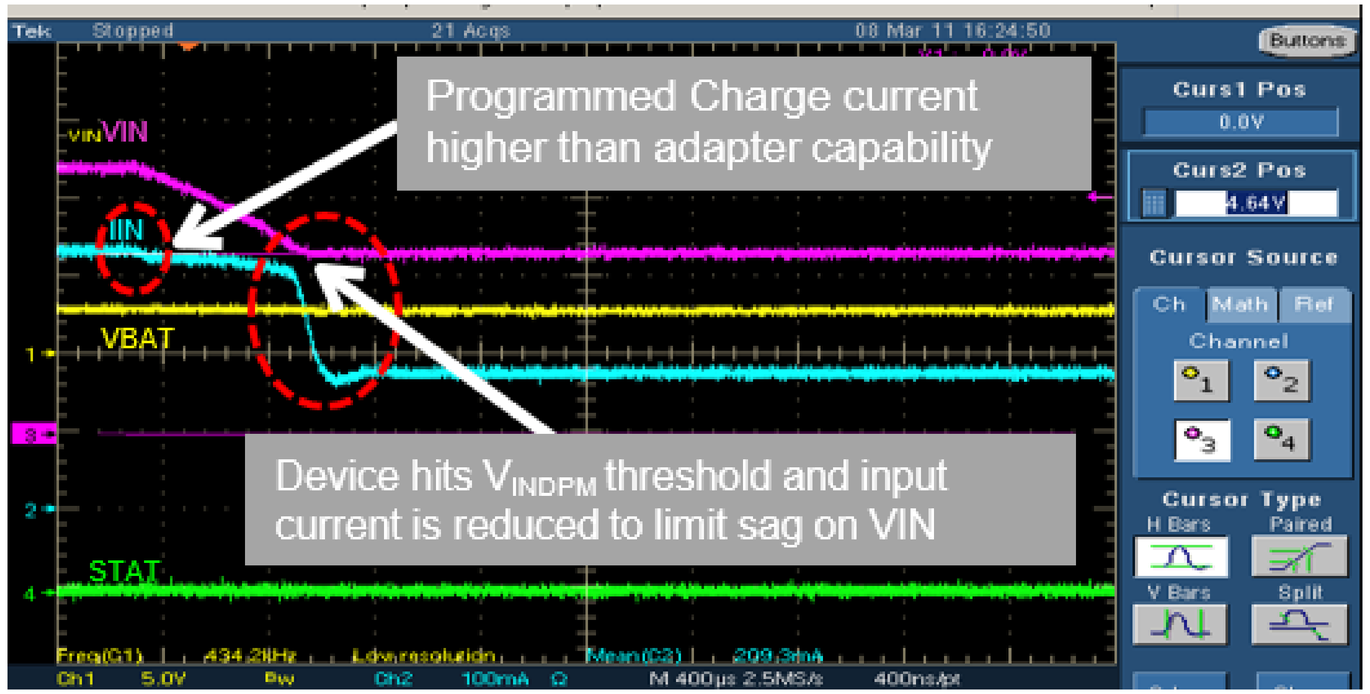
Input voltage dynamic power management (V_{INDPM})

What is V_{INDPM}?

- A V_{INDPM} control loop prevents the adapter voltage from dropping below the set V_{INDPM} threshold.
- For most adapter types, the adapter output voltage (V_{IN} to the charger IC) will start to droop as it is overloaded.
- When the input voltage drops, the device will limit the input current, while charging can still occur.
- Without V_{INDPM}, the device can enter a "hiccup mode" if the input source is overloaded (V_{IN} falls to undervoltage lockout [ULVO] trip level).
- In hiccup mode, user sees charging start and stop and a reduced charging rate.

How does V_{INDPM} work?





Texas Instruments

Does V_{INDPM} = DPPM?

- No!
  - V_{INDPM} prevents the adapter from hitting a brownout condition through the current-regulating loop.
  - A charger can have V_{INDPM} and not have **p**ower **p**ath (D**PP**M).
  - Charge current and system current are combined, and the charger does not know how much current is being delivered only to the battery.

- DPPM enables the charger to know exactly how much current is going to the battery.
  - With this information, the charger can reduce the charge current and extend the charging safety timer in the event that the system demands higher currents.

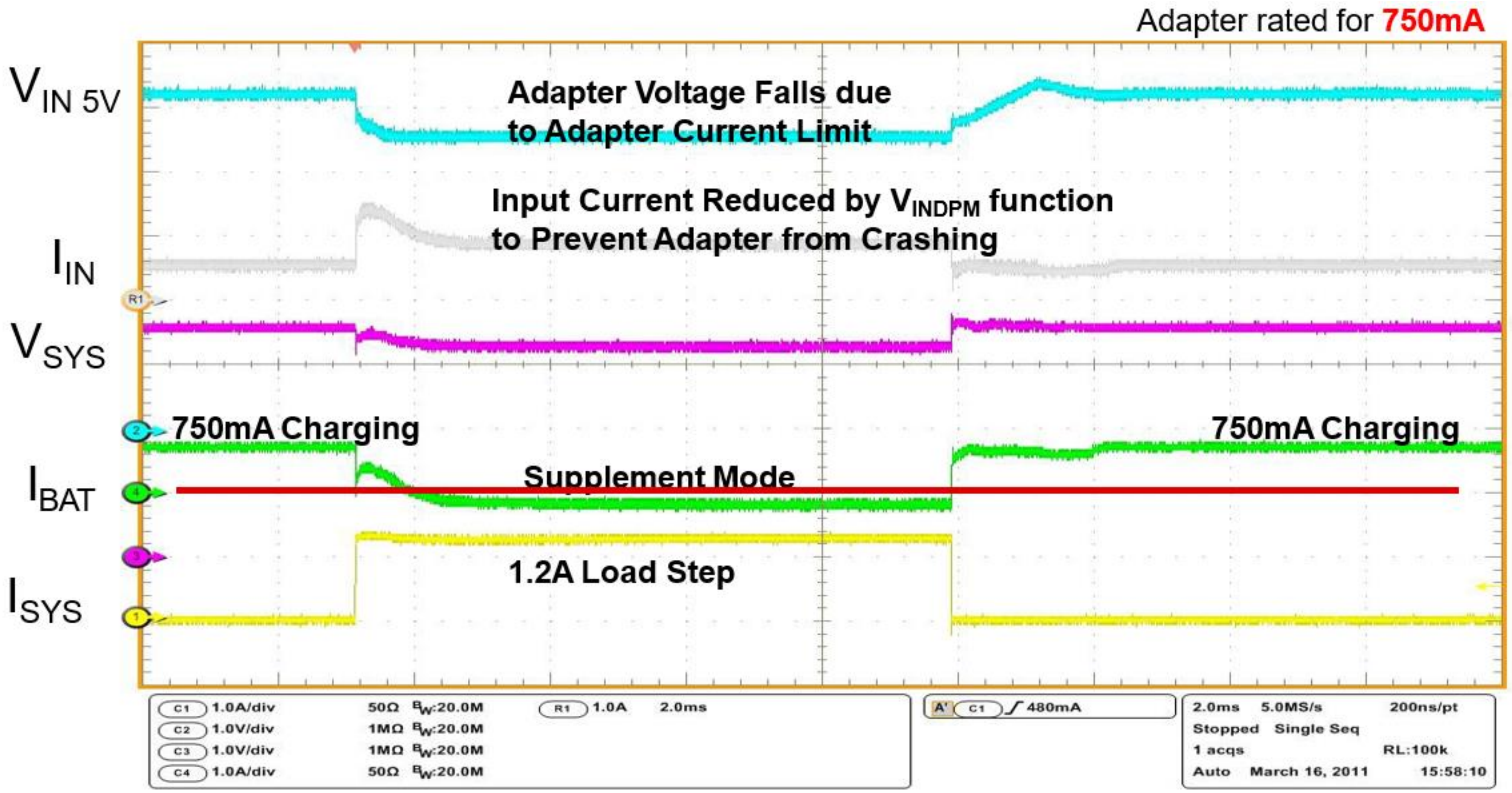
- Which one does your design require?
  - For devices that stay plugged into adapter for long periods, power path. Power path ensures that the adapter exclusively powers the system, reducing battery cycle counts.
  - Non-power-path is suitable for low-cost or very-high-current applications.

Supplement mode – use case

Using supplement mode

- Smartphone plugged in, user starts playing a game.
- Load step on the SYS rail draws more current than the adapter can support.
- V_{INDPM} reduces input current to prevent V_{IN} from collapsing.
- Supplement mode turns on wherein the system load is **supplemented** by the battery while still drawing current from the adapter.

Supplement-mode scope capture



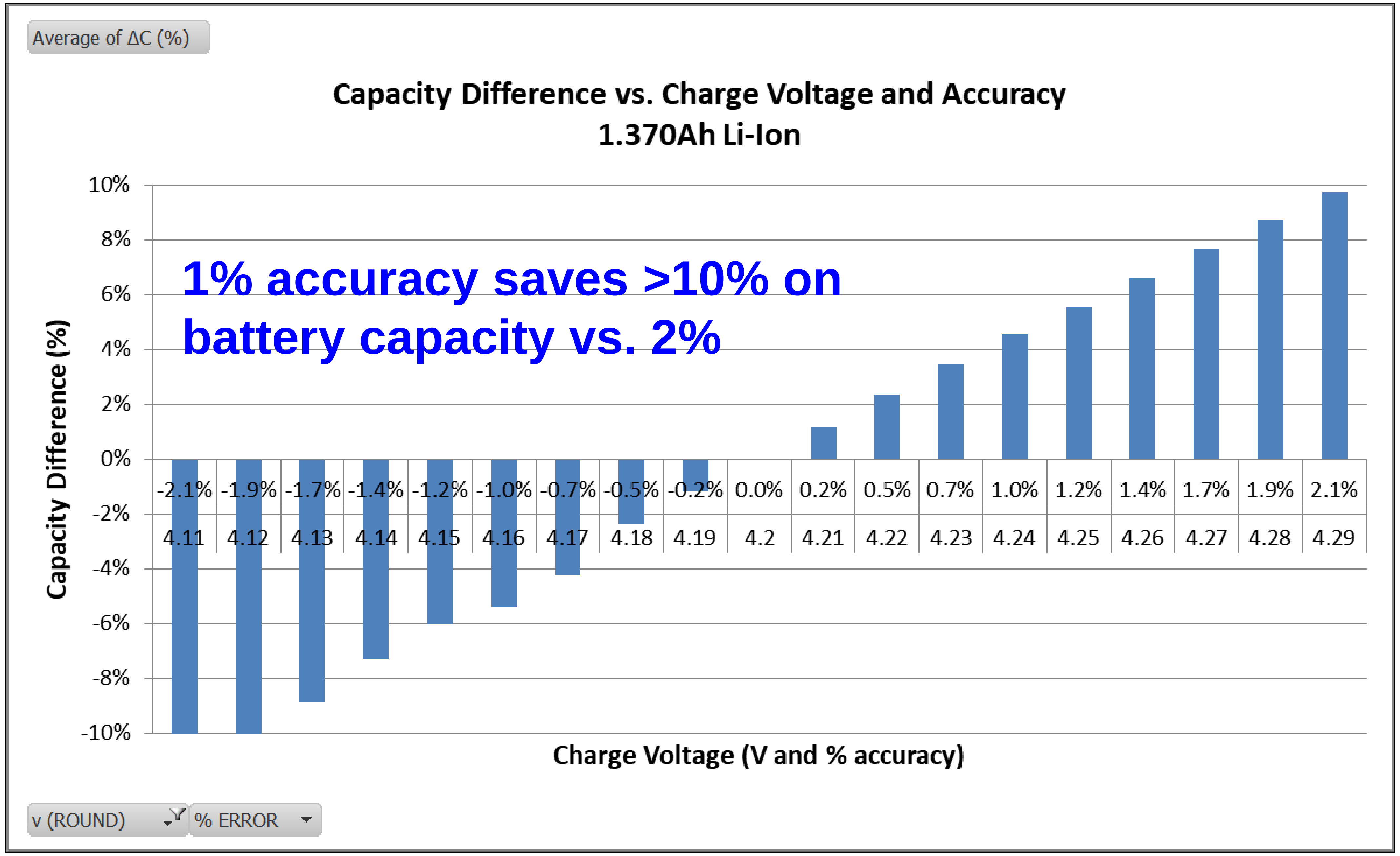
Charging accuracy

Charge voltage accuracy

Impact of charge accuracy

- The higher the charge voltage, the higher the initial capacity.
- Overcharging can shorten battery cycle life and at extreme scenarios can cause thermal runaway.
- Undercharging results in an underutilization of the battery's maximum capacity.
- ±1% charge accuracy helps better utilize battery capacity while maintaining lifetime.

Charge accuracy vs. capacity difference



Charge and termination current accuracy

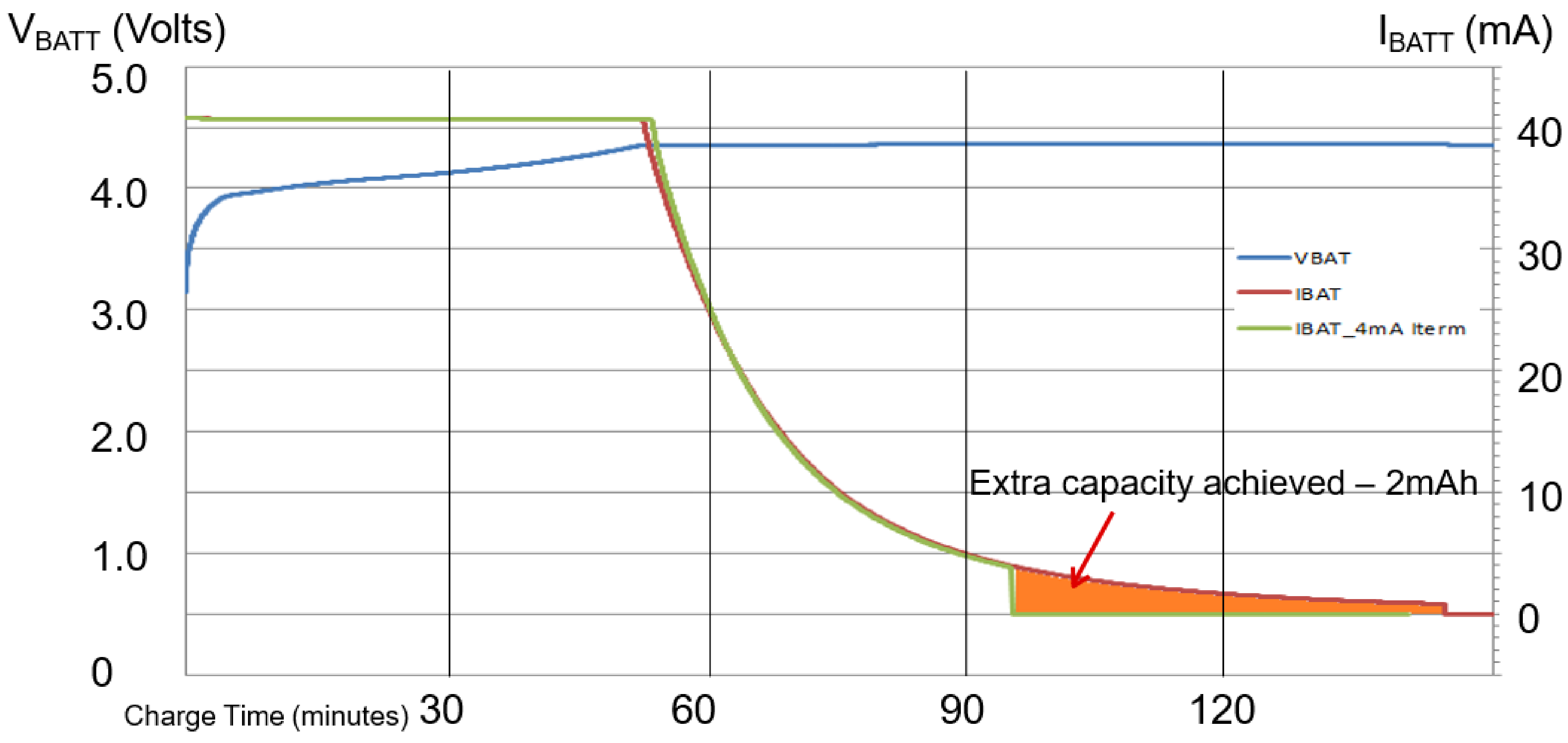
Impact of charge accuracy

- High charging accuracy enables a more consistent user experience across many devices.
- Lower termination current will charge the battery closer to full capacity. However, setting it too low can impact charging duration.
- Good termination accuracy necessary to get the most out of your battery and deliver a consistent full capacity being restored.

Featured products

BQ25100 | 250-mA 1-mA termination 1S linear charger
BQ25618 | 1.5-A 20-mA termination 1S buck charger

Benefits of accurate termination



- Charged 41-mAh battery at 40-mA fast charge current (1C).
- Termination at 4 mA (10%) or 1 mA.
- Shaded area represents additional 5% capacity restored on each charge.

Power consumption

Low battery leakage

Impact of leakage/I_Q

- Low battery quiescent current (I_Q) is critical for extending the shelf life of small batteries.
- For further extend the battery shelf life, look for products that support “ship mode” or “shutdown mode,” where the I_Q can be as low as 2 nA.

For a device that uses a 50-mAh battery and must sit in storage, how much capacity is lost?

BAT leakage current	250nA	1 µA	5 µA	10 µA	20 µA	50 µA
Lost battery capacity (mAh) 3-month shelf time	0.5%	2.2%	10.9%	21.8%	43.7%	100.0%
Lost battery capacity (mAh) 6-month shelf time	1.1%	4.4%	21.8%	43.7%	87.4%	100.0%
Lost battery capacity (mAh) 12-month shelf time	2.2%	8.8%	43.8%	87.6%	100.0%	100.0%

Table 1: Battery capacity percentage lost for a 50-mA battery for different shelf-life durations

Featured products

BQ25175 | 800-mA 350-nA I_Q 1S linear charger
BQ25302 | 2-A 200-nA I_Q 1S buck charger
BQ25155 | 500-mA 450-nA I_Q 1S linear charger

Leakage/I_Q – functional modes

I_Q modes

- Many chargers offer multiple power modes to allow a high level of system customization:
  - **Ship mode.** Minimal circuitry is powered inside the charger looking for a user input. System is off. Best for devices sitting in storage before reaching the user.
  - **Low-power mode.** Default mode of the device when the battery is connected. Limited feature set (no I^2C or ADC).
  - **Active battery mode.** I^2C is enabled for communication with host. ADC channels enabled.

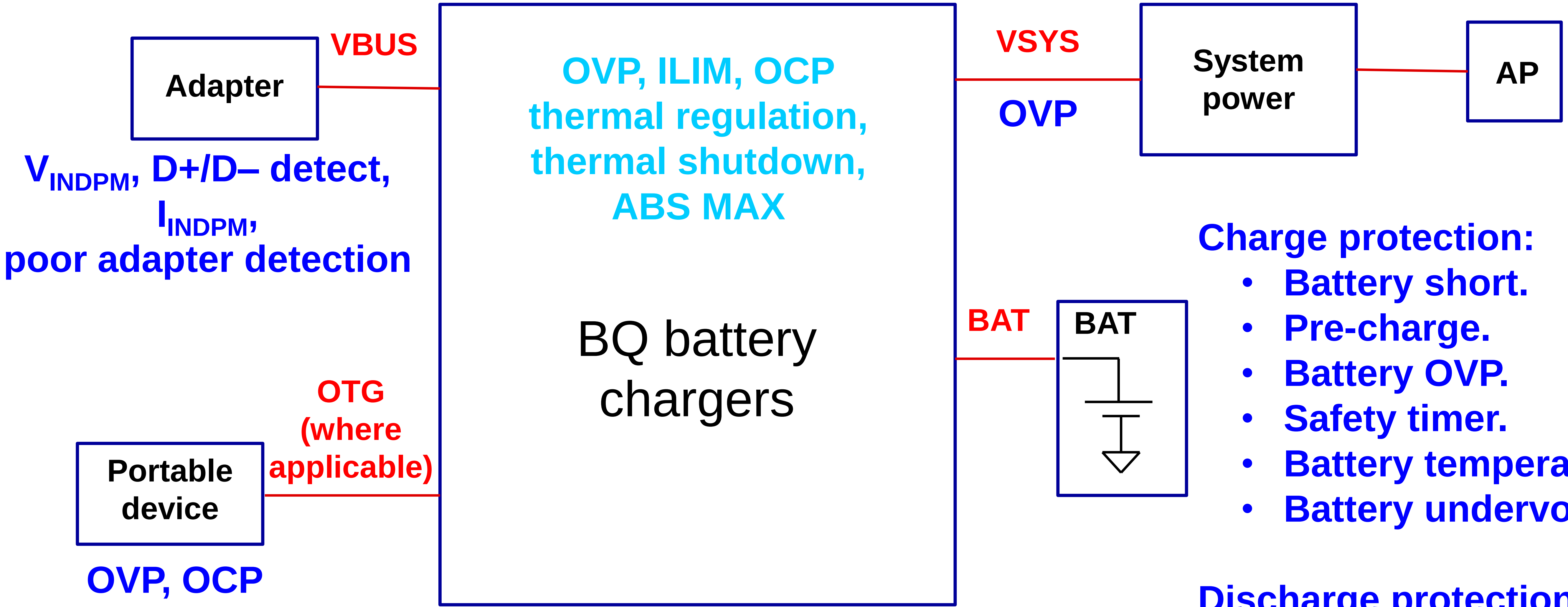
BQ25155 example

Battery-only mode	I_Q (typ)
Ship mode	10 nA
Low-power mode	460 nA
Active battery mode	18 µA

Protections

Safe charging – system protections

Various types of integrated protection features



Charge protection:
- Battery short.
- Pre-charge.
- Battery OVP.
- Safety timer.
- Battery temperature monitoring.
- Battery undervoltage.

Discharge protection:
- Overcurrent.
- Short circuit.

*Note: Pack-side protection is integrated into the battery pack.

Protection against voltage transients

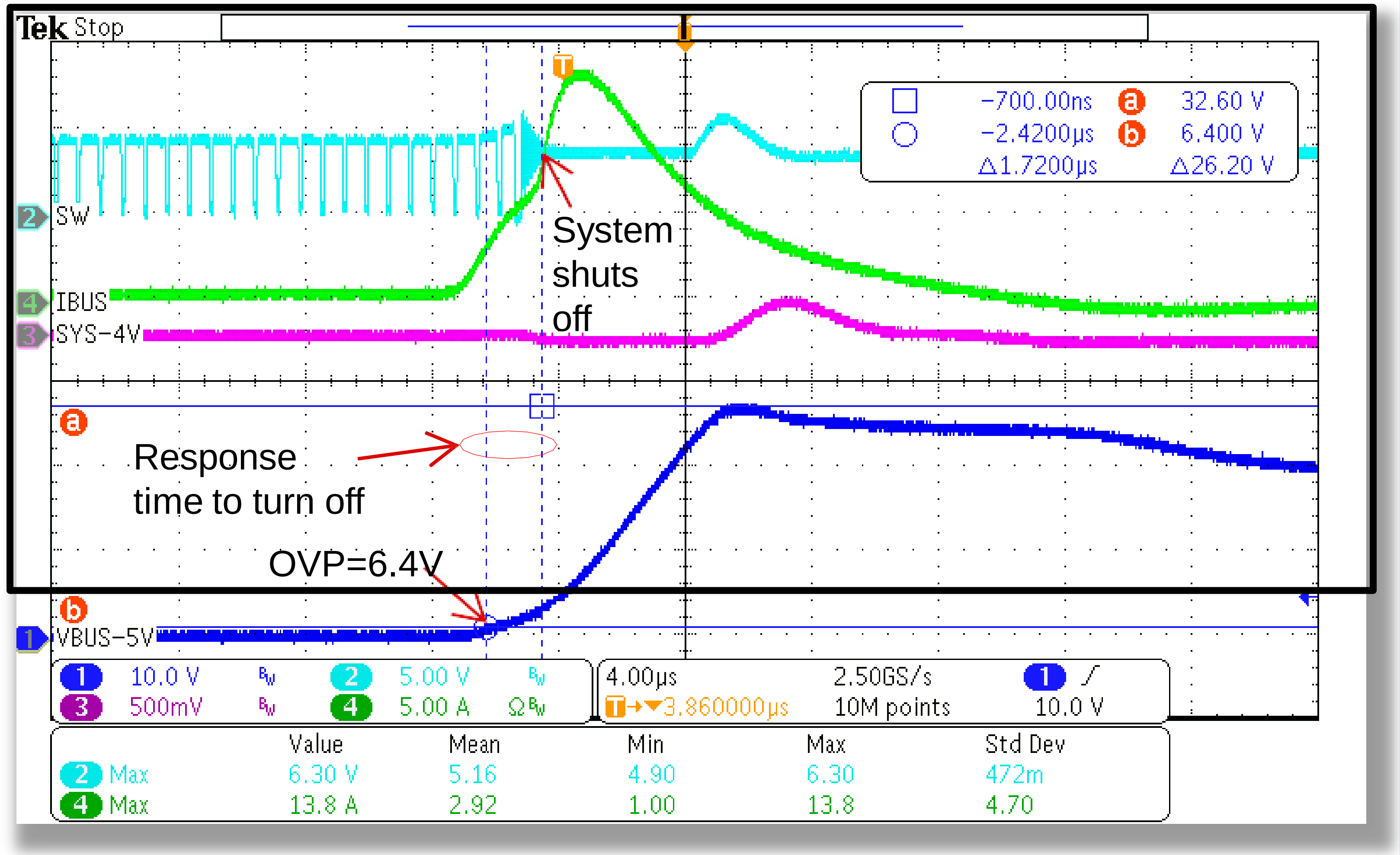
Safe charging overview

- Chargers often directly interface to the adapter cable and require protection against transient voltage spikes.
- Integrated OVP enables the charger to protect the system from any spikes at the input without damaging the charger or downstream devices when using low-cost adapters or converters with poor regulation.
- OVP is not the absolute maximum rating; electrical overstress can occur when voltage or current exceeds absolute maximum ratings.
- Chargers with integrated OVP save board area and cost.

Featured products

BQ25171-Q1 | 800-mA 40-V absolute maximum 1S linear charger
BQ25798 | 5-A 30-V absolute maximum 1S to 4S buck-boost charger

VBUS OVP response – scope capture

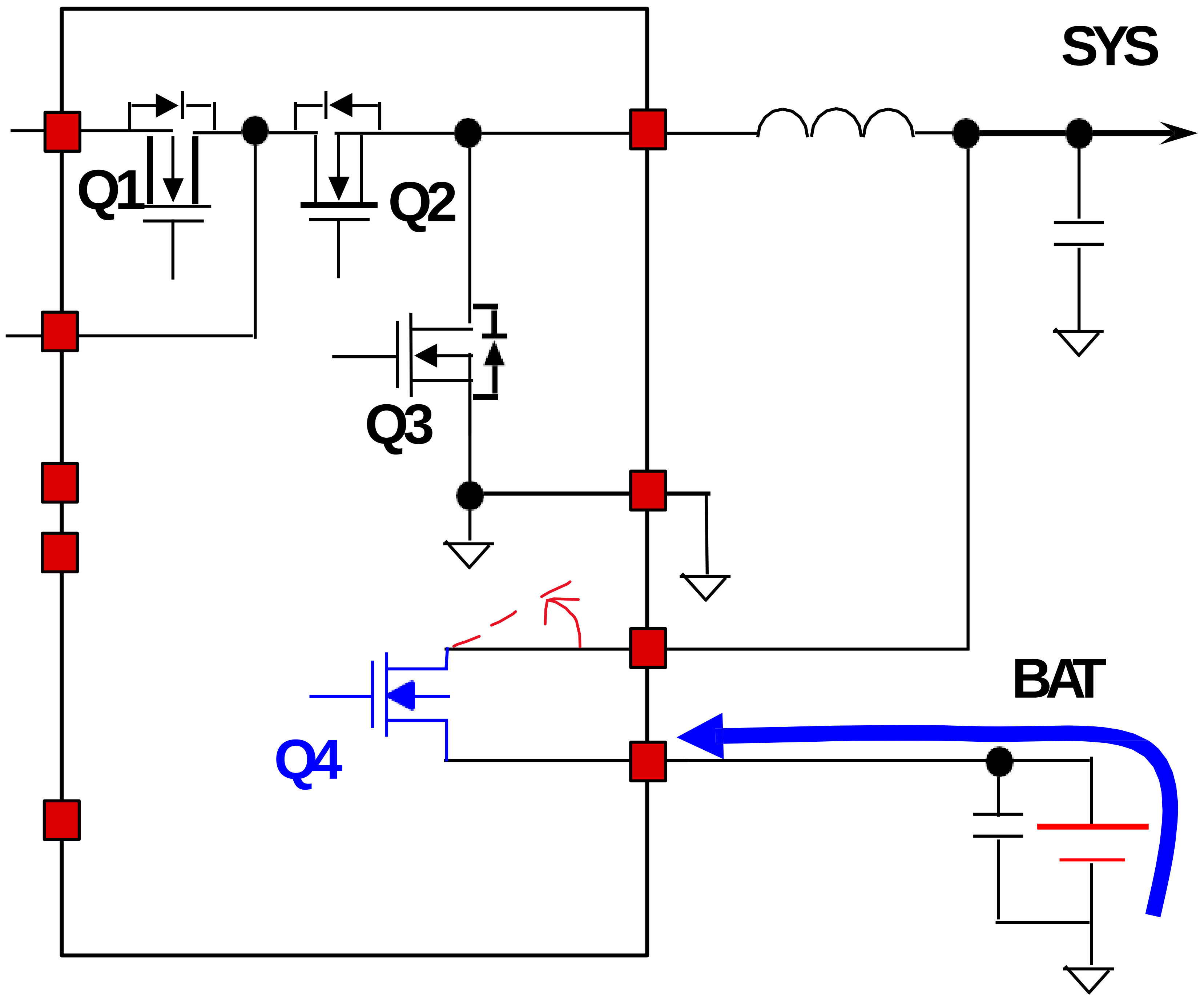


Battery undervoltage lockout (BUVLO)

What is BUVLO?

- In BUVLO, BATFET is off; isolate the SYS from the battery.
- Turning off BATFET (Q4) when below the UVLO threshold prevents deep battery discharge.
- BUVLO voltage threshold is configurable for variable applications, typically around 2.2 V to 3.0 V.
- Preventing over discharge increases the lifespan of the battery.
- Less need for an additional battery-protector IC.

BUVLO control loop

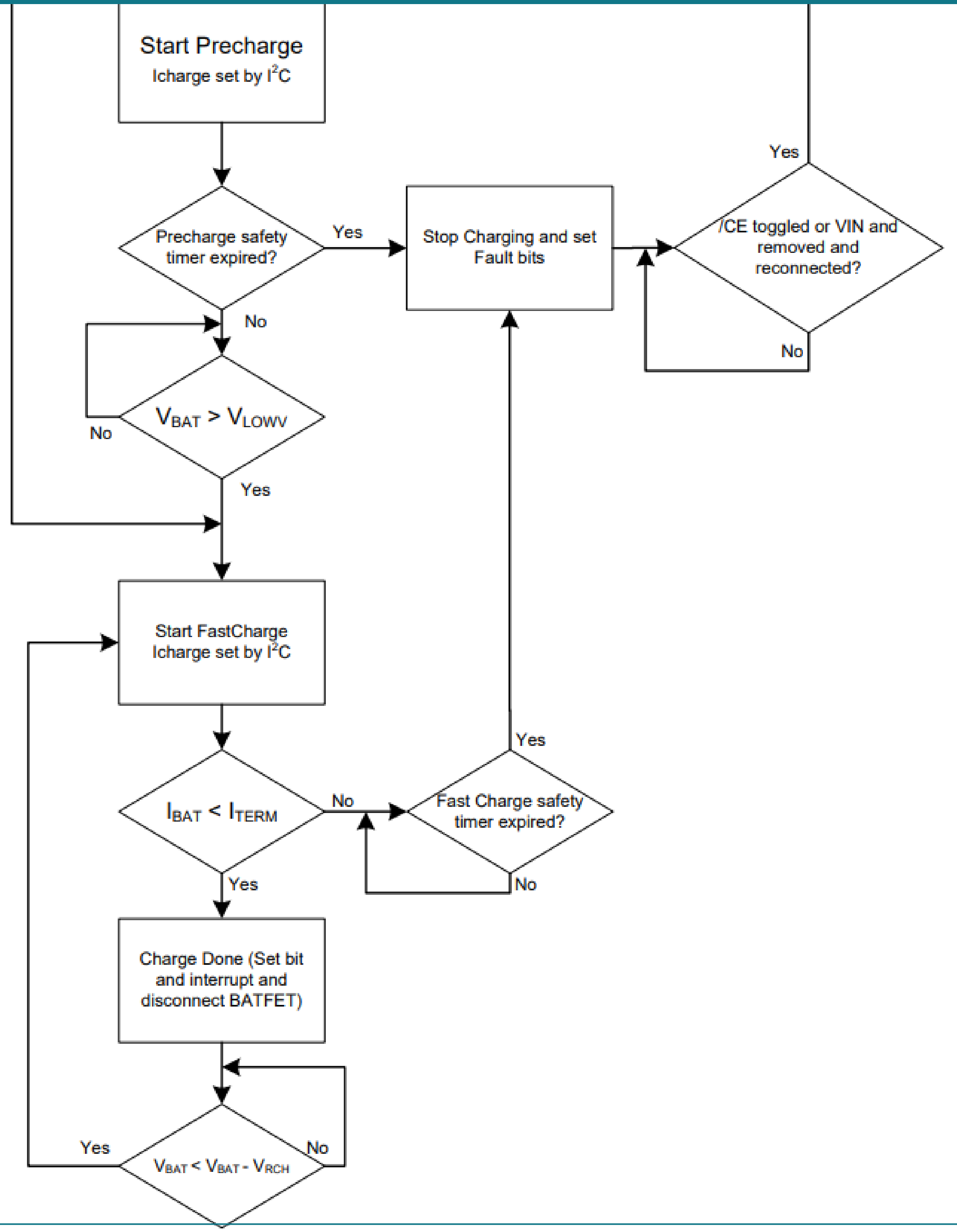


Safety timers

Safety timer modes of operation

- 10-hour safety timer limits the time during which the device can be in fast charge mode.
- 30-minute safety timer for pre-charge.
- Prevents continuous charging of a damaged battery or defective board.
- Safety timer duration doubles during faults that reduce charging current (V_{INDPM}, TS).
- Configurable by the host on I^2C chargers or through the TMR pin on stand-alone offerings.

Safety timer – flow chart



Thermal regulation and protection loops

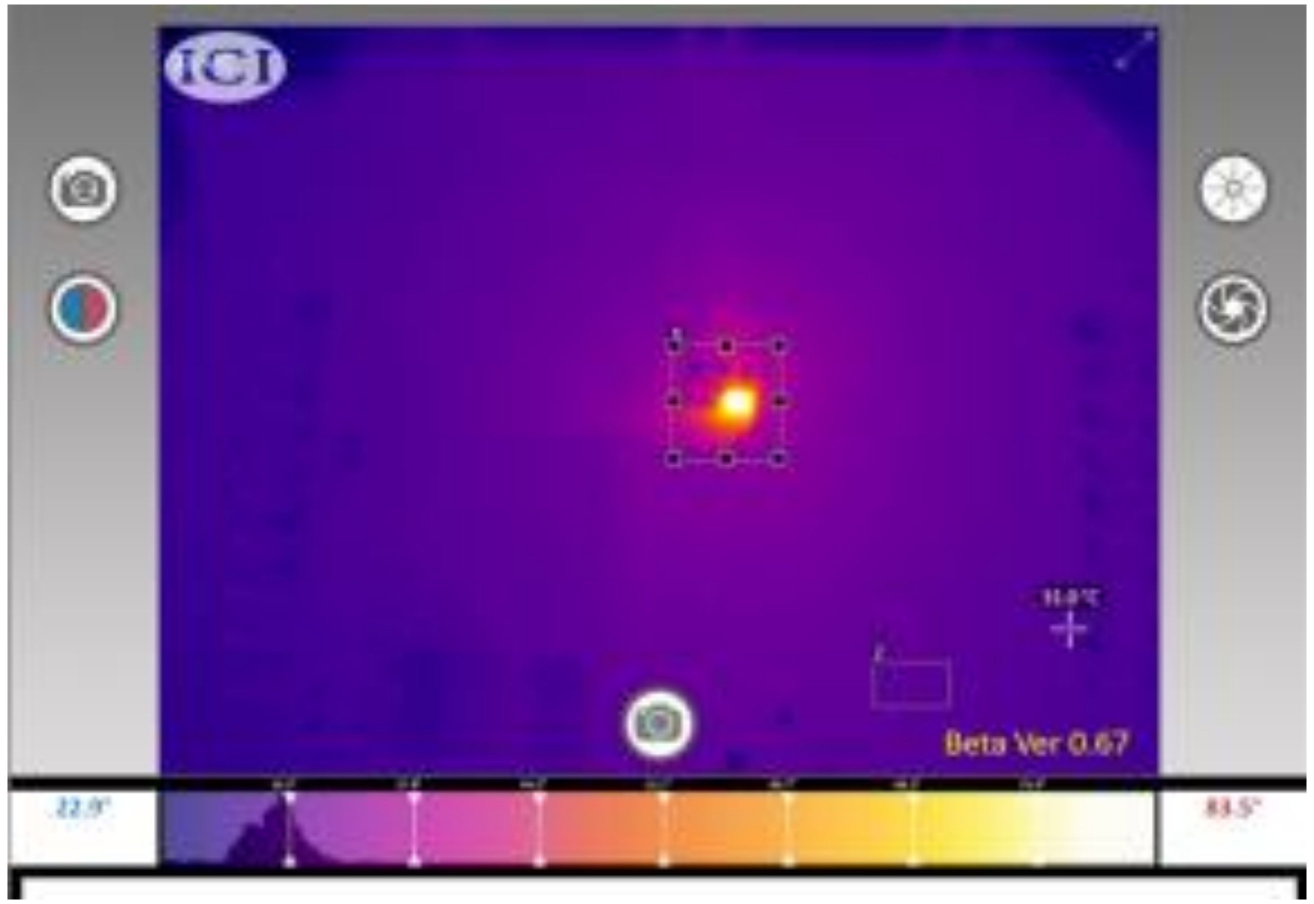
Thermal management functions

- TREG – regulates the IC junction temperature by reducing charge current above 125°C.
- TSHUT – turns off the charger when the IC junction temperature is excessive, >150°C.
- Slow down the safety timers when the charge current is reduced by the thermal loop, avoiding a false safety timer fault.

Calculating thermal budget

- Maximum power dissipated in the IC occurs at the minimum fast charge voltage (usually 2.5 V to 3 V).
- $R_{\theta JA}$ represents the junction-to-ambient thermal resistance, available in data sheets or EVM user's guides.

Power dissipation



$$P_{LOSS} = (V_{IN} - V_{BAT}) \times I_{CHG}$$

$$T_J = T_{AMB} + R_{\theta JA} \times P_{LOSS}$$

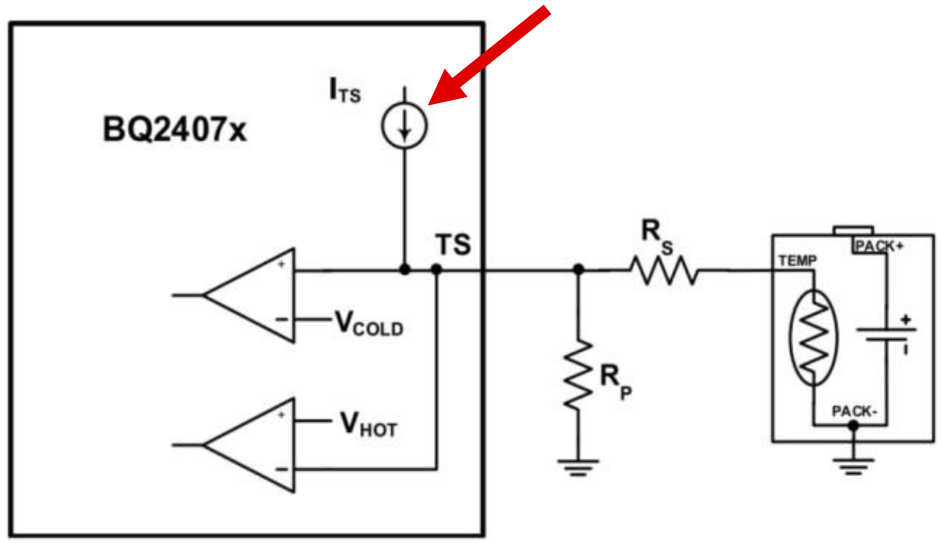
NTC monitoring

Types of NTC monitoring

- Charging the battery at safe temperatures is very important to improve battery life.
- Charging is allowed at safe temperatures, typically 0 – 60C
- TI chargers have two types of NTC monitoring: current and voltage based

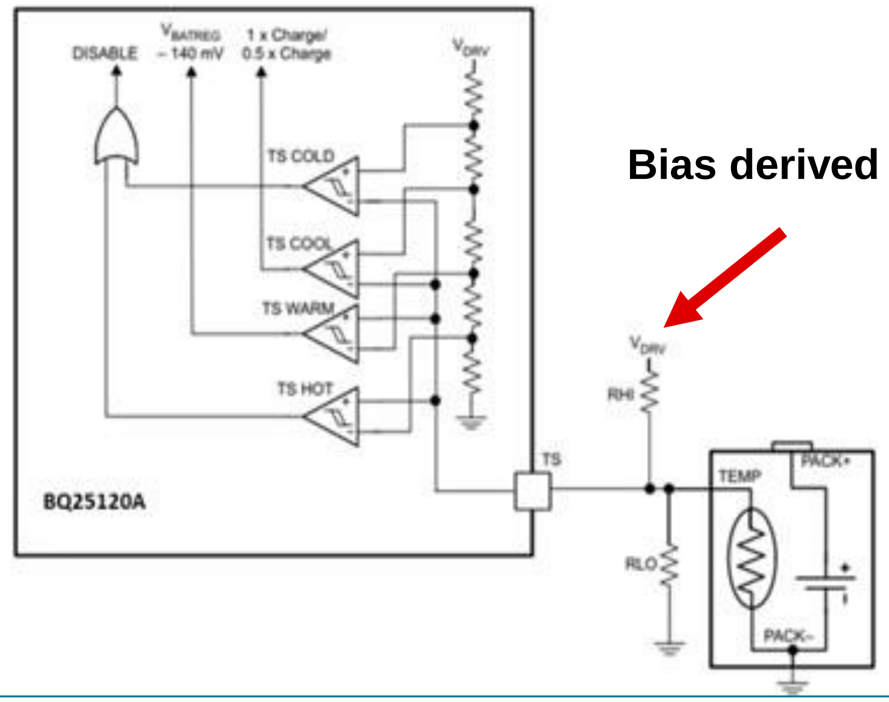
Current-based monitoring

Internal current source



Voltage-based monitoring

Bias derived from adapter



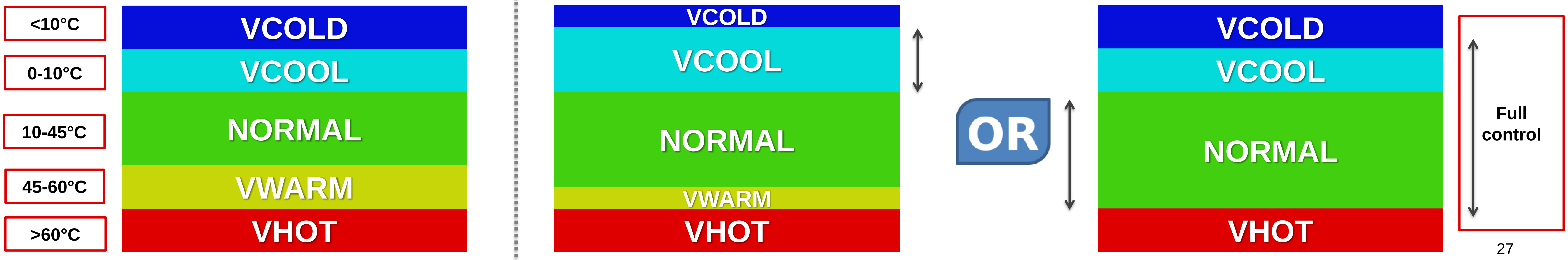
Battery temperature monitoring – beyond JEITA

Using the charger's temperature-monitoring capability

- Various applications these days demand operation over wide thermal regions.
- Making BOM changes or adding Rs/Rp to adjust for JEITA is often not possible.
- Using a charger that can support software configurability of cutoffs and actions provides design and BOM flexibility.

Most chargers:
Fixed thresholds

TI chargers with configurable JEITA:
Variable thresholds on software



Input detection (D+/D–)

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What is USB D+/D– detection?

D+/D– detection overview

- Industry standard:
  - Used to identify current and communications capability of adapters.
  - USB Battery Charging Specification Rev 1.2 (**BC1.2**) compatibility.
- Why USB D+/D– detection?
  - Maximize current potential of adapter.
  - More efficient power management.
  - Universal charging for convenience.
  - Less e-waste.

Featured products

BQ25611D | 3-A 1S buck charger with USB detection

OTG mode

OTG boost

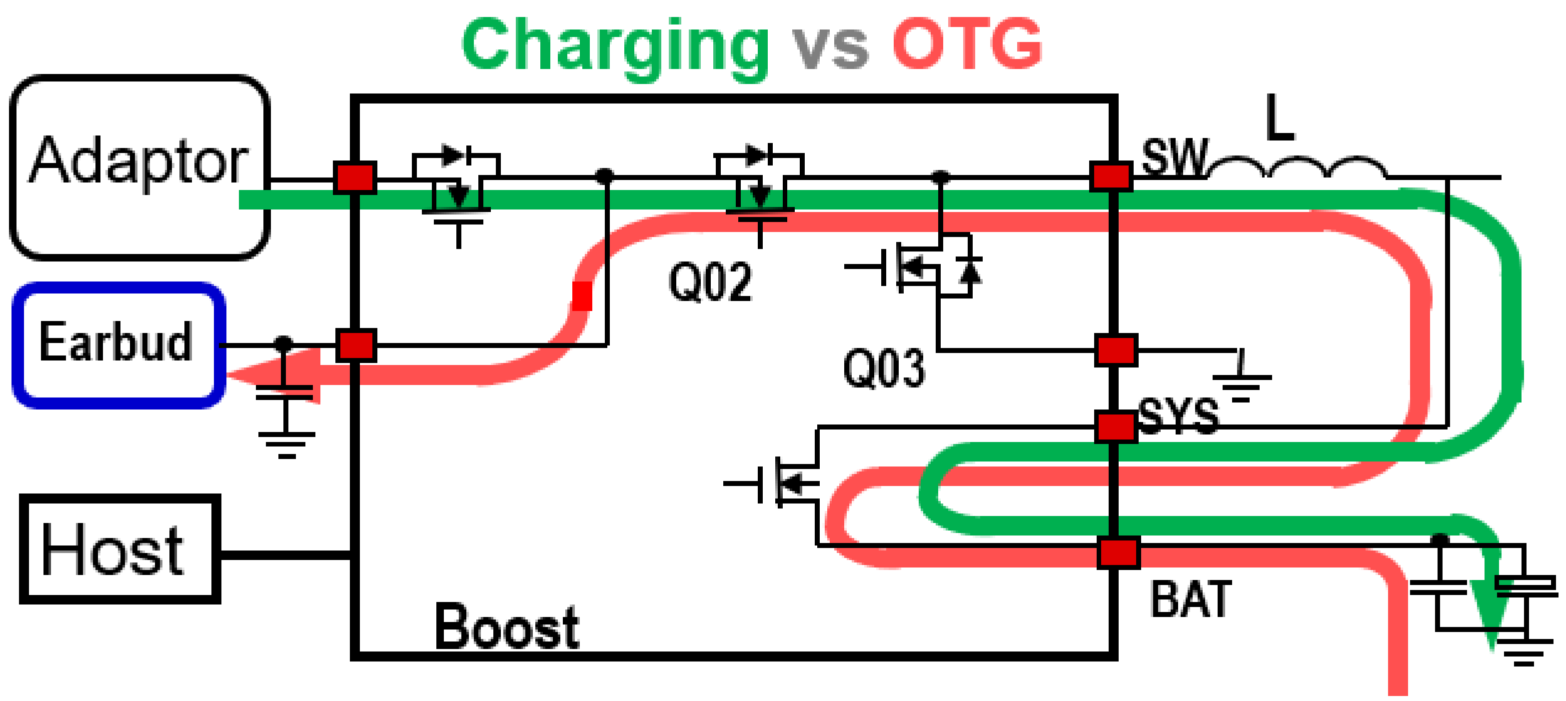
OTG overview

- OTG boost saves a switching converter for power-bank-type applications.
- Provides an adjustable boost output voltage.
- Battery temperature monitoring for safe discharging.

Featured products

BQ25619 | 1.5-A buck charger
BQ25611D | 3-A 1S buck charger

OTG control loops



Chargers – application diagrams

BQ25171-Q1: Application diagram for lithium-based batteries

Wide input voltage range supports 1S or 2S charging with 18-V OVP
Abs Max: 40 V

CHM_TMR programs chemistry and charge timer:
Safety timer disable
10 hours
5 hours

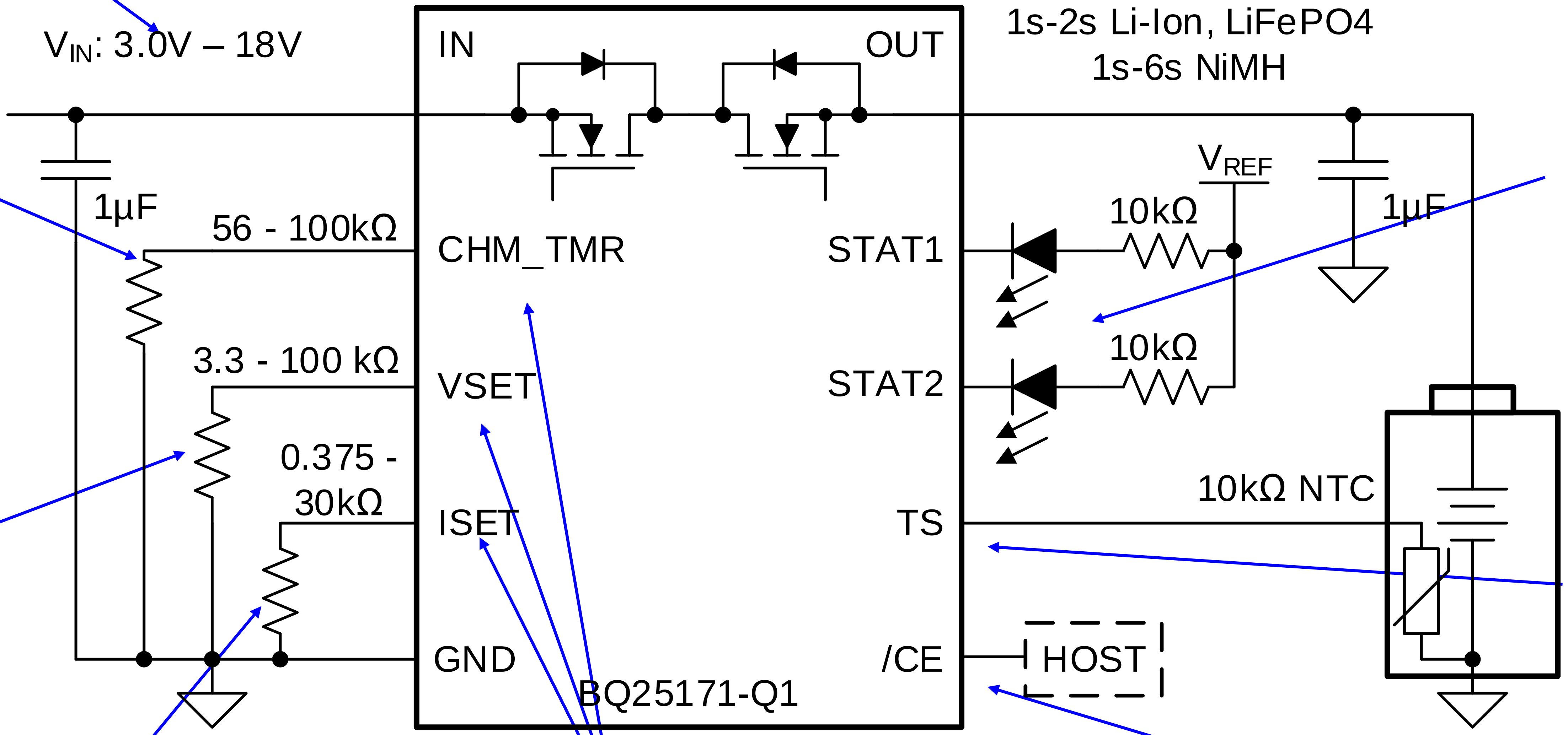
VSET programmable levels:

1S:	**2S:**
3.5 V	7.0 V
3.6 V	7.2 V
3.7 V	7.4 V
3.8 V	
3.9 V	
4.05 V	
4.1 V	8.2 V
4.2 V	8.4 V
4.35 V	

Continuously programmable charge-current pin from 10 mA to 800 mA

3.0-mm-by-3.0-mm[2] QFN 10-pin package

Automatic charge cycle control of pre-charge, fast-charge and CV modes with IPRECHG and ITERM
Battery OVP and OCP



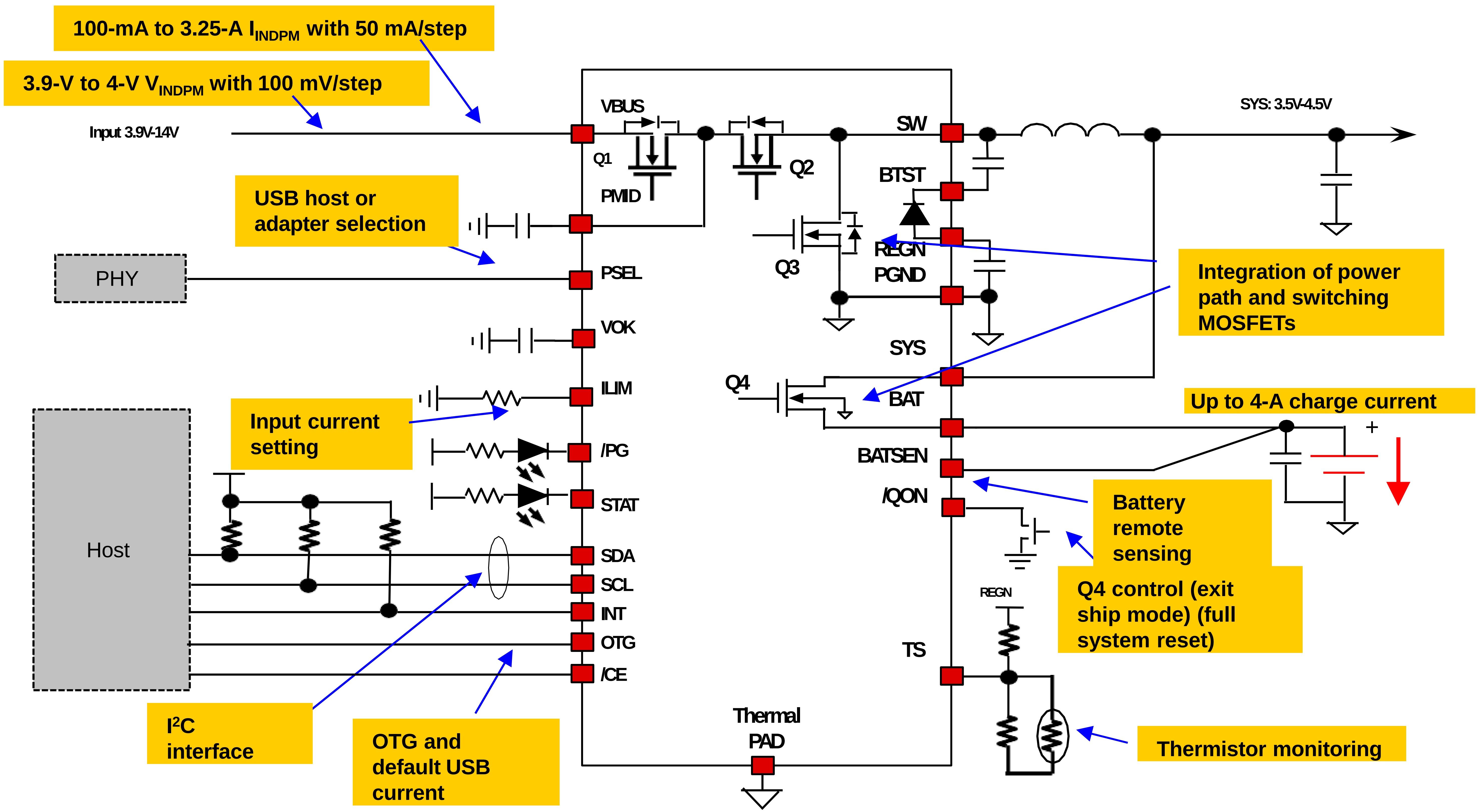
Four-state battery charger status indicator

Battery temperature sensing for safe battery charging with hot/cold profile

/CE pin for immediate host control of charger function

Pin-short and pin-open protection

BQ25898 application diagram



Additional resources to help complete your design

TI.com charger selection

- TI.com/chargers is a great tool to select the right charger for your system.
- You can select multiple parameters like battery chemistry, control topology and features to meet system requirements.

Cell chemistry

OR

- [ ] Lead Acid
- [x] Li-Ion/Li-Polymer
- [ ] LiFePO4
- [ ] Lithium Phosphate/LiFePO4

Control topology

OR

- [ ] Flash Charger
- [x] Linear
- [ ] Switch-Mode Boost
- [ ] Switch-Mode Buck
- [ ] Switch-Mode Buck-boost

Features

- [x] Thermal Regulation
- [ ] USB C/PD
- [ ] USB D+/D-/BC1.2
- [ ] USB OTG
- [x] UVLO
- [x] VINDPM

Compare	Part Number (Filter by part number)	Number of series cells	Cell chemistry	Control topology	Charge current (Max) (A)	Operating Vin (Max) (V)	Battery charge voltage (Min) (V)	Battery charge voltage (Max) (V)	Absolute Vin (safety rating) (Max) ((V))	Control interface	Features	Package Group
☐	BQ25125 - Low IQ highly integrated battery charge management solution for wearables and IoT - New	1	Li-Ion/Li-Polymer	Linear	0.3	5.5	3.6	4.65	20	I2C	Integrated Buck Converter, Integrated LDO, JEITA BAT Temp Monitoring (Thermistor Pin), OVP, Power Path, Temp Monitoring (Thermistor Pin), Thermal Regulation, UVLO	DSBGA | 25
☐	BQ25150 - Low IQ linear battery charge management solution with LDO and ADC - New	1	Li-Ion/Li-Polymer	Linear	0.5	5.5	3.6	4.6	20	I2C	Integrated LDO, Power Path, JEITA BAT Temp Monitoring (Thermistor Pin), Temp Monitoring (Thermistor Pin), Integrated ADC, Thermal Regulation	DSBGA | 20
☐	BQ25120A - 700nA Low Iq Highly Integrated Battery Charge Management Solution	1	Li-Ion/Li-Polymer	Linear	0.3	5.5	3.6	4.65	20	I2C	Integrated Buck Converter, Integrated LDO, JEITA BAT Temp Monitoring (Thermistor Pin), OVP, Power Path, Temp Monitoring (Thermistor Pin), Thermal Regulation, UVLO	DSBGA | 25

How to leverage TI to expedite your design process

- TI E2E™ design forums.
- Application-specific system design pages.
- Reference designs.
- Training videos.
- All accessible from our home page.

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