TI POWER

Small chargers pack a powerful punch: combining buck-boost and USB Type C™ power delivery for maximum power density

Battery Management Deep Dive Training

October 2020

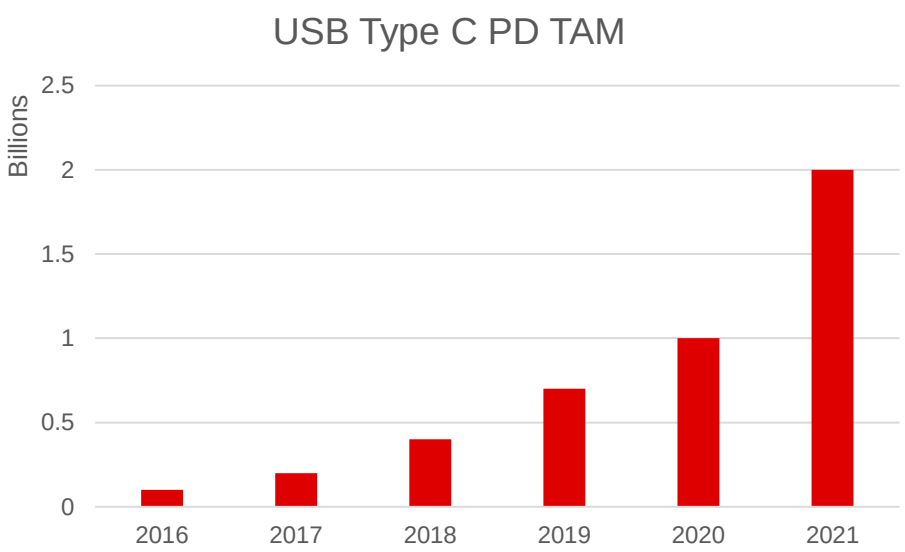
Steve Preissig

Agenda

- **USB Type-C™ PD market introduction**
- **Design consideration of a full integrated buck-boost charger for USB-PD**
  - *High integration level to maximize power density and facilitate system design*
  - *Efficiency optimization*
  - *Seamless transition among boost, buck-boost and buck operating modes*
  - *NVDC power path management*
  - *Minimize battery quiescent current, ship mode and shutdown mode*
  - *Dual-input power mux driver to support two input sources*
  - *Programmable JEITA for battery charging at different temperature*
  - *USB On-the-Go (OTG) mode and back up mode*
- **Overview of TI buck-boost charger product portfolio and reference design**

USB Type-C PD market and applications

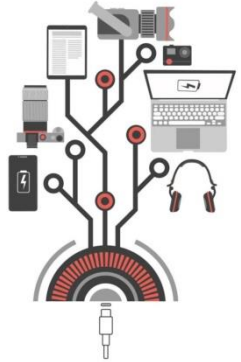
- New generation of personal electronics and industrial applications are employing USB Type-C PD charging
- Up to 100W of power can be delivered implementing USB Type-C PD charging



Why USB Type-C PD charging?

- **Before USB Type C:**
  - Need multiple different adapters to charge different applications

- **After USB Type C:**
  - Single adapter could be used to charge different applications
  - Universal charging trend is growing very fast in the past couple years

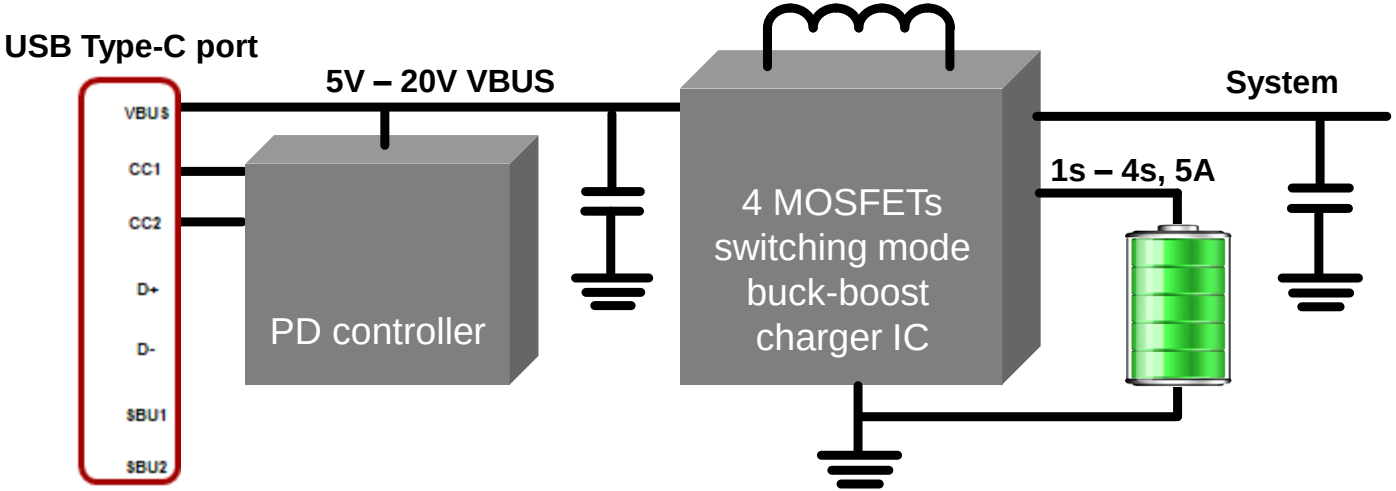


USB power delivery (PD) over USB Type-C

Precedence	Mode of operation	Nominal voltage	Maximum current
Highest	USB PD	Up to 20 V	Up to 5 A
	USB Type-C current @ 3A	5 V	3 A
	USB Type-C current @ 1.5A	5 V	1.5 A
	USB BC1.2	5 V	Up to 1.5 A
	USB 3.1	5V	900 mA
Lowest	USB 2.0	5V	500 mA

- **What is USB Power Delivery (PD)?**
  - USB Power Delivery is a charging technology, which uses USB Type-C cables and connectors to deliver higher levels of power to your devices.
  - USB PD adapter normally outputs 5 V and is compatible with USB 5 V adapter. It increases output voltage from 5 V to 9 V / 15 V / 20 V after handshake with charger to provide high voltage charging.

Overview of USB-PD system with buck-boost charger



1 cell

2 cells

2~4 cells

4 cells

- Step up/down buck-boost, the Vin and Vout combination could be very flexible
- Wide input voltage 5 V ~ 20 V, to charge multi-cell battery 1S~4S
- Support up to 100 W power delivery, 5V/3A, 9V/3A, 15V/3A, 20V/3A, 20V/5A

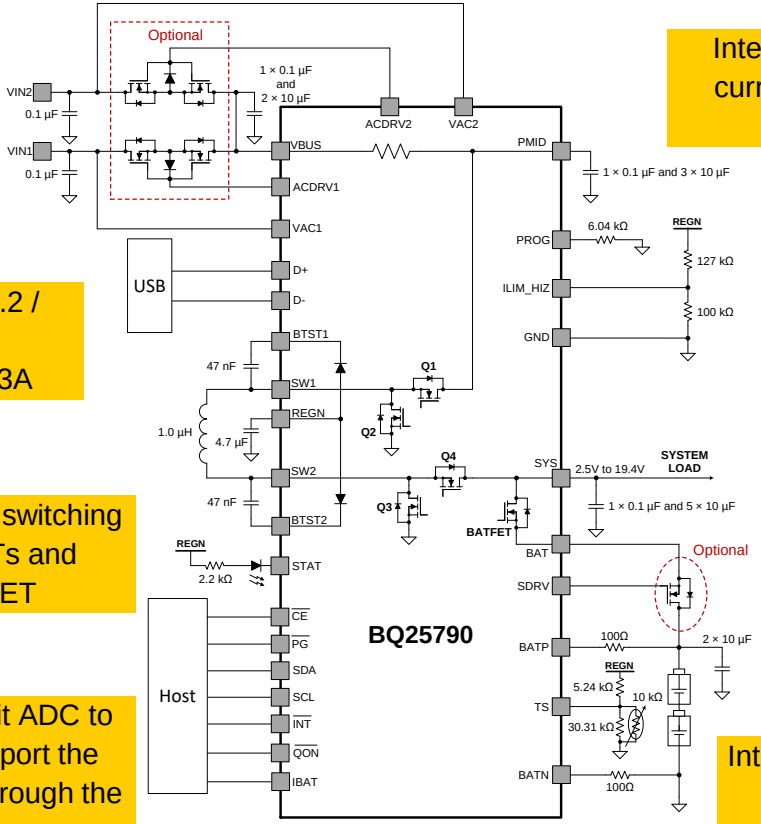
Fully integrated buck-boost charger: BQ25790

Dual-input power mux drivers to select adapter or wireless

D+/D- supports BC1.2 / HVDCP
IINDPM = 0.1A – 3.3A

Integrated 4 switching MOSFETs and BATFET

Integrated 16-bit ADC to monitor and report the system status through the I2C bus



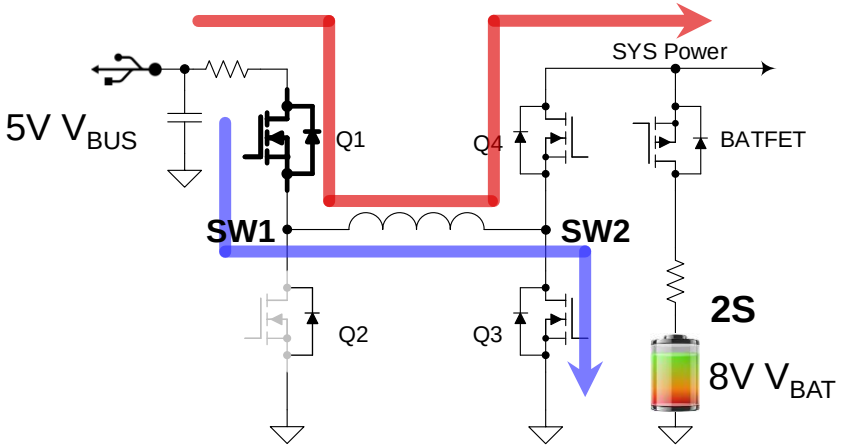
Integrated input current sensing circuitry

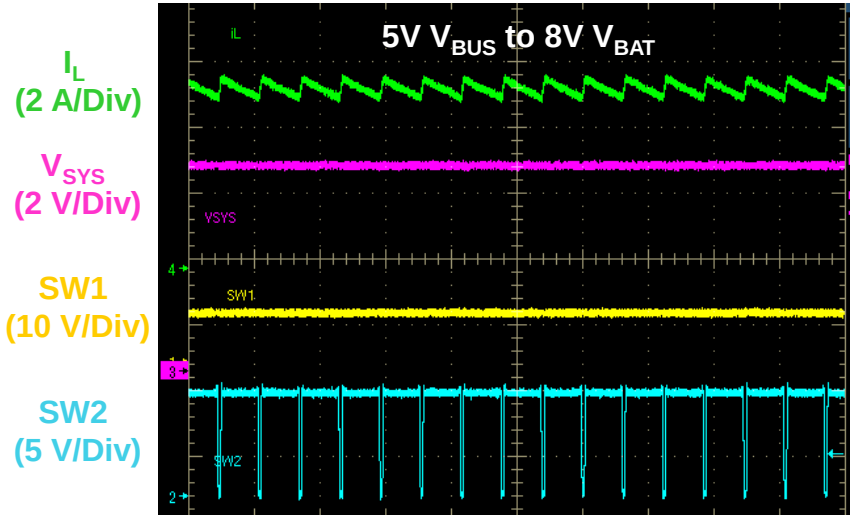
Integrated BATFET for NVDC power path management

Integrated ship FET driver for minimizing quiescent current

Integrated TS pin for NTC battery temperature sensing

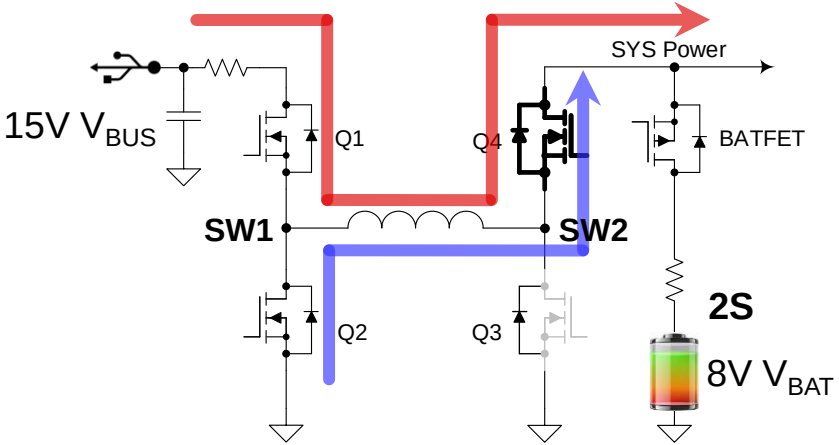
5V charges 2S battery in boost mode

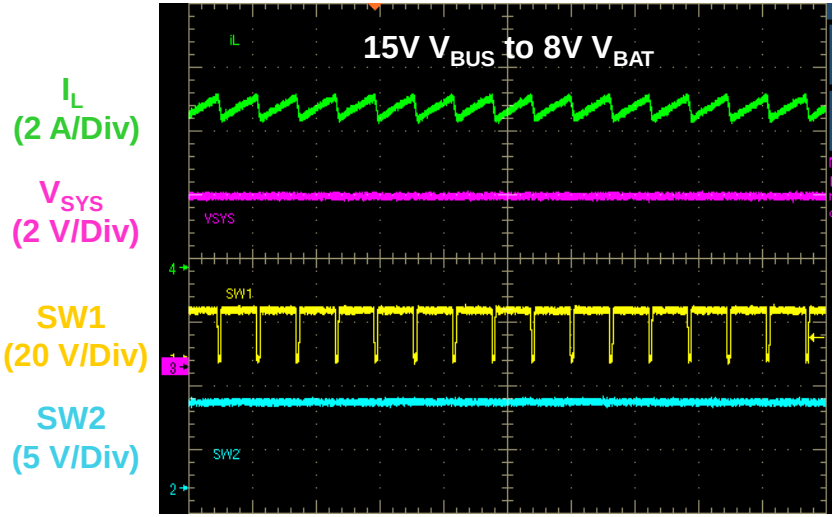




- Follow similar operation as a boost converter. Q2 always off and Q1 always on.
- In single converter switching cycle, only two MOSFETs Q3 and Q4 are switching.

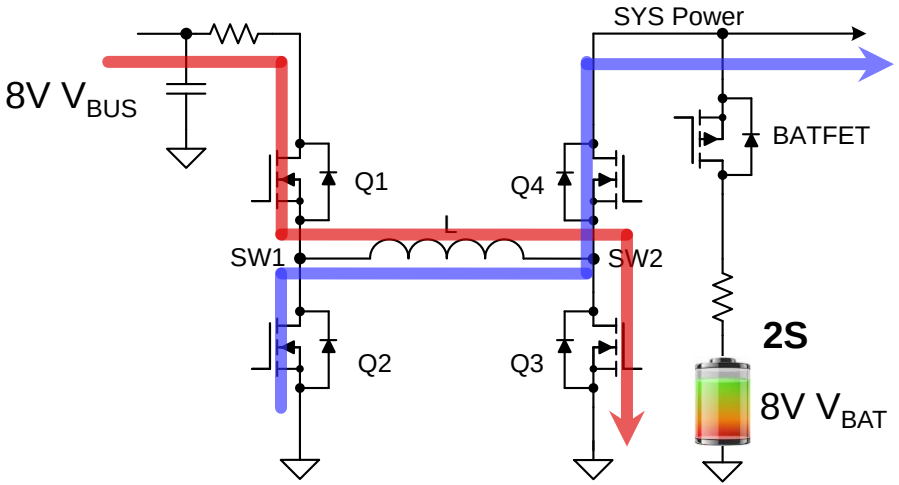
15V charges 2S battery in buck mode

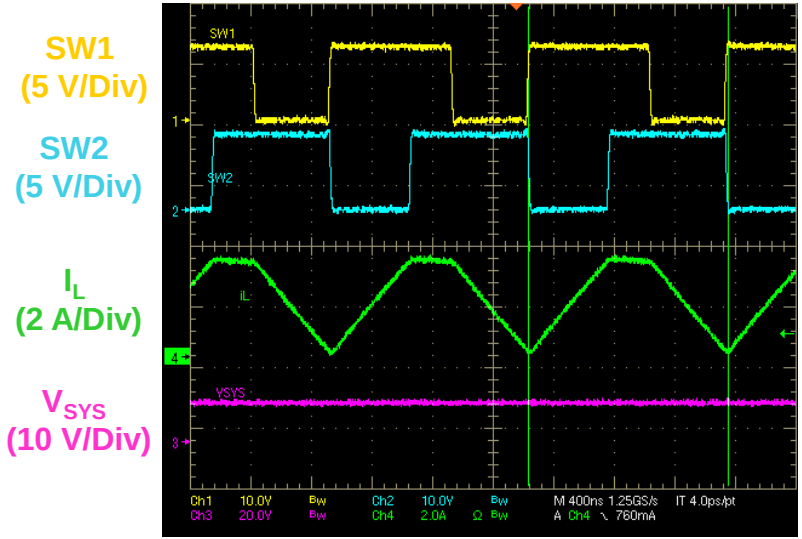




- Follow similar operation as a buck converter. Q3 always off and Q4 always on.
- In single converter switching cycle, only two MOSFETs Q1 and Q2 are switching.

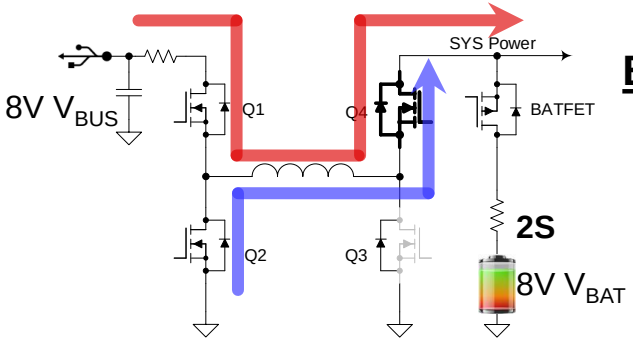
8V charges 2S battery in buck-boost mode (traditional)



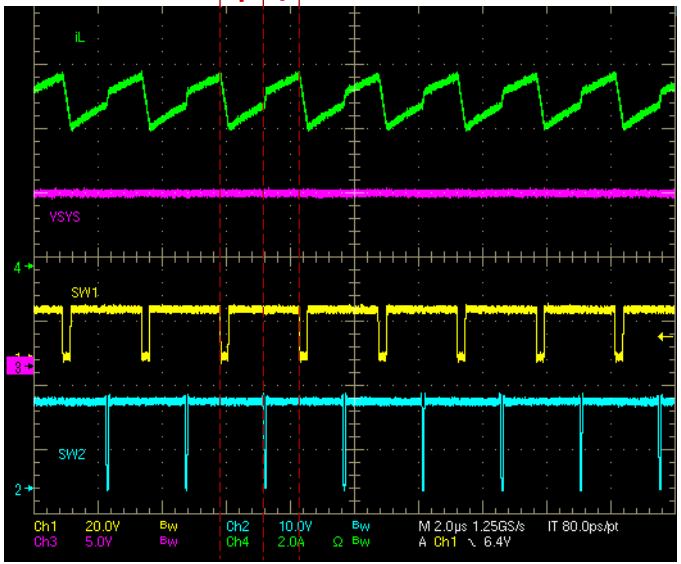


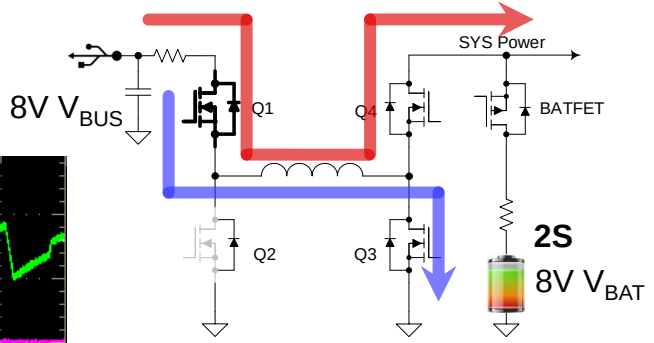
- All four MOSFETs are switching within a single switching cycle, higher switching loss than the buck or boost mode operation.
- Larger inductor current ripples than buck or boost operation, higher losses.

8V charges 2S battery in buck-boost mode (TI solution)



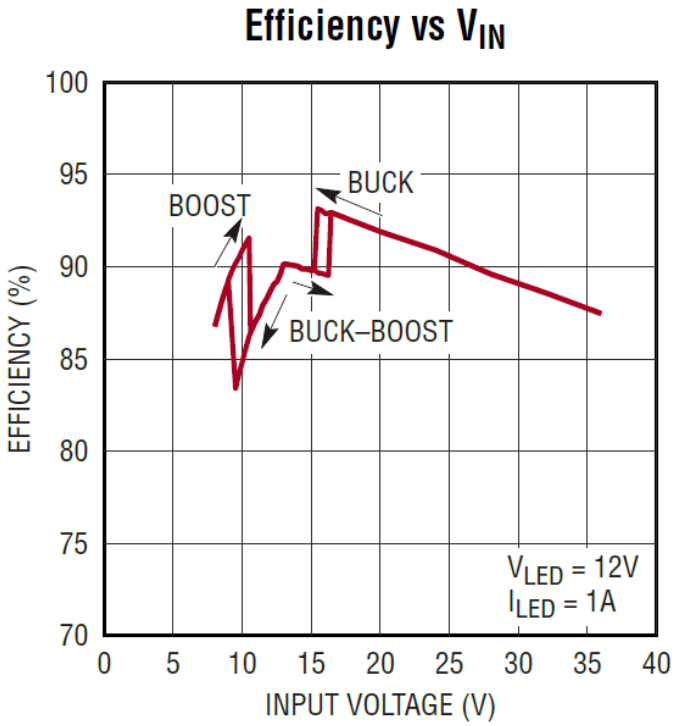
Buck **Boost**



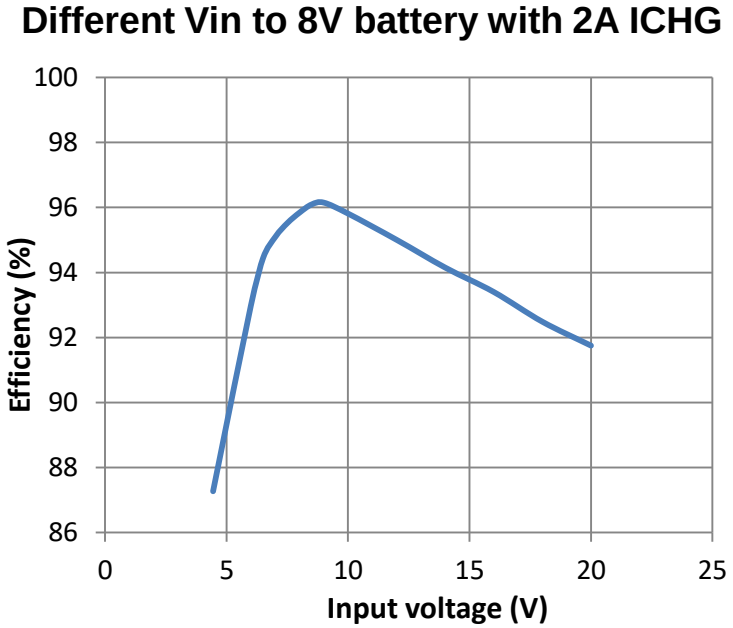


- The pure buck and boost mode are interleaving to achieve buck-boost operation.
- Equivalently, there are only two switching MOSFETs in one switching cycle.

Efficiency comparison

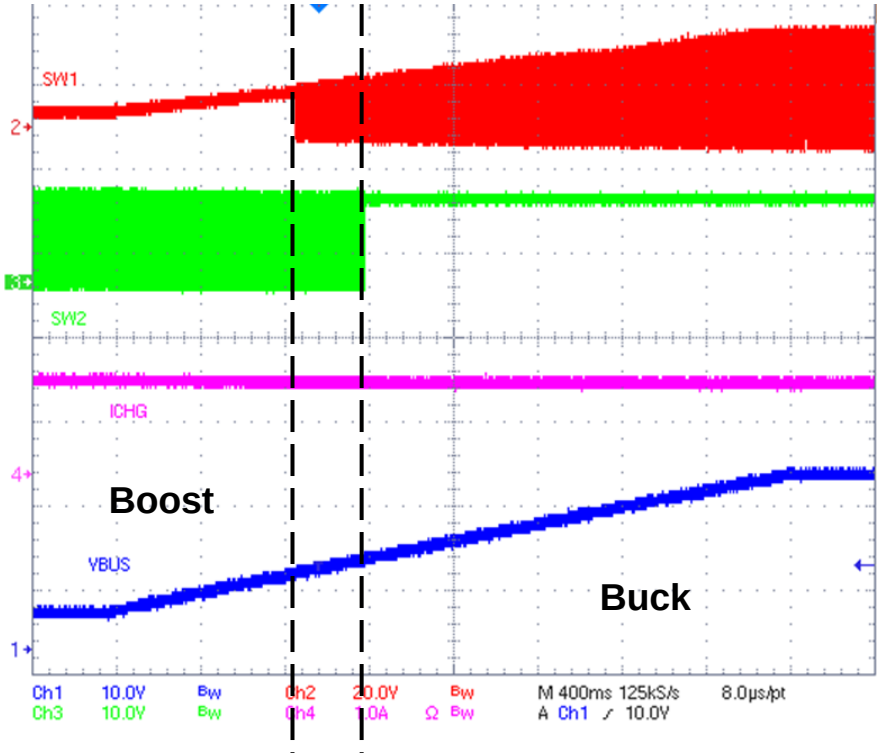


Traditional buck-boost operation



With high efficient buck-boost mode, there is no efficiency valley when Vin is changed

Seamless transition among different operating modes

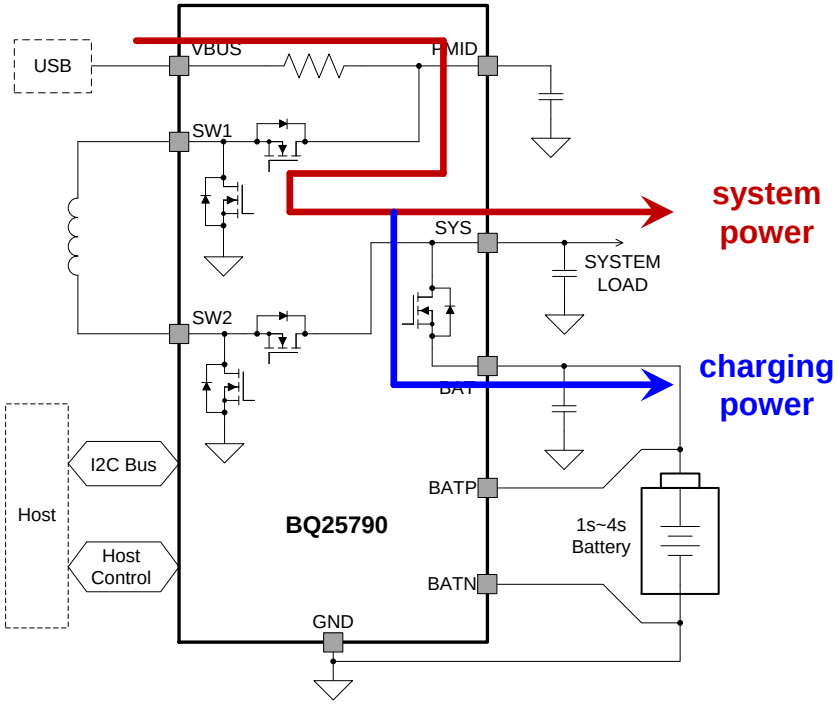


- Keep VBAT=8V, sweep VBUS from 5V to 20V, charge is enabled with 1A current
- The operating modes transient from boost, to buck-boost, then to buck mode
- The charging current is always kept at 1A regardless of VBUS voltage

No Dead Zone

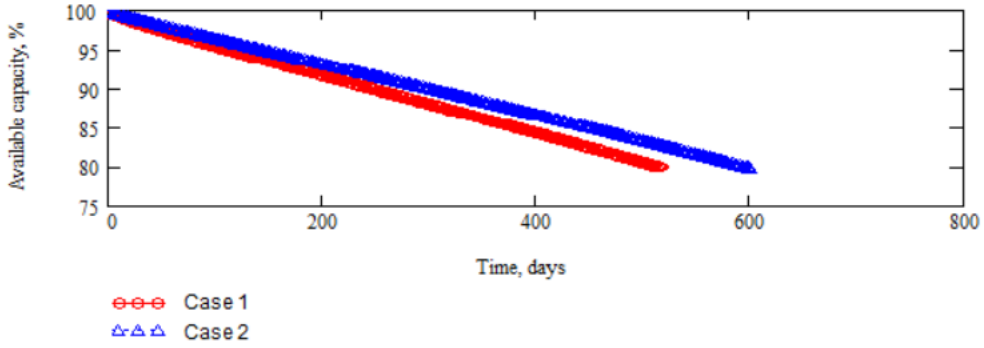
Integrated BATFET for NVDC power path management

- System can be powered from input source with deeply discharged battery
- System powered from the adapter through the buck-boost converter; charge current controlled by the BATFET
  - Extend battery life for applications with adapter attached for long period of time
- Separate charge current path from system current path, prioritize the system current with battery supplement the system when the adapter is overloaded
- Ideal topology when powering system and charging battery simultaneously



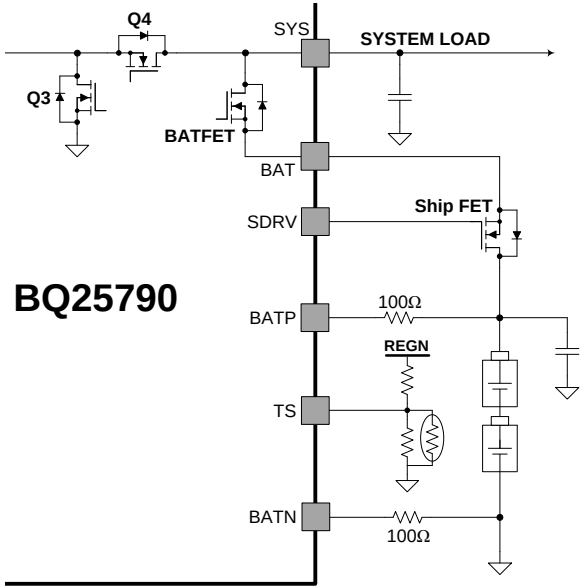
Extend battery life – 20% more operation time

- **Case 1:**
  - Charge from 0 to 100%.
  - No termination control. Charge is always enabled.
    - System load can discharge the battery below recharge threshold.
    - Battery is repetitively recharged before target time.
- **Case 2:**
  - Charge from 0 to 100%.
  - With Power Path control. Charge can be disabled while powering-up the system.
    - Battery is charged much less cycles before target time.



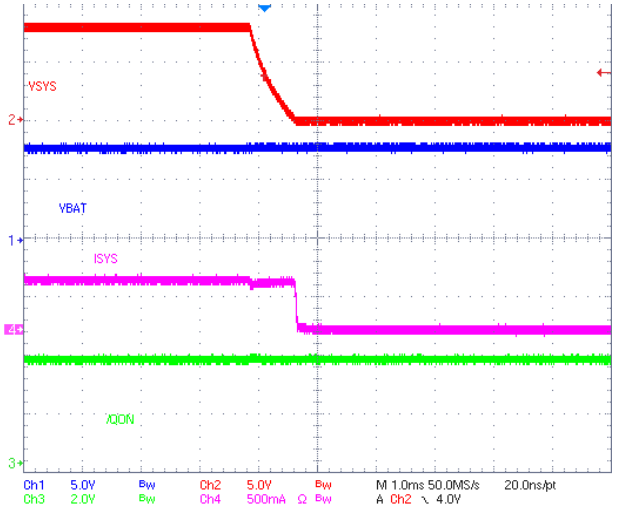
Swollen Battery

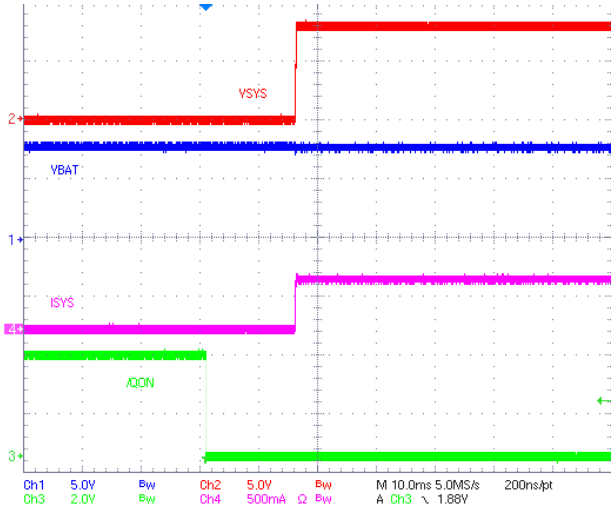
Minimize battery quiescent current, ship and shutdown mode



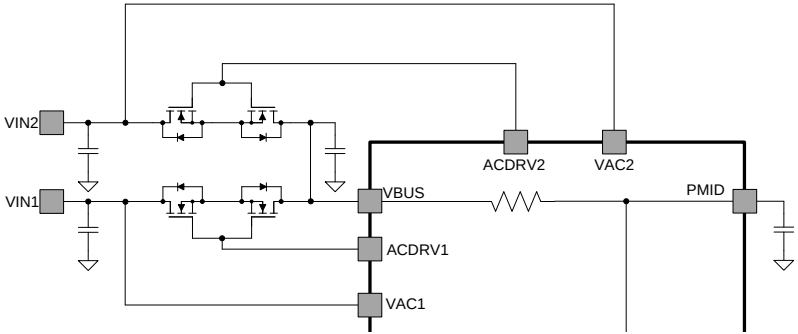
- Ship mode, 12uA Iddq
- Shutdown mode, 600nA Iddq

- The integrated BATFET is only one-directional blocking
- SDRV to drive the external ship N-FET, cut off the leakage current from battery to system
- Ship FET is optional, provides design flexibility

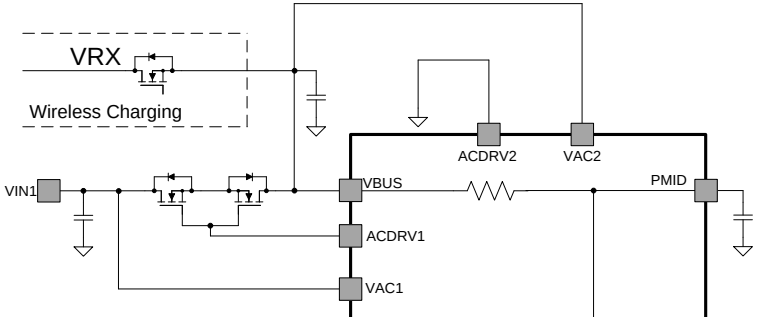




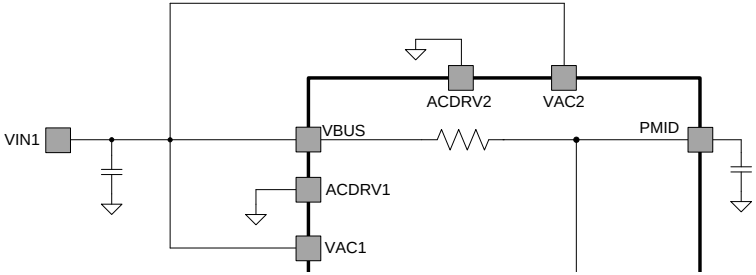
Dual-input power Mux for sources selection



Dual-input application with 4 NFETs



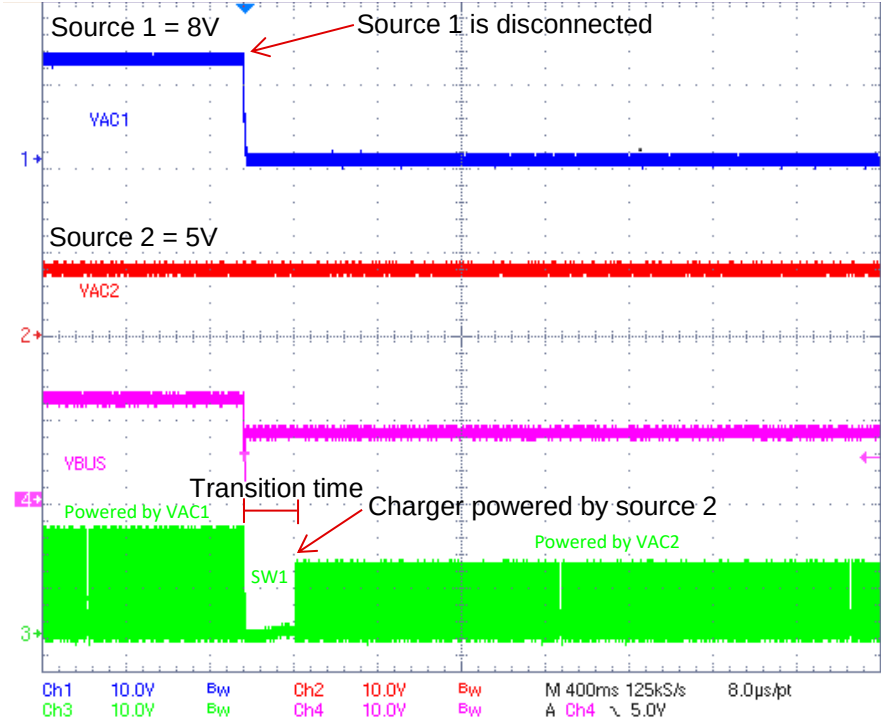
Dual-input application with 2 NFETs

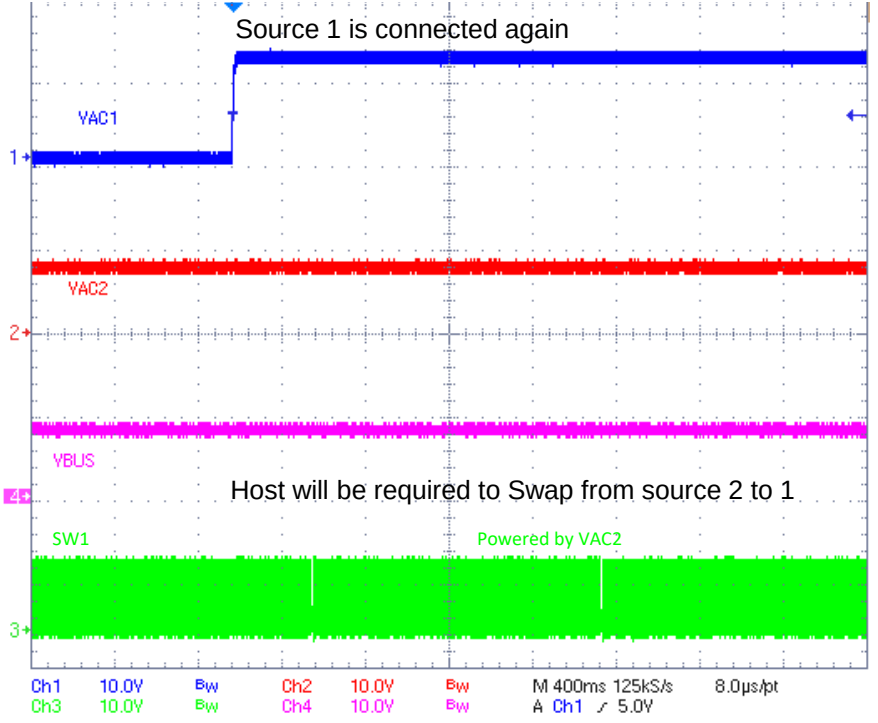


Single input application

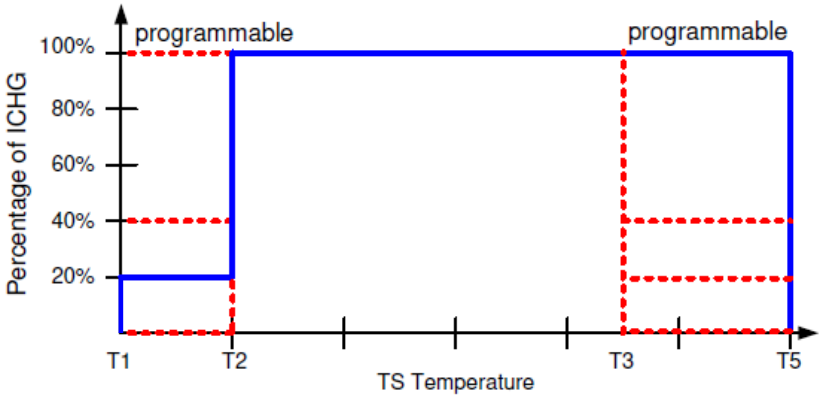
- At POR, charger detects the NFETs to determine which configuration it would be
- The first connected input source V_{IN} will be selected, and if two connected at the same time, selected input 1
- The host manages via I2C to swap between the two inputs
- When both inputs are present, if the selected input becomes invalid, the mux will swap the selected source to the other one automatically

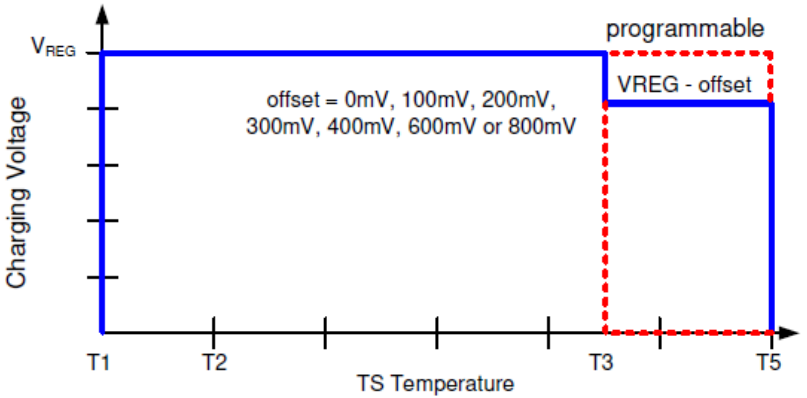
Input source transition from port 1 to port 2





Programmable JEITA protection



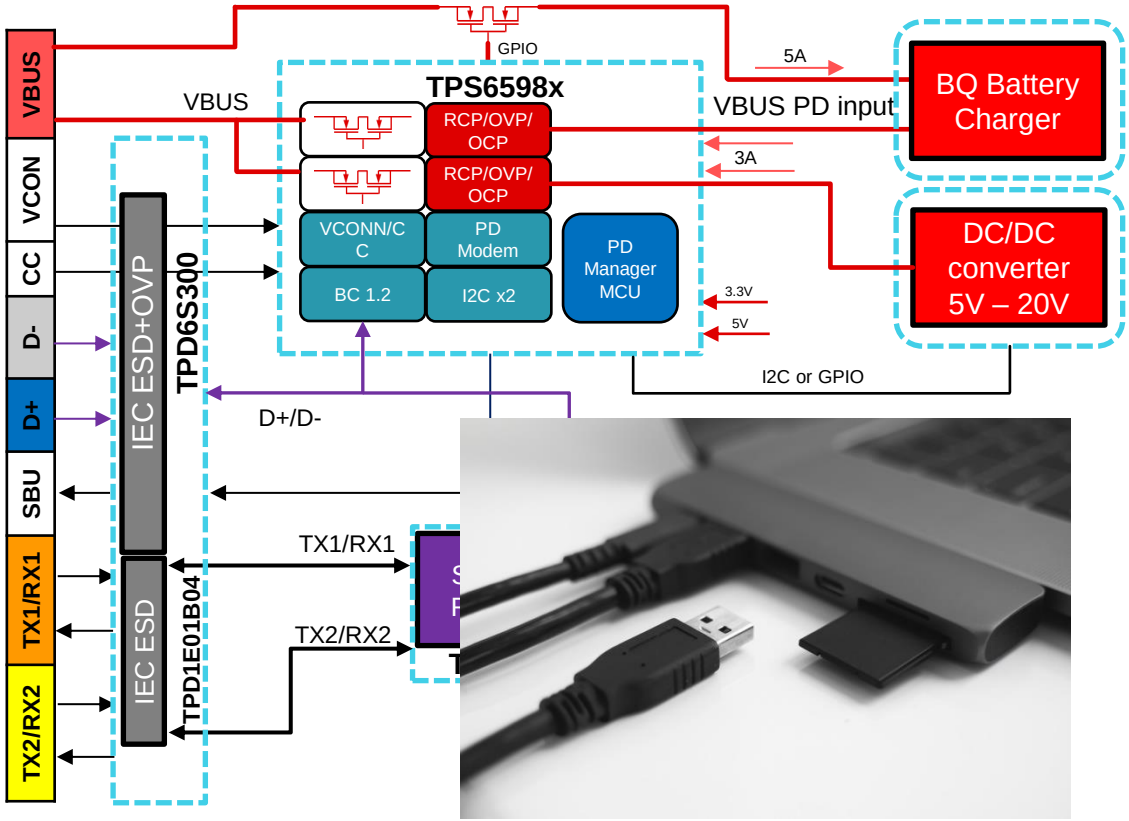


With one set of resistor divider (5.24kΩ + 30.31kΩ) as an example:

T_{COLD} (°C)	T_{COOL} (°C)	T_{WARM} (°C)	T_{HOT} (°C)
0	5, 10(default), 15, 20	40, 45(default), 50, 55	60

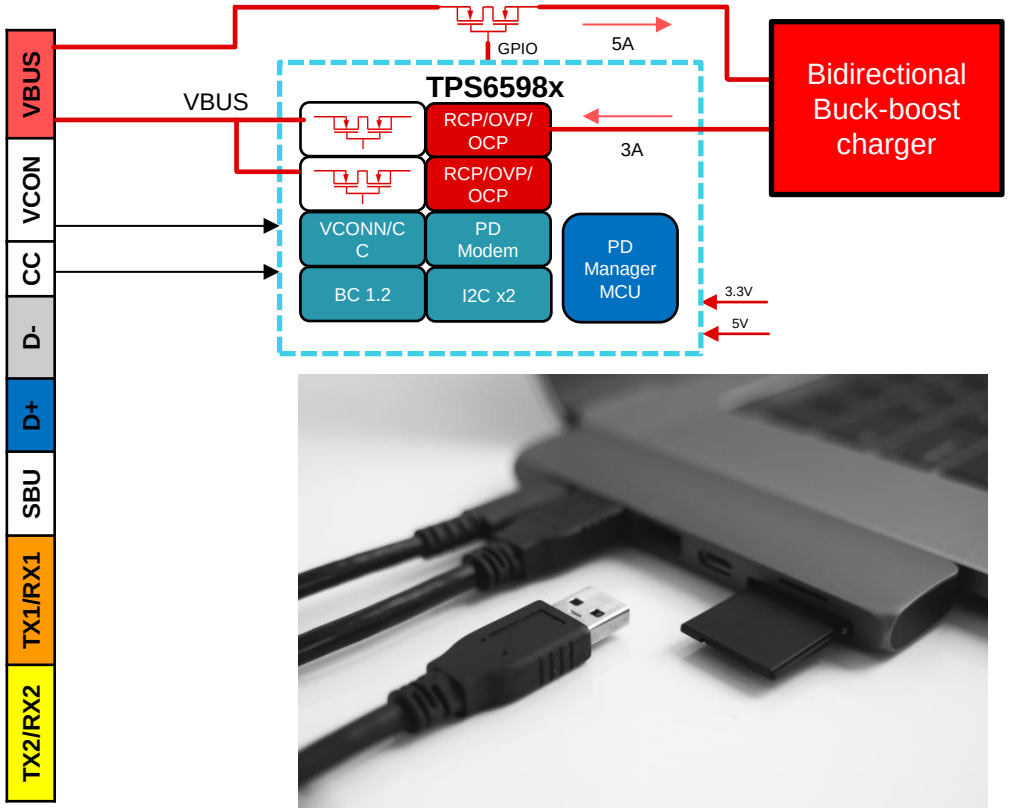
- Multiple temperature settings to program the COOL and WARM temperature for custom JEITA requirements
- Flexibility to set the VBAT voltage to VBAT-(800mV to 100mV) to ensure safe charging of battery in warm conditions

USB on-the-go (OTG) mode and fast role swap (FRS)



- **OTG:**
  - Start from no adapter condition
  - Enable the DC/DC converter to power the external device connected to the Type-C port
- **FRS:**
  - Start from the adapter present condition
  - The Type-C port is usually connected to a hub or docking stations
  - The adapter is charging the battery, and powering the other accessories connected to the hub
  - DC/DC converter is always enabled and standby with 5V output voltage
  - When the adapter is gone, PD controller turns the load switch, applies the DC/DC 5V output to VBUS, avoid the other accessories shutdown

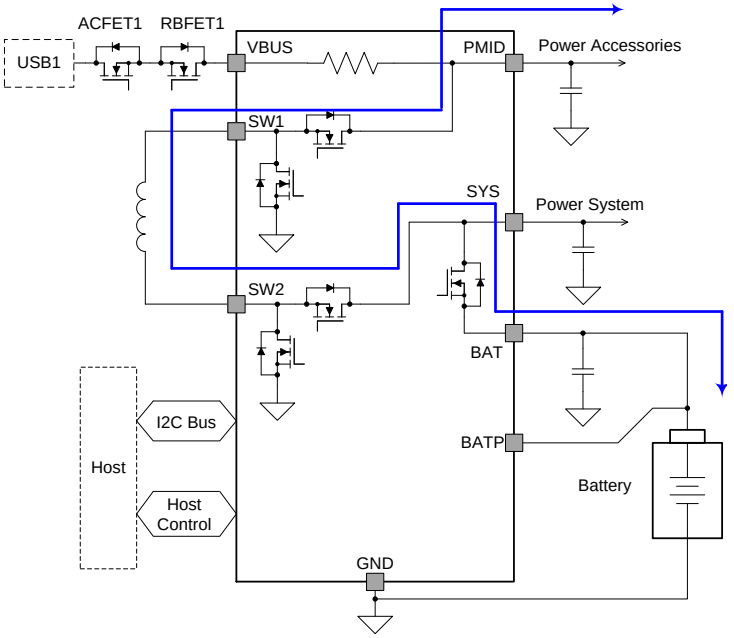
OTG and FRS by buck-boost charger

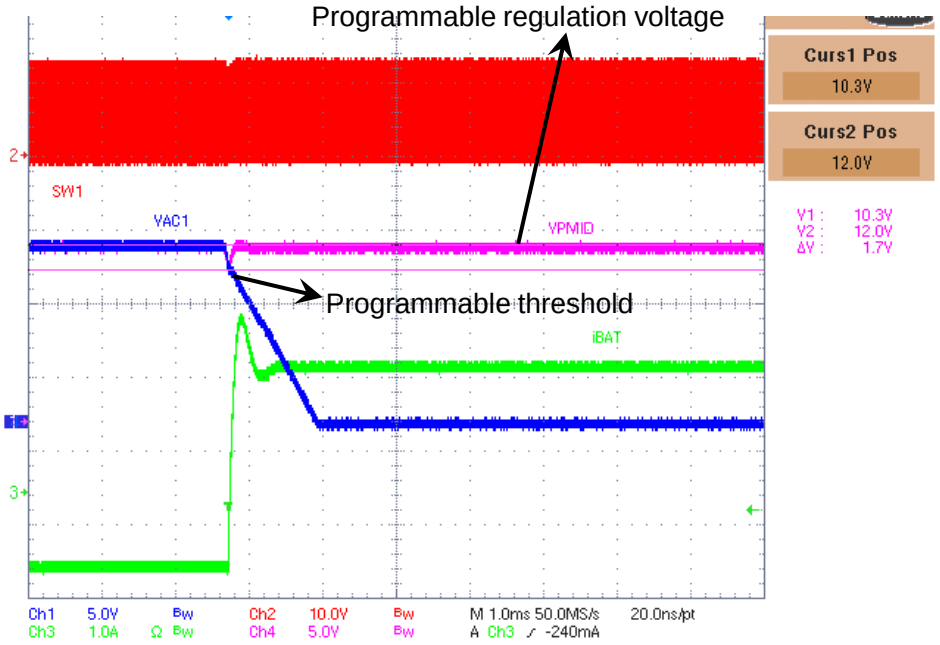


Both OTG and FRS can be implemented by the buck-boost charger bi-directional operation

- **OTG:**
  - When external device connected to the Type-C port, enable the buck-boost charger reversed operation to output voltage at VBUS
  - PD3.0 PPS compatible, 2.8V – 22V output voltage range with 10mV step size
  - Output supports CC/CV mode
- **FRS:**
  - When the adapter is present, the charger monitors the VBUS voltage
  - If VBUS drops lower than the preset threshold, the buck-boost charger starts the reversed operation, hold up VBUS to avoid the other accessories shutdown
  - Ultra-fast turn around of the buck-boost charger from forward mode to reversed mode is critical to prevent VBUS from dropping

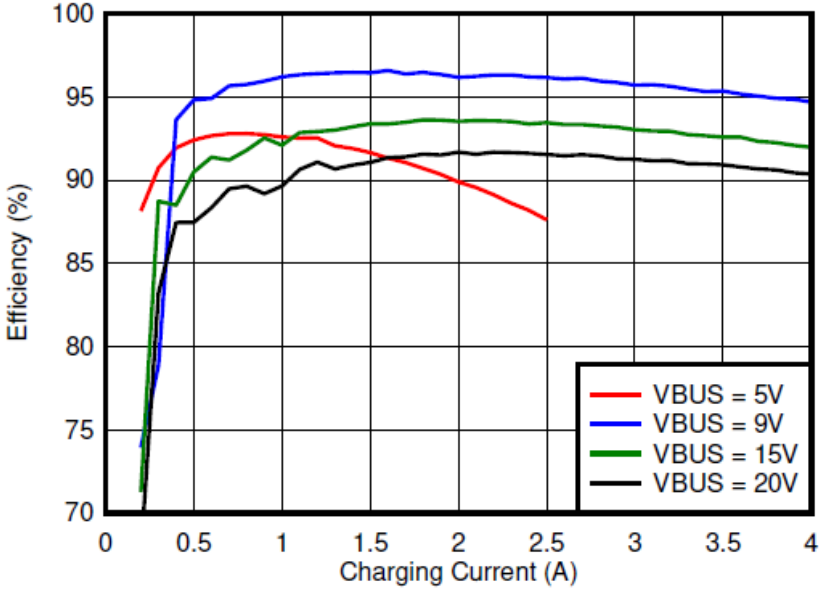
Ultra-fast transition from forward mode to reversed mode





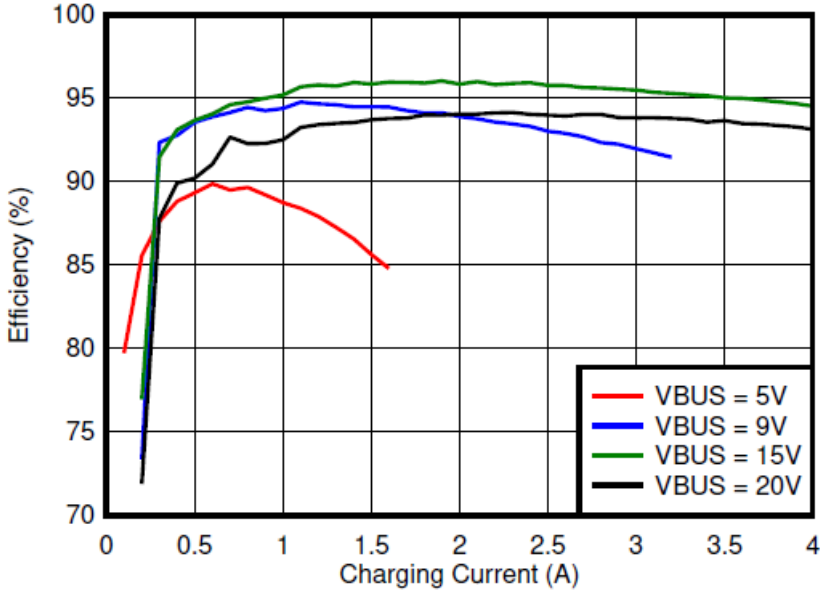
Ultra-fast transition from forward mode to reversed mode minimizes the VBUS undershoot when the adapter is disconnected

BQ25790 charging efficiency summary



VBAT = 8V, Fsw = 1.5MHz with L1 = 1µH, PFM disabled

Figure 1. 2s Battery Charge Efficiency vs. Charge Current

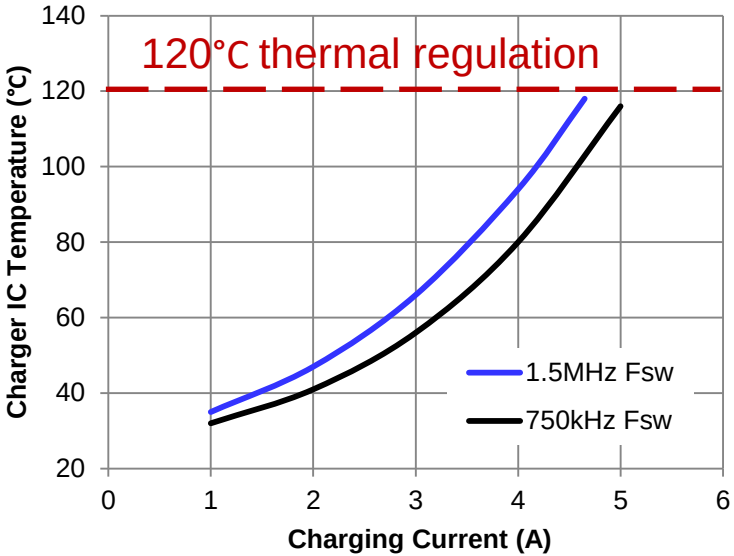


VBAT = 12V, Fsw = 1.5MHz with L1 = 1µH, PFM disabled

Figure 2. 3s Battery Charge Efficiency vs. Charge Current

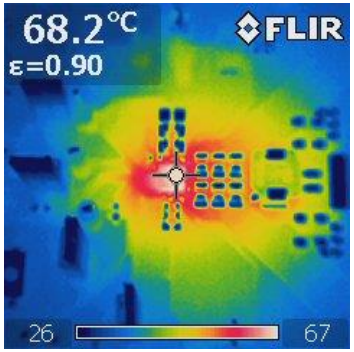
Charger IC temperature at heavy load conditions

15 V_{BUS} charges 8 V_{BAT} with different current

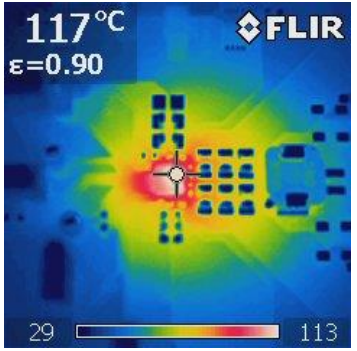


The integrated solution can handle up to 45W charging power

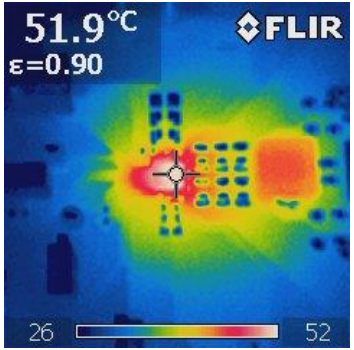
1.5MHz, 3A ICHG



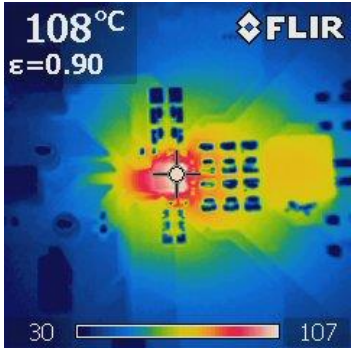
1.5MHz, 4.6A ICHG



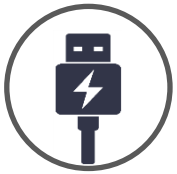
750kHz, 3A ICHG



750kHz, 5A ICHG



BQ25790/92 features overview

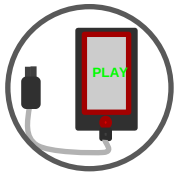


Integrated USB Source Detections

D+/D- and ICO to set input maximum current limit upon adapter plug in

1s-4s Li-ion Autonomous charging

Configurable battery voltage to charge from 3.6V – 24V input for full temperature range spec (-40 to 125C)



Power Path Management

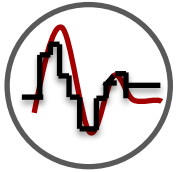
Dedicated charge control while powering up system. Termination control extends battery life time

USB On-the-Go

Boost up the battery voltage to the input port and provides regulated 2.8V – 22V output

Flexible JEITA

Programmable temperature ranges, battery voltage and charge current

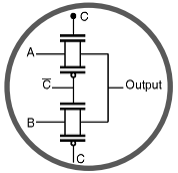


16-bit ADC

High performance 16-bit Sigma Delta ADC integrated to monitor VBUS, IBUS, VBAT, IBAT, VSYS, TS, etc.

Ship mode and Shutdown Mode

0.6uA Shut down mode current enables longer shelf battery life for better user experience



Dual-Input Mux

Dual input power mux control to support priority based selection

Buck-boost charger solution for applications >45W

Features

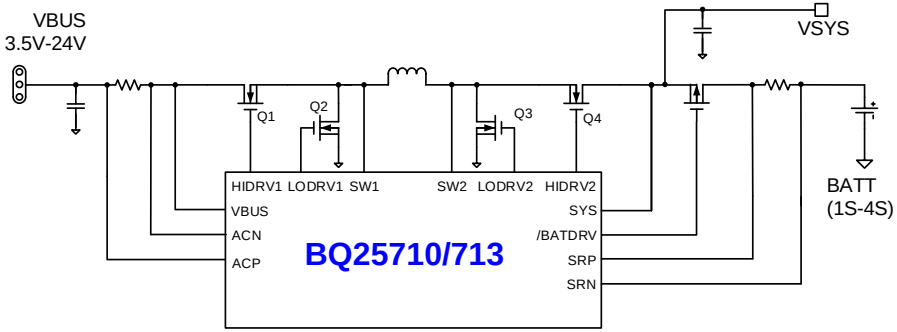
- Buck boost charger for 1-4 cell battery
  - Seamless transition among buck, buck-boost and boost modes
  - Unique buck-boost operation to achieve high Eff
- Wide input range from 3.5V to 24V
  - Input current setting up to 6.4A with 50mA step size
  - Max Power Tracking with input voltage and current regulation to optimize adapter output power
- USB OTG with adjustable output from 3V to 20.8V
  - 8mV VOTG step size compatible with USB-PD 3.0
  - IOTG regulation up to 6.4A with 50mA step size
- V_{MIN} Active Protection (VAP) to Prevent System Crash
- Programmable 800kHz/1.2MHz switching frequency
- Pass Through Mode for Efficiency/Thermal Improvement

Applications

- Ultrabook and 2-in-1 Tablet
- Handheld Terminal, Power Banks
- Industrial and Medical Equipment

Benefits

- OTG current regulation with uninterrupted OTG power source
- Instant-on with no battery or depleted battery
- Integrated ADC for voltage/current/power monitoring
- Battery supplements system when adapter is fully-loaded
- 710 SMBus / 713 I2C port for system optimization and status reporting
- Package: 32-pin QFN 4x4x0.75mm (RSN)



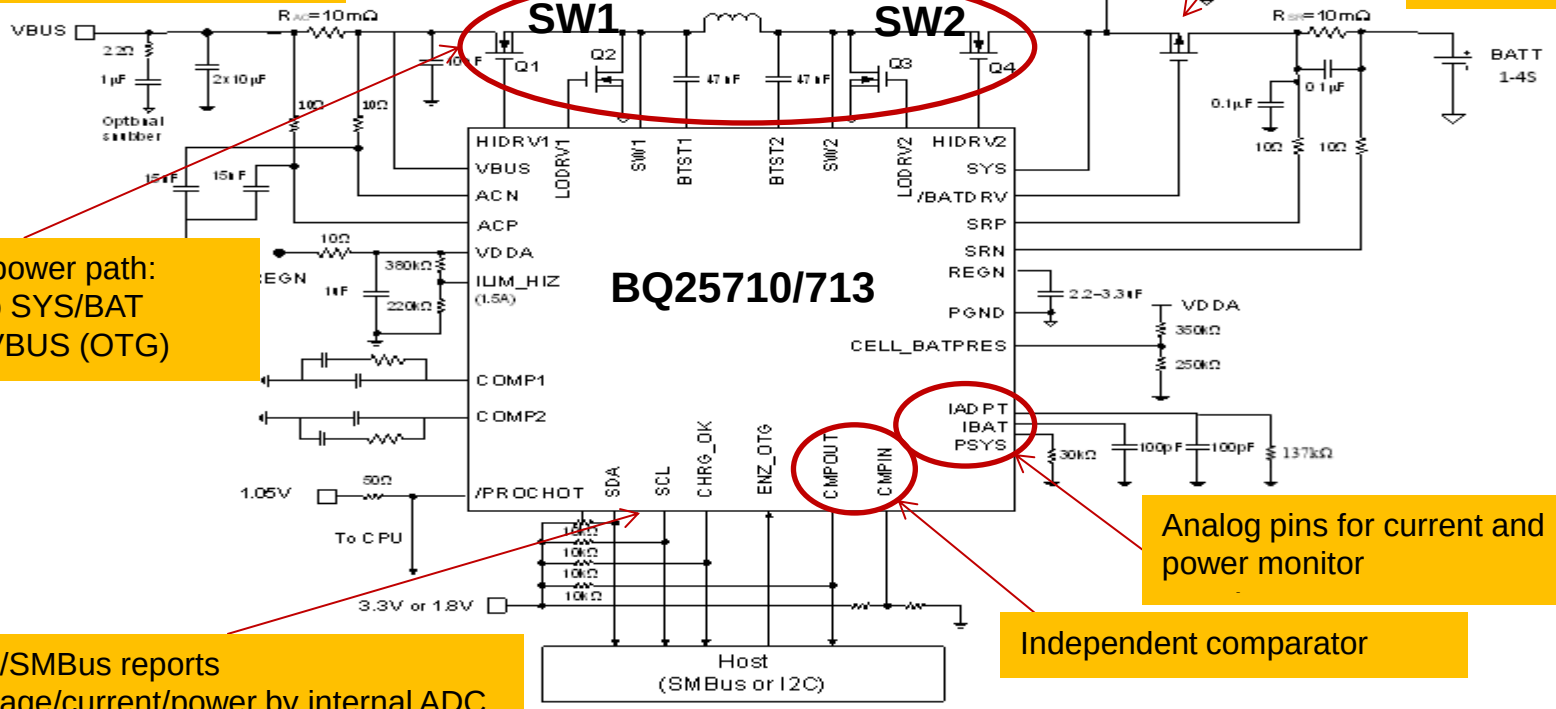
BQ25710/13 application diagram

VBUS: 3.5V-24V
OTG: 3V to 20.8V with 8mV step
(BQ25710/13)

Ext. FETs for efficiency optimization, fitting different power levels

Power Path with BATFET

VBAT: 1-4 cell



Bidirectional power path:
1. VBUS to SYS/BAT
2. BAT to VBUS (OTG)

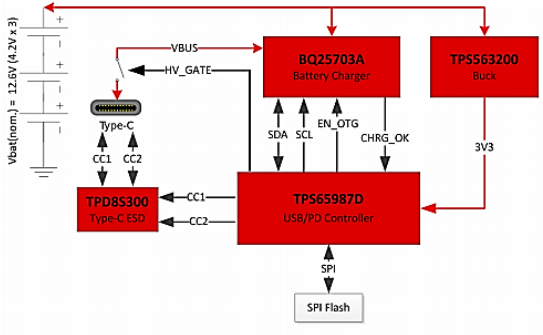
Analog pins for current and power monitor

Independent comparator

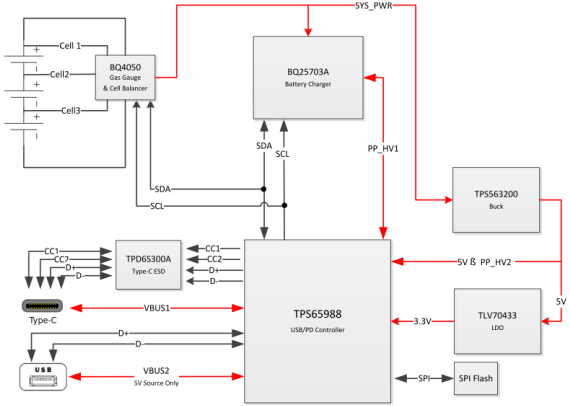
I2C/SMBus reports voltage/current/power by internal ADC

TI reference designs for PD charging solutions

- **TIDA- 01627:** USB Type-C PD reference design with single port sink-source PD controller and 1-4S buck-boost controller

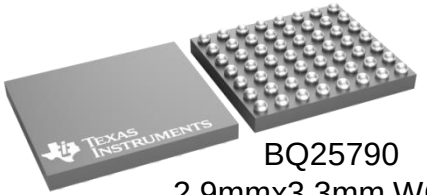


- **TIDA – 01515:** Dual port sink-source USB Type-C PD reference design with 1-4S buck-boost controller and a multi-cell gauge for battery monitoring

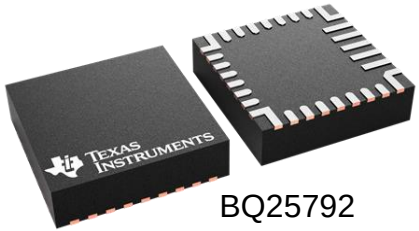


Resources

Switch-mode buck-boost battery chargers supporting USB Type-C PD	Flash and switched-cap chargers supporting USB Type-C PD	USB Type-C and PD Controller IC	USB Type-C™ and PD Short-to-VBUS protection IC
BQ25790, WCSP package	BQ25871	TPS65987D	TPD6S300A
BQ25792, QFN package	BQ25970		



BQ25790
2.9mmx3.3mm WCSP



BQ25792
4mmx4mm QFN

Training content:

- Technical article "Universal and fast charging – a future trend for battery-powered applications"
- Technical article "Maximize power density with buck-boost and USB Type C™ Power Delivery"
- Video "What could you achieve with universal and fast charging?"
- White paper "USB Type-C and USB power delivery power path design considerations"
- USB Type-CTM & USB Power Delivery overview page https://www.ti.com/interface/usb/type-c-and-power-delivery/overview.html

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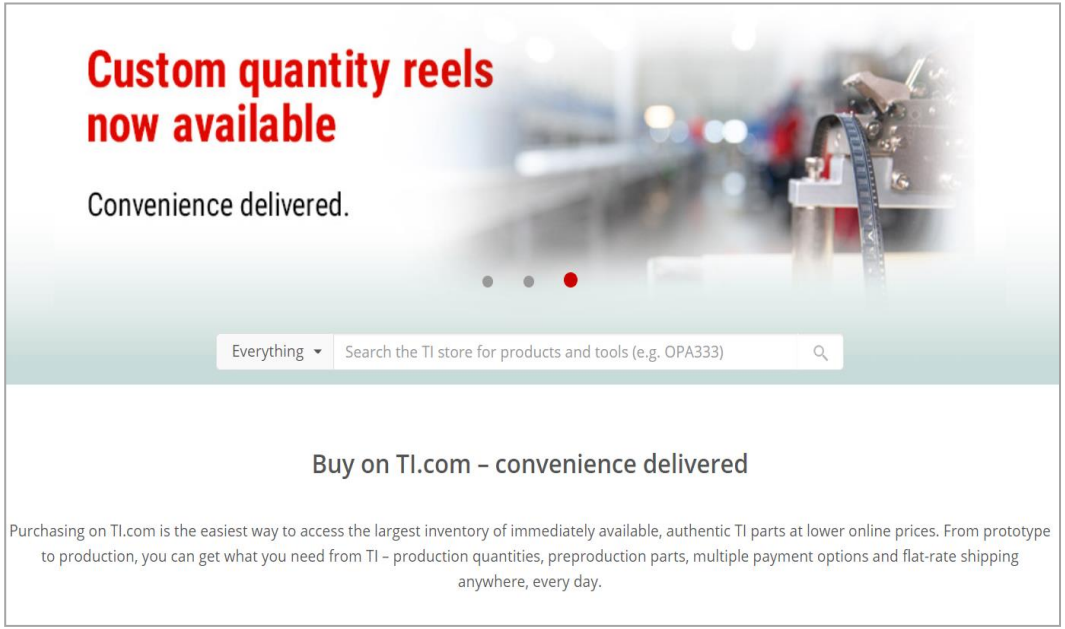

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