Texas Instruments

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

JEFF FALIN

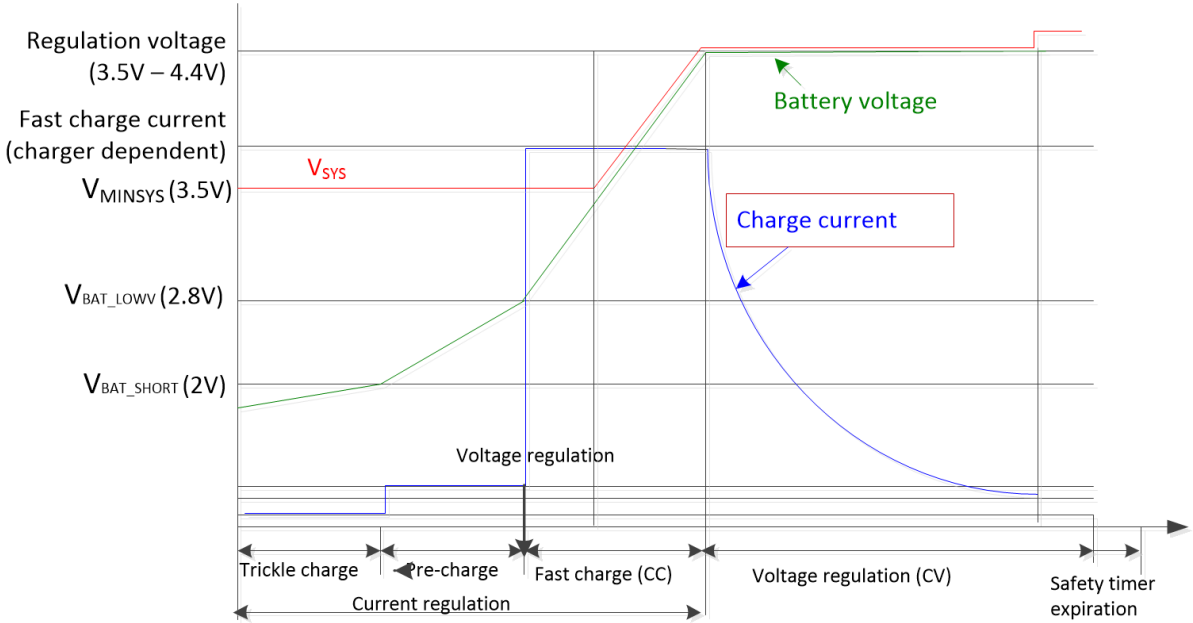
RESOLVING BATTERY CHARGING COMMON APPLICATION ISSUES

Agenda

- Review of Li-ion battery charging and charger topology
- Most common issues for battery charging:
  - Battery not charging
  - Long charge time
  - High charge currents cause board thermal issues
- Summary

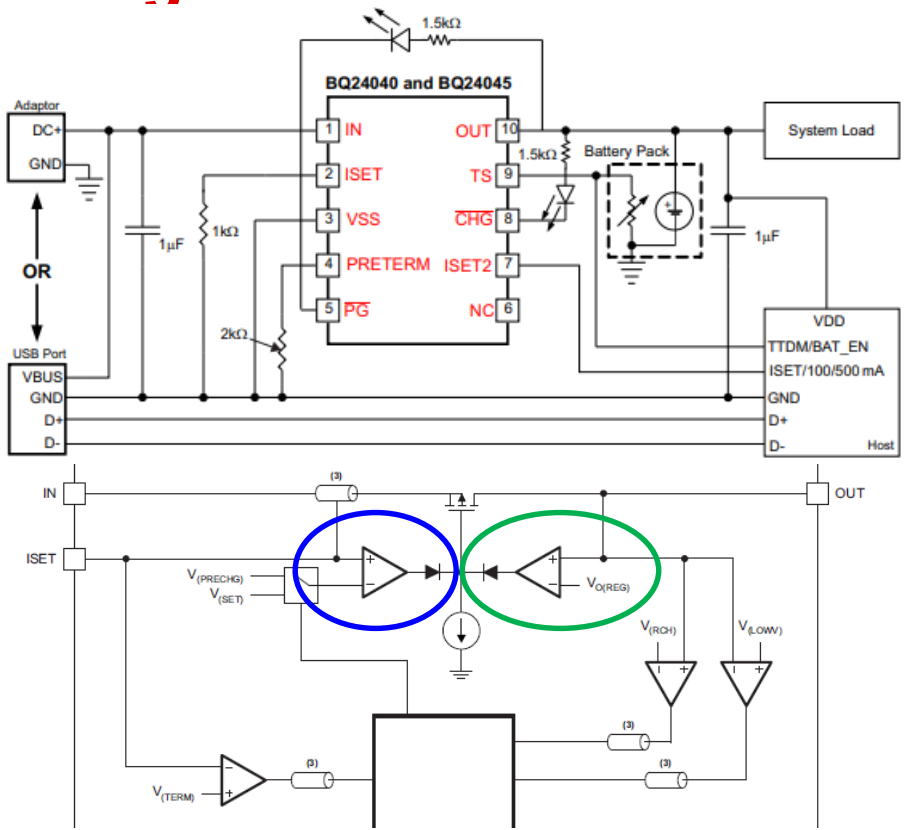
Complete Li-ion battery charging profile

- **Trickle charge** for very low V_{BAT}
  - 50-100mA
- **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



Simple standalone linear charger

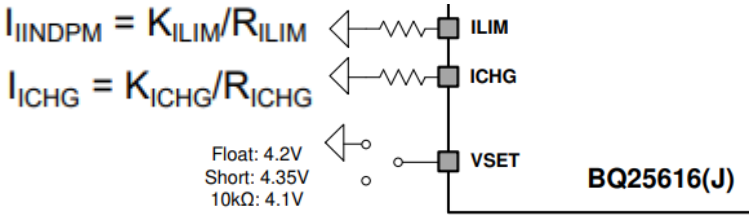
- Asynchronous state machine with analog feedback loops for
  - Constant current regulation
  - Constant voltage regulation
- Comparators for
  - Input protection
    - UVLO
    - Sleep comparators
    - OVP
  - Output short protection
  - TS pin
- Status pin: /CHG, /PG



Benefits and limitations of standalone charger

Benefits

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



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

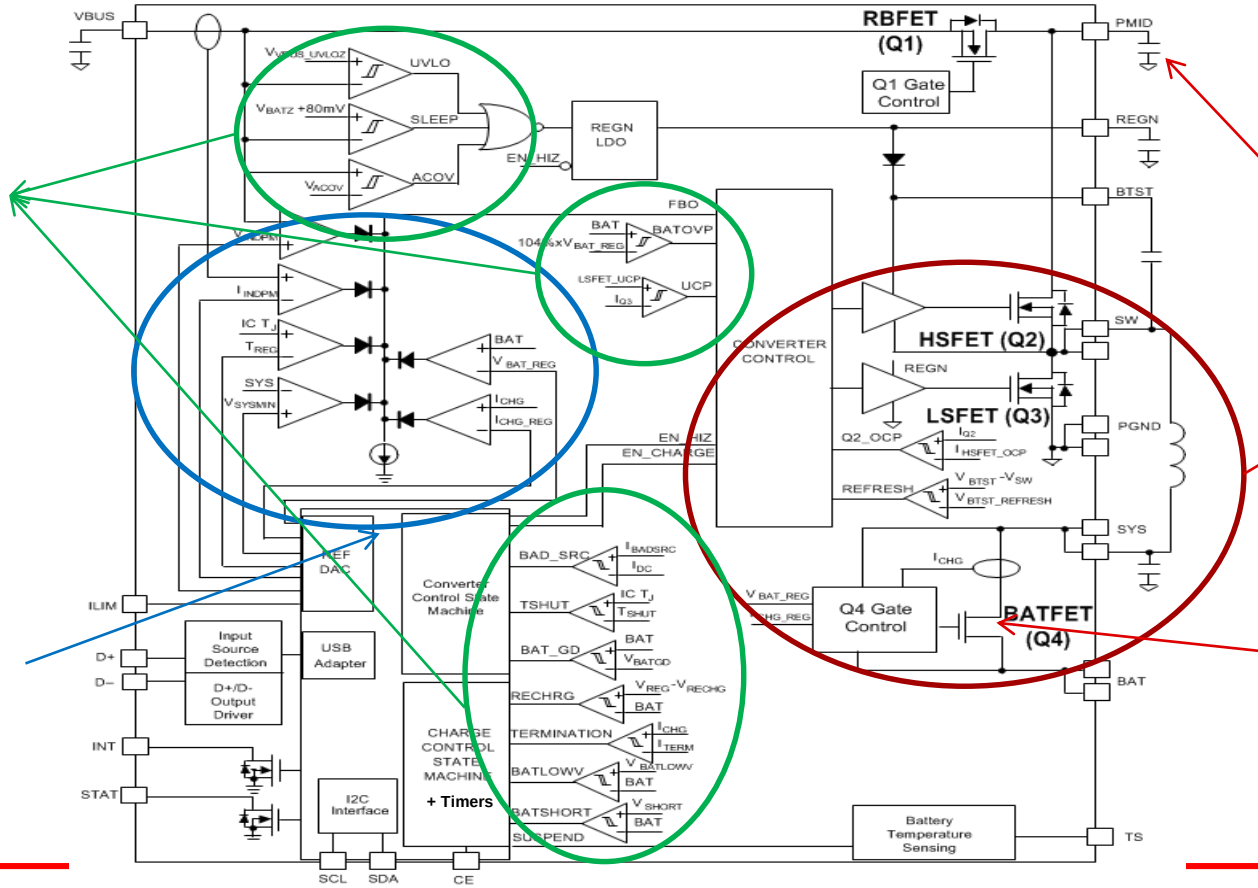
Limitations

- 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

Host controlled buck switching charger

Comparators feed state machines for UVLO or VBUS OVP, VBAT OVP, VBAT LOWV, ITERM, BATSHORT, IC temp



Converter feedback amplifiers modulate duty cycle to regulate SYS_{MIN} voltage or battery voltage, charge current, input current or input voltage

Buck converter with PMID input

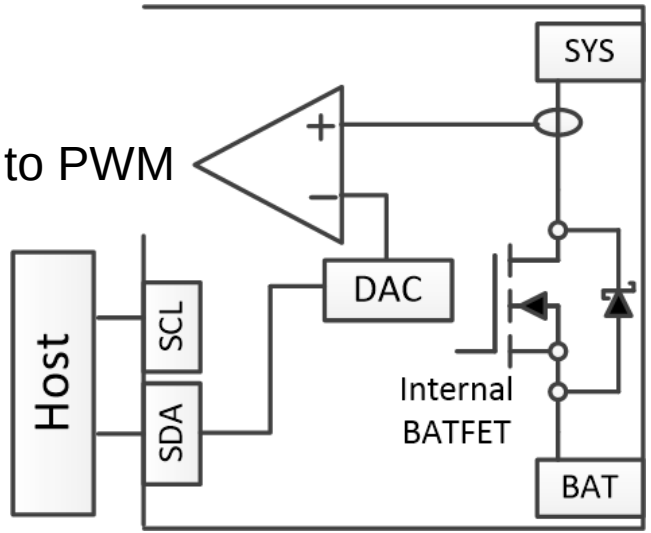
BATFET in NVDC power path charger provides accurate termination and instant power on with SYS_{MIN}

Benefits and limitations of host controlled

Benefits

Example from BQ2579x 1s-4s, 5-A charger:

- 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}

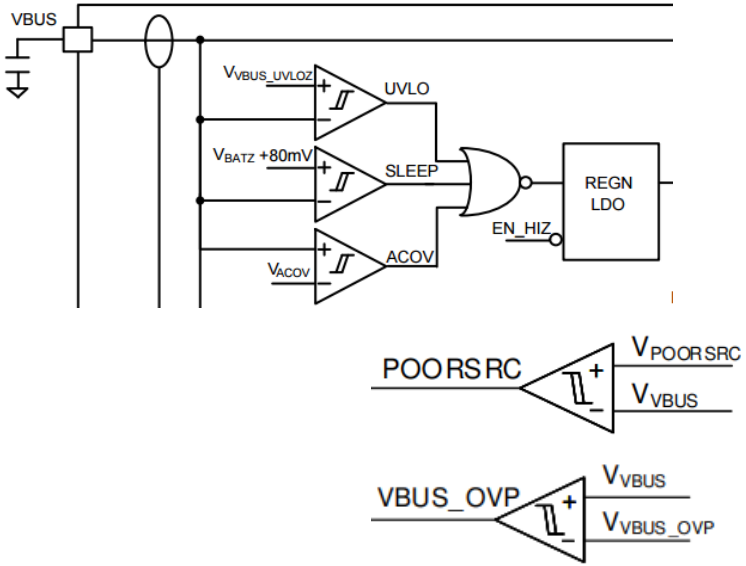


Limitations

- Host software required

Most common issue 1: Battery not charging

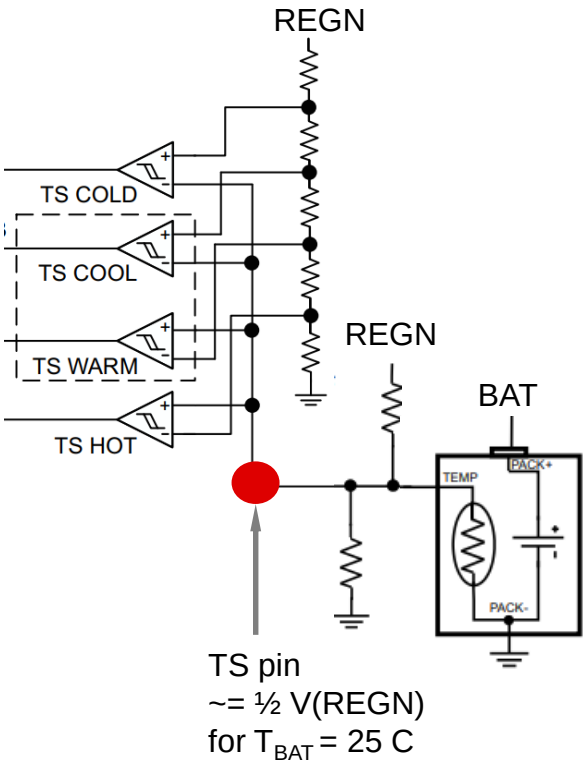
Not charging: Input protection/control related



PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
REGN LDO						
$V_{(REGN)}$	REGN LDO output voltage	$V_{(VBUS)}$ = 9 V, $I_{(REGN)}$ = 40 mA	5.6	6	6.4	V
		$V_{(VBUS)}$ = 5 V, $I_{(REGN)}$ = 20 mA	4.7	4.8		V
$I_{(REGN)}$	REGN LDO current limit	$V_{(VBUS)}$ = 9 V, $V_{(REGN)}$ = 3.8 V	50			mA

Issue	Solution
Input power bad: - sleep mode because V_{BUS}<V(BAT) + V_{SLP} - disabled because V_{BUS} < UVLO or BAD (POOR) SRC - Overvoltage	Increase power source output voltage
Charge enable (CE) pin or bit not properly configured	Configure **BOTH** pin via hardware and bit via software
LDO (REGN) voltage below regulation	Reduce loading on LDO to below min allowed

Not charging: Battery safety related



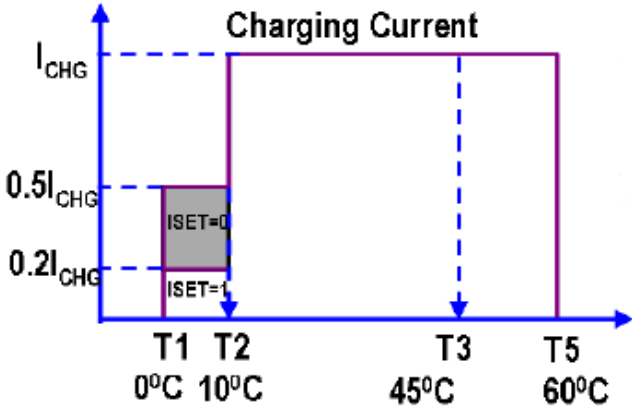
Issue

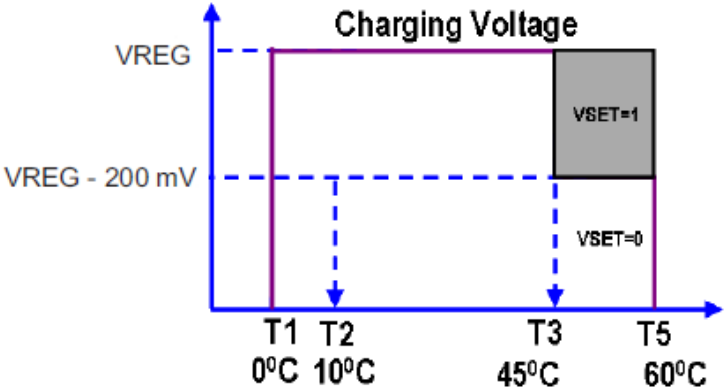
- Battery temperature outside of safety range

Solution

- Check V(TS)
- Either gauge or charger can monitor not both

JEITA





Not charging: Timer related

Precharge current limit
Type : RW
POR: 120mA (3h)
Range : 40mA-2000mA
Fixed Offset : 0mA
Bit Step Size : 40mA

Pre-charge safety timer setting
Type : RW
POR: 0b
0h = 2 hrs (default)
1h = 0.5 hrs

3	EN_TIMER	R/W	by Softwareby by Watchdog	Charging Safety Timer Enable 0 – Disable 1 – Enable (default)
2	CHG_TIMER[1]	R/W	by Softwareby by Watchdog	Fast Charge Timer Setting 00 – 5 hrs 01 – 8 hrs 10 – 12 hrs (default) 11 – 20 hrs
1	CHG_TIMER[0]	R/W	by Softwareby by Watchdog	

Issue	Solution
Pre-charge timer expired -fixed value for all standalone and many I2C chargers	**Increase pre-charge current.** For standalone charger with I_{PRE}= % of I_{CHG} per ISET pin, use parallel FET and resistor. **Increase pre-charger timer** if available
Fast charge timer expired - fixed value or capacitor set value for standalone	1. **Identify cause of long charge time.** 2. Increase or disable timer for host controlled chargers. 3. Monitor status registers and/or STAT/INT for fault then *toggle /CE pin or CE bit* to restart charge.

Most common issue 2: Long charge time

Long charge time due to watchdog timer expiration

- **Host controlled charger I2C registers that could be reset:**
  - Input current limit / ILIM pin enable
  - Charge, pre-charge, term current
  - Safety timer
  - Battery regulation/pre-charge voltage
  - JEITA settings
  - Charge enable/disable

3	WD_RST	R/W	0h	Reset by: WATCHDOG REG_RST	I2C watch dog timer reset Type : RW POR: 0b 0h = Normal (default) 1h = Reset (this bit goes back to 0 after timer resets)
2-0	WATCHDOG_2:0	R/W	5h	Reset by: REG_RST	Watchdog timer settings Type : RW POR: 101b 0h = Disable 1h = 0.5s 2h = 1s 3h = 2s 4h = 20s 5h = 40s (default) 6h = 80s 7h = 160s

Issue	Solution
• I2C watchdog timer bit not periodically pinged causing registers to reset to defaults	• Disable watchdog (not recommended) • Modify software to periodically ping the watchdog bit

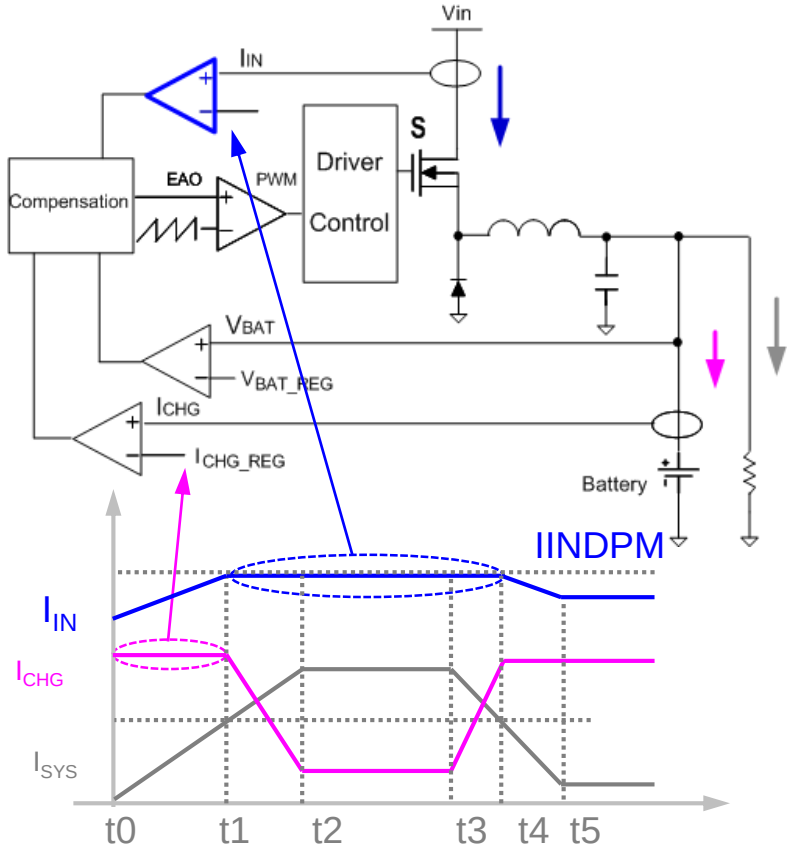
Long charging time due to IINDPM

Issue

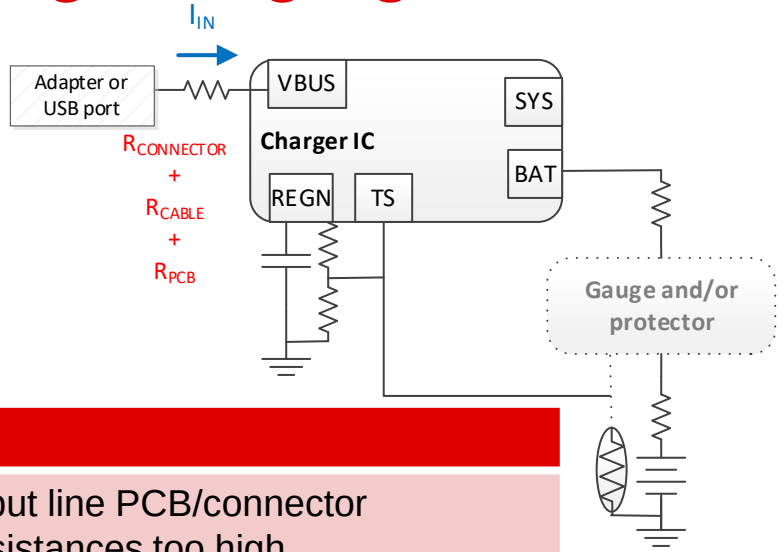
- Input power too low for I(SYS) + I(CHG) because IINDPM setting too low

Solution

- Reduce load on SYS
- Increase power source and IINLIM resistor setting
- Disable ILIM resistor clamp if available (resets after watchdog expires)
- Change IINDPM from D+/D- detection after USB enumeration



Long charging time due to input side impedance

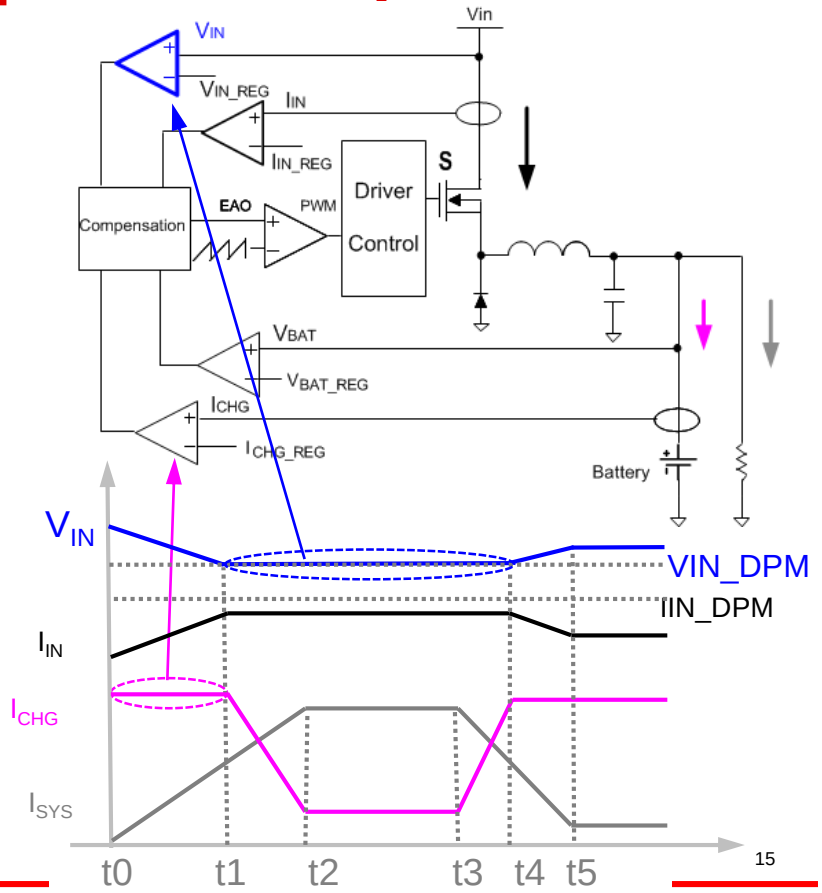


Issue

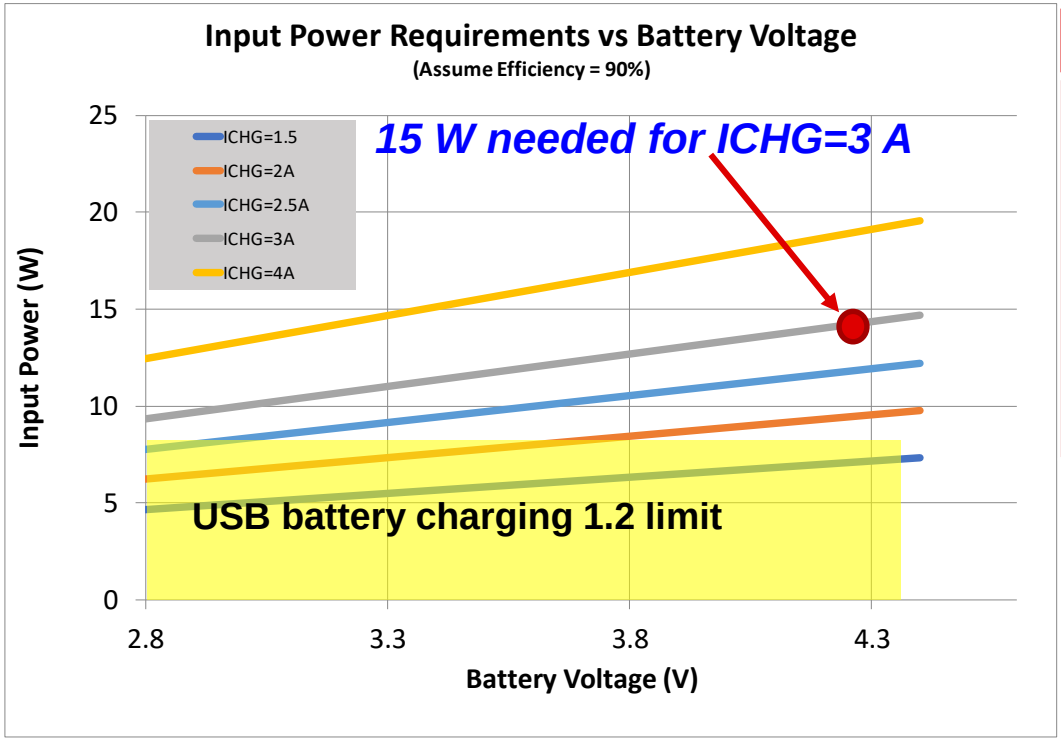
- Input line PCB/connector resistances too high

Solution

- Use higher quality connector/cable
- Lower VINDPM threshold
  - Caution: Avoid 100% duty cycle
  - Caution: Avoid overstressing adapter



Long charge time due to input power limitation



Issue

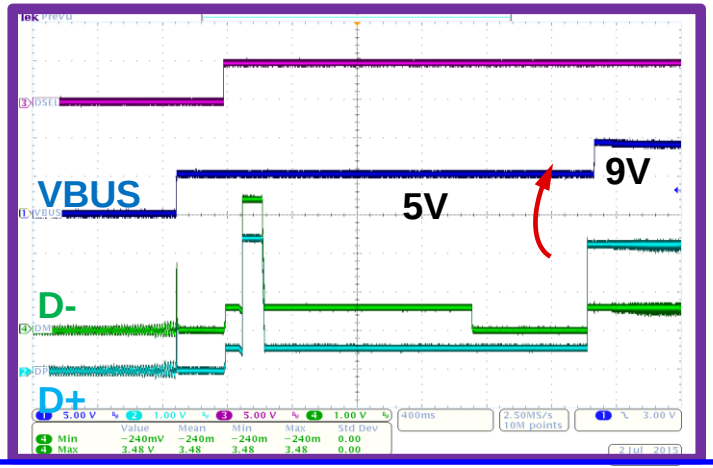
- Input power limited by
  - Legacy USB Adapters (5W/10W)
  - Connector current limit (< 1.8A)
  - Cable IR drop (V=300mΩ * 1.8A)
- Higher battery charging current requires more input power.
  - Up-to ***15 W*** required for 3-A charging.

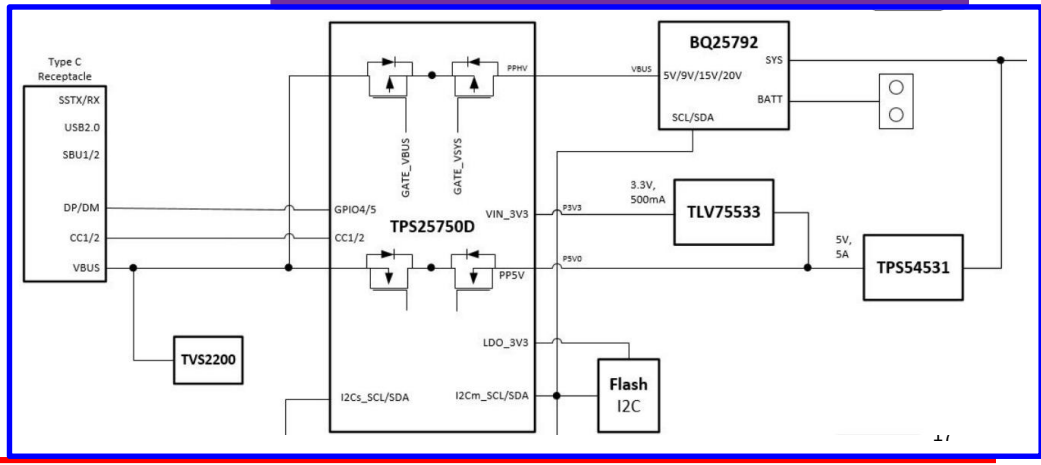
Solution

- Higher efficiency charger
- High voltage adapter (HVDCP)

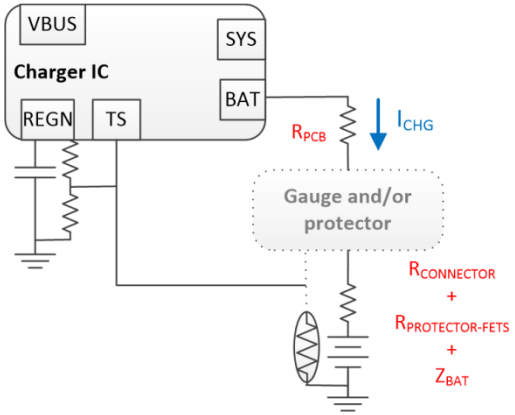
Adjustable high voltage adapters

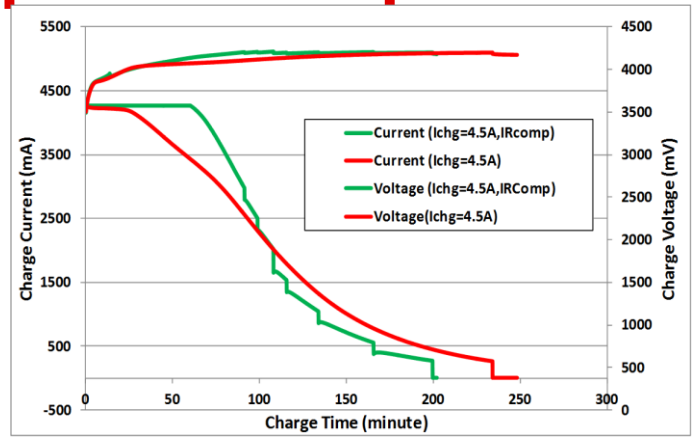
- **Adjustable HV adapter:**
  - Compatible with USB 5-V adapter
  - Can increase output voltage from 5 V to 7 V/9 V/12 V after handshake
    - Voltage based by using D+/D- voltage signaling.
- **USB TYPE-C with Power Delivery**
  - Profile 1, 10 W→ 5 V/2 A
  - Profile 2, 18 W→ 5 V/2 A, or 12 V/1.5 A
  - Profile 3, 36 W→ 5 V/2 A, or 12 V/3 A
  - Profile 4, 60 W→5 V/2 A, or 12 V/3 A or 20 V/3 A
  - Profile 5, 100 W→5 V/2 A, or 12 V/5 A or 20 V/5 A





Long charging time due to output side impedance



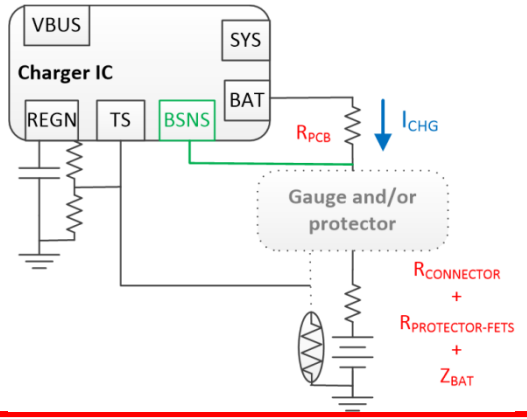


Issue

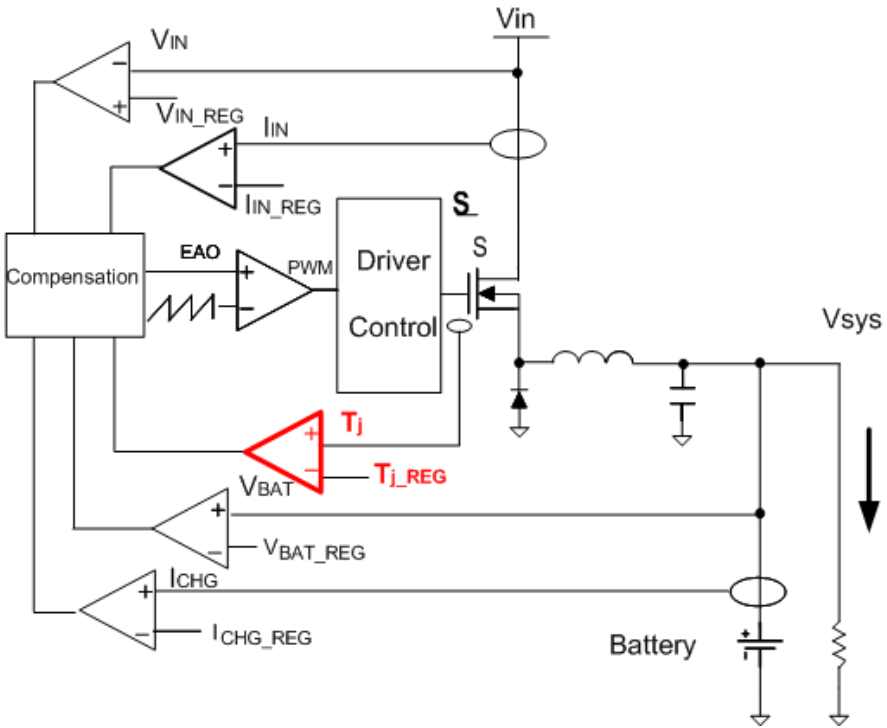
- Battery PCB/connector resistances too high

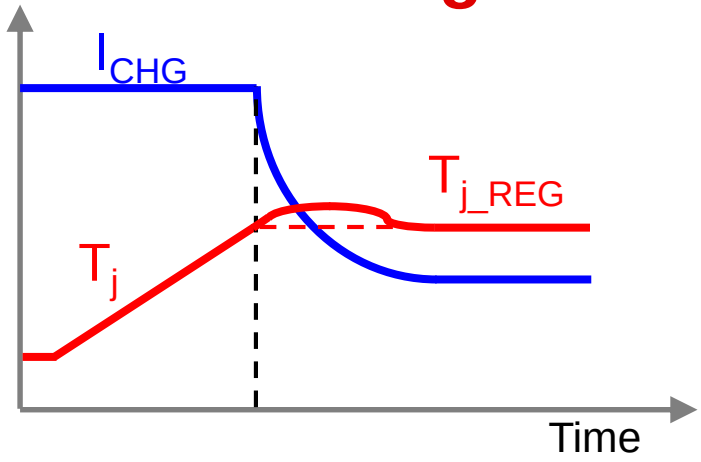
Solution

- Increase I_{TERM} current at expense of full charge
- IR Comp: Increase VBATREG to offset $V_{DROP} = I_{BAT}*R_{OUT}$
- Choose a charger with remote sense



Long charging time due to IC thermal regulation





Issue

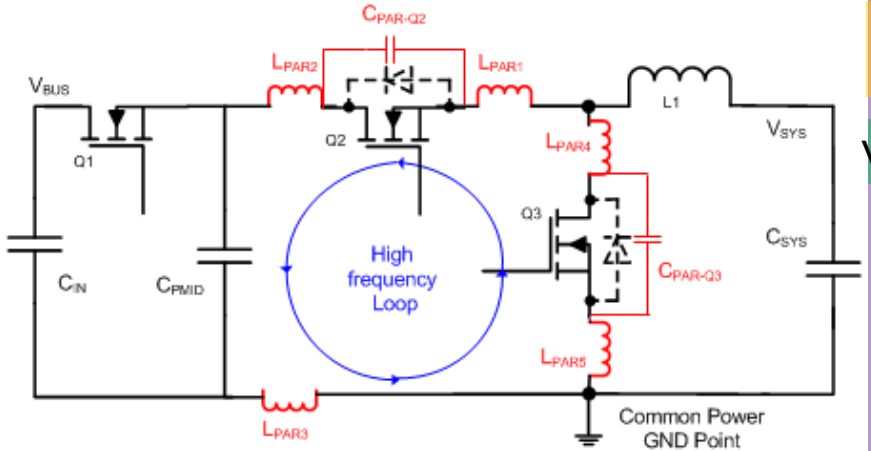
- High temp of IC

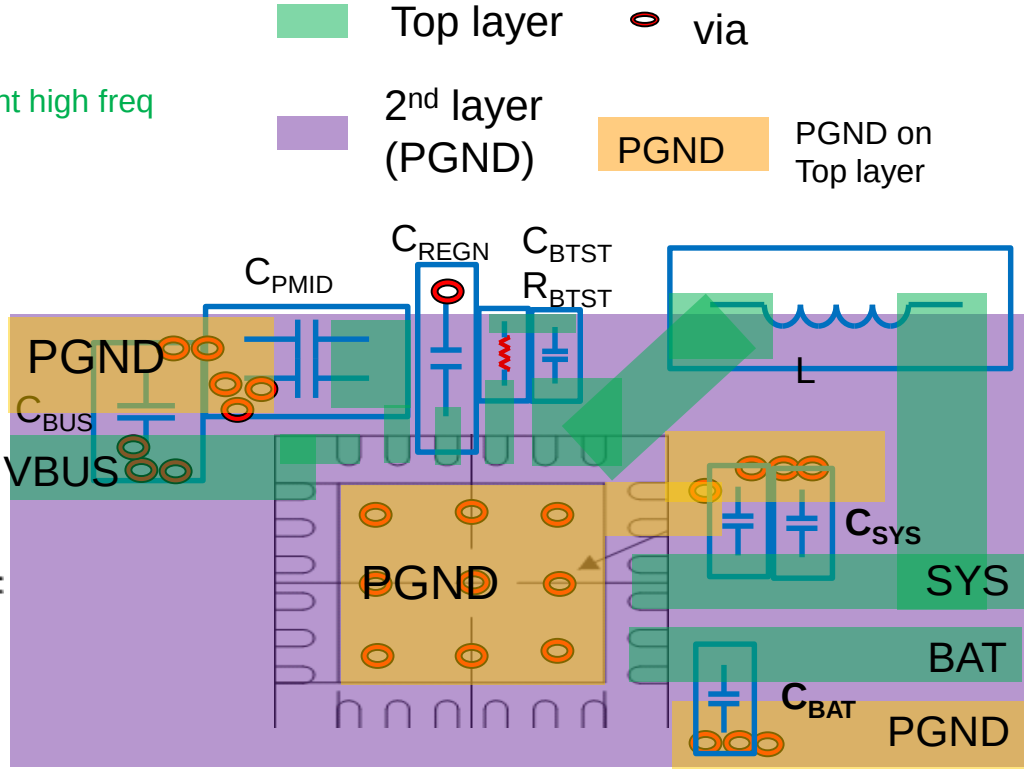
Solution

- Improve PCB layout and heat sinking for the charger

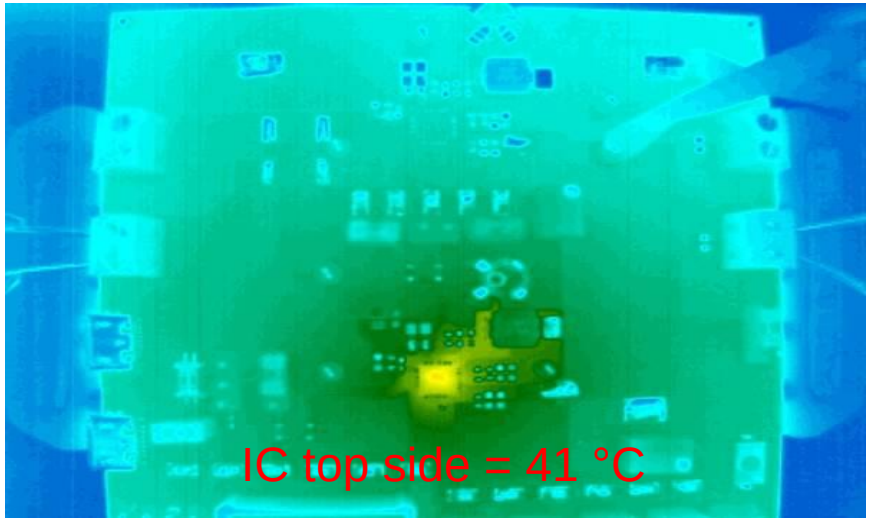
Improve board layout for heatsinking (and lower EMI)

- Use thermal pad connected to internal PGND with vias for heatsinking
- Layout priorities for lower EMI:
  - C_{PMID} – IN for buck (OUT for OTG boost) to shunt high freq switching noise to GND
  - C_{REGN}, C_{BTST}
  - C_{SYS}, C_{BAT}
  - L1 – *adding more R and L not an issue*





Long charge time due to board/case overheating



BQ25890 in 4-mm x 4-mm QFN with vias to internal and bottom GND layers

V(VBUS = 9 V, V(BAT)=3.8 V, ICHRG = 3 A

Issue

- Board/case temp exceeds thermal budget requires lower ICHRG

Solution

- Increase number of board layers for heatsinking or add airflow
- Connect pins and/or thermal pads to large copper planes
- More space between heat generating components
- Change to more efficient charger

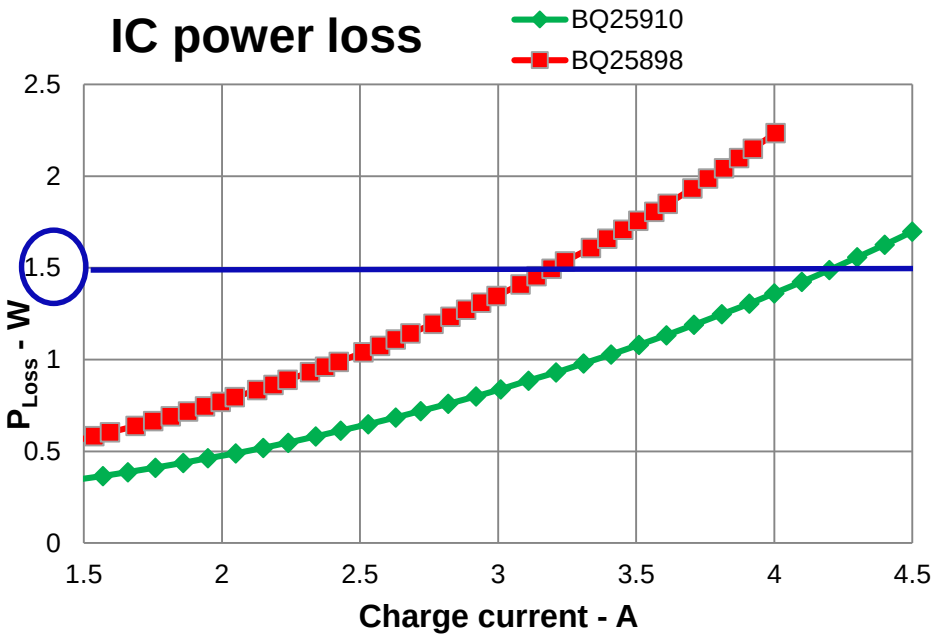
Most common issue 3:
Very high I_{CHRG} exceeds board thermal budget

Choose higher efficiency charger for faster, cooler charging

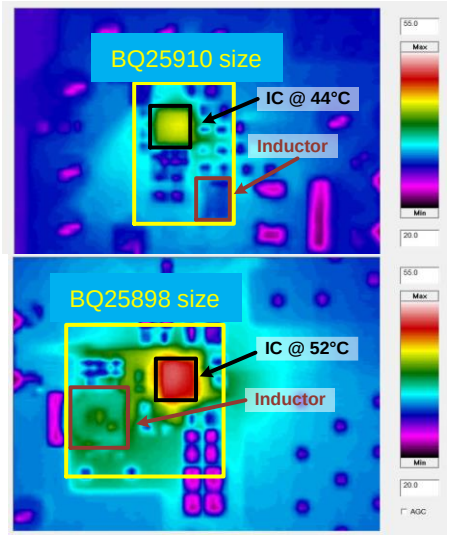
IC	Topology	Inductor DCR (Ω)	High side FET $R_{DS(ON)}$ (Ω)	Low side FET $R_{DS(ON)}$ (Ω)	%eff @ V_{BUS} = 9 V, V_{BAT} = 3.8 V, I_{CHRG} = 3 A	%eff @ V_{BUS} = 5 V, V_{BAT} = 3.8 V, I_{CHRG} = 2 A
BQ2561X	1S buck	10	62	71	89	92.4
BQ25898	1S buck	10	24	12	91.5	93.7
BQ25910	1S 3-level buck	10	32	20	93.5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

Small efficiency increase → higher charge current

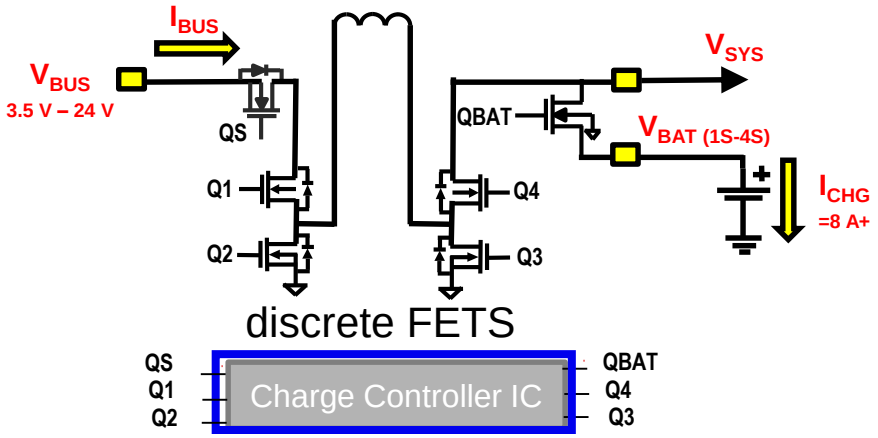


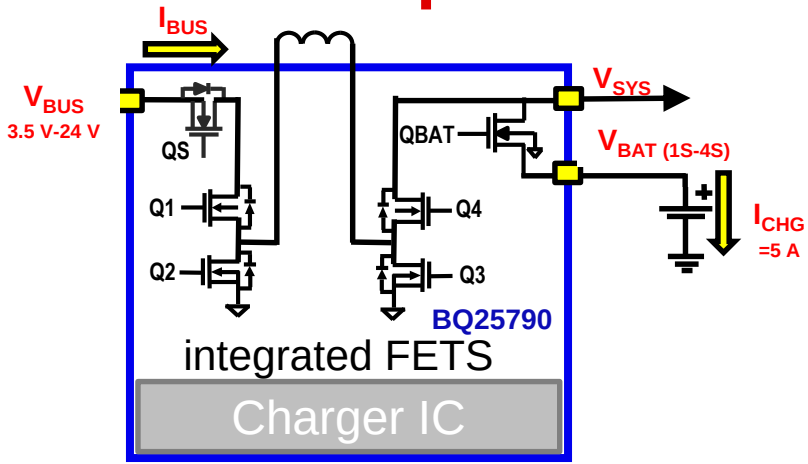
Thermal performance at
V_{IN} = 9 V, V_{BAT} = 3.8 V, I_{CHG} = 3 A



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 smaller inductor.

Balance small solution size and thermal performance





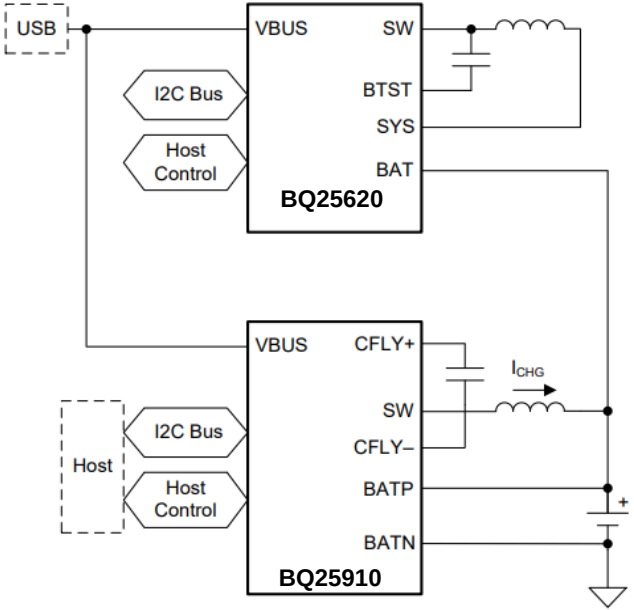
Component	Dimensions (mm)	Area (mm^2)	Power dissipation
BQ25713QFN	4 x 4	16.00	Minimal
5xFETs	3.3 X 3.3	54.50	**Distributed**
2xR_{SNS} in 1206	3.2 X 1.6	10.24	Minimal
Total		**80.74**	

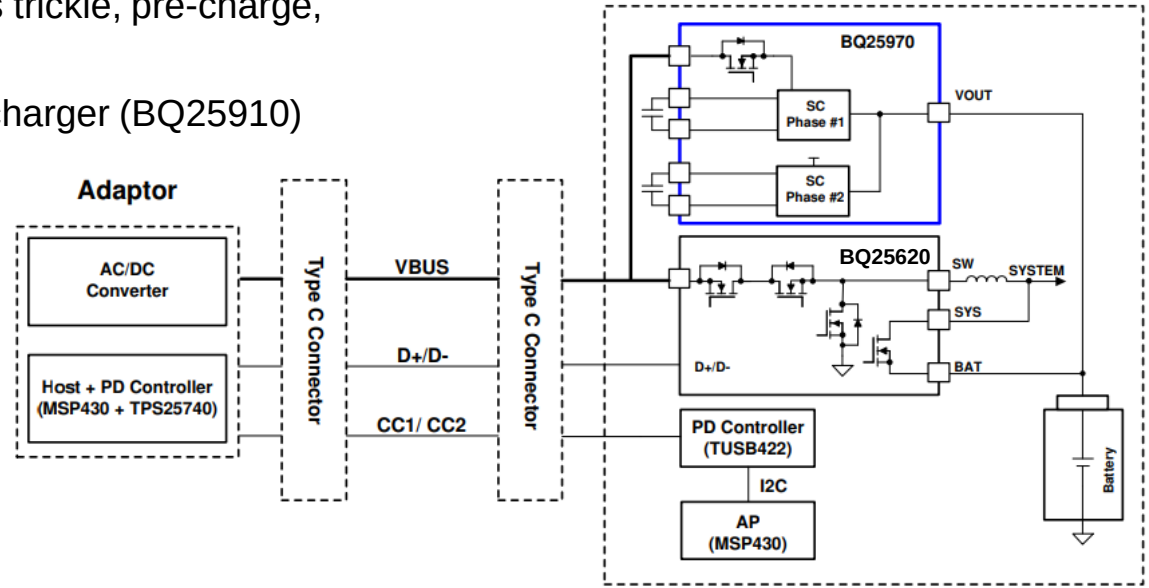
Component	Dimensions (mm)	Area (mm^2)	Power dissipation
BQ25790 WCSP	2.9 x 3.3	**9.6**	**One spot**
BQ25790 QFN	4.8 x 4.8	**23**	**One spot**

Discrete solution: large areas for thermal dissipation and higher power
Integrated solution: small solution size and easy to design but lower power

Parallel chargers

- Primary charger (like BQ25620) provides trickle, pre-charge, termination
- Secondary, high efficiency 3-level buck charger (BQ25910) provides fast, higher charging current





- BQ25970 switch cap charger communicates with “smart” adapter/USB-C PD to provide minimum required headroom across pass element
- 97% Efficient power stage for 8-A fast charge

Summary

- **All issues are solvable!!!**
- **Battery not charging**
  - Account for input protection/operation
  - Protect the battery
  - Design for safety timers
- **Long charge (taper) time**
  - Optimize IINDPM, VINDPM settings
  - HVDCP adapter
  - Improve heat sinking (and EMI) with good PCB board layout
- **Very high ICHRG exceeds board thermal budget**
  - Higher efficiency chargers
  - Parallel chargers
- **QUESTIONS?**

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