TI POWER

Key battery charger features to improve user experience

Battery Management Deep Dive Training

October 2020

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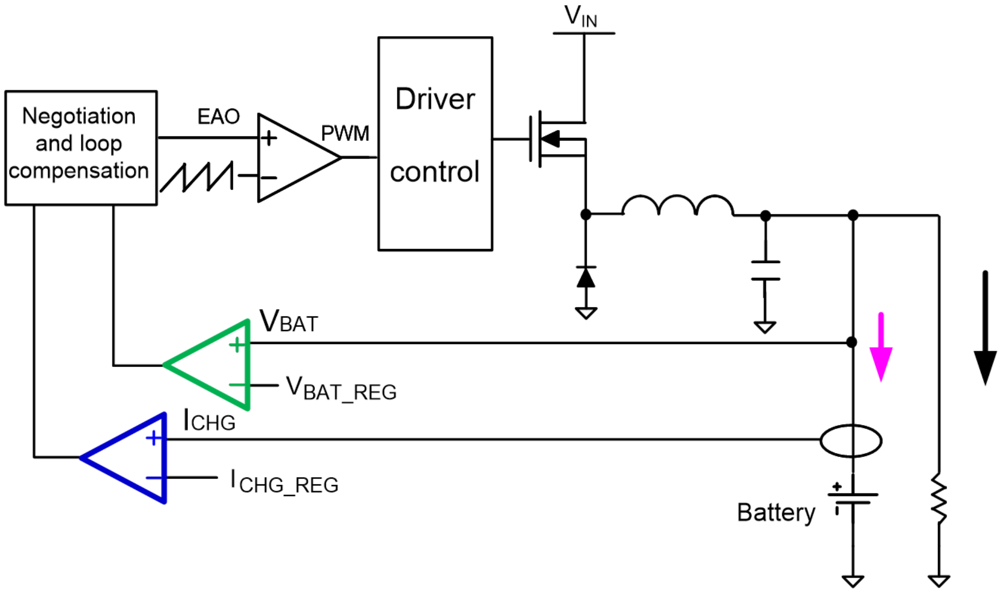
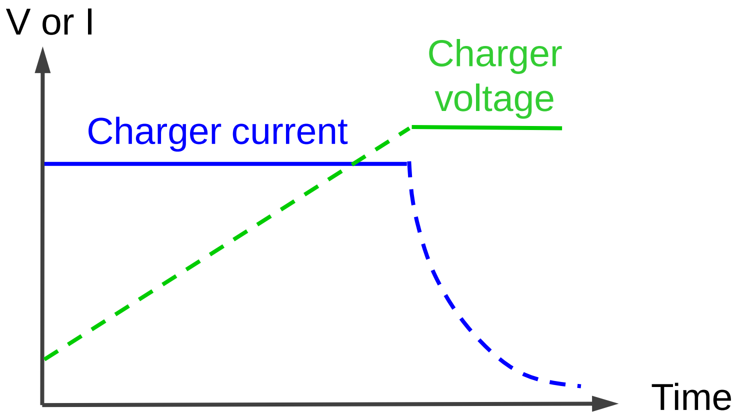
Agenda

- Battery charger system and end user care-abouts
- Basic battery charger: CC/CV
- Battery charger features to address end user care-abouts
- Summary

Simplest switching battery charger



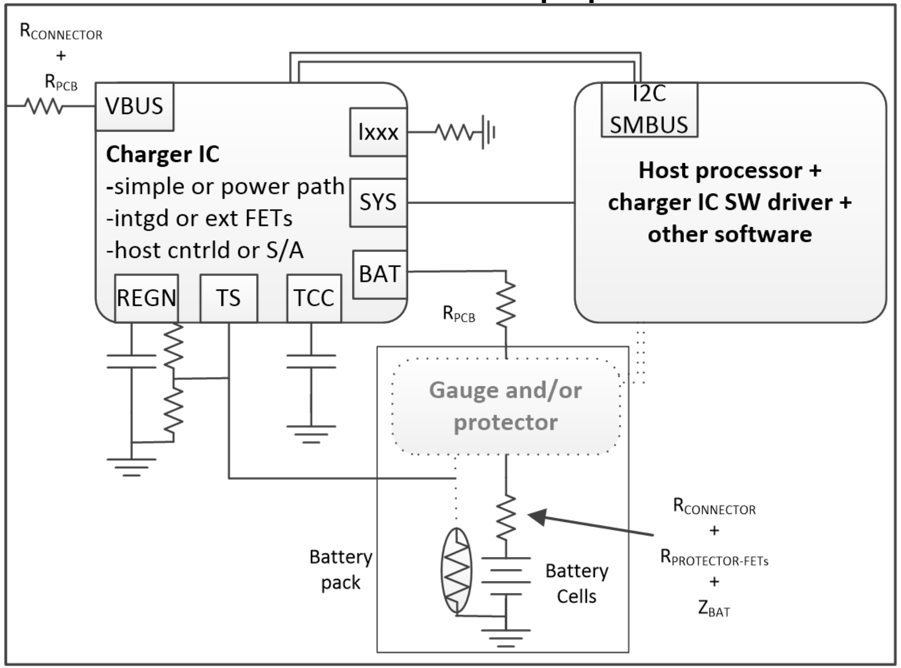


- **DC/DC converter with**
  - Current loop for constant current (CC) charging
  - Voltage loop for constant voltage (CV) or taper charging

Key care-abouts for a charging system

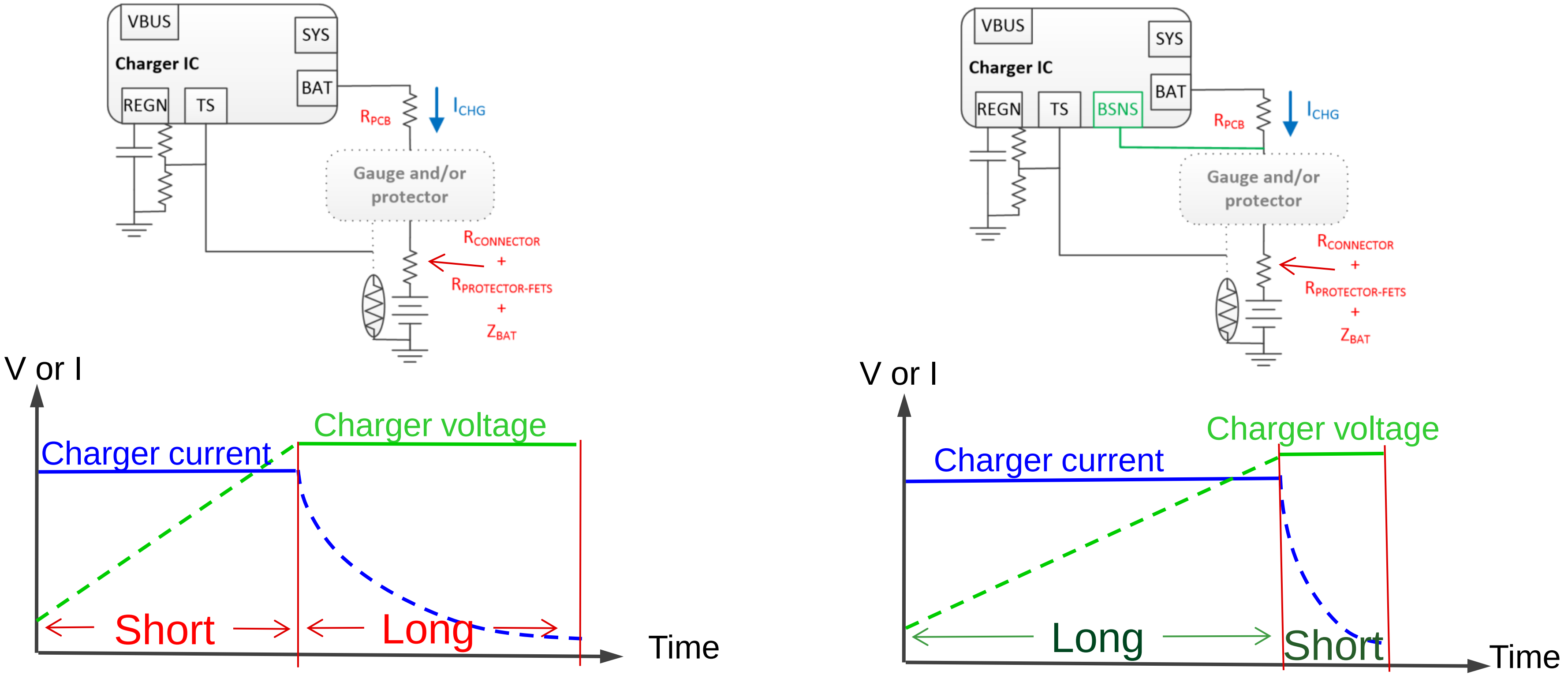
or

Portable end equipment



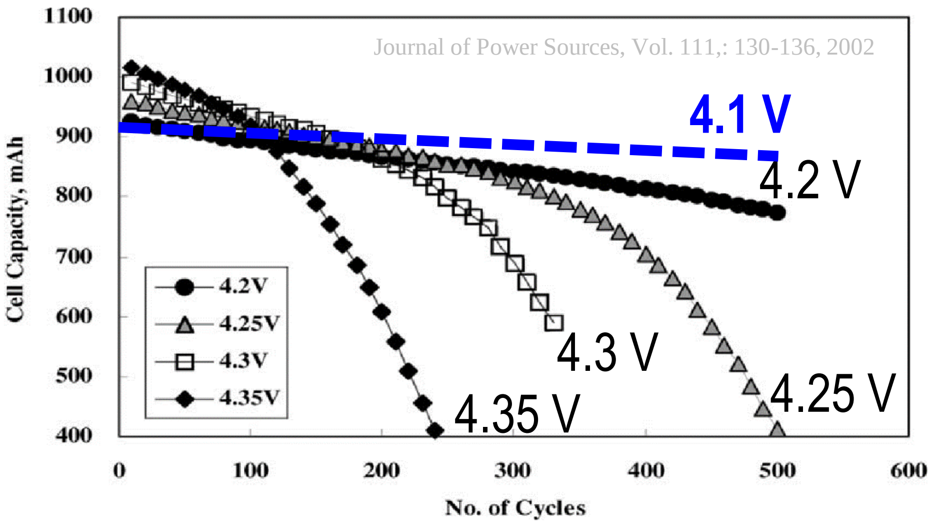
- **End user care-abouts**
  - Cool to touch and safe battery charging
  - Long battery life
  - Short (fast) charge time (max possible charge current)
  - Small, thin end equipment size
  - Power at plug in, even with discharged battery or for transient demand

Increase time in CC mode = less time in CV/taper



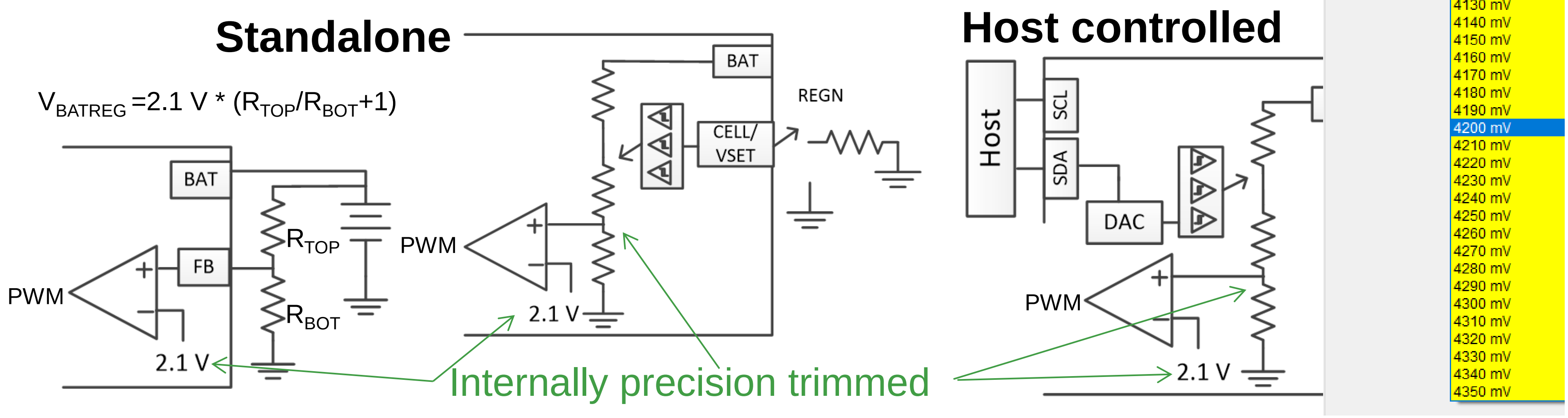
Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

Importance of charging voltage accuracy at termination



- The higher the voltage, the higher the initial capacity
- Overcharging shortens battery cycle life (i.e., number of cycles)

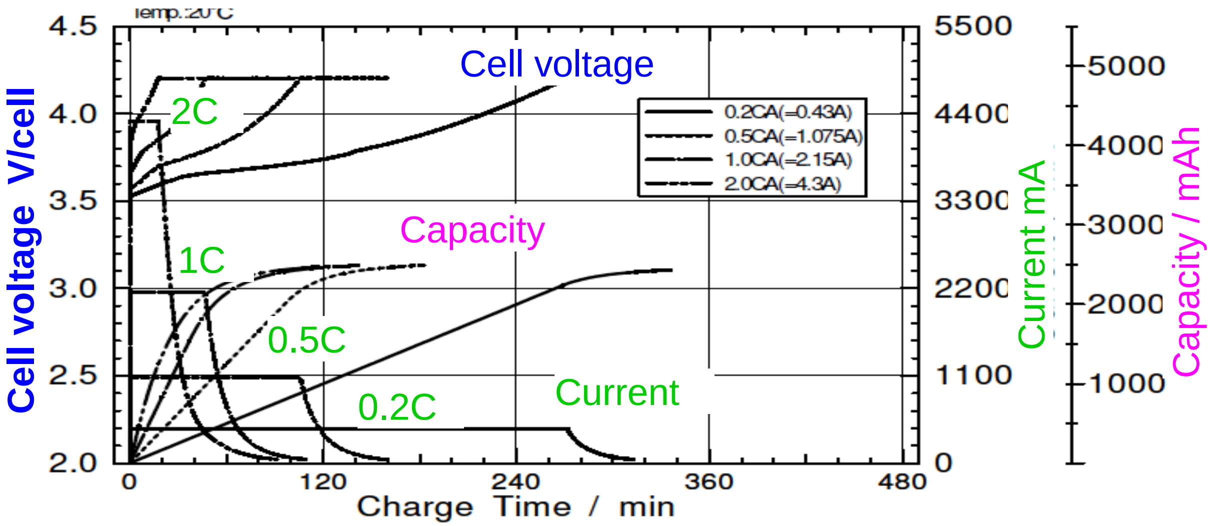
Implementing charging voltage accuracy



	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Charge voltage regulation						
V_{REG_ACC}	Host controlled charge voltage regulation accuracy	**T_J = 0 to 85°C**	**-0.5**		**0.5**	%
	Standalone charge voltage regulation accuracy (w/o resistor accuracy)	V_{REG} = 4.2 V, R_{VSET}>50 kΩ, **T_J = 0°C - 85°C**	**4.183**	**4.20**	**4.217**	**V**

Cool/safe charge	**Long battery life**	**Fast charge**	**Small size**	**Power at plug**

Charging current accuracy

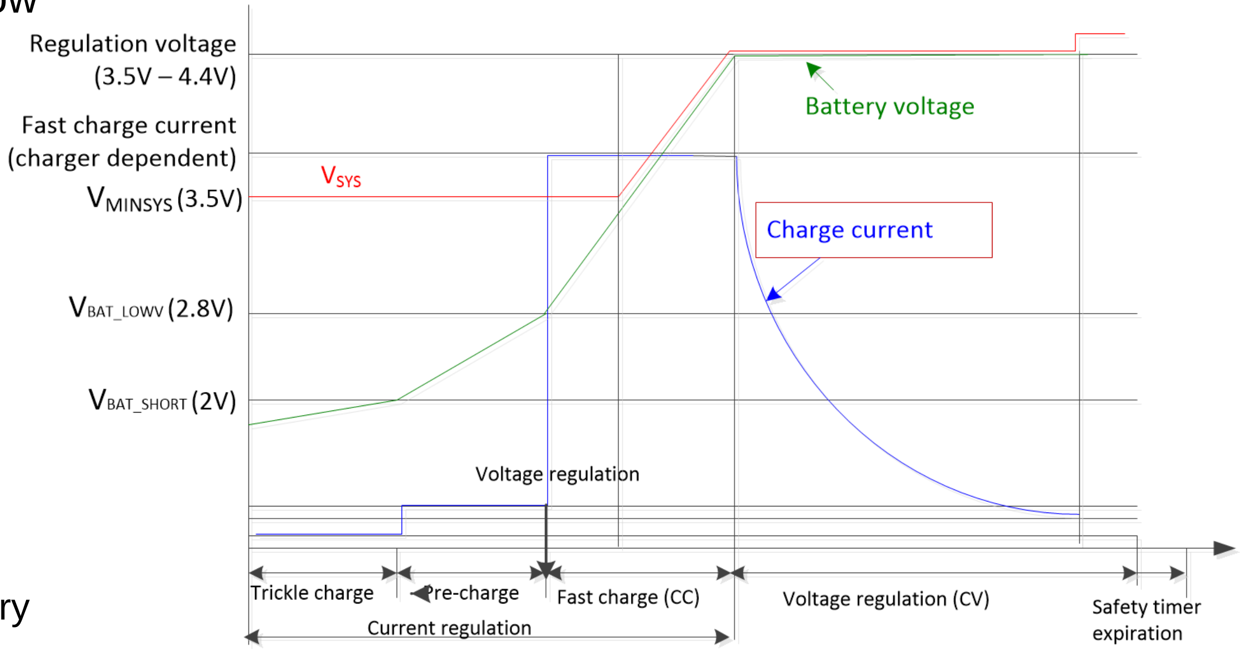


	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Charge current regulation						
I_{CHG_ACC}	Host controlled charge current accuracy	V_{BAT}= 3.1 V or 3.8 V, I_{CHG}=1792 mA **T_J = –40°C to +85°C**	**-5**		**5**	%
	Standalone charge current accuracy	R_{ICHG} = 372 Ω, V_{BAT} = 3.1 V or 3.8 V, **T_J = –40°C to 85°C**	**1.72**	1.82	**1.89**	A

Cool/safe charge	**Long battery life**	**Fast charge**	**Small size**	**Power at plug**

Complete Li-ion battery charging profile

- **Pre-charge** current when V_{BAT} low
  - Close the protector of deeply discharged battery
  - S/A is % of I_{FAST_CHRG}
  - ~10-20% accuracy typical
- **Term** current when V_{BAT} = CV
  - Stopping charge to prevent overcharge for long battery life
  - S/A is % of I_{FAST_CHRG}
  - ~10-20% accuracy typical
- **~5-24 hour safety timer**
  - Prevent charge of damaged battery
  - S/A fixed or uses external cap



Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

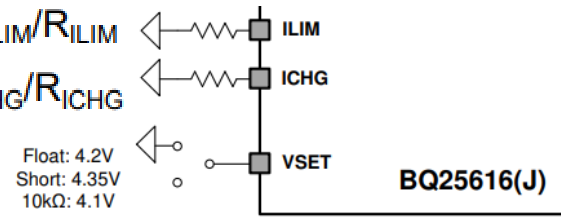
Benefits and limitations of standalone charger

Benefits

- Simple and no software
- Pin level and/or resistors set charge voltage and currents

$I_{IINDPM} = K_{ILIM}/R_{ILIM}$

$I_{ICHG} = K_{ICHG}/R_{ICHG}$



K_{ICHG}	ICHG pin setting ratio	$ICHG=K_{ICHG}/R_{ICHG}$, VBAT = 3.1V, T_J = –40°C - 85°C	639	677	715	AxΩ
		$ICHG=K_{ICHG}/R_{ICHG}$, VBAT = 3.8V, T_J = –40°C - 85°C	639	677	715	AxΩ

Limitations

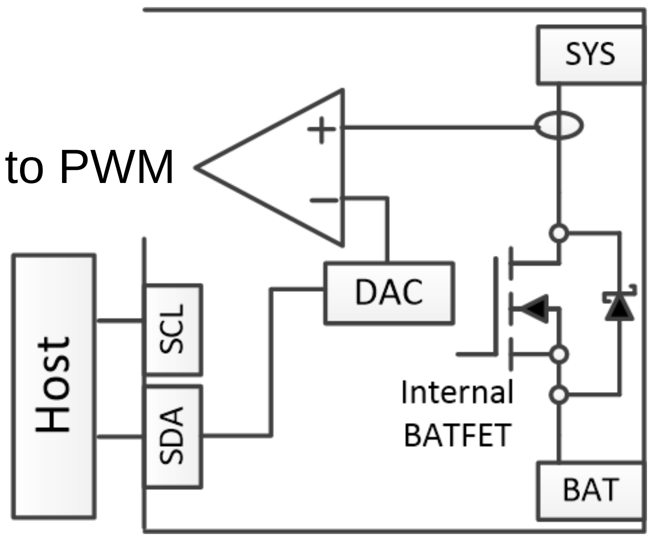
- Pre-charge/term currents are fixed 10% of fast charge
- Resistor tolerance affects regulation accuracy
- Hardware required to dynamically change I_{CHG}
- Limited status reporting

CHARGING STATE	STAT INDICATOR
Charging in progress (including recharge)	LOW
Charging termination (top off timer may be running)	HIGH
Sleep mode, charge disable, boost mode	HIGH
Charge suspend (input over-voltage, TS fault, safety timer fault or system over-voltage)	Blinking at 1 Hz

Benefits and limitations of host controlled

Benefits of BQ25790

- I^2C/SMBus register with high resolution and accuracy (no resistors necessary) set
  - **CV**: 3 V – **18.8 V** in **10 mV steps**
  - I_{PRE}/I_{TERM}: 40 mA - 1 A / 40 mA – 2 A in 40 mA steps
  - **CC**: 10 mA – **5 A** in **10 mA steps**
  - Safety timer: 5 hr, 8 hr, 12 hr, 24 hr
  - Enable/disable: PFM, OOA, ship mode, etc.
- **Status/fault registers** report operation
  - Loop: CC, CV, I_{INDPM}, V_{INDPM}, T_{REG}
  - Status/Fault: PG, VBUS OVP, VBAT OVP, etc.
- Integrated **ADC:** V_{BUS}, V_{BAT}, I_{BUS}, I_{BAT}, T_{DIE}

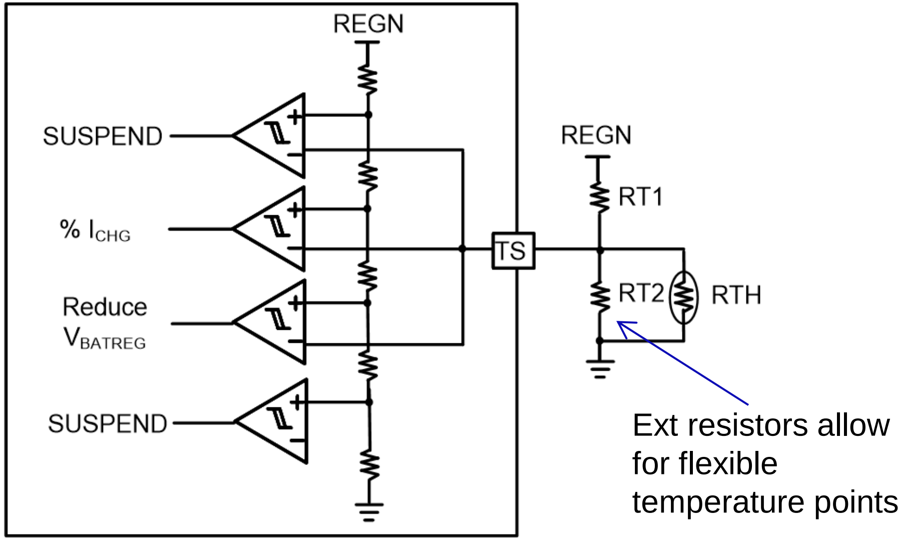


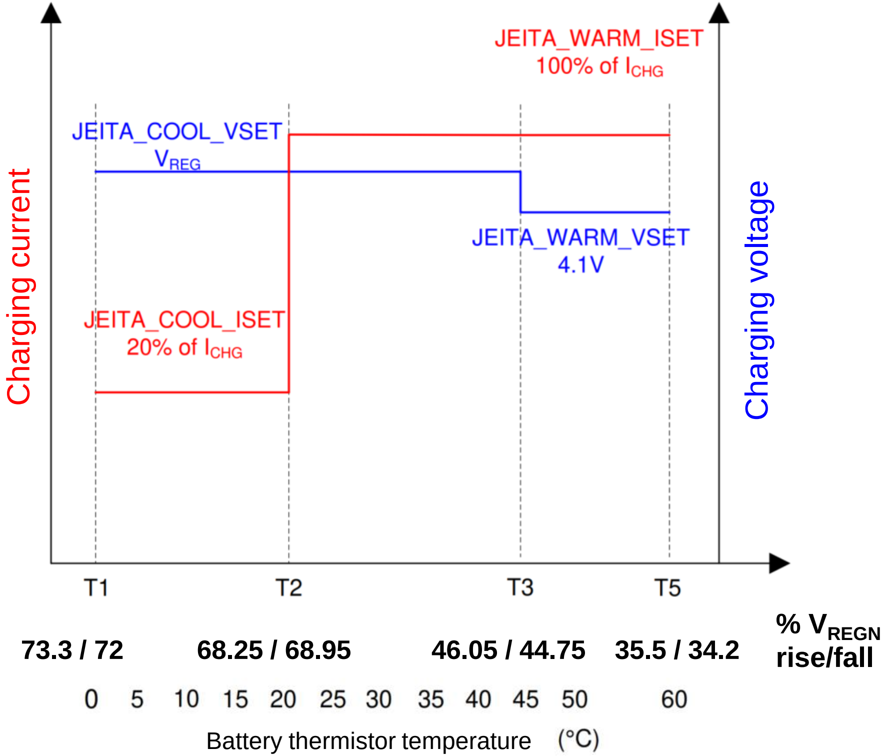
Limitations

- Host software required

Cool charge	Long battery life	Fast charge	Small size	Power at plug

Faster charging with JEITA temperature profile

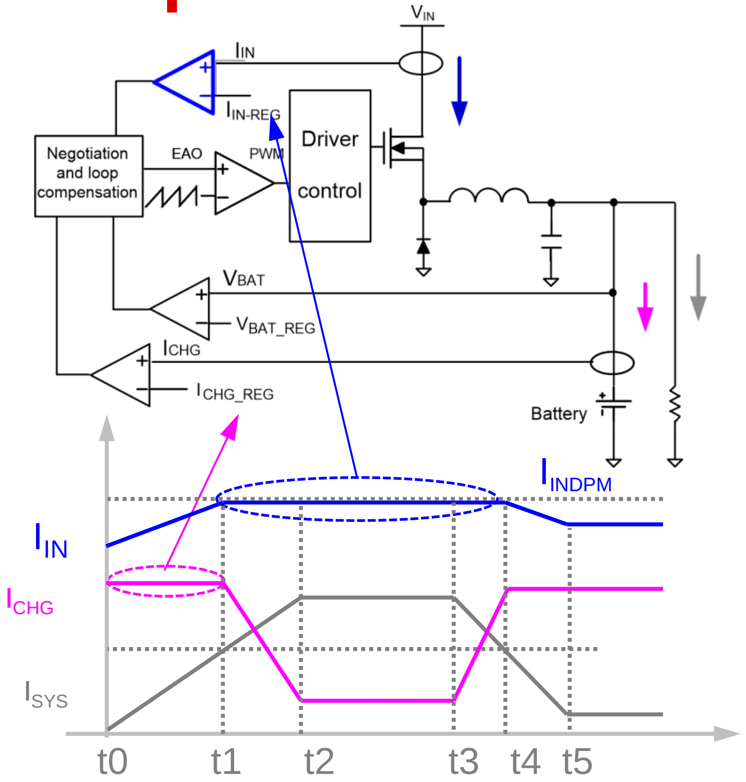




- JEITA profile
  - Wider temp range for charging = shorter charge time
  - Does not compromise safety or battery life

Cool/safe charge	**Long battery life**	**Fast charge**	**Small size**	**Power at plug**

Max power from the adapter with I_{INDPM} loop



Q: How to handle different input sources?

- **Different input sources with *known* current capability**
  - OEM adaptor
  - USB port
- **Input current DPM**
  - Limit the input current with the system load as high priority

Benefit:

Maximize the utilization of adaptor capability ***without*** overloading for faster charging

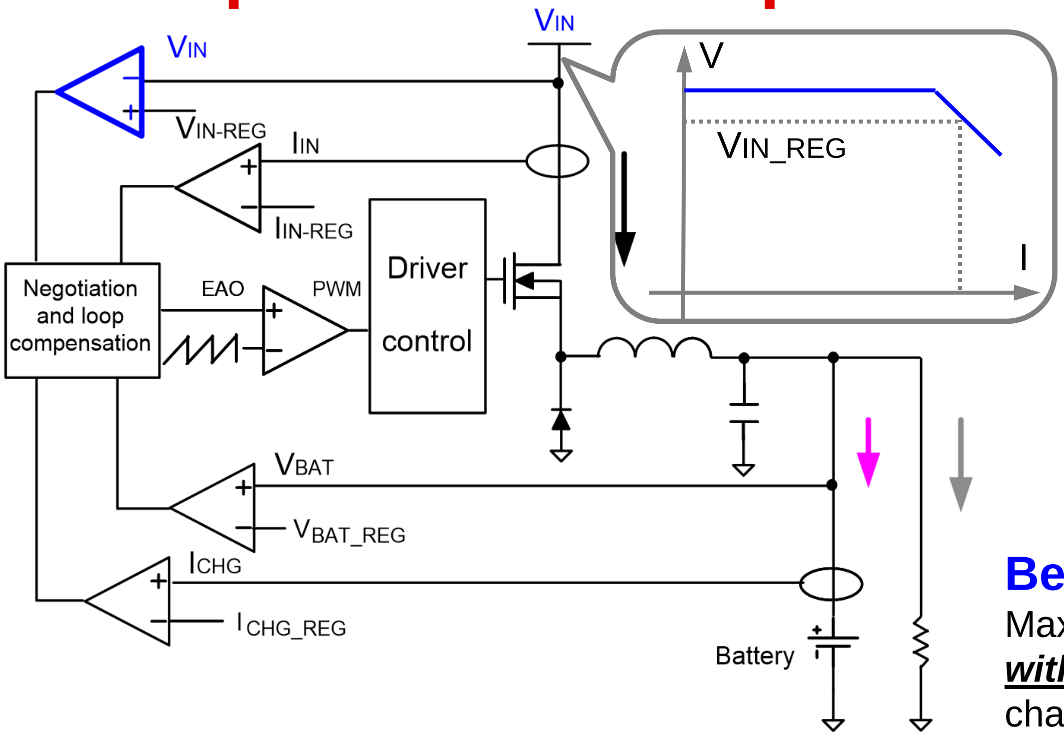
Cool/safe charge	**Long battery life**	**Fast charge**	**Small size**	**Power at plug**

D+/D- adapter detection

- Industry standard
  - USB Battery Charging Specification Rev 1.2 (**BC1.2**)
  - Universal charging for convenience
  - Less e-waste

Port definition	Examples	Output current
SDP (standard downstream port)	Laptop USB port	5 V @ **100 mA** (low power) 5 V @ **500 mA** (high power)
DCP (dedicated charging port)	USB wall adapter	5 V @ 500 mA to 2.4 A
CDP (charging downstream port)	Audio docking station	5 V @ 900 mA to 1.5 A
Non-standard adapters	Apple iPhone®, iPad® adapters	5 V @ 1 A / 2.1 A / 2.4 A
HVDCP	Negotiable high voltage adapters	5 V / 9 V / 12 V @ 1 A – 2 A

Max power from adapter with V_{INDPM} loop



Q: How to handle third party adaptors or highly resistive PCB traces or cables?

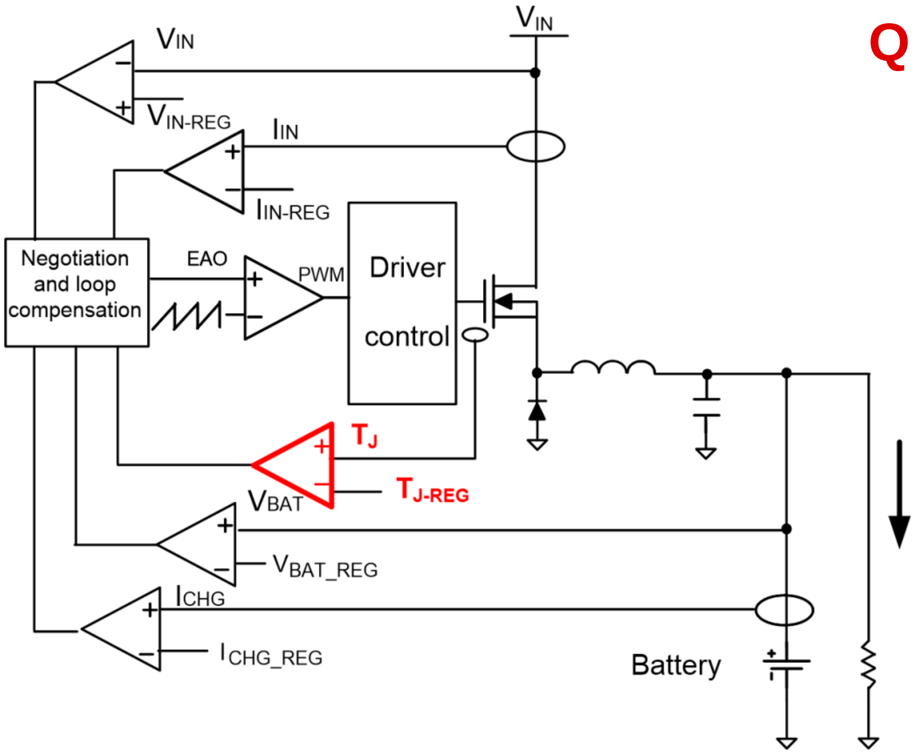
- **Different input sources with *unknown* current capability**
  - Non-OEM adaptors
  - Traveler adaptor
- **Input voltage DPM**
  - Prevent input voltage collapse with the system load as high priory

Benefit:

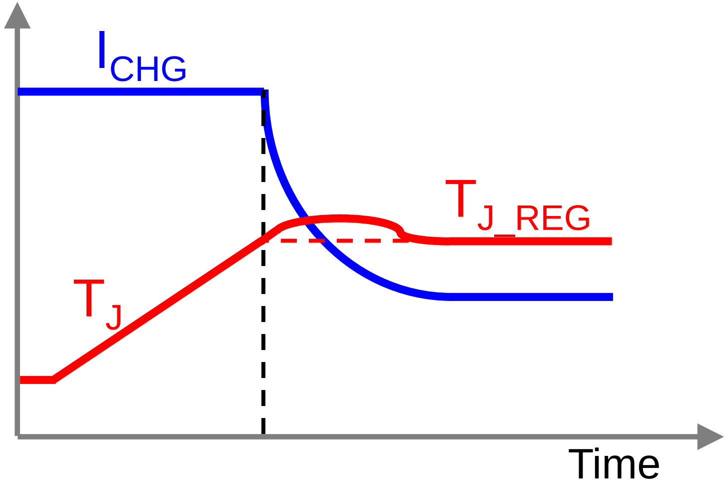
Maximize the utilization of adaptor + cable capability ***with*** limited overloading for fastest possible charging

Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

Cool, safe charging with thermal regulation loop



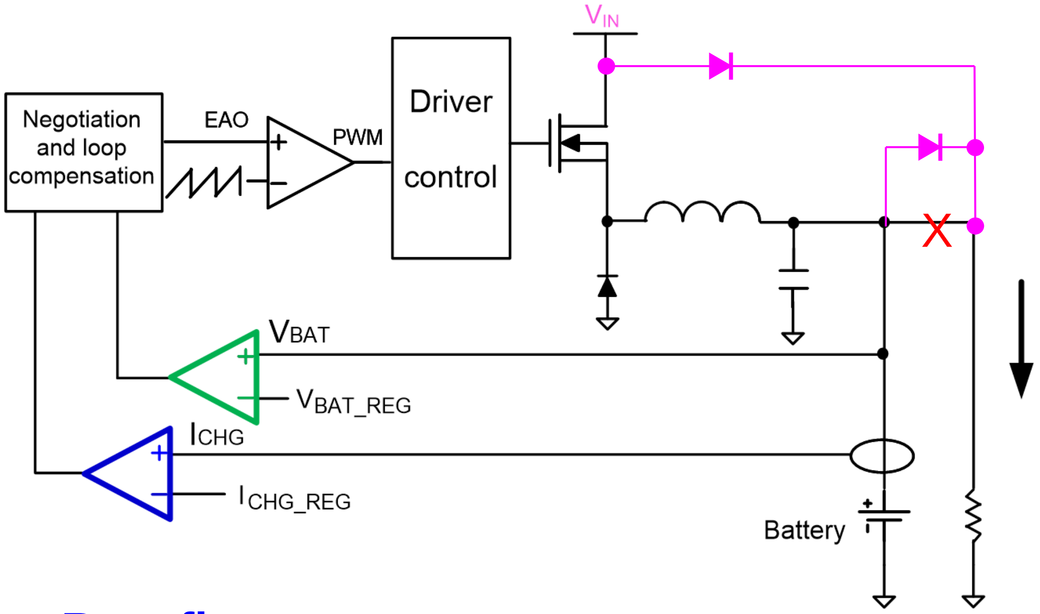
Q: What to do if the device is too hot?



- **Thermal regulation**
  - Better customer experience
  - Safe charging
  - Continuous charging current

Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

Charger architecture: Traditional power path



Q: What happens if the battery is deeply discharged/dead?

Traditional architecture:

- Separate the system and the battery during charging
- Two diodes (or MOSFET) makes the power path (OR)
- $P_{max} = P_{adaptor}$ when adaptor is present

Limitations:

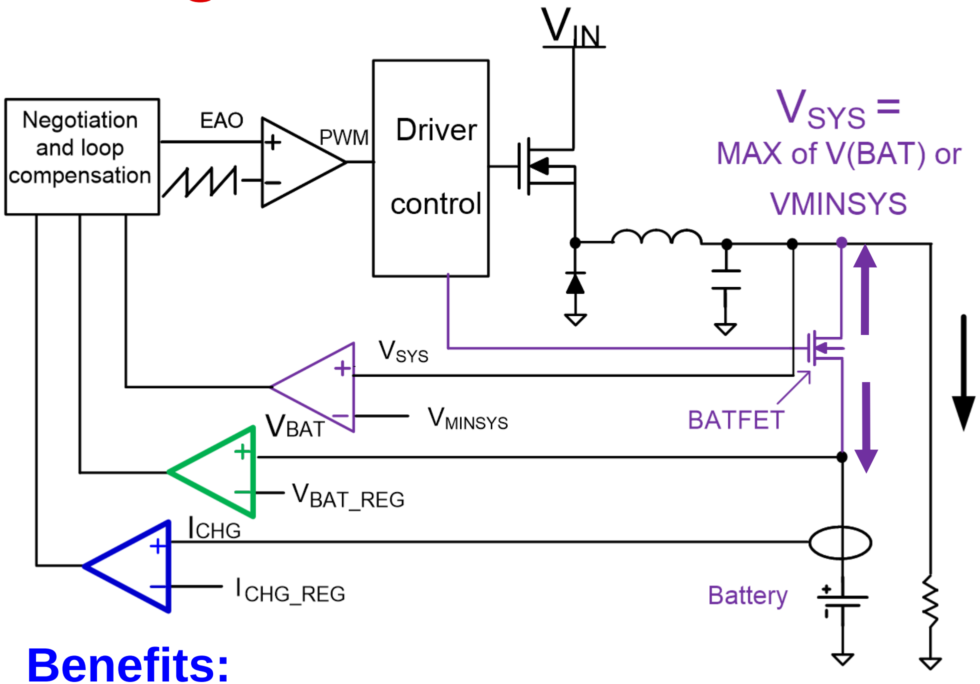
- No extra battery power w/ adaptor
- Wide system voltage: from the adaptor voltage to the minimum battery voltage

Benefits:

- Direct power path from adaptor to system
- High power operation from adaptor

Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

Charger architecture: Narrow voltage DC power path



Q: Can a small adaptor power higher power systems?

NVDC architecture:

- Added FET separates the system and battery
- Regulate to V_{MINSYS} when $V_{BAT} < V_{MINSYS}$ to power system even with deeply discharged battery
- More accurate I_{CHRG}, I_{PRE}, I_{TERM}
- $P_{MAX} = P_{BUCK} + P_{BATTERY}$ when adaptor is present

Benefits:

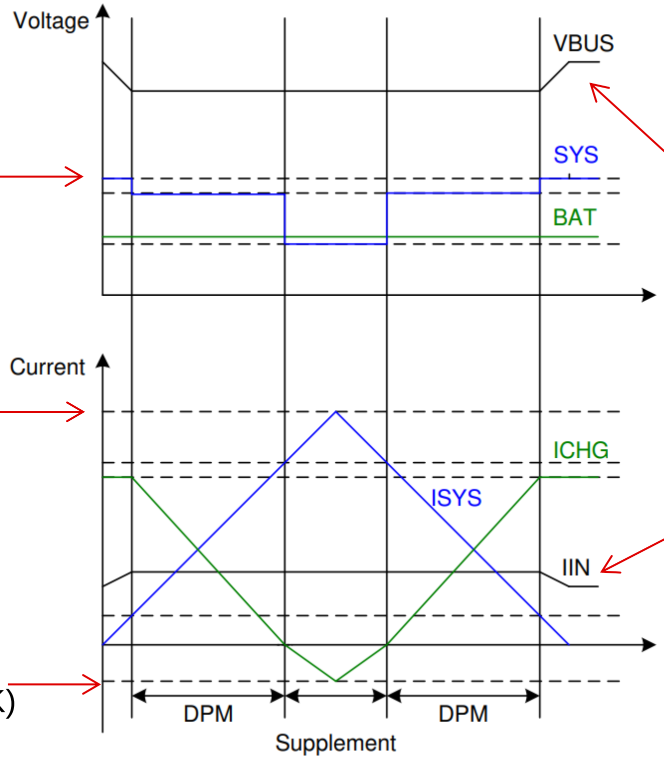
- Power path (OR) + supplement (ADD)
- Narrow system voltage – no adaptor voltage

Limitations:

- All power to be processed by charger

Cool/safe charge	Long battery life	Fast charge	Small size	Power at plug

NVDC supplemental mode improves SYS performance



V_{MINSYS}

$I_{SYS(PK)}$

$I_{BATFET-DISCHARGE(PK)}$

I_{INDPM} or V_{INDPM} limits input current to prevent further V_{BUS} droop

Cool/safe charge	Long battery life	Fast charge	Small size	Power for trans

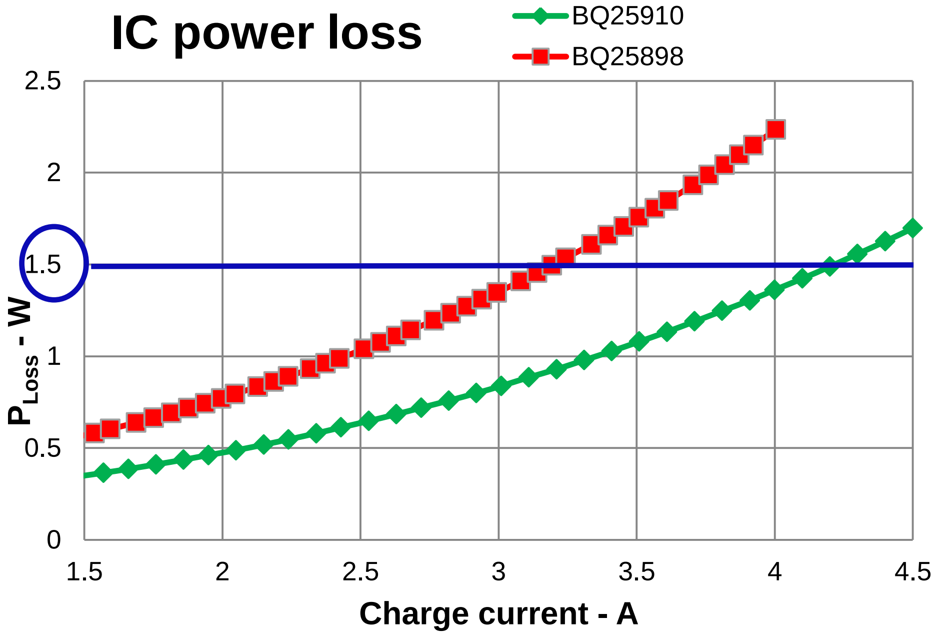
High efficiency for faster, cooler charging

IC	Topology	Inductor DCR (Ω)	High side FET $R_{DS(ON)}$ (Ω)	Low side FET $R_{DS(ON)}$ (Ω)	%eff @ V_{BUS} = 9 V, V_{BAT} = 3.8 V, I_{CHRG} = 3 A	%eff @ V_{BUS} = 5 V, V_{BAT} = 3.8 V, I_{CHRG} = 2 A
BQ2561X	1S buck	10	62	71	89	92.4
BQ25898	1S buck	10	24	12	91.5	93.7
BQ25910	1S 3-level buck	10	32	20	93.5	94.8

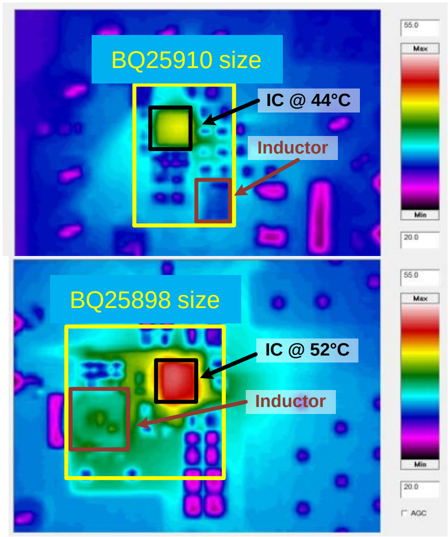
- Charger efficiency and therefore power loss for device to dissipate are a function of
  - $R_{DS(ON)}$ of FETs, both internal and external
  - Inductor with low DCR
  - Appropriate charger topology

Cool charge	Long battery life	Fast charge	Small size	Power at plug

Small efficiency increase → higher charge current



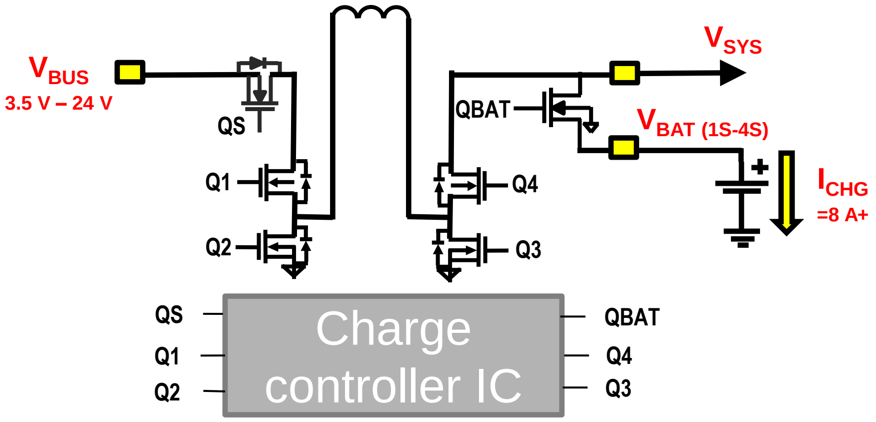
Thermal performance at
V_{IN} = 9 V, V_{BAT} = 3.8 V, I_{CHG} = 3 A



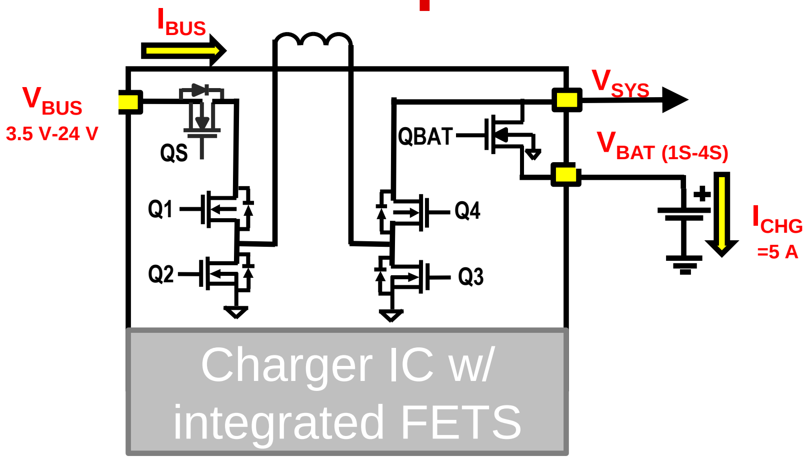
- For 1.5 W loss budget, BQ25898 gives I_{CHG} = 3.2 A but >3% more efficient BQ25910 can provide 4.2 A of charge current (a **31% increase**) in a 36% smaller solution size due to small inductor

Cool charge	**Long battery life**	**Fast charge**	**Small size**	**Power at plug**

Balance small solution size and thermal performance



Component	Dimensions (mm)	Area (mm²)	Power dissipation
BQ25713QFN	4 x 4	16.00	Minimal
5xFETs	3.3 X 3.3	54.50	**Distributed**
2xR_{SNS} in 1206	3.2 X 1.6	10.24	Minimal
Total		**80.74**	



Component	Dimensions (mm)	Area (mm²)	Power dissipation
BQ25790 WCSP	2.9 x 3.3	**9.6**	**One spot**
BQ25790 QFN	4.8 x 4.8	**23**	**One spot**

Cool charge	Long battery life	Fast charge	Small size	Power at plug

Summary

Feature	Cool, safe charge	Long battery life	Short charge time	Small size	Power at plug + high demand
CC/CV reg. accuracy	X	X	X		
Trickle + pre-charge	X	X			
Host control resolution and reporting	X	X	X		
Thermistor monitor	X	X	X		
Max input power	X		X		
Power path w/ supplement mode		X			X
High efficiency charger	X		X	X	
Topology and integration	X			X	

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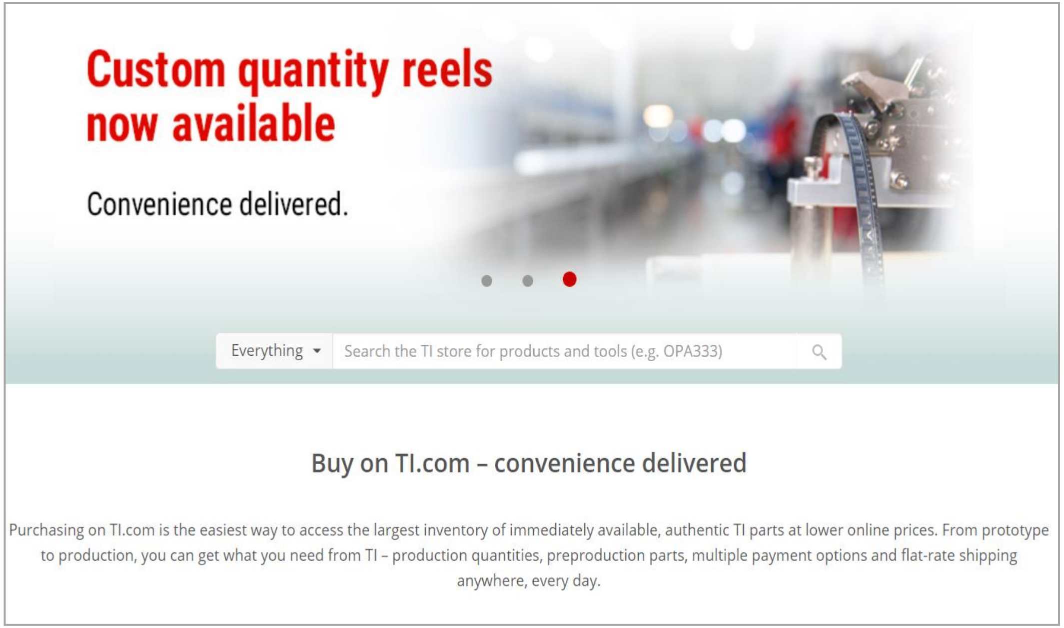

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