

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

JING YE

ACHIEVING HIGH POWER DENSITY AND ULTRA-FAST USB BATTERY CHARGING WITH NEW CHARGER TOPOLOGIES

TI BQ products are everywhere

In your pocket



Smartphone and tablet



Smart watch

On the highway



Electric vehicles

In the air



Commercial drones



Stratosphere balloon

Other applications

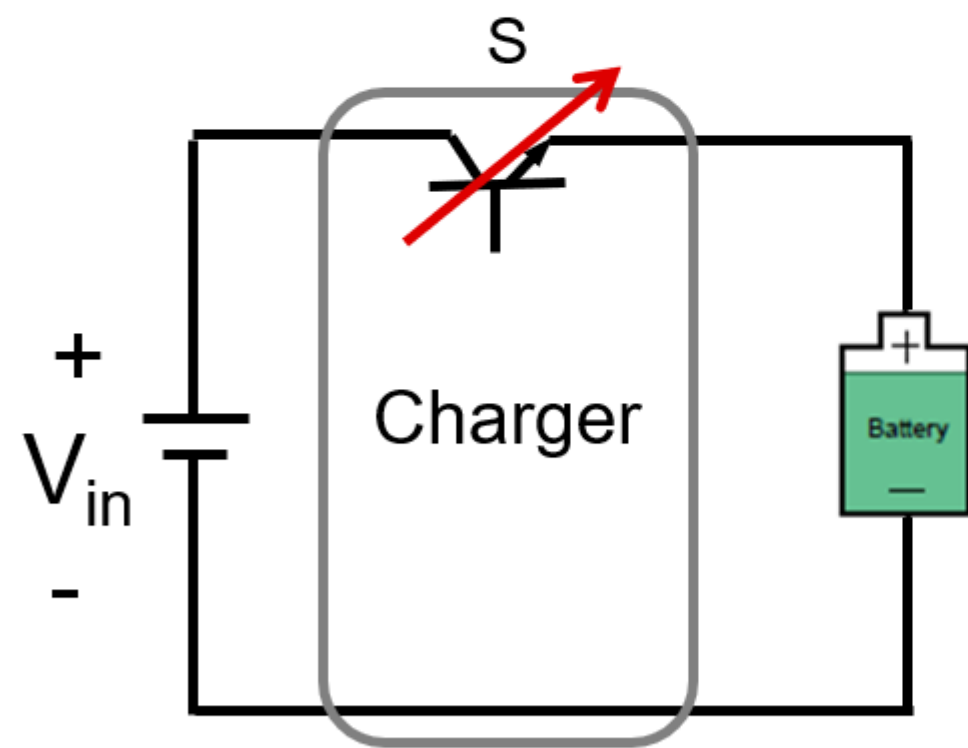
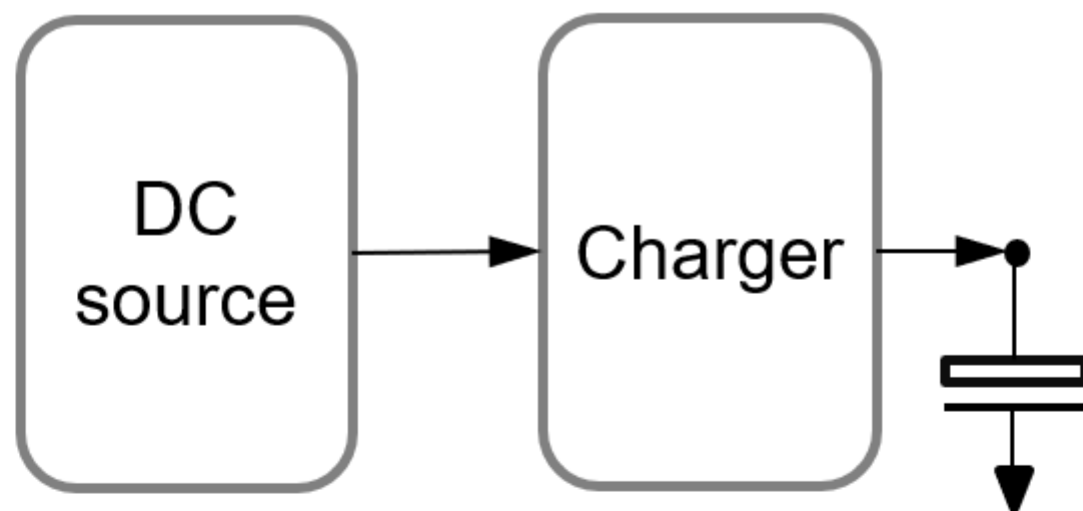


Surveillance camera

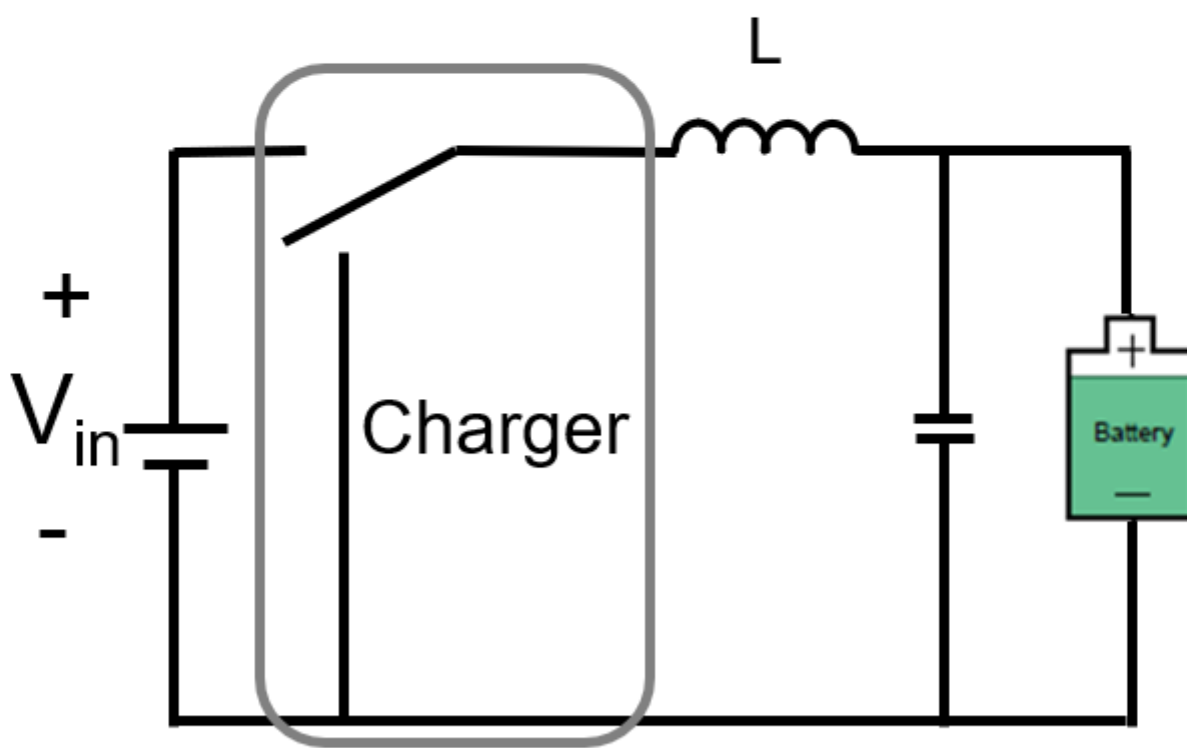


Vacuum cleaner

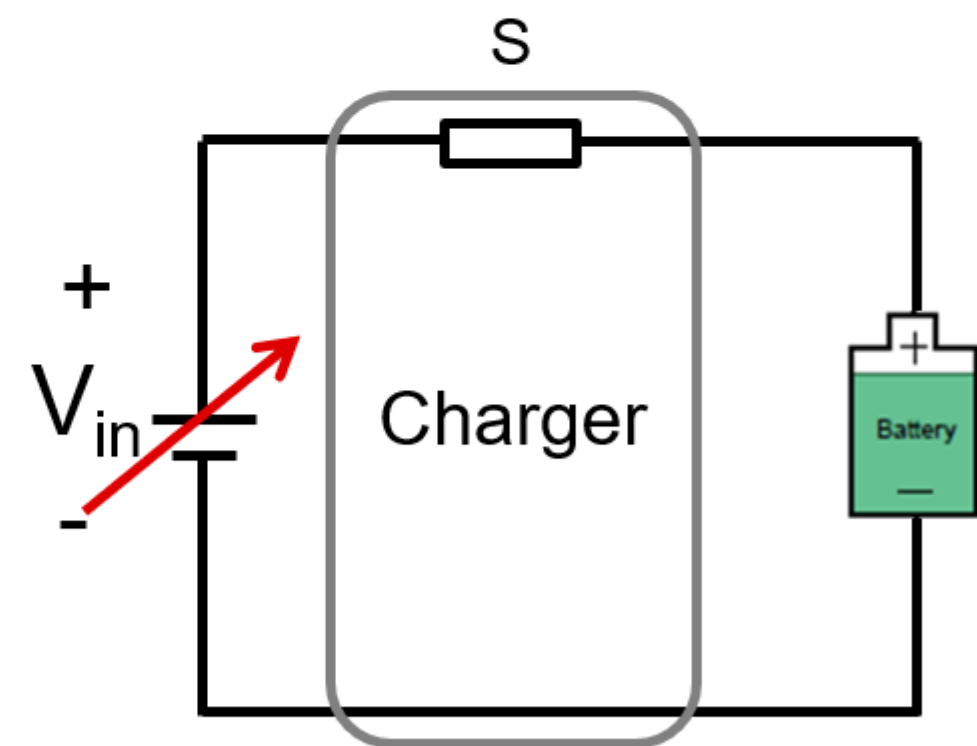
Battery charger topologies



Linear charger

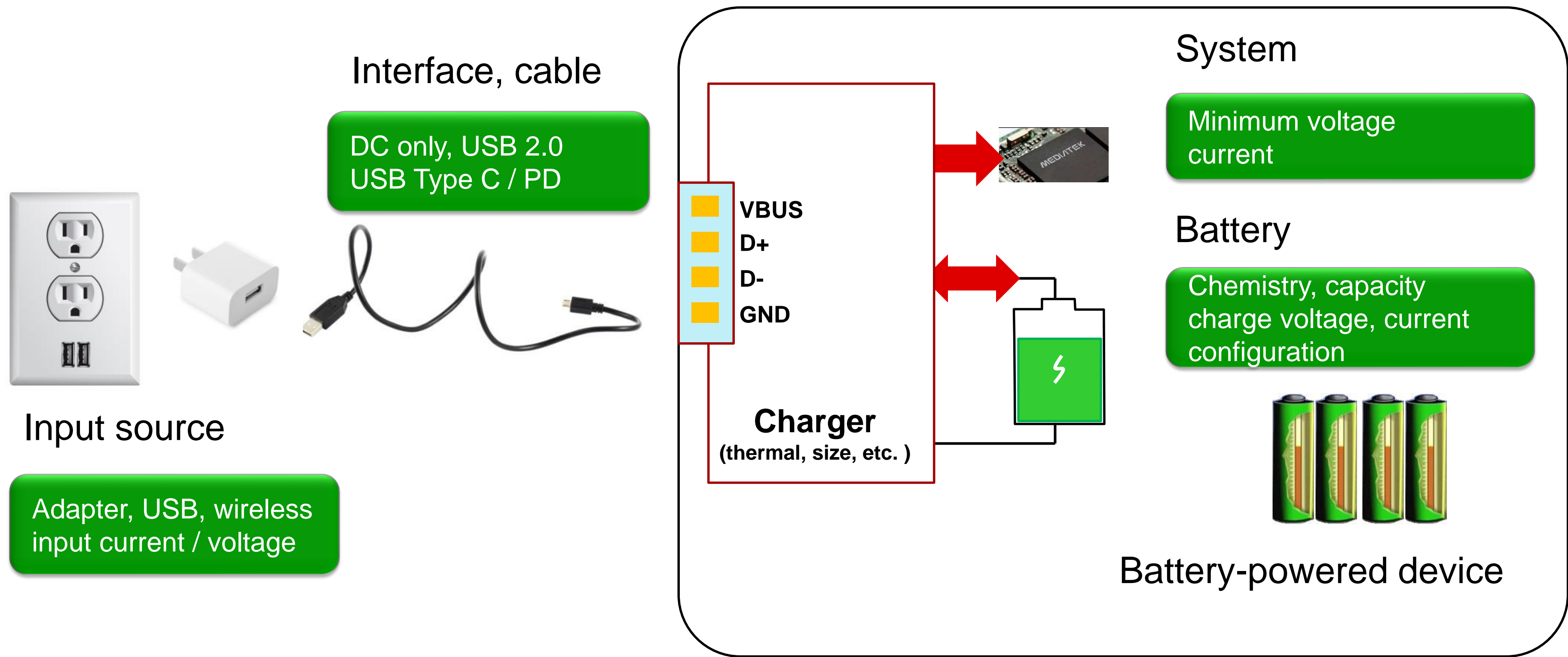


Switch-mode charger



Inductor-less charger

High power density charging considerations



Power supply specifications

<u>USB 1.0</u> 1.5Mbps	<u>USB 1.1</u> 12Mbps	<u>USB 2.0</u> 480Mbps High power 2.5W 5V/0.5A	<u>USB 3.0</u> 5Gbps BC1.1 7.5W 5V/1.5A BC1.2 25W 5V/5A	<u>USB 3.1</u> 10Gbps PD2.0 Type C 100W 20V/5A	<u>USB 3.2</u> 20Gbps PD3.0 Type C PPS 100W 20V/5A	<u>USB 4</u> 40Gbps PD3.1 V1.0 PPS 100W 20V/5A	<u>USB 4</u> 40Gbps PD3.1 V1.1 PPS 240W 48V/5A
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Custom fast charging protocol

(e.g. Qualcomm Quick Charge)

Quick Charge 1.0
10W 5V/2A

Quick Charge 2.0
18W 9V/2A

Quick Charge 3.0
36W 12V/3A

High voltage dedicated charging port (HVDCP)

Quick Charge 4

100W 20V/5A
Compatible with USB PD PPS 27W 9V/3A

Quick Charge 5

QC5 100W 20V/5A
USB PD PPS 100W 2S battery



Wireless charging



1996

2001

2011

2013

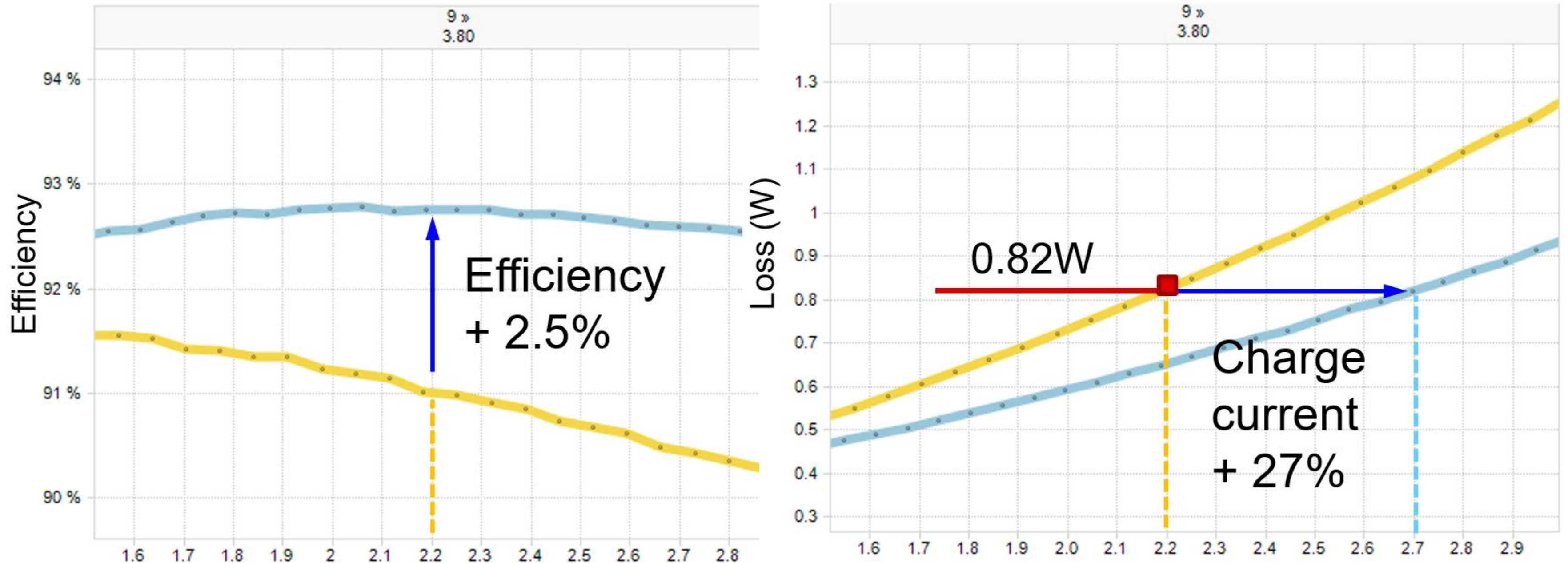
2015

2017

2019

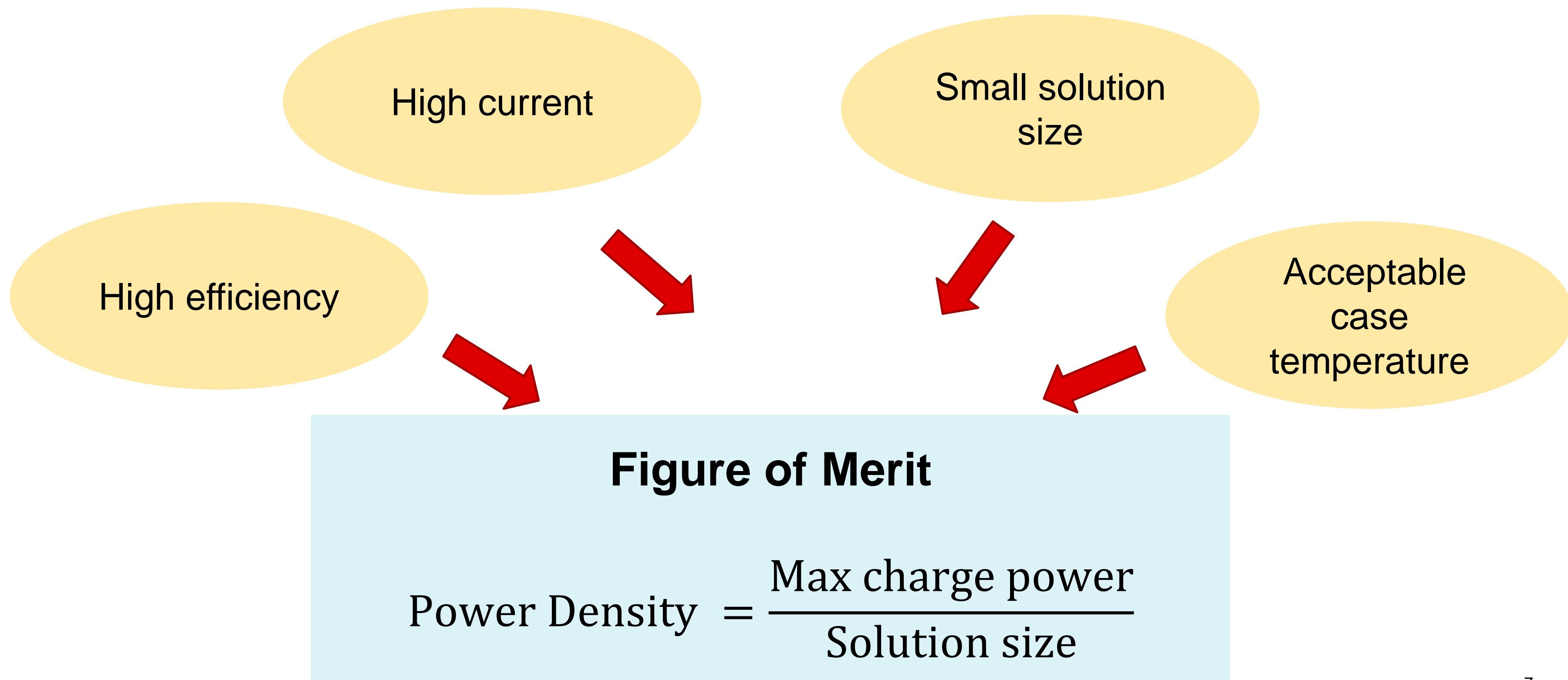
2021

Efficiency is key to high power density



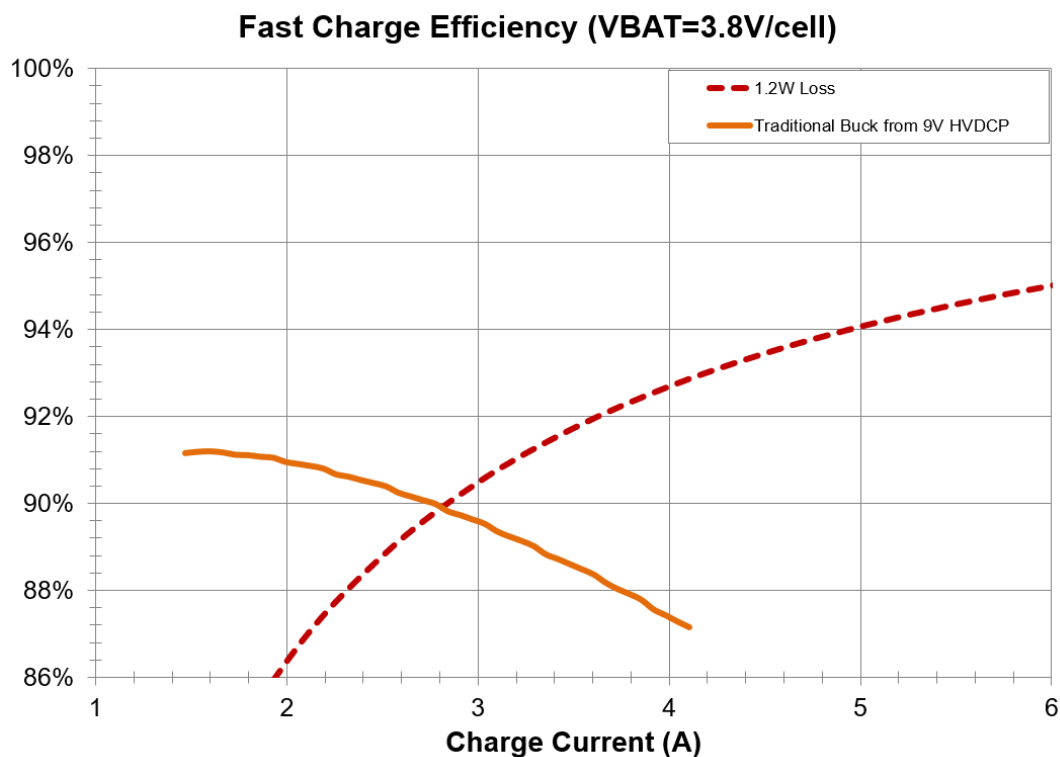
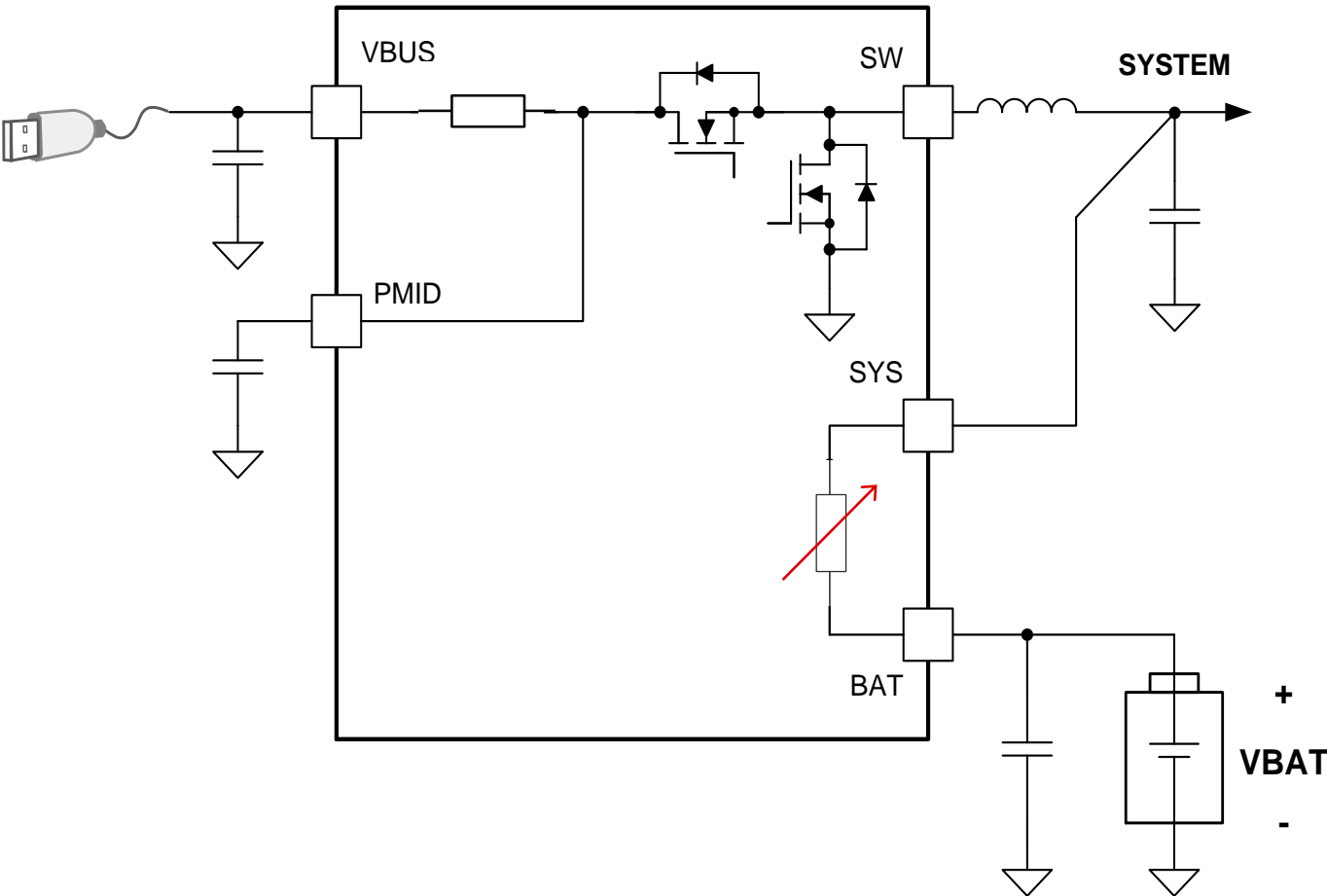
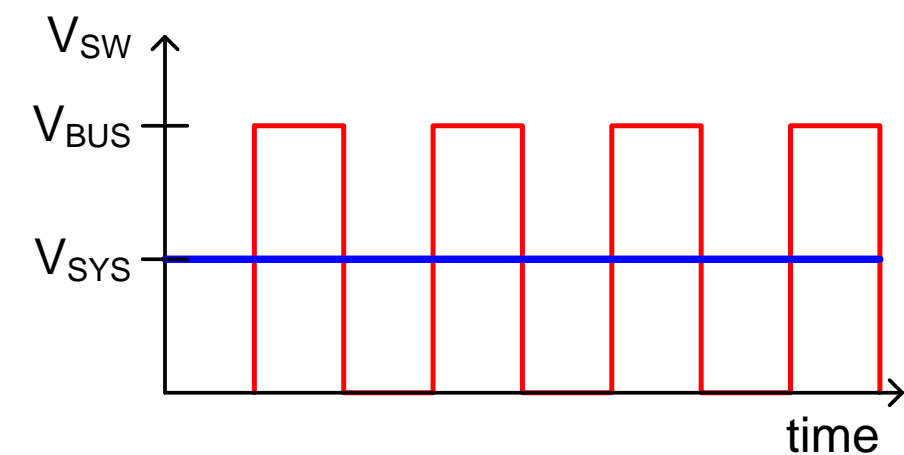
At 90% efficiency, a 2.5% efficiency improvement represents a 27% increase in charging current from 2.2 A to 2.7 A with the same loss budget.

High power density charging figure of merit

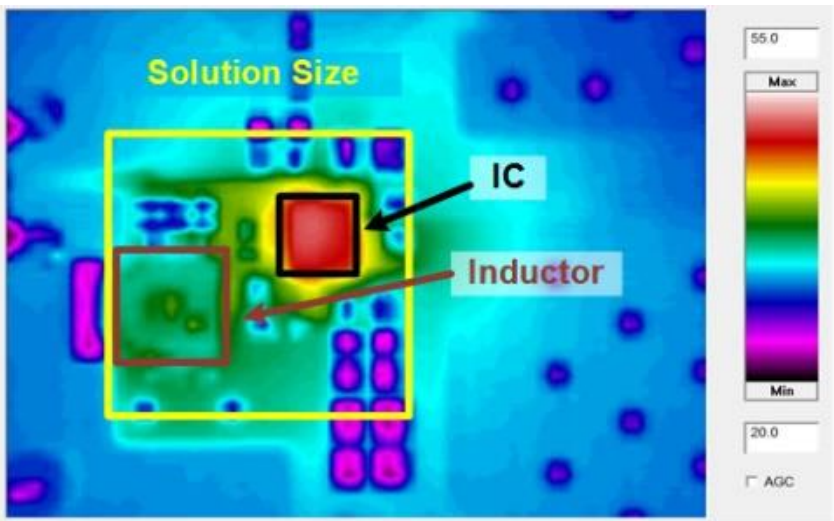


High power density charging solutions

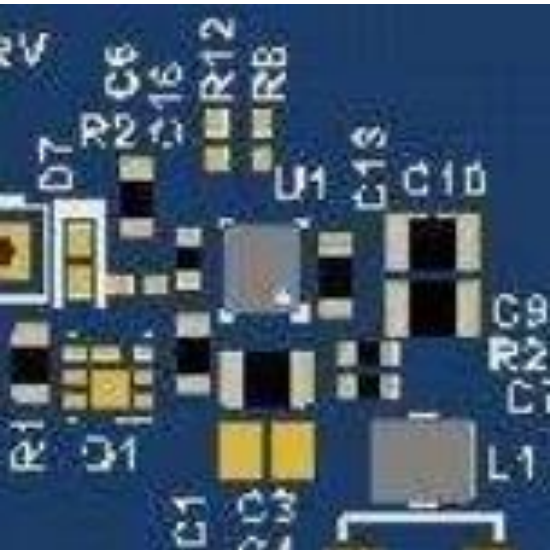
Traditional buck charger (2-level)



Power loss: 1.2 W
ICHG 2.8A

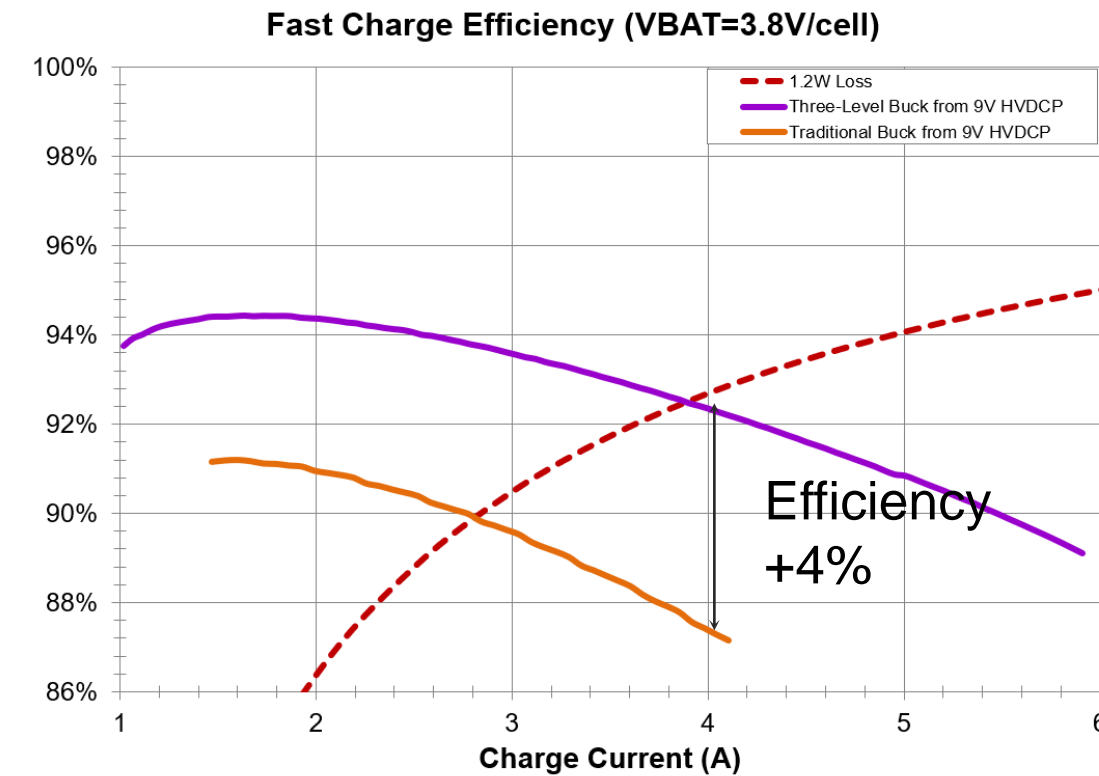
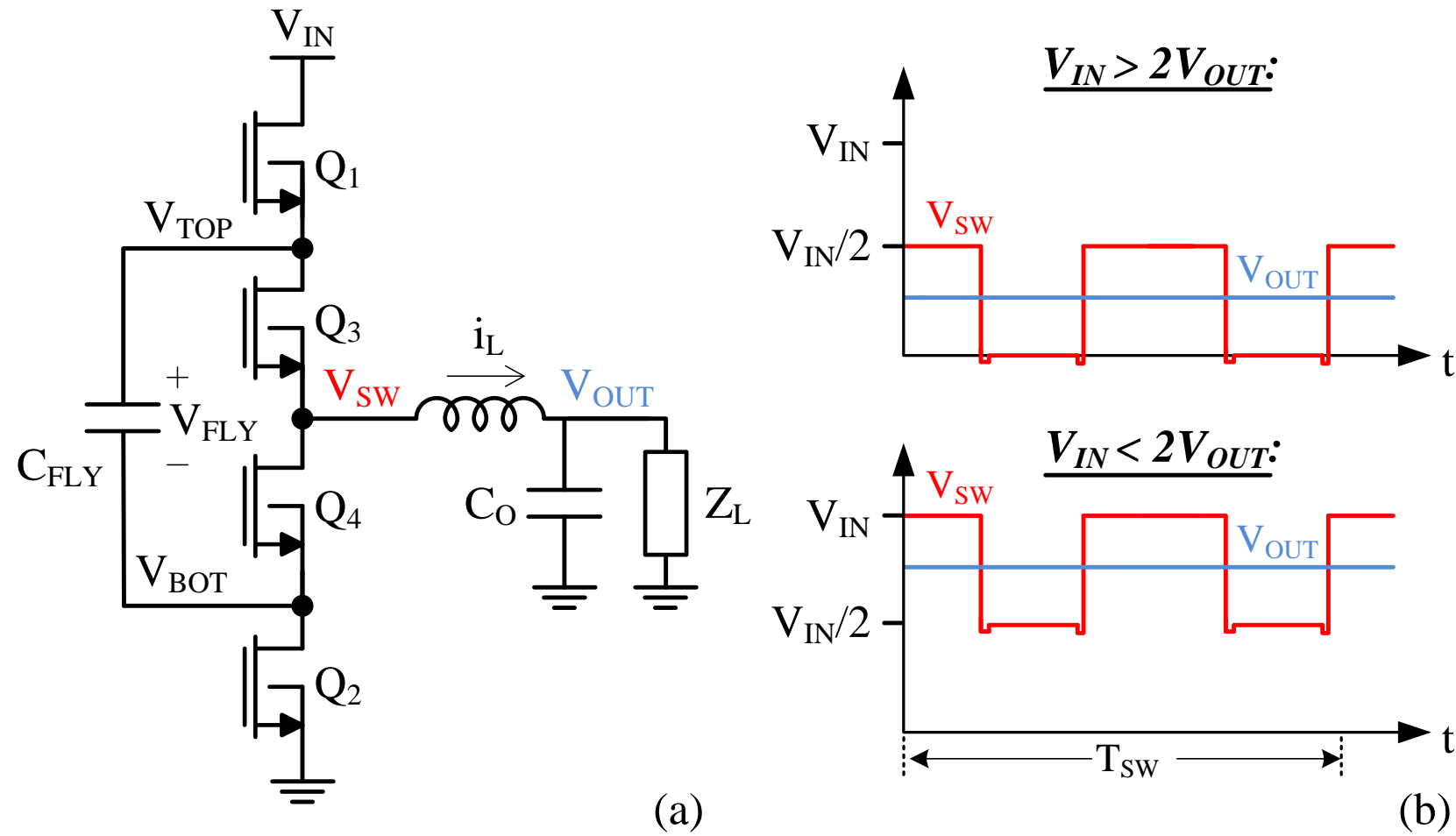


ICHG = 3A from 5V,
IC 50.2°C

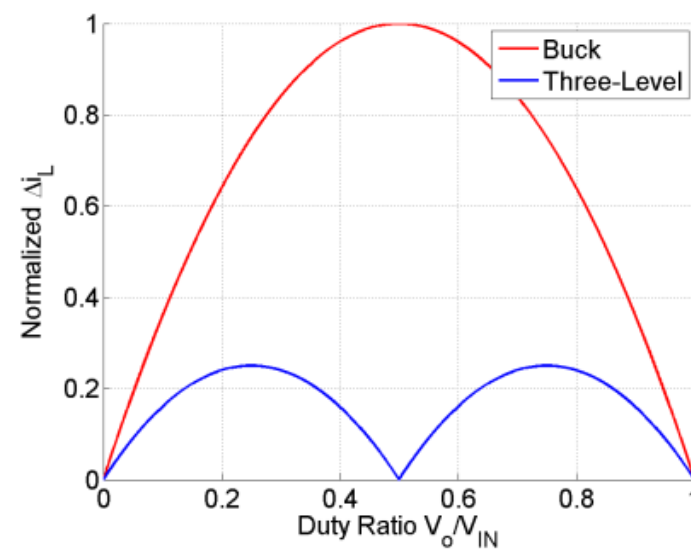


IC=7mm²,
L=10mm²,
Total =17mm²

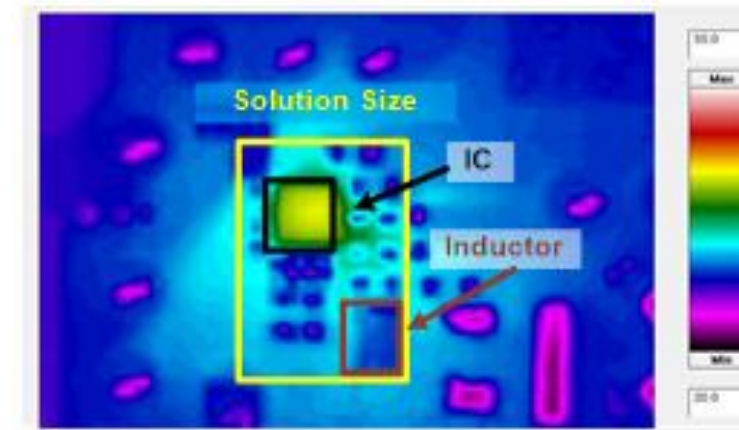
Three-level buck switch mode charger



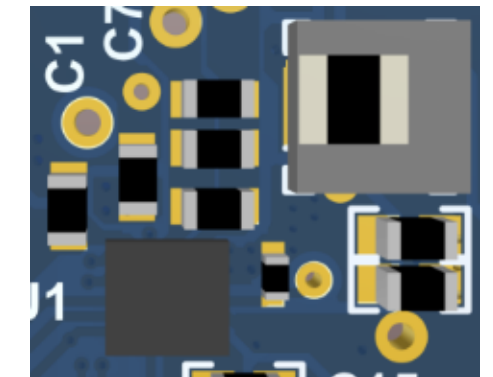
Power loss 1.2 W
ICHG 3.5 A



- ✓ Reduced inductance need
- ✓ Reduced DCR and power loss
- ✓ Reduced FET switching loss



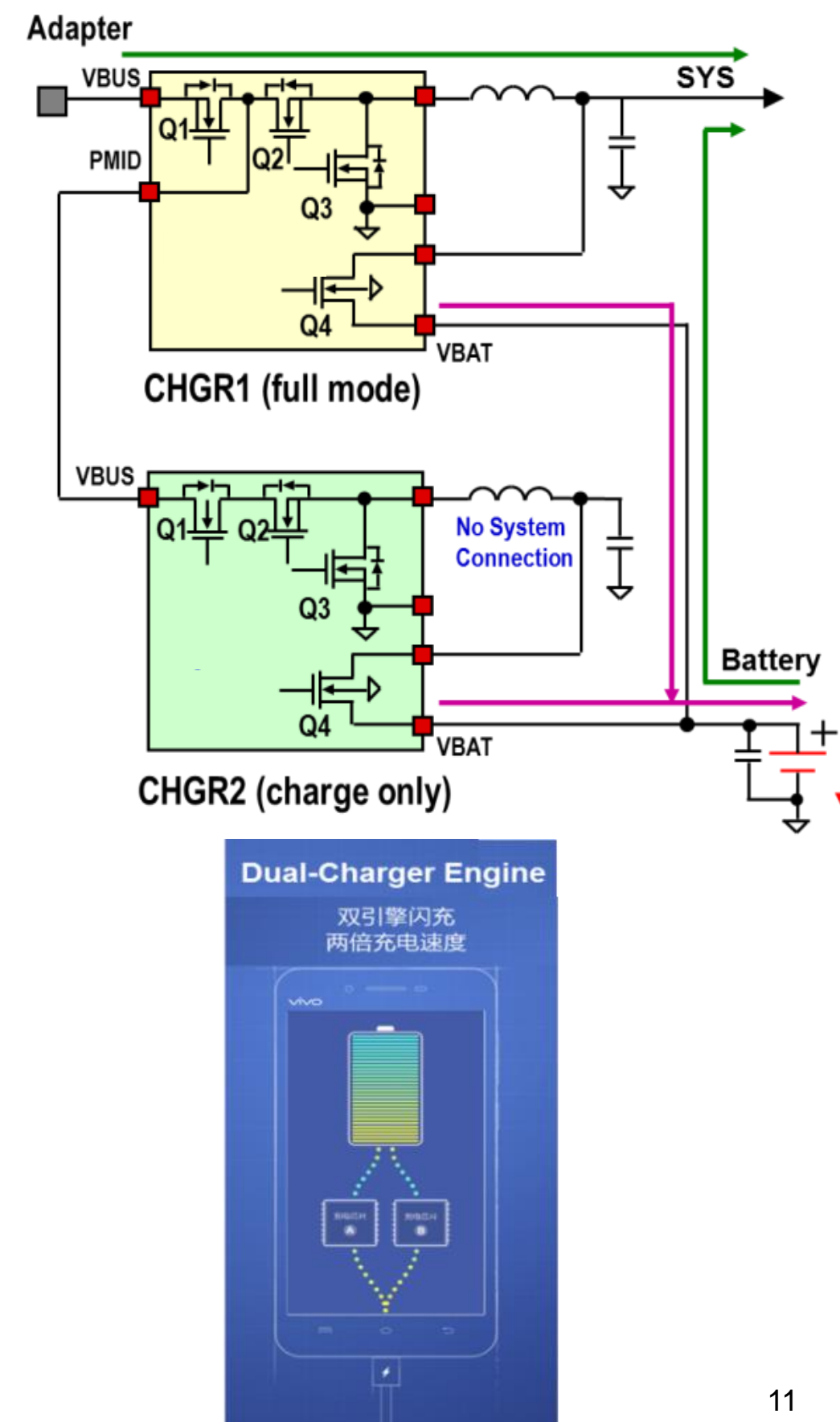
ICHG = 3A from 9V,
IC temp 45.5°C



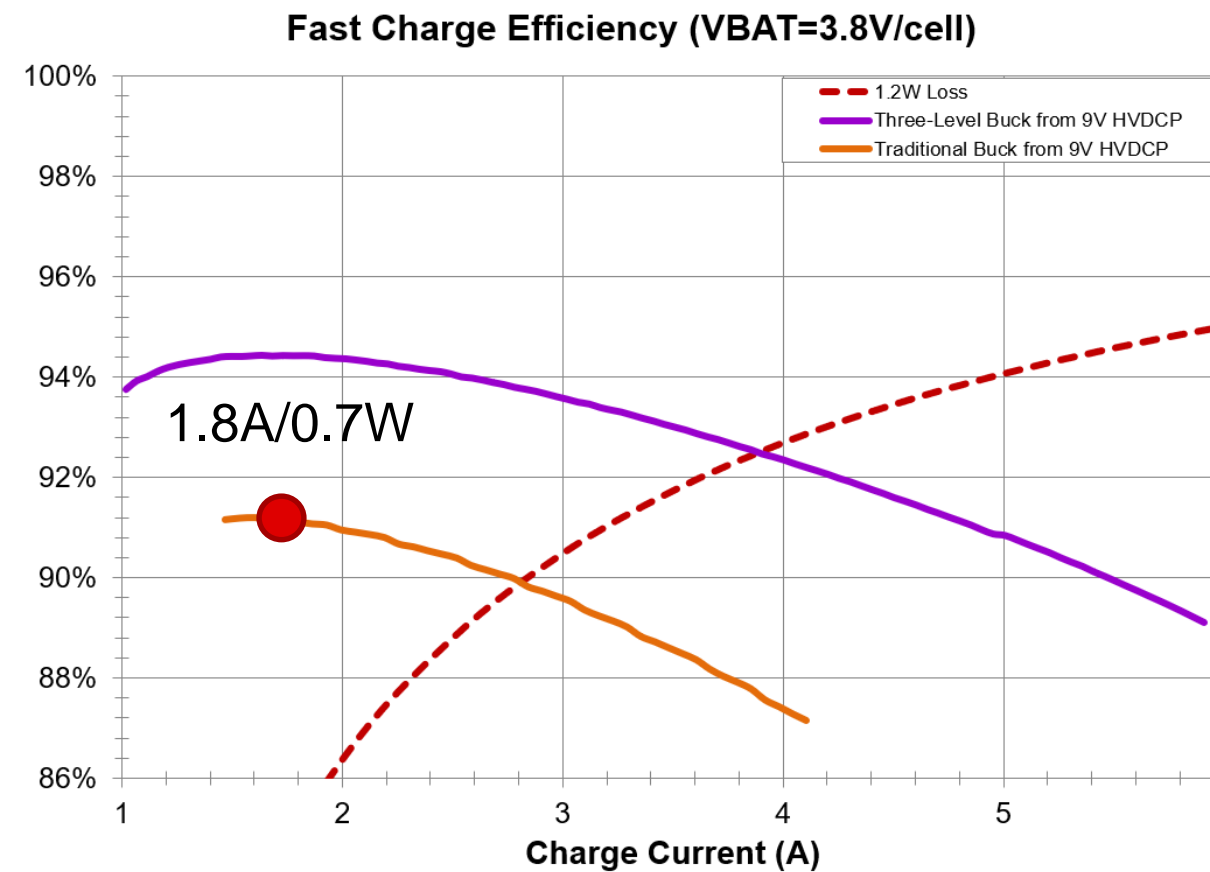
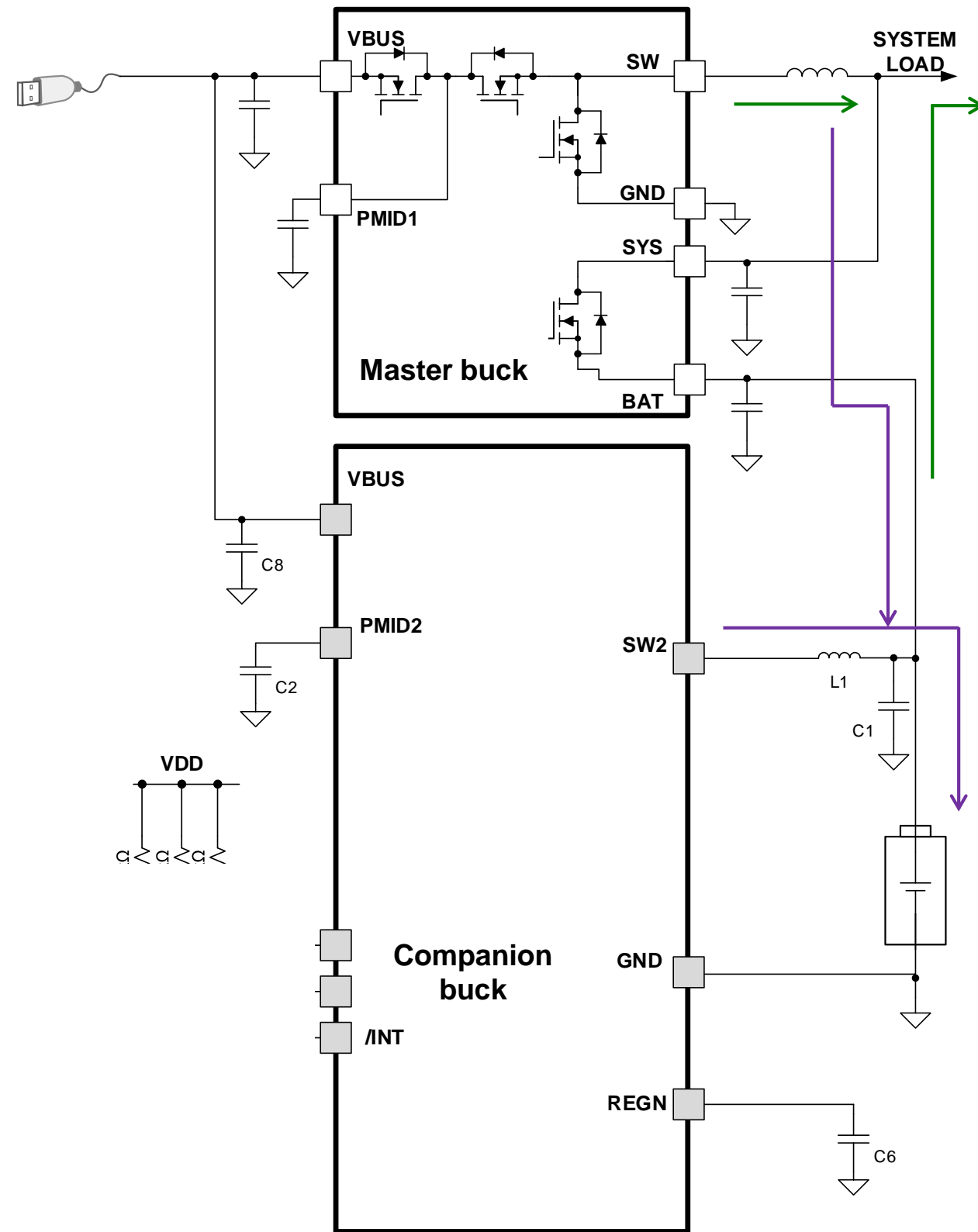
IC=9.2mm², L=5mm²,
CFLY=2.56mm²
Total =16.7mm²

Dual-charger solution

- Dual charger was pioneered by Texas Instruments.
 - Main charger (CHGR1) active most of the time for charging cycle and for system regulation under dynamic load
 - Companion charger (CHGR2) active for fast charge phase and for part of the constant voltage phase
- Dual charger can effectively spread the power loss and provide fast and cool charging in compact equipment
 - Thermal budget is 1.3 W - 1.5 W with a bigger solution size
- The keys to this solution are high efficiency and ease of use



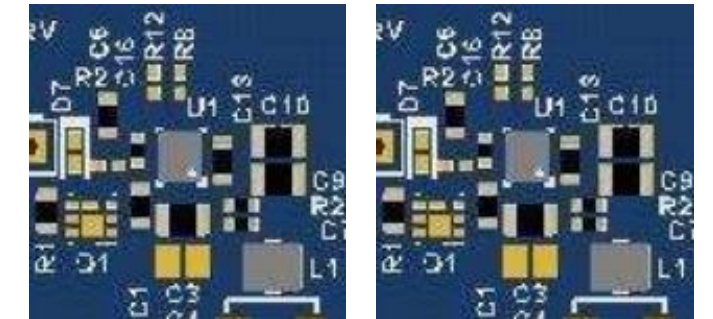
Dual chargers with two bucks



Power loss 1.4 W
ICHG 3.4 A

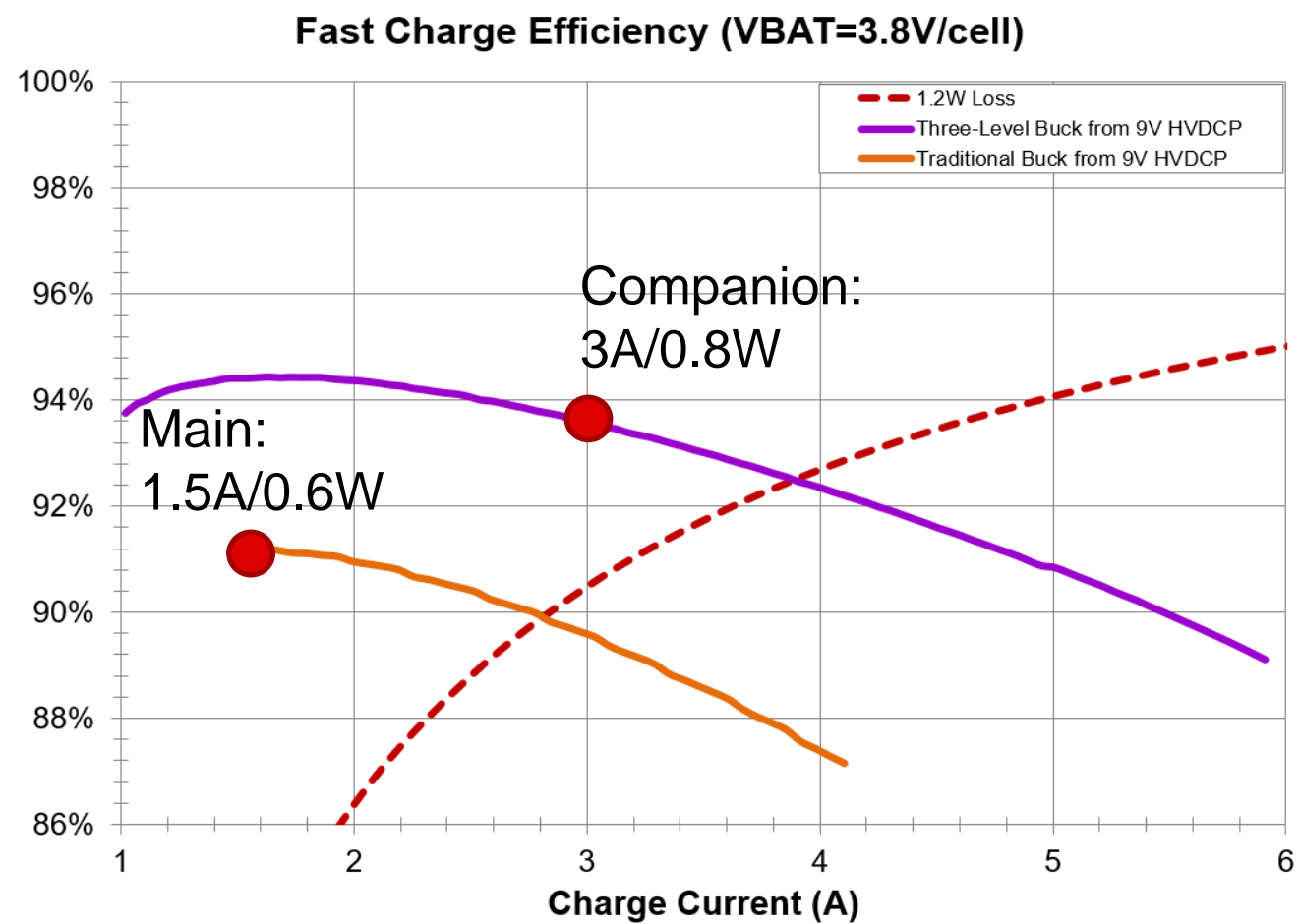
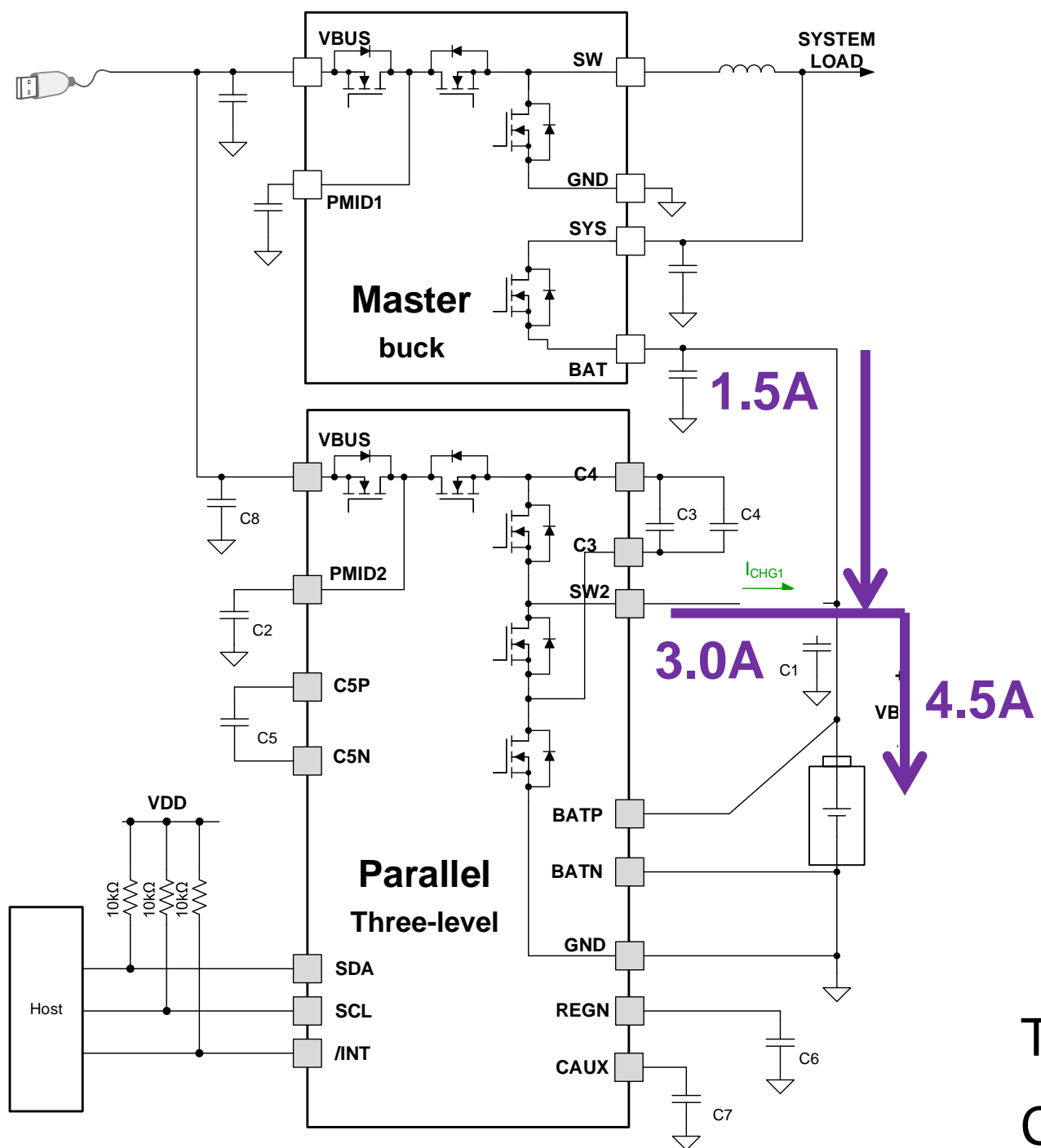
Total charging current (3.6 A, 1.4 W loss):

Companion charger (1.8 A, 0.7 W loss) + Master charger (1.8 A, 0.7 W loss)



IC 7mm² IC 7mm²
L 5mm² L 5mm²
Total: 24 mm²

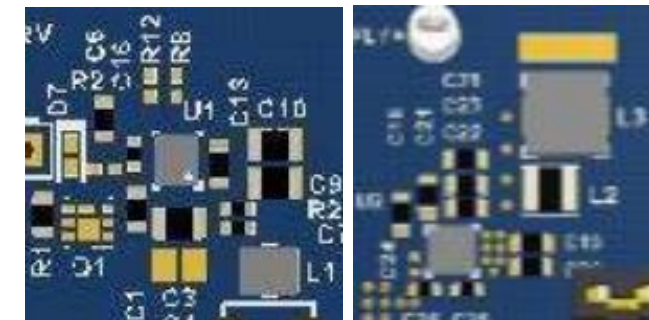
Dual-charger structure with three-level buck



Power loss 1.4 W
ICHG 4.5 A

Total charging current (4.5 A , 1.4 W loss):

Companion charger (3 A, 0.8 W loss) + master charger (1.5 A, 0.6W loss)



IC 7 mm² IC 5.9 mm²
L 5 mm² L 5 mm²
CFLY 2.56 mm²
Total: 25.44 mm²

USB PD is changing the way of charging

- New generation of portable devices are employing USB Power Delivery (PD).
- The compound annual growth rate of PD is estimated 29%, and projected number of USB PD port shipment is over 127 billion in 2030, according to Future Market Insights.
- USB PD power supply delivers up to 20 V/5 A, or 100 W.

Smart home applications



Power banks, Bluetooth® speakers, electronic point-of-sale



Industrial and medical equipment

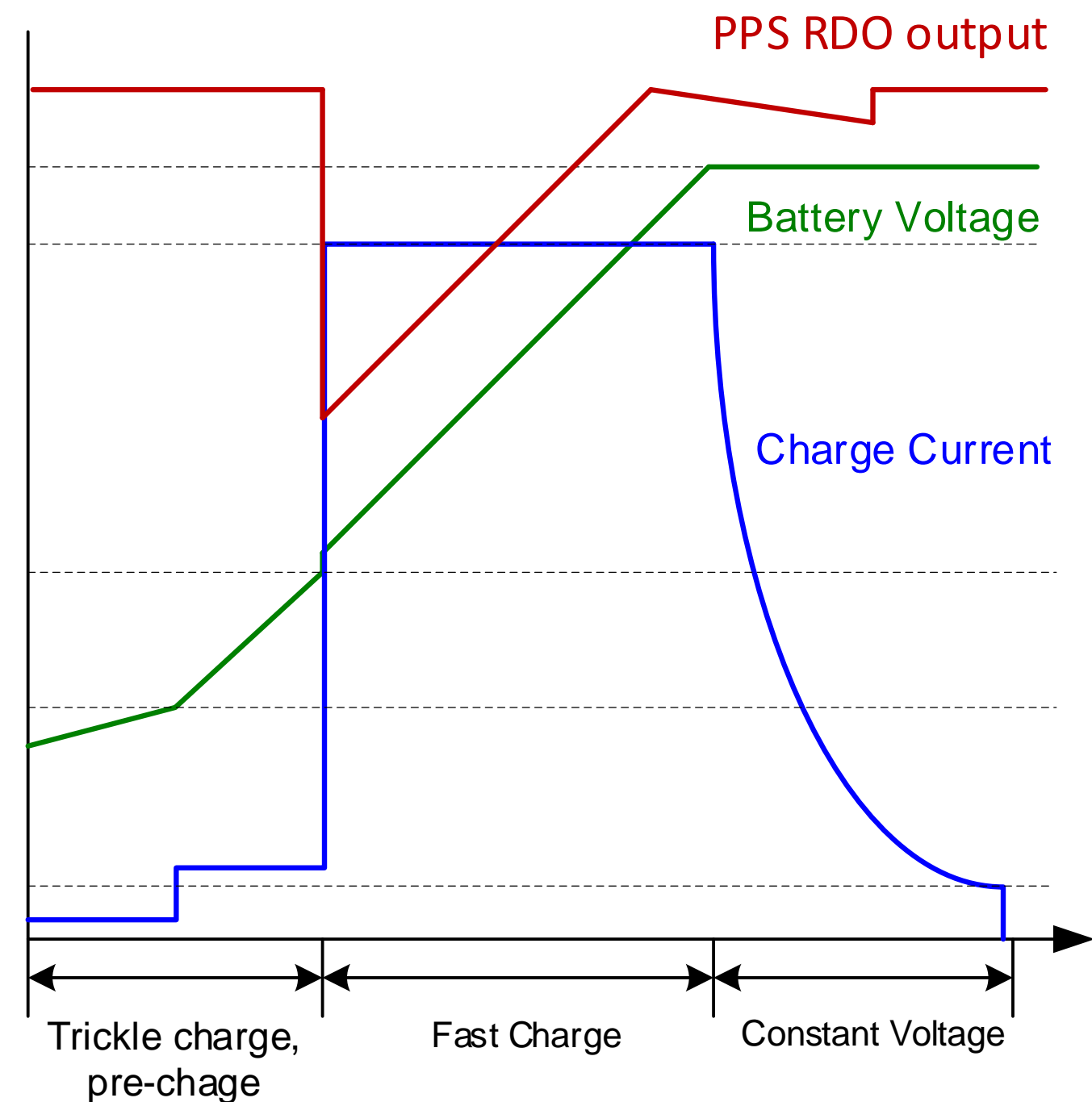


Notebooks and tablets

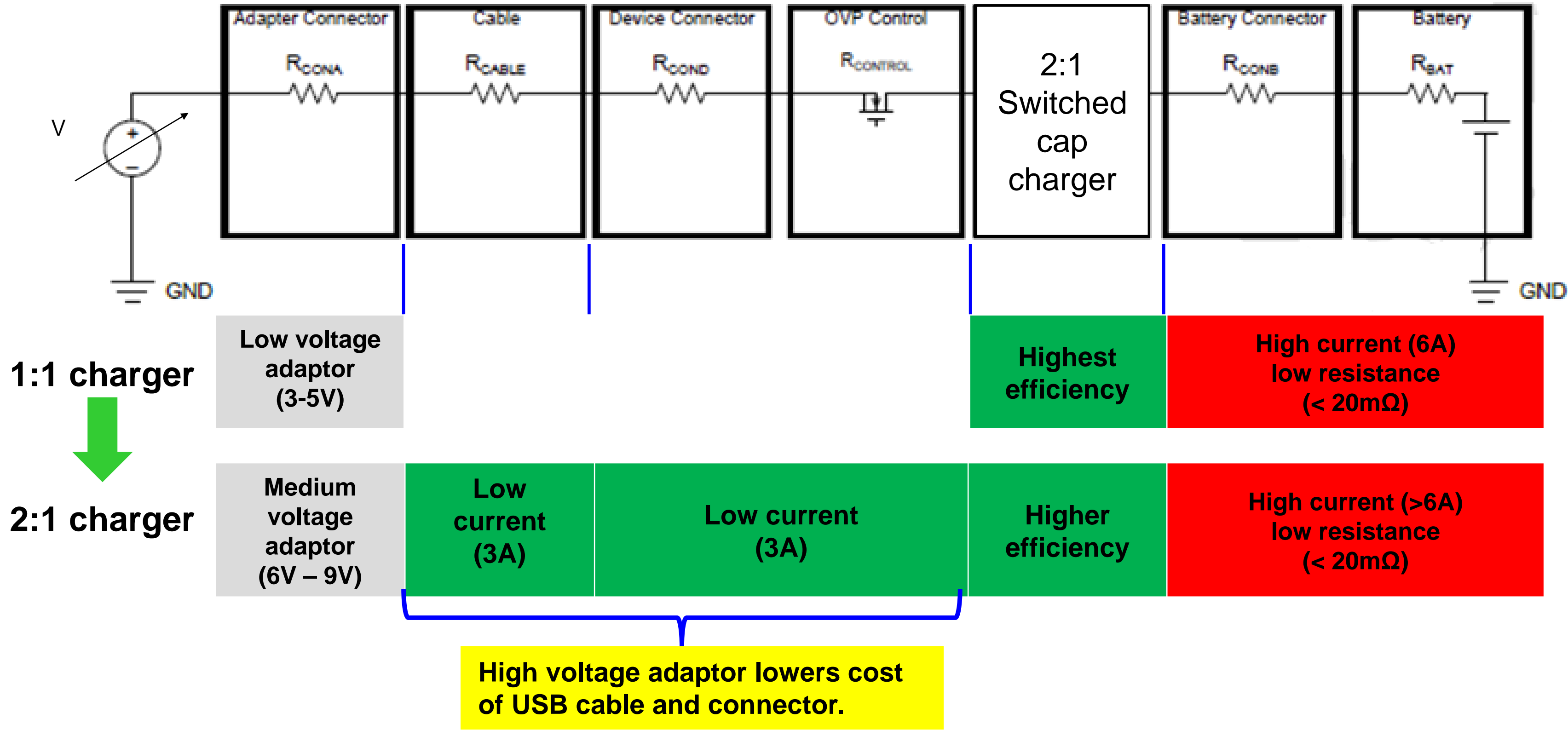


PD 3.0 offers programmable power supply

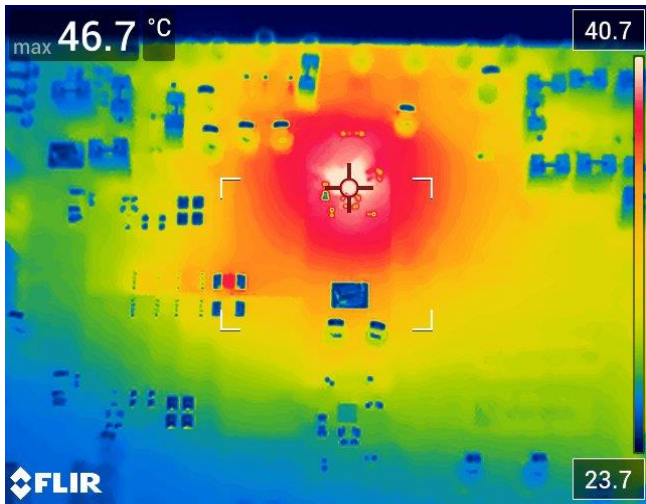
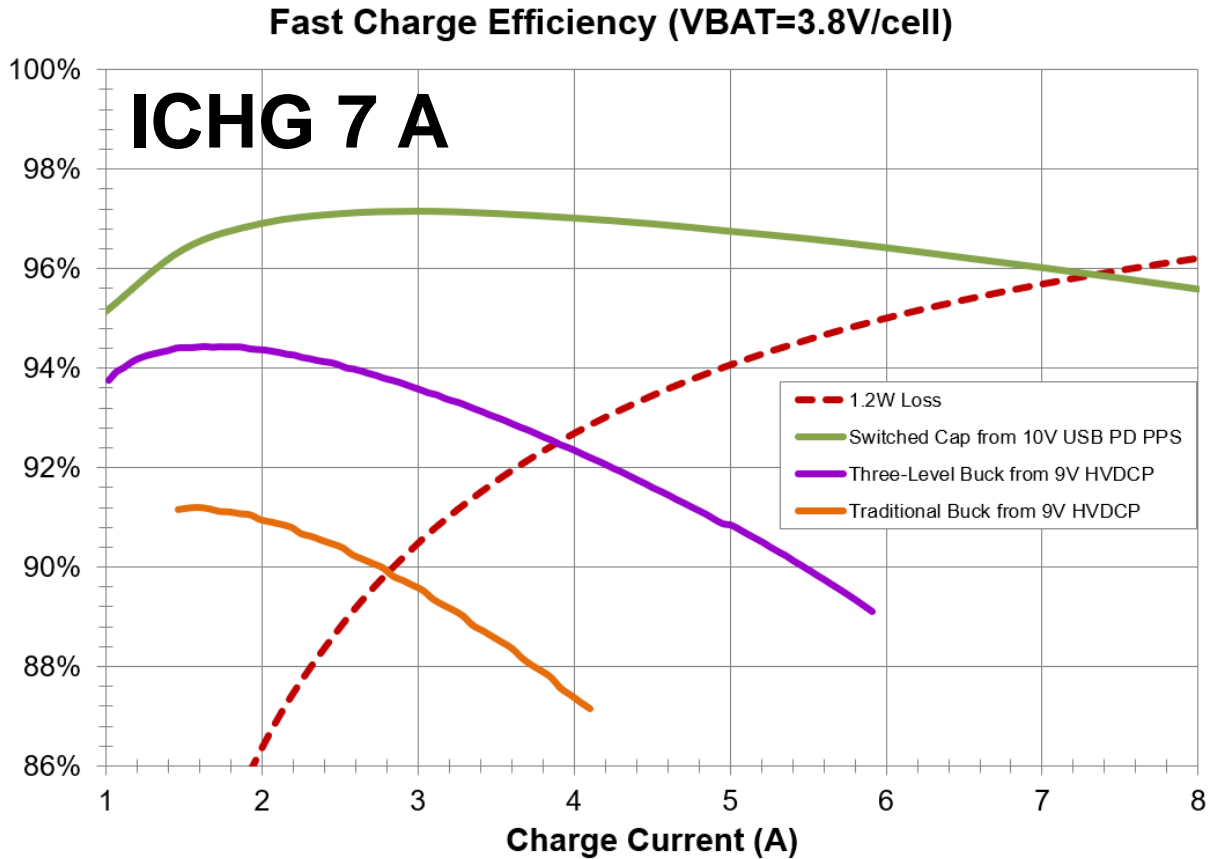
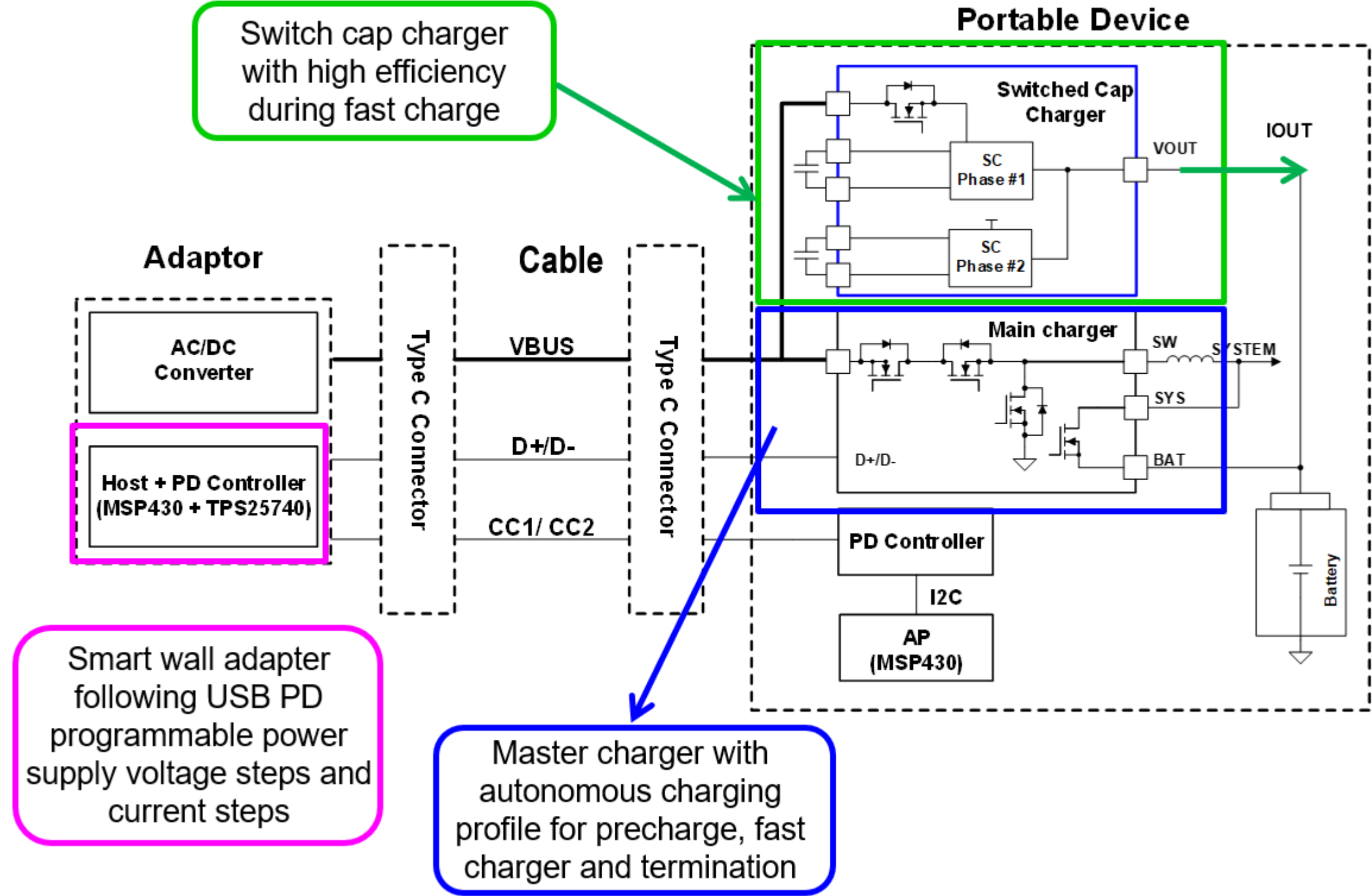
- Programmable power supply (PPS) enables sink directed charge
 - The sink adjusts its output voltage to achieve source's output target current
 - Current foldback feature is available for source to automatically limits its output current
- Sink controls the source's output voltage with 20 mV precision
- Sink controls the source's output current with 50 mA precision
- The goal is to improve efficiency in the portable devices, so less heat is generated



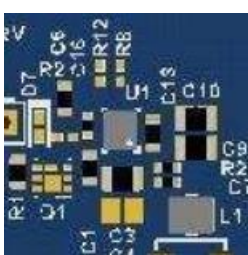
High current fast charge



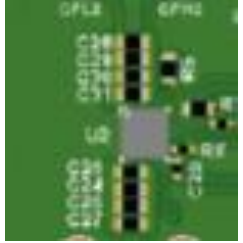
Switched cap charging configuration



ICHG = 6A
IC temp 46.7°C



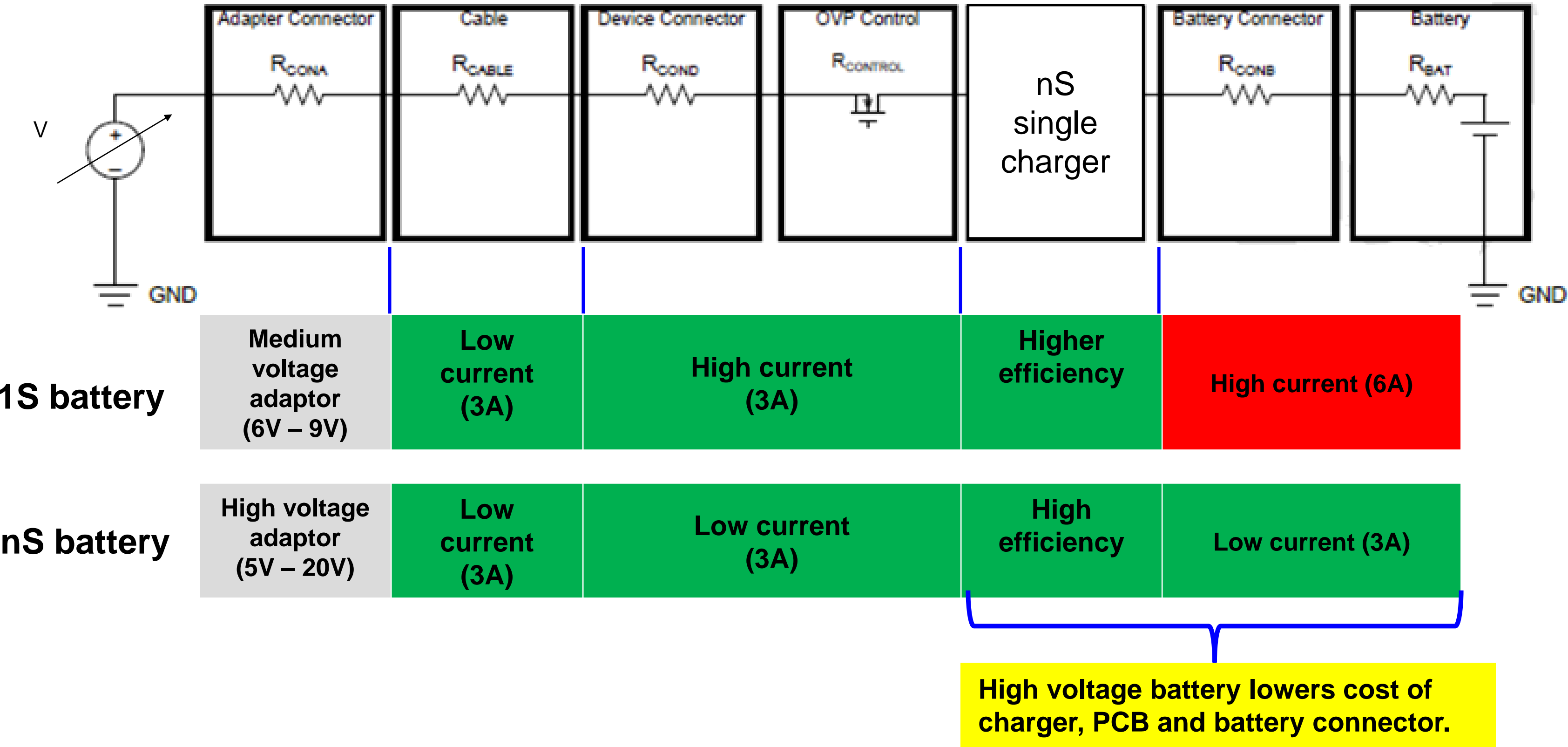
IC 7mm²
L 5mm²



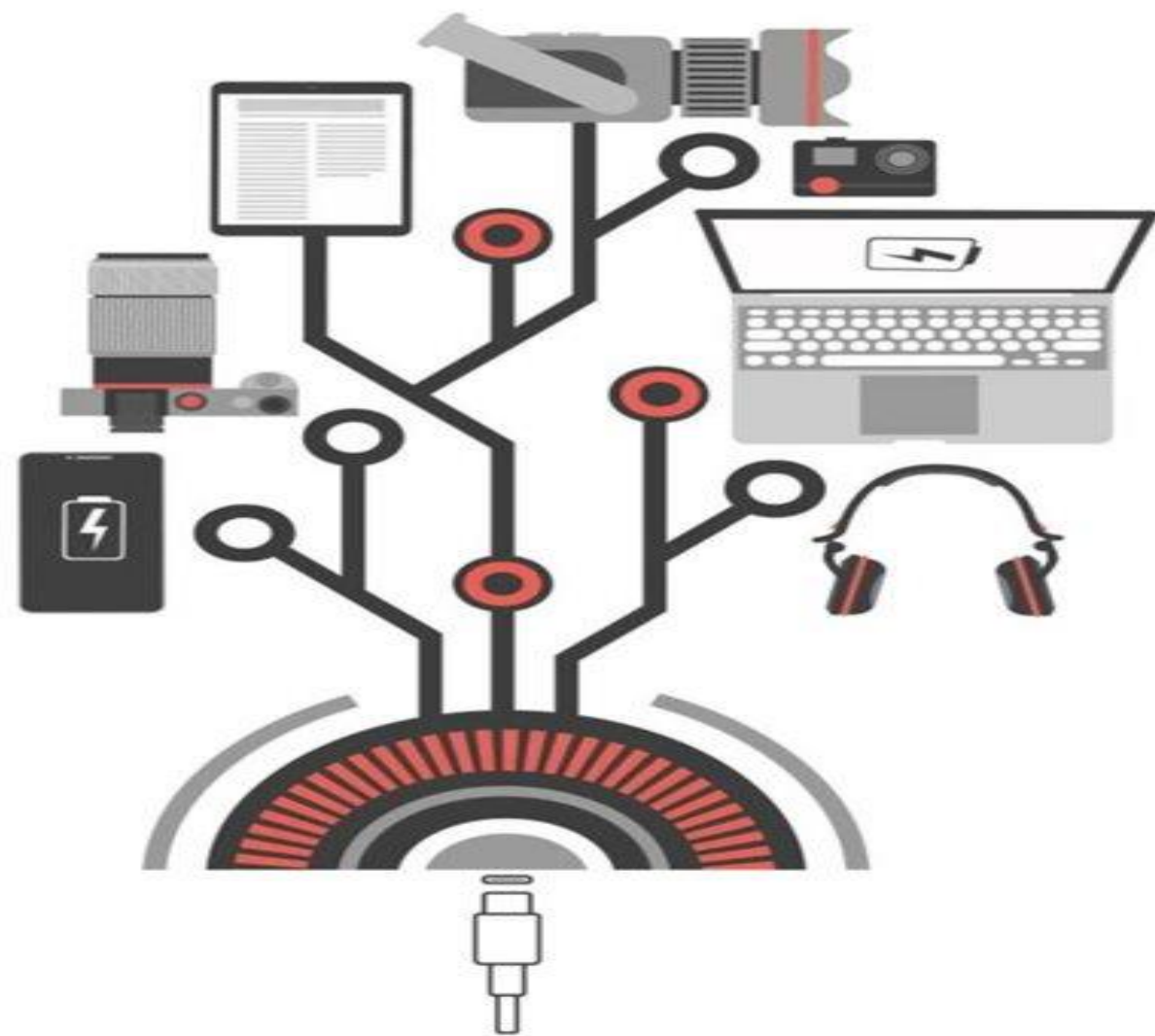
IC 9.52mm²
CFLY 7.68mm²

Total: 29.2mm²

High voltage fast charge



USB PD-compatible multi-cell charger

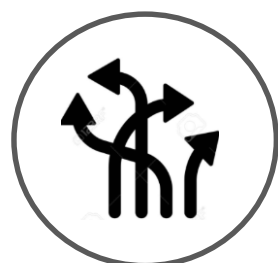


- Many different applications are under the USB Type-C umbrella
- Buck boost charger provides a universal USB PD solution, increases device interoperability and reduces e-waste



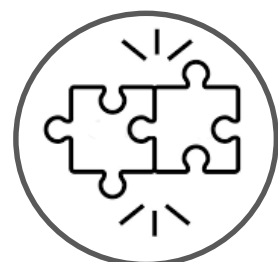
High efficiency converter

Maximize power transfer and minimize system thermal dissipation.



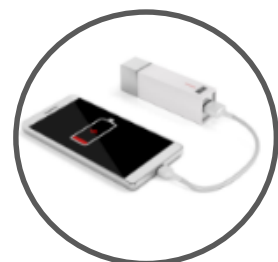
Input source flexibility

Configurable battery voltage and charging profile to charge from wide USB spectrum.



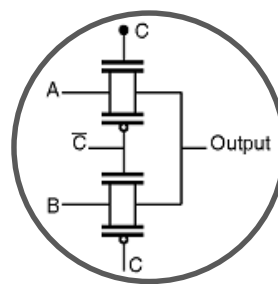
Backward compatible

Input USB range from legacy USB 1.0 5 V to recent USB PD 20 V



USB PD dual-role port configuration

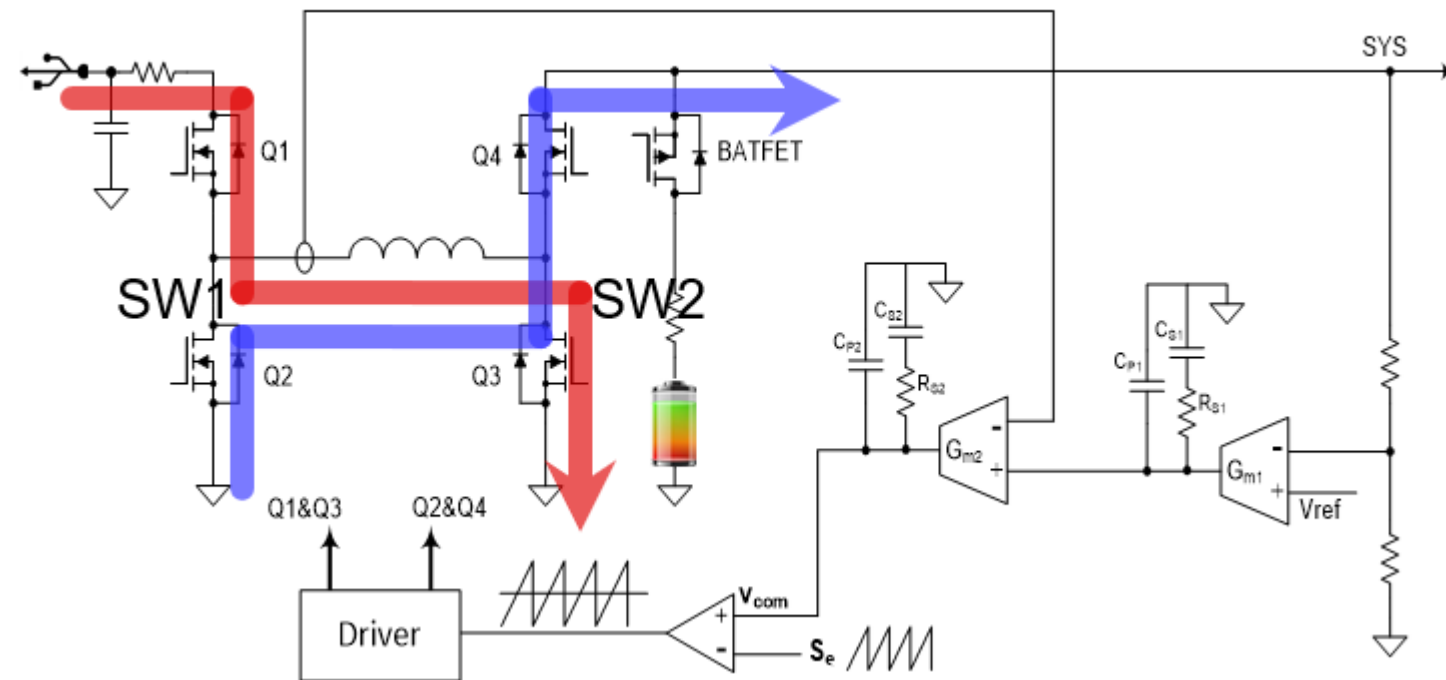
Bi-directional power path of forward charging and reverse on the go with fast role swap integrated.



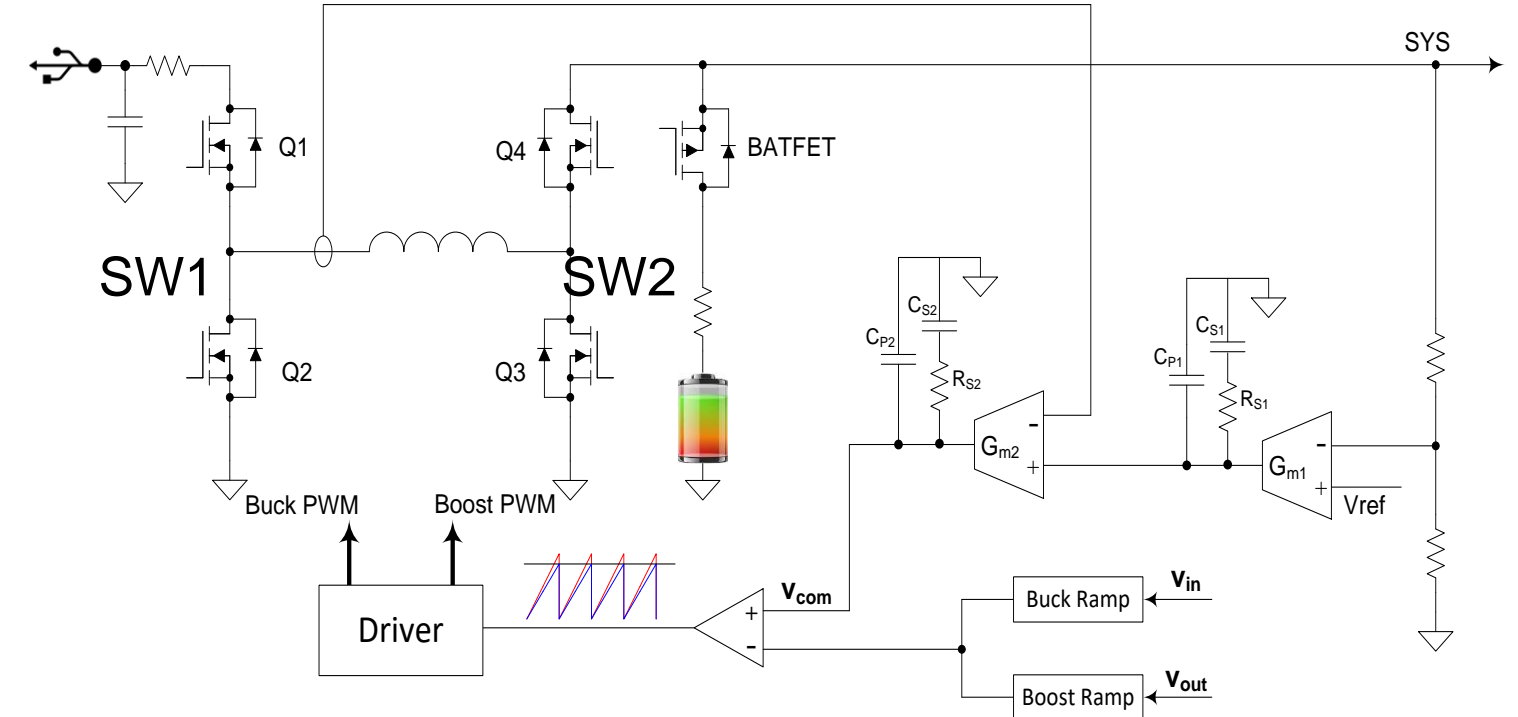
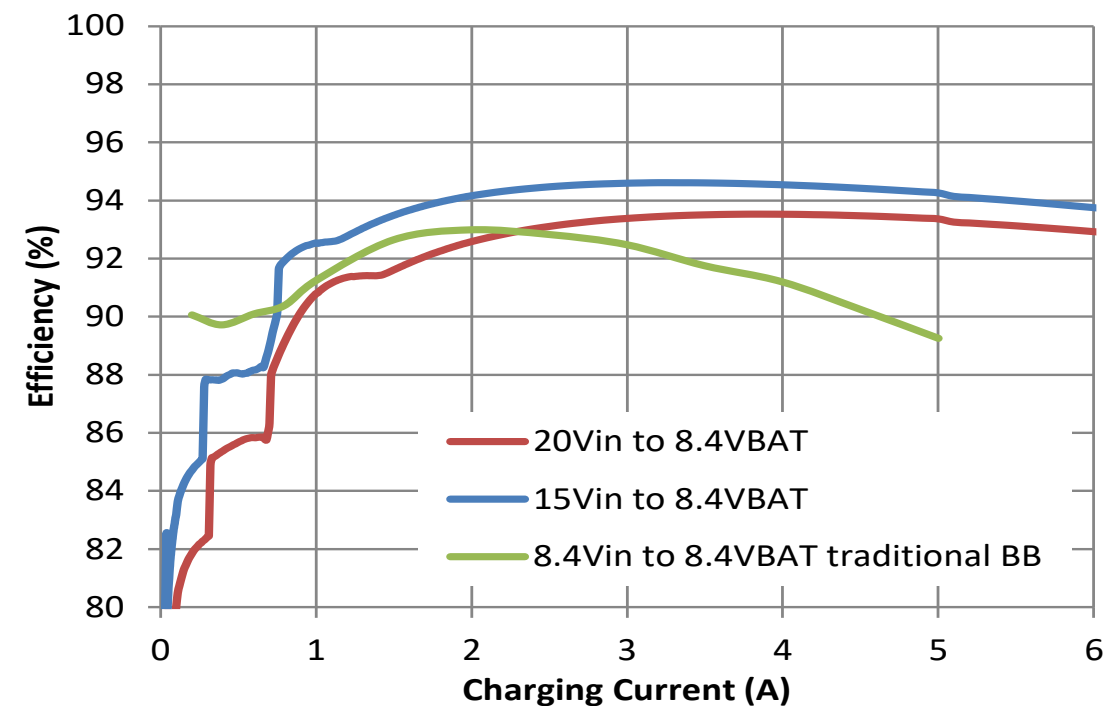
Dual-input mux

Priority-based selection of multiple wired USB, or wireless port.

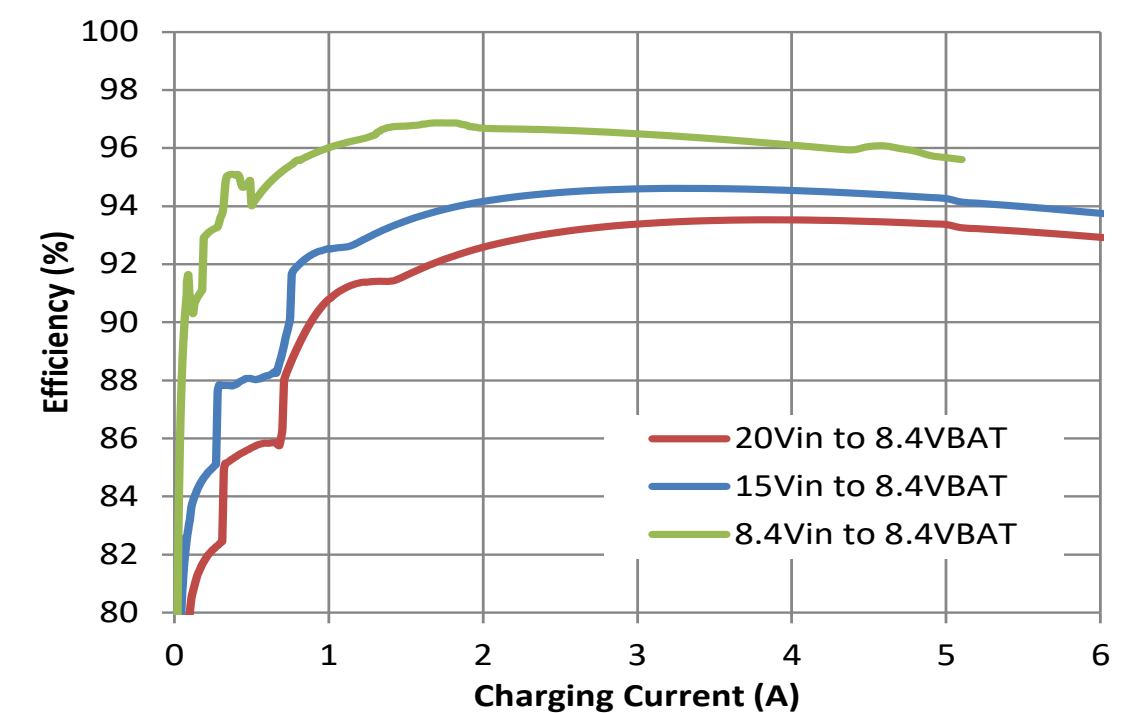
Buck-boost operation



In traditional buck-boost, 4 MOSFETs switch in one cycle, equivalently doubling the switching frequency and resulting in high switching losses and a large inductor current ripple.

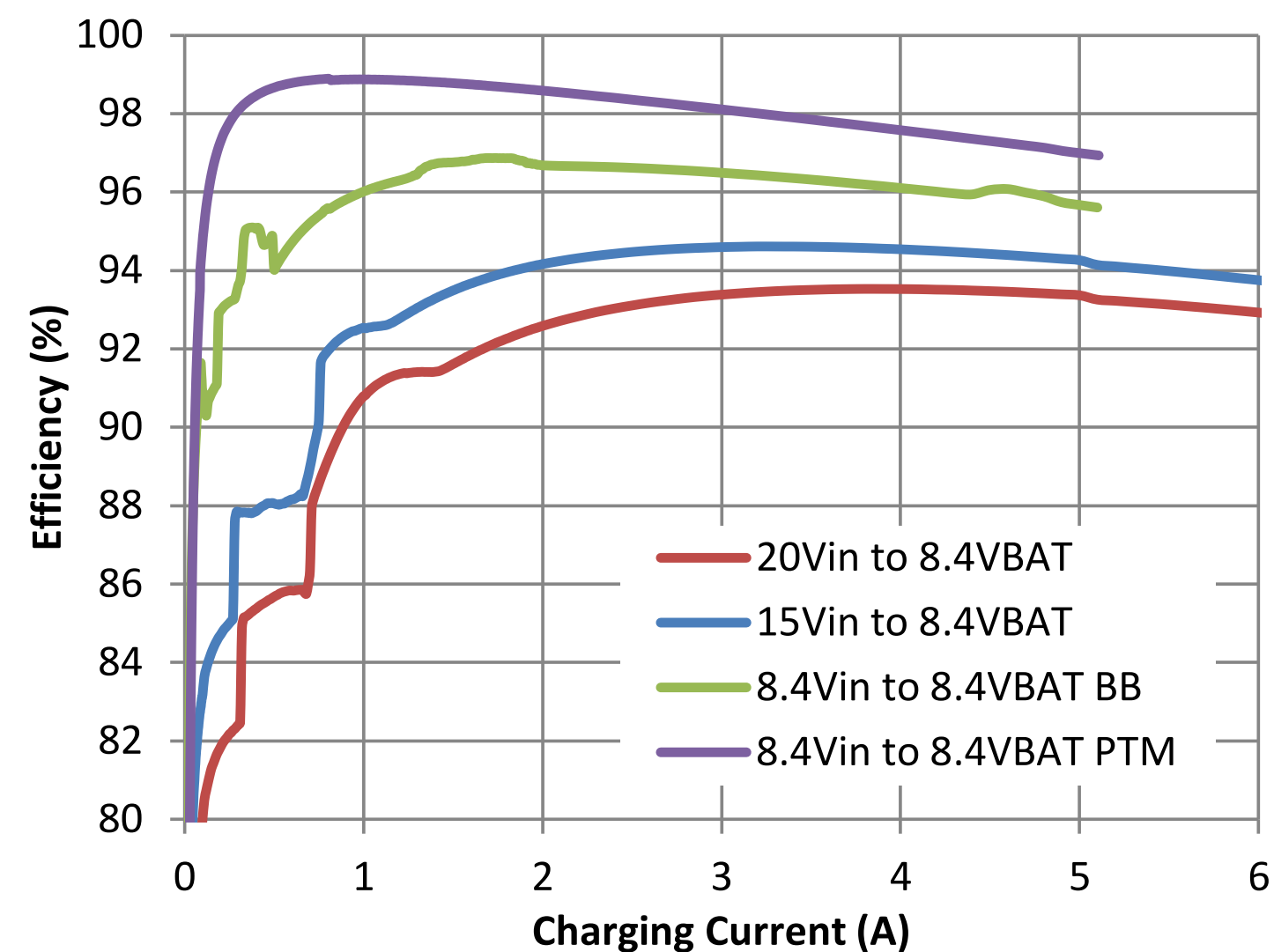
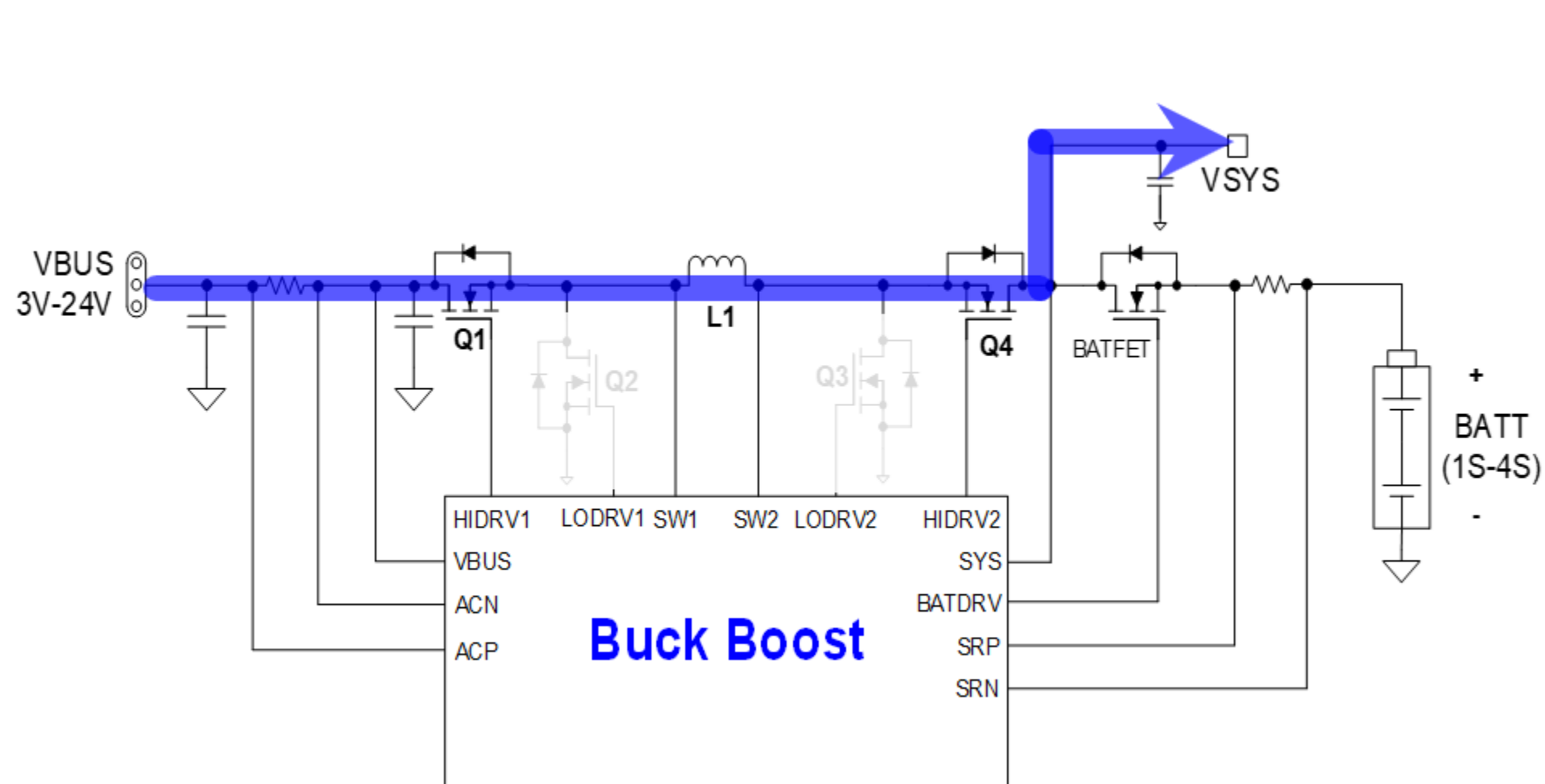


In TI's unique buck-boost operation, two PWM signals fight each other, and the dominant PWM sets the converter in normal buck and boost mode alternately.



Pass-through mode operation

- To keep Q1 and Q4 always on, keep Q2 and Q3 always off
- The input power passes through Q1, L1 and Q4 directly into the system
- Only Q1, Q4 and L1 conduction losses, negligible switching loss and no inductor core loss



High power density charging solutions

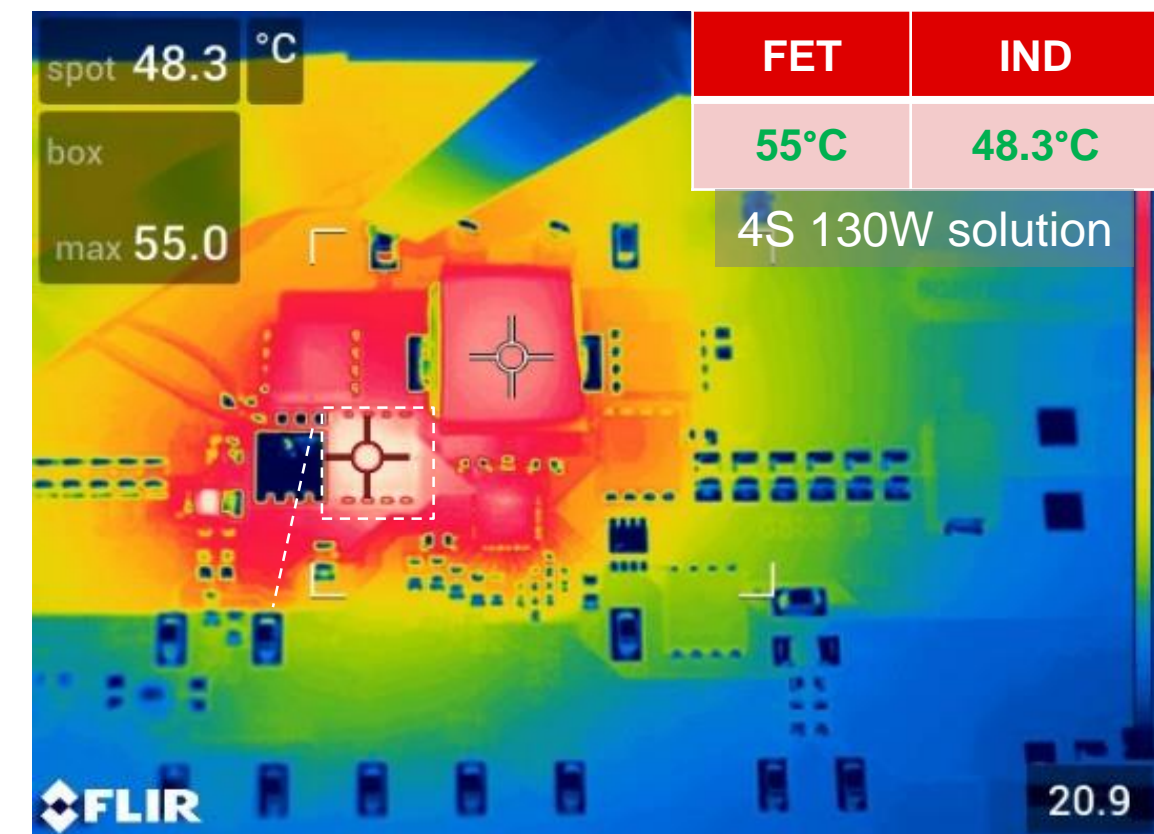
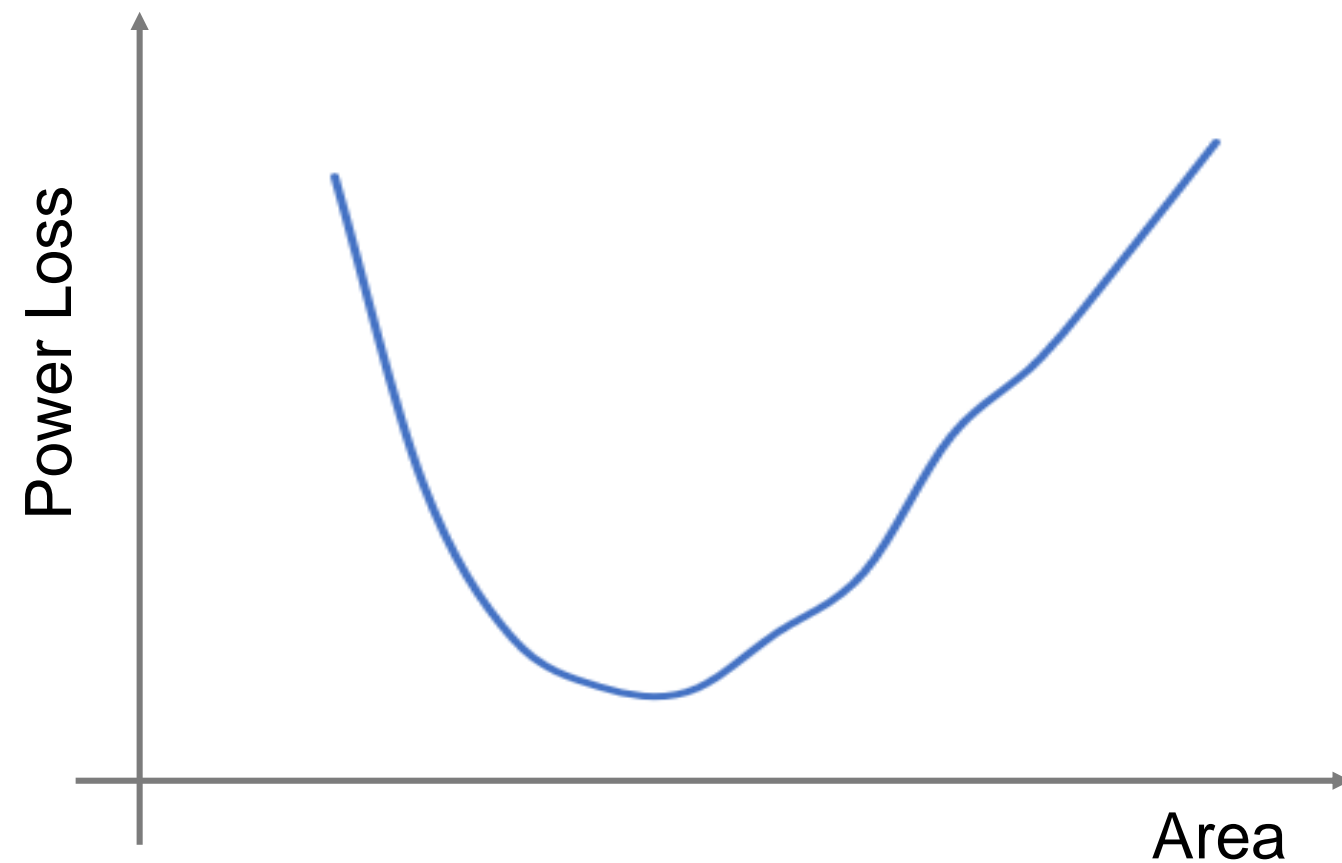
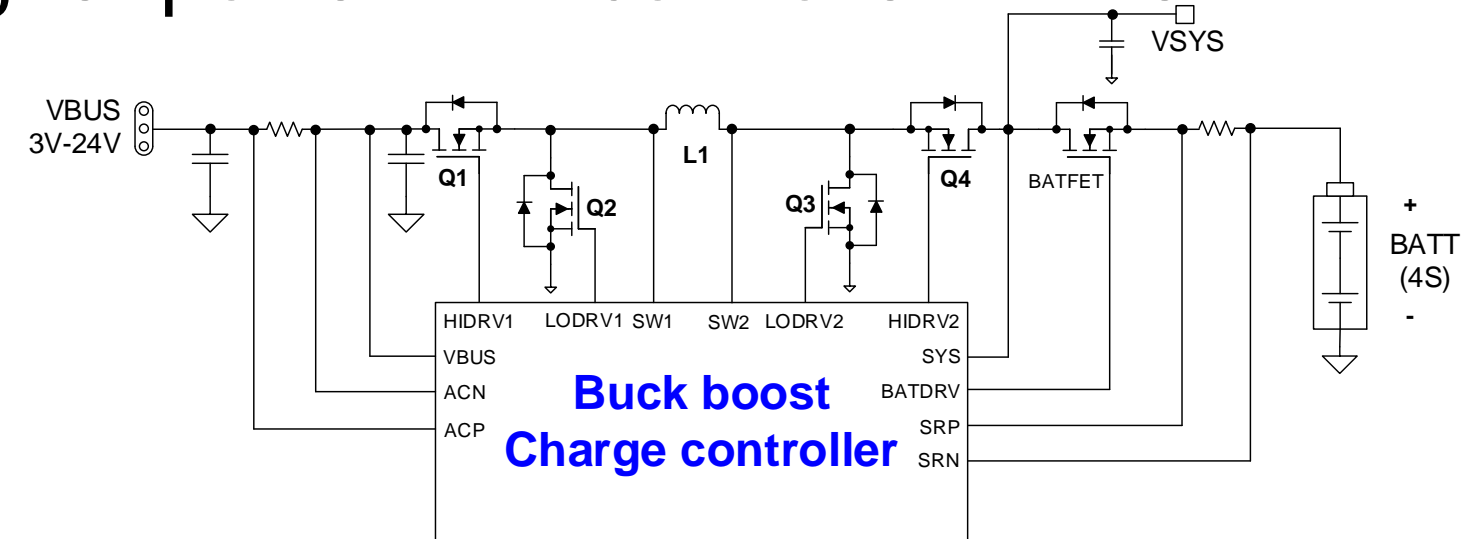
- **Cost effective charging system**
 - Single charger
 - Autonomous charging without host
- **Moderate charging system from HVDCP**
 - Dual chargers with two-level or three-level buck as companion
 - Autonomous charging without host
- **Fast charging system from USB PD with high output current**
 - Dual chargers with switch capacitor charger as companion
 - Host active monitor during charging phase
- **Fast charging system from USB PD with high output voltage**
 - Buck boost charger supports universal charging with flexible battery configurations.
 - Increase output power with multi-cell battery, save cost of high current traces, connectors and cables.

What limits the iFET solution?

Power loss!

- Switching regulator power loss:
 - Conductive loss
 - Gate charge loss
 - Deadtime loss
 - Switching loss
 - Reverse recover loss
 - IC bias loss

- Higher power with controller with ext. FET.



TI switched mode charger topologies

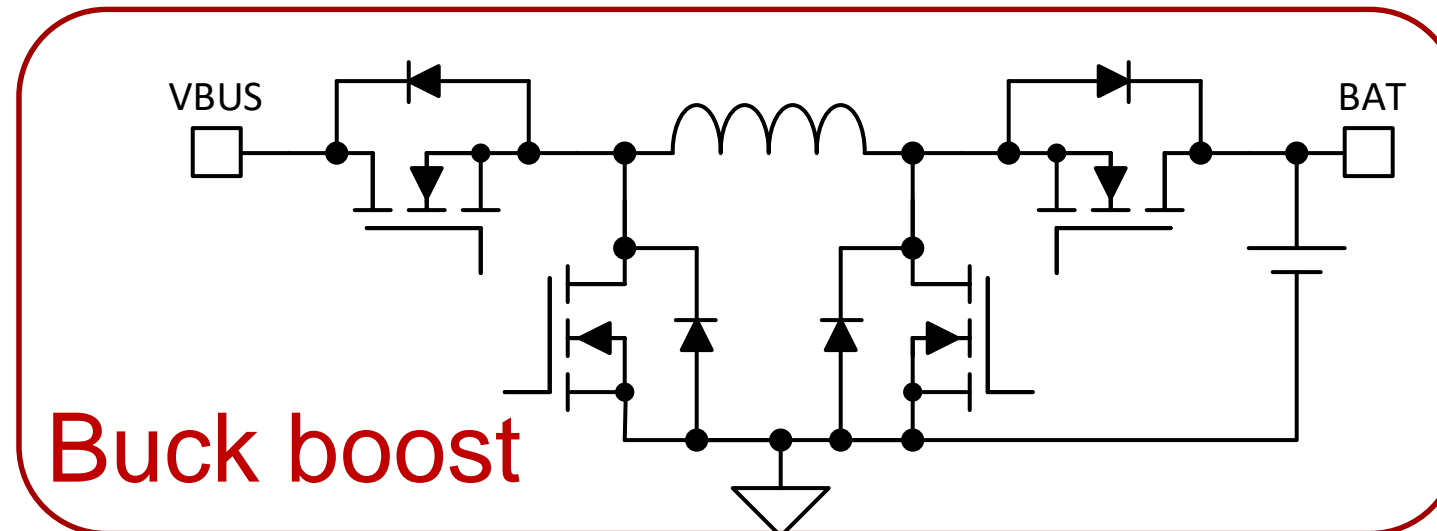
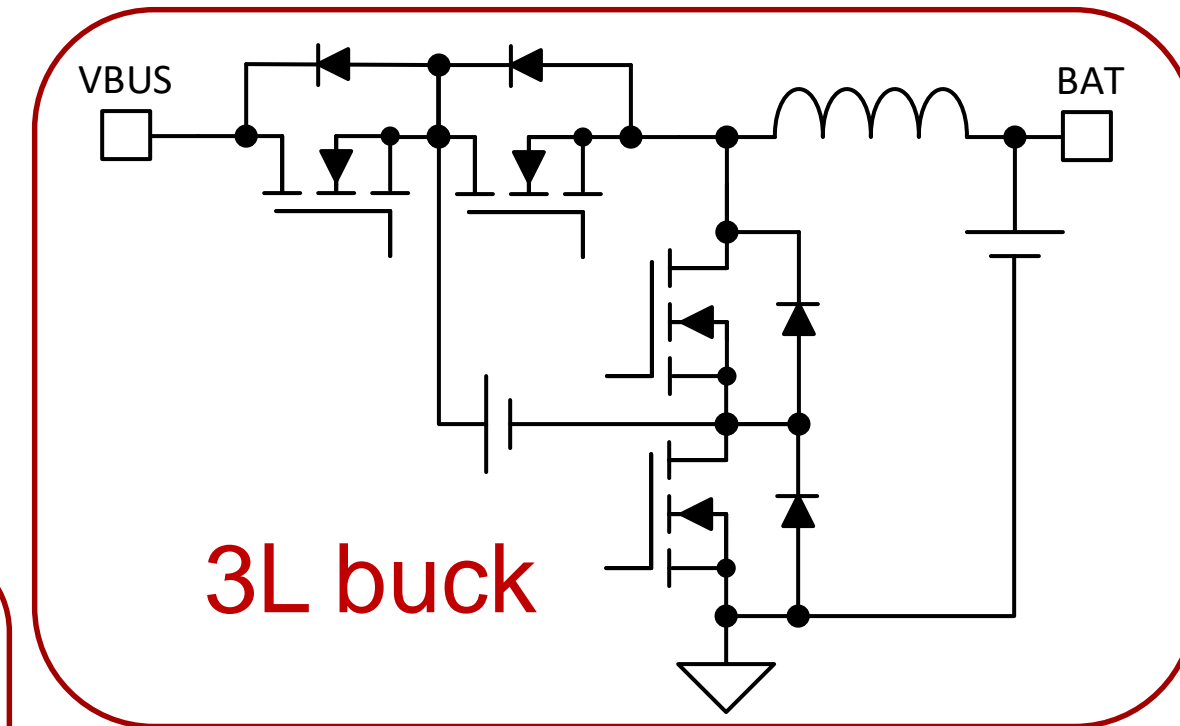
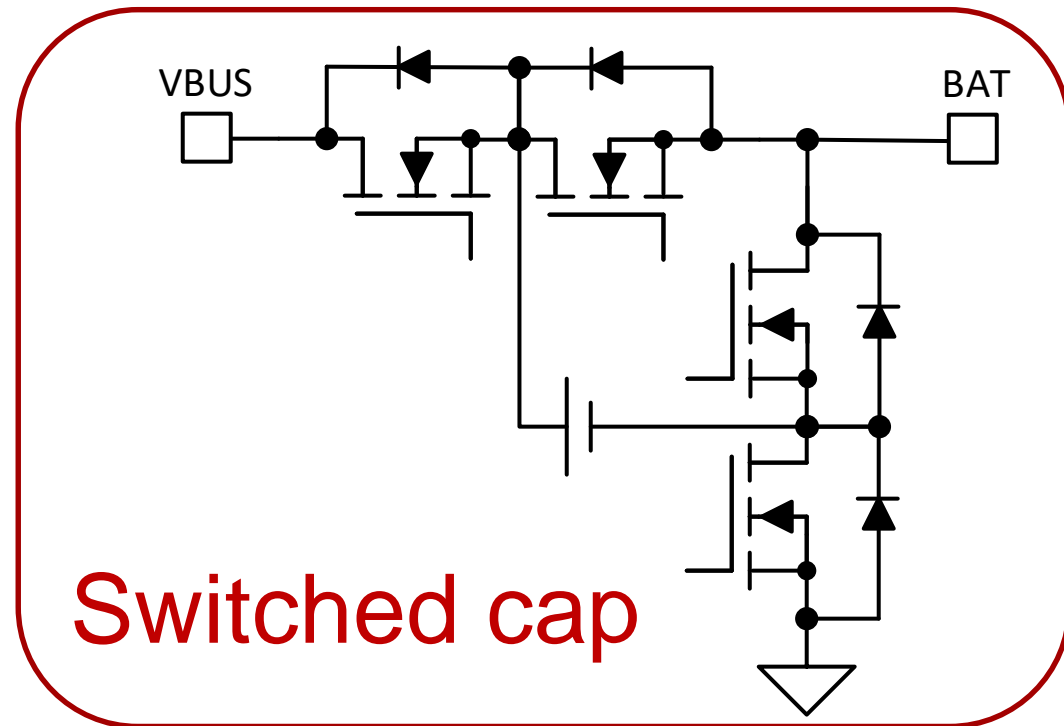
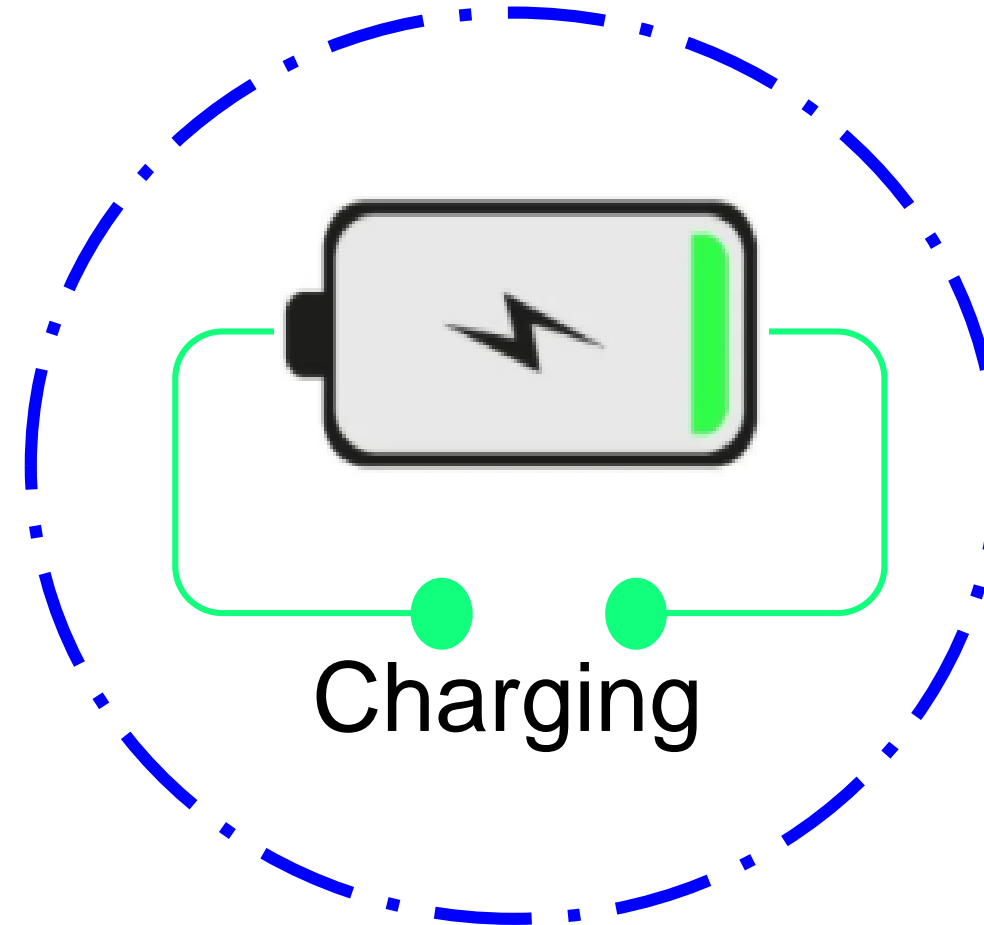
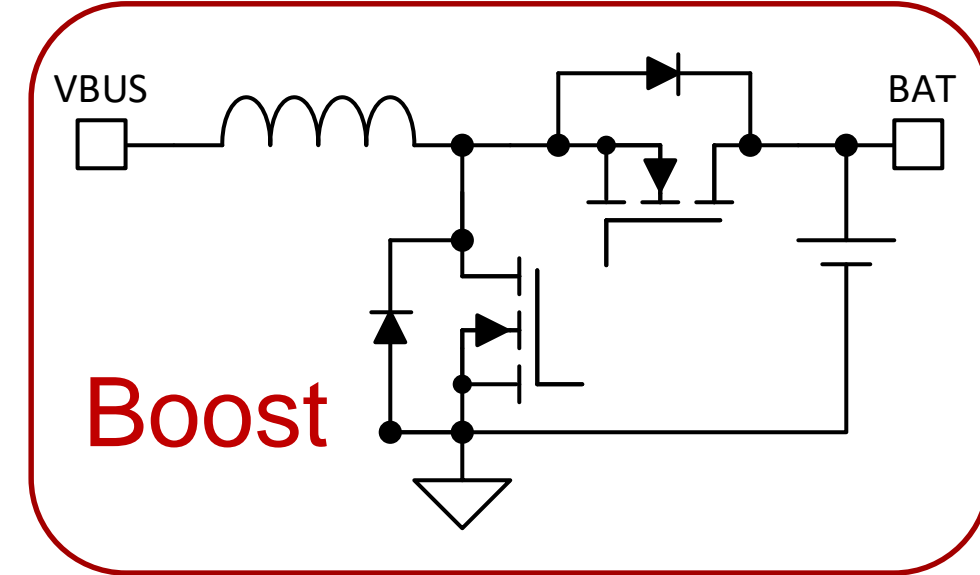
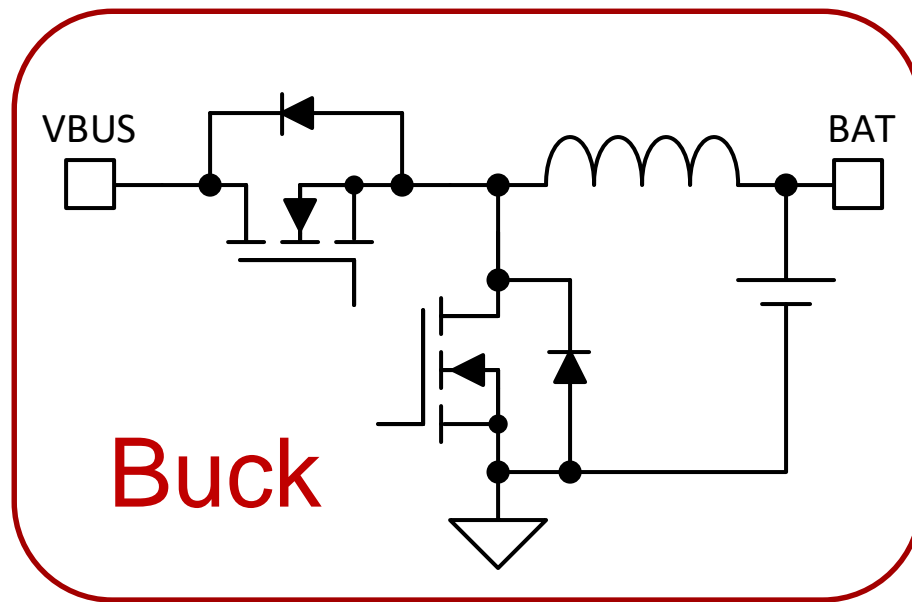
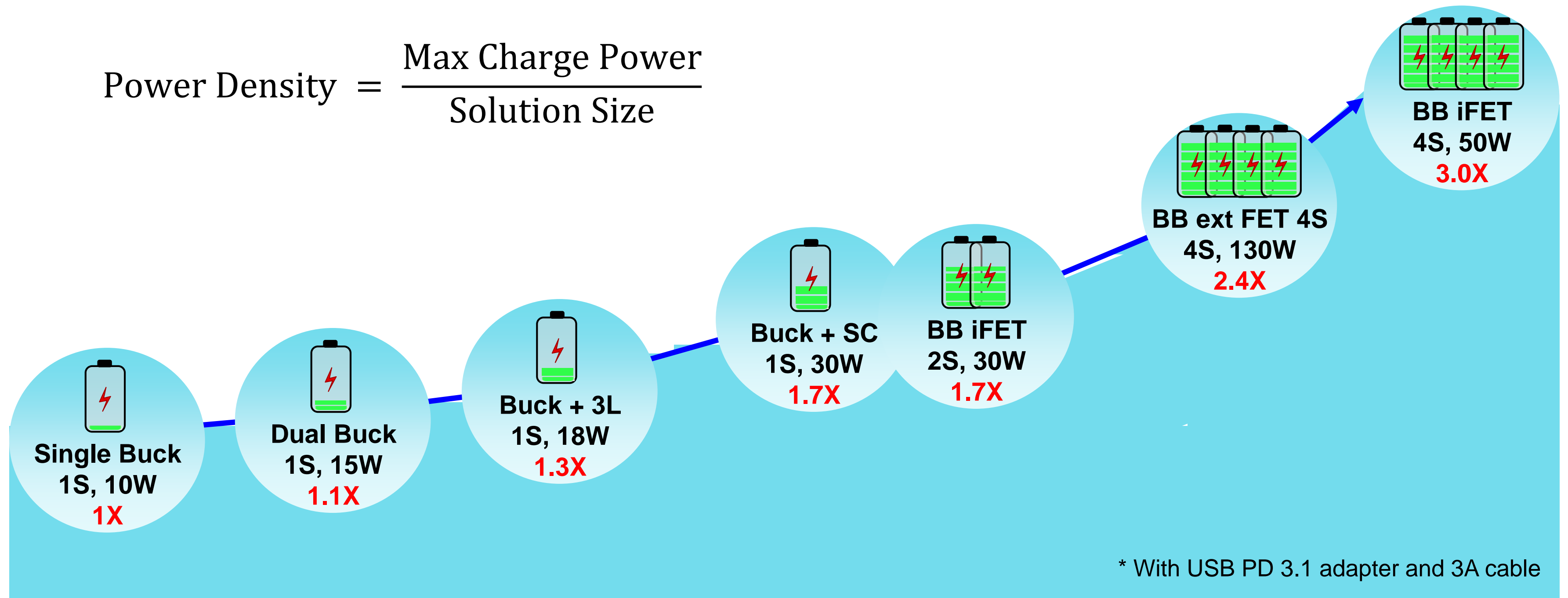


Figure of merit

$$\text{Power Density} = \frac{\text{Max Charge Power}}{\text{Solution Size}}$$



Battery charger reference

Battery charger quick search tool (CQS) on TI.com

<http://www.ti.com/power-management/battery-management/charger-ics/products.html>



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