TI POWER

Achieving simple, safe and efficient charging

Battery Management Deep Dive Training

October 2020

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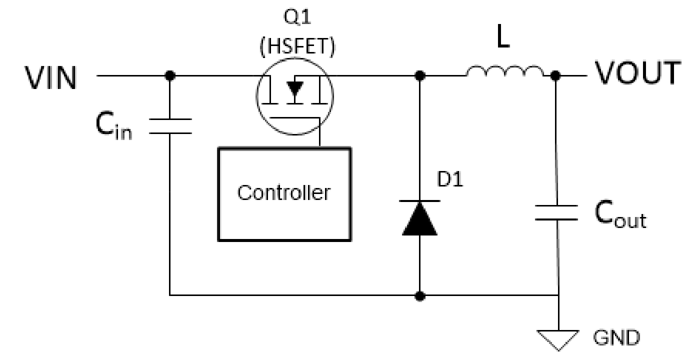
Texas Instruments

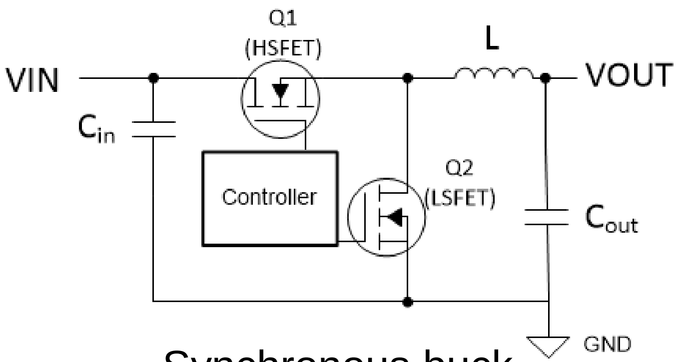
Agenda

- How to build a basic charger
  - Advantages vs disadvantages of different converter topologies
- How to customize a standalone switching charger
  - Maintain minimal BOM count
- Improve safety of final design

Basic converter topology



Nonsynchronous buck



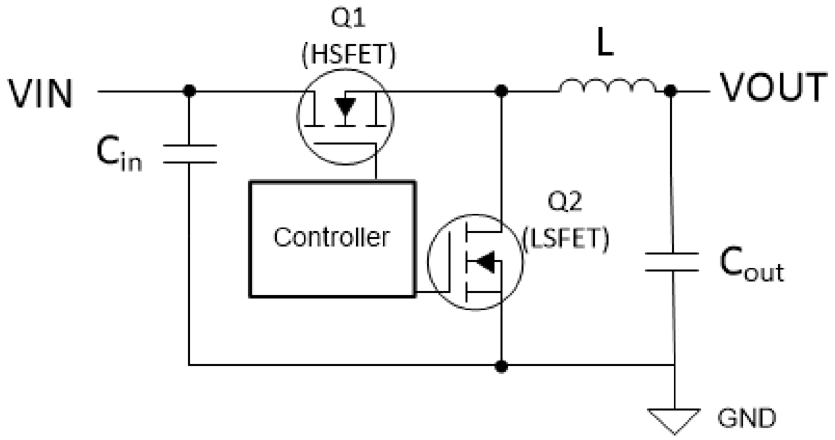
Synchronous buck

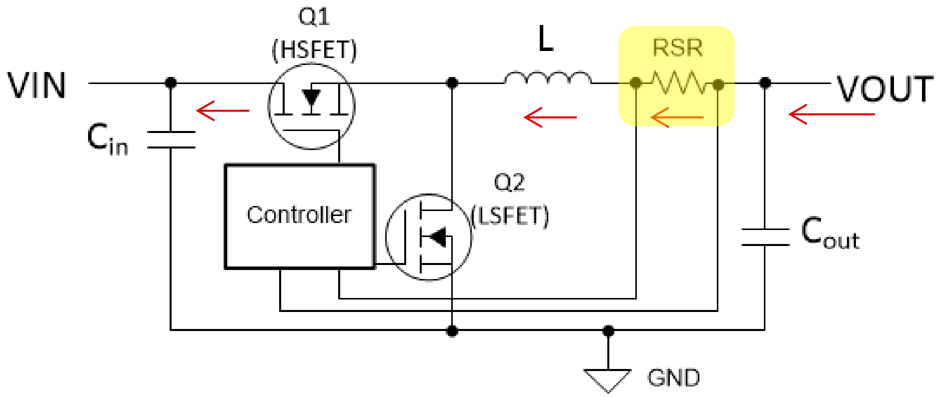
	Nonsync	Sync
Solution size	**Larger** IC + power diode	**Smaller** Both FETs integrated
Efficiency (low side conduction loss)	Diode D1 loss: $I_{DS} \times V_f \times (1 - D)$	LS FET Q2 loss: $I_{DS} \times (I_{DS} \times R_{DS(ON)}) \times (1 - D)$
Layout	High frequency converter loop area larger due to external diode	High frequency converter loop area smaller due to integrated FETS

Battery charger considerations

What is missing from a synchronous topology?

To regulate current, a current sense resistor is required to provide the charging current information to the control loop



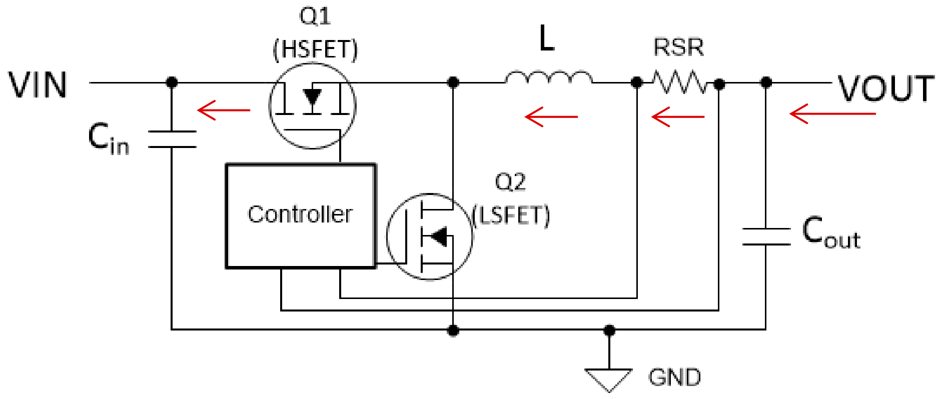


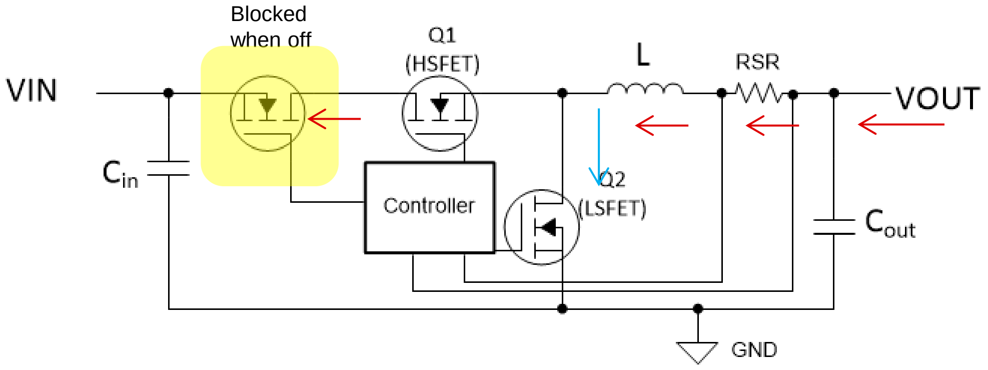
Simple battery charger architecture

What happens if input is shorted to GND?

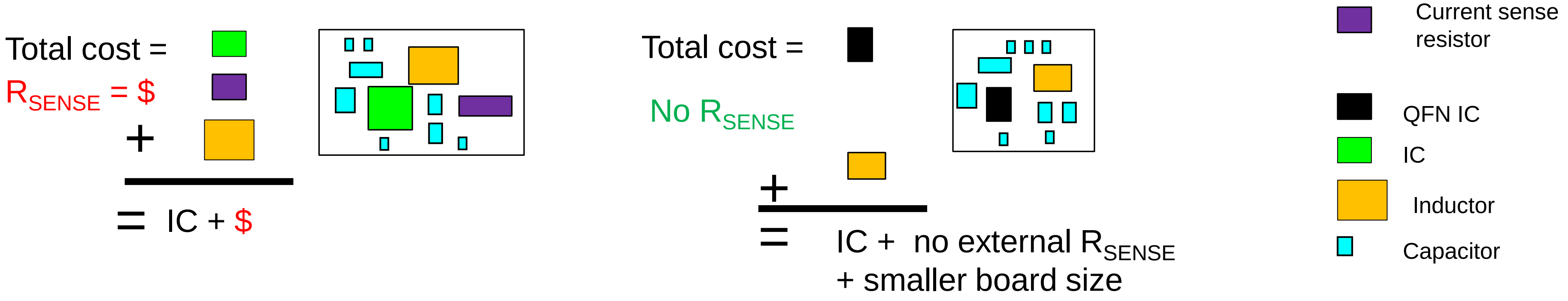
What needs to be included
for $V_{IN} < V_{BAT}$

– An input reverse blocking FET is required to prevent reverse discharge





Limitations of R_{SENSE}



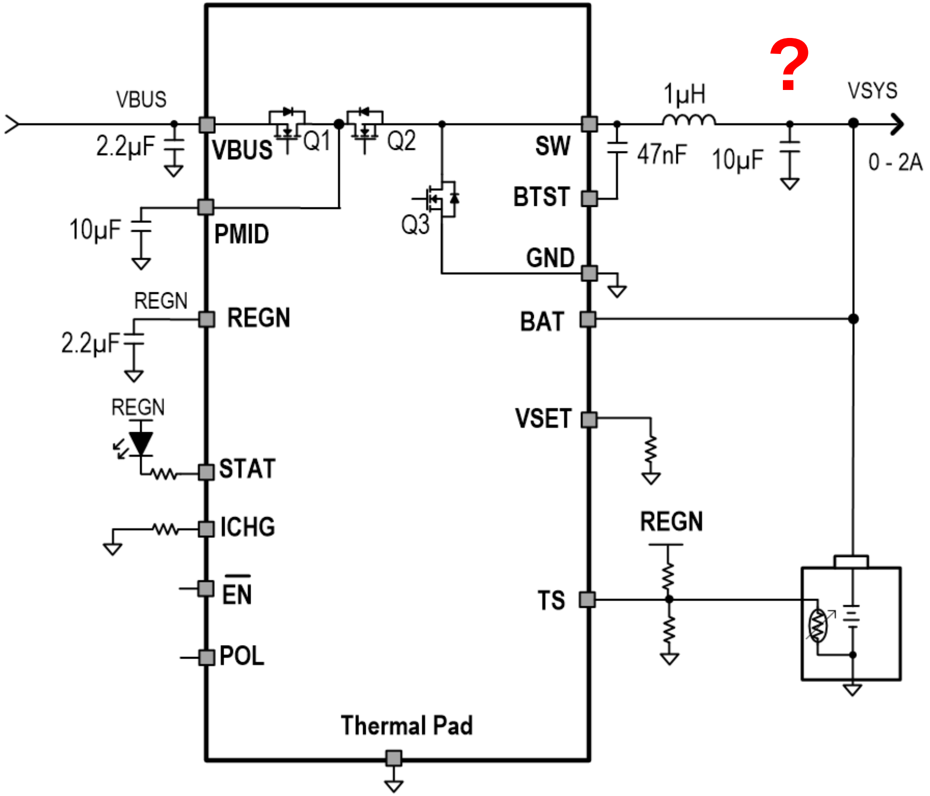
Topology	$R_{DS(ON)}$ (mΩ)	Power loss @ I_{CHG} = 2 A (mW)	Power loss @ I_{CHG} = 3 A (mW)
Integrated FET	19.5	78	175.5
External sense resistor	10	40	90

Full charge current sensed across R_{SENSE}. Efficiency decreases due to conduction losses from power dissipated across R_{SENSE}.

BQ25302 senseless current architecture

Q: What is missing?

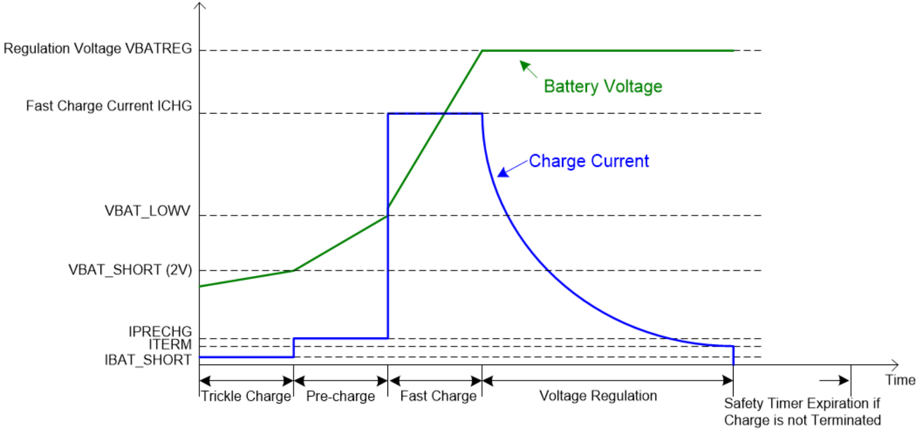
- New topology without sense resistor
- ↓ Conduction loss ↑ Efficiency
- Minimal external components



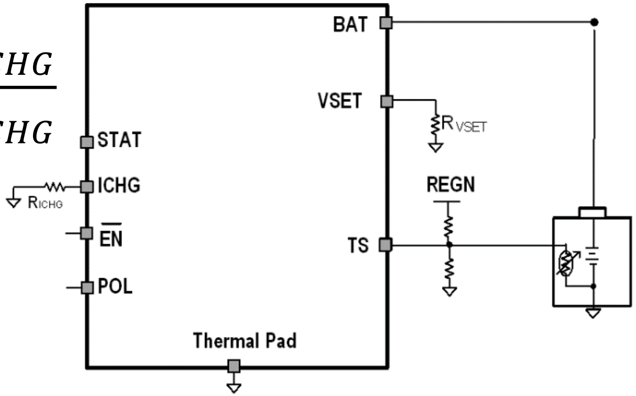
Customizing standalone charger

Q: How to minimize BOM?

- I_{CHG} resistor
  - Linear charger to provide battery short protection
  - Precharge/termination fixed at 10% fast charge
  - Fast charge = K_{ICHG}/R_{ICHG}
- V_{SET} resistor
  - Set short, precharge and charge regulation voltage
  - 4 different charge regulation voltage settings



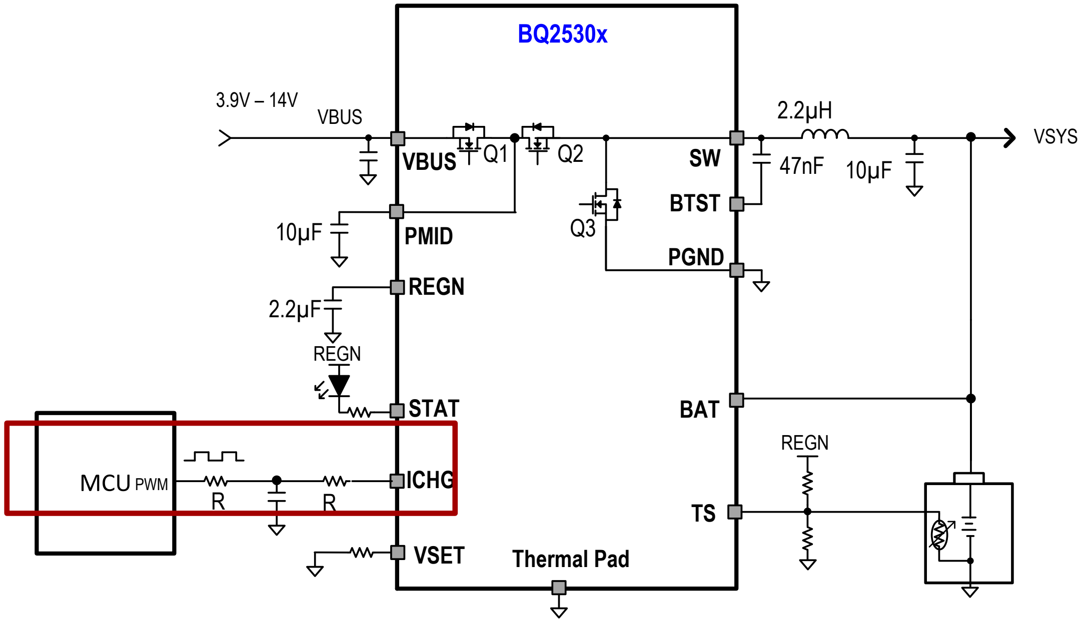
$$I_{CHG} = \frac{K_{ICHG}}{R_{ICHG}}$$



MCU programmable charge current I_{CHG}

1 GPIO pin vs I²C bus

$$I_{CHG} = \frac{40(1 - V_{CC} \cdot D)}{2R(k\Omega)}$$

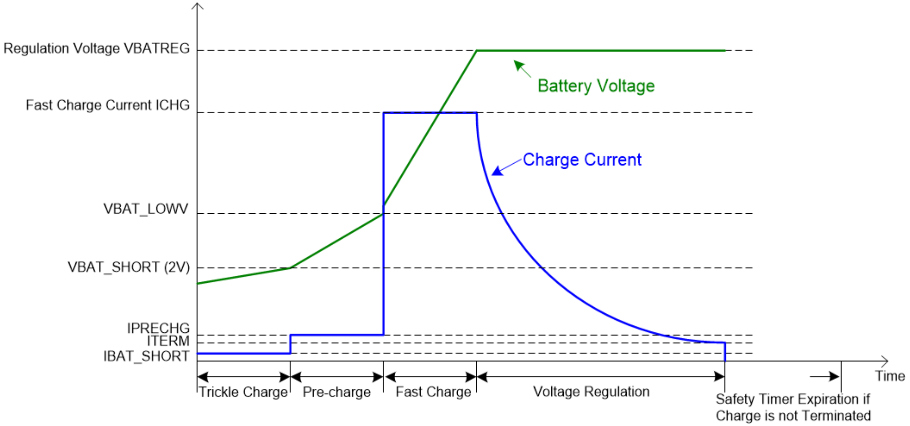


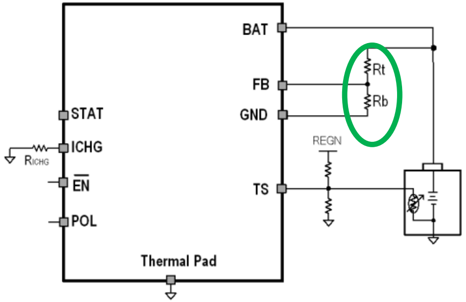
V_{CC} – MCU GPIO drive voltage
D – Duty cycle of PWM
I – 300 mA to 3000 mA

GPIO voltage programs the charge current continually

Benefit of resistor divider

- Wide charge regulation voltage range to charge Li-ion and lithium phosphate
  - – Deeply discharged battery
  - – Precharge to fast charge
  - – Max charge regulation
  - – Recharge threshold
  - – Battery OVP
- Remote BAT_{SENSE} tied to battery
  - – ↑ Time in CC ↓ Time in CV

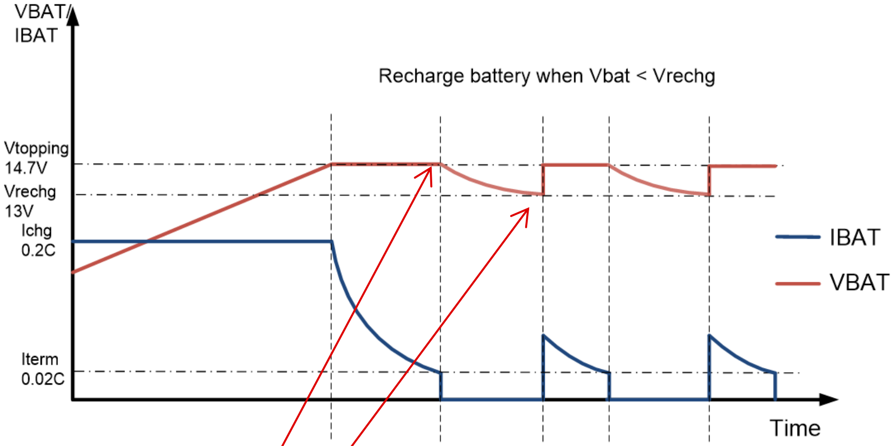


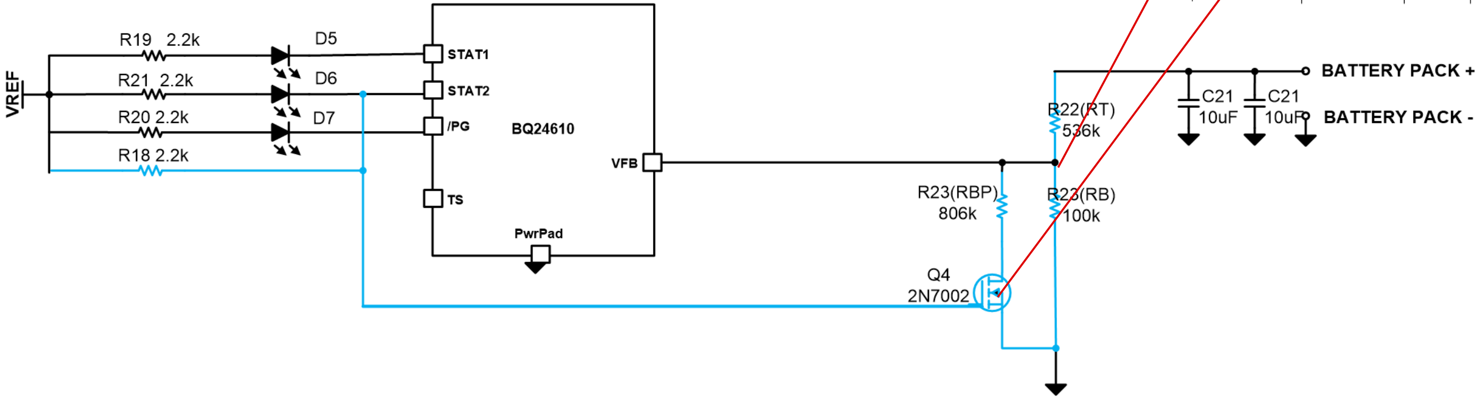


$$V_{REG} = V_{FB}\left(1 + \frac{R_t}{R_B}\right)$$

Lead-acid battery charging

- Lead-acid battery chemistry
  - Low cost
  - Backward compatible
  - Safety considerations





Limitation of external resistor divider

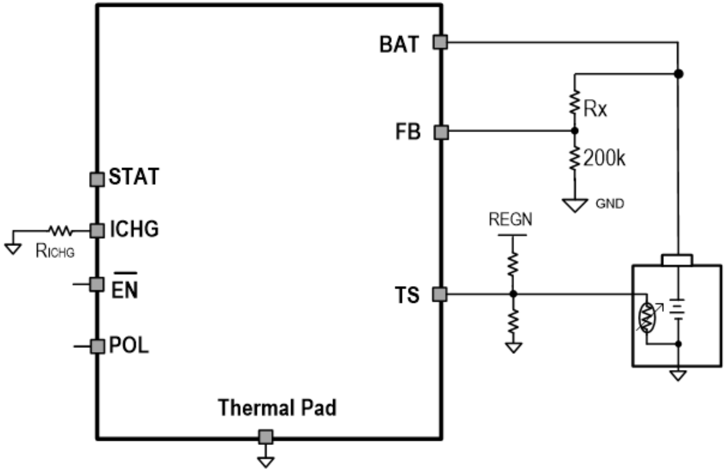
- A device can take up to thirty days to ship from a factory to a storefront
- Six months on the shelf is not uncommon

Desirable

- Out-of-the-box battery operation
- 0.2 µA BAT I_Q

Undesirable

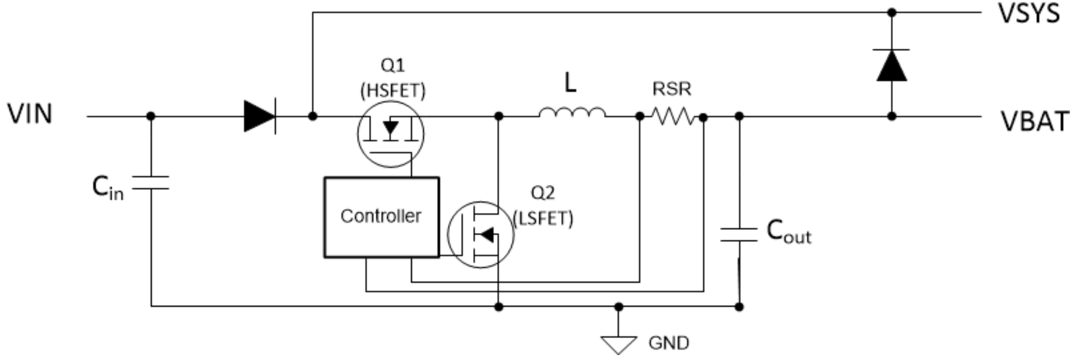
- Depleted battery after storage



Charge controller architecture

Power path:

- Two diodes OR condition to the system of
  - Adaptor power
  - Battery power
- Separate the system and the battery



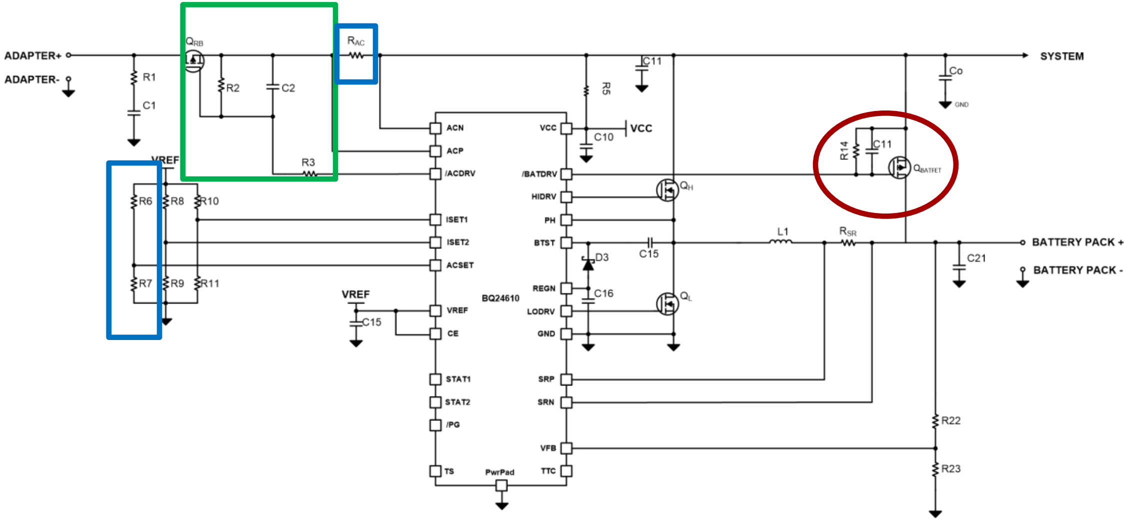
Benefits:

- Instant power up with dead or no battery
- Extend battery life with termination

Customizing advanced features

Q: What if I don't need certain features?

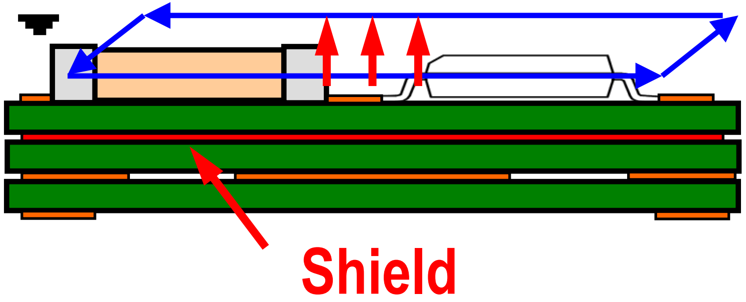
- Power path
  - Remove PFET and float BATDRV
- Input protection FETs
  - Diode for reverse voltage protection and float ACDRV
- Input current regulation
  - Remove R_{AC}



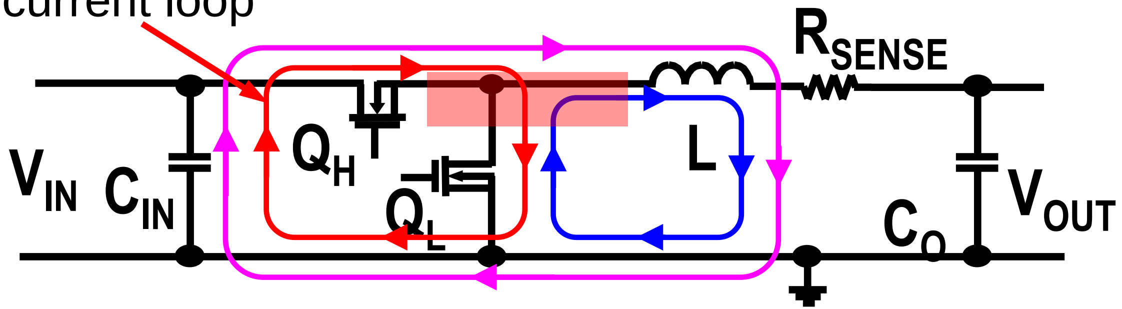
Schematic review tips on E2E

Layout guidelines

- Minimize EMI
  - Small high frequency current loop
  - Small area for high dv/dt node
  - Good ground plane

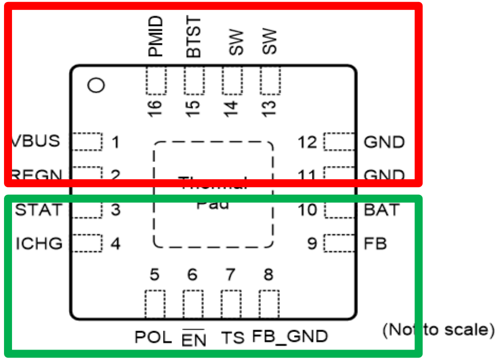


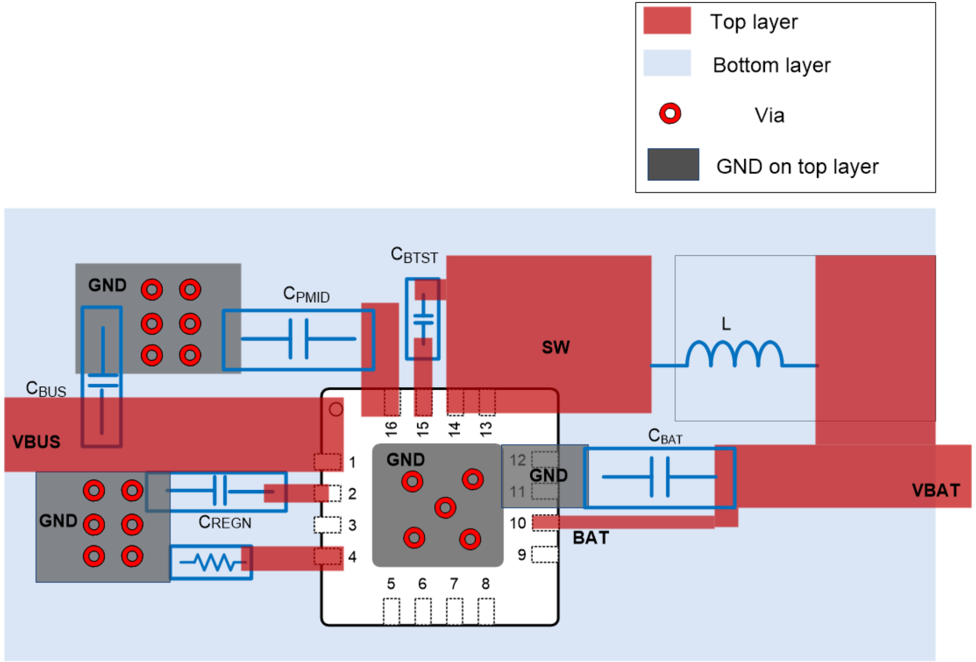
High frequency
current loop



BQ2530X layout

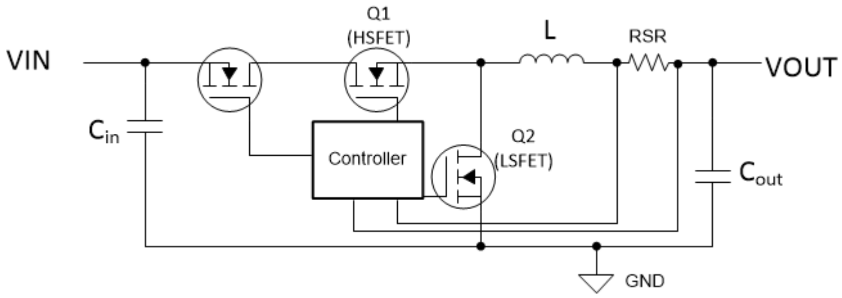
- Safe pinout
  - Isolate analog/power pins
- Easy AGND/PGND isolation
  - Same layer routing
- Decrease board cost

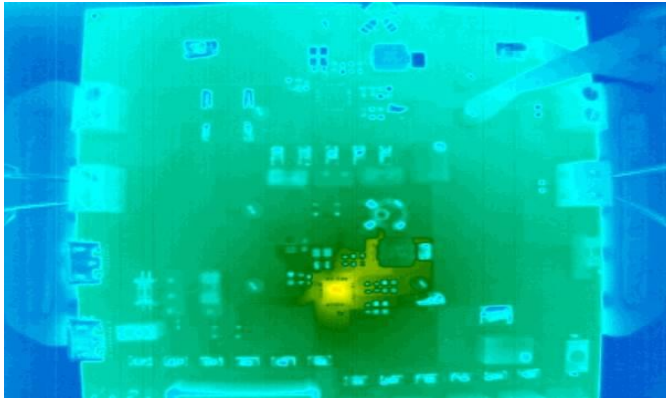




Efficiency loss considerations

- Switching losses
  - $P_{SW} = \frac{1}{2} \cdot V_{IN} \cdot I_{CHG} \cdot (T_{ON} + T_{OFF}) \cdot F_{SW}$
- Conduction losses
  - $P_{COND\_TOP} = D \cdot I_{CHG}^{2} \cdot R_{DS(ON)}$
  - ↑ Junction temp → ↑ MOSFET $R_{DS(ON)}$
- Controller
  - Localized to power stage
- Charger
  - Localized to package



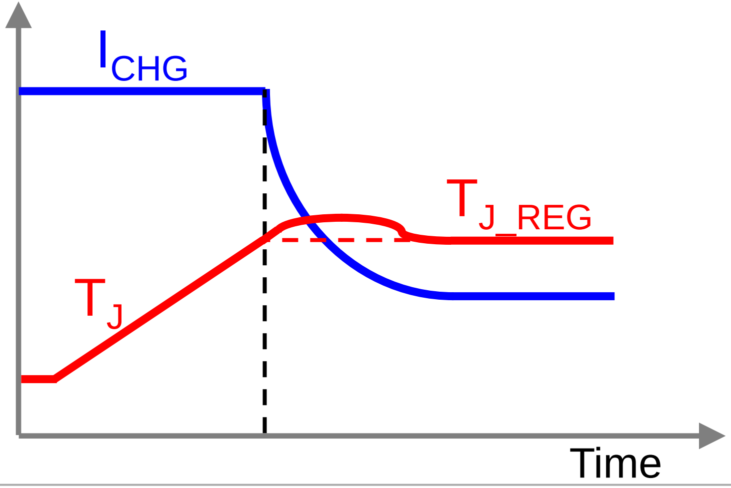


Thermal junction regulation

- T_J thermal regulation
- Thermal shutdown

Recommended operating condition

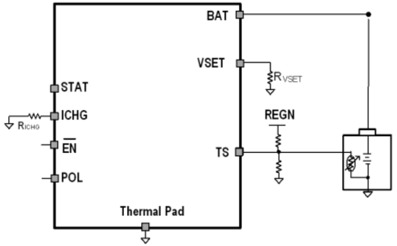
PARAMETER		MIN	NOM	MAX	UNIT
T_A	Ambient temperature	–40		85	°C



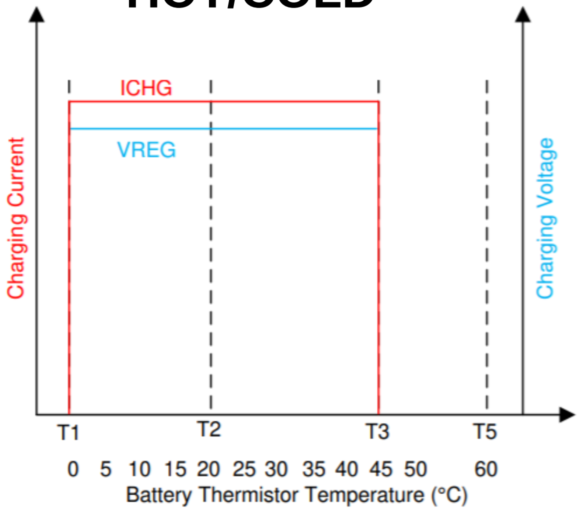
- **Thermal regulation**
  - Better customer experience
  - Safe charging
  - Continuous charging current

Battery temperature profile

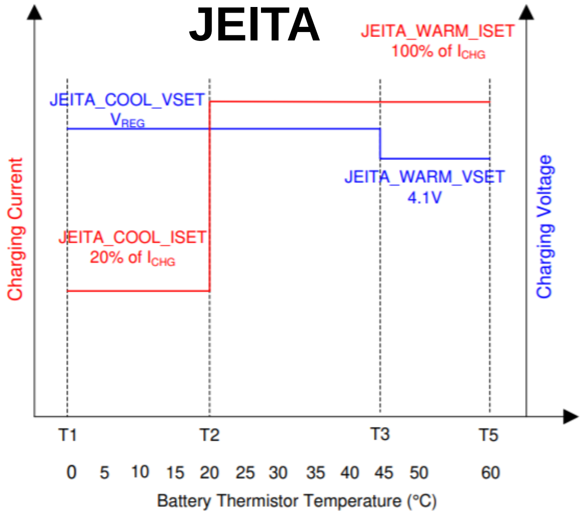
- STAT visual blinking 1 Hz fault reporting
  – REGN ON during fault
- Battery temp monitoring
  – HOT/COLD
  – JEITA



HOT/COLD

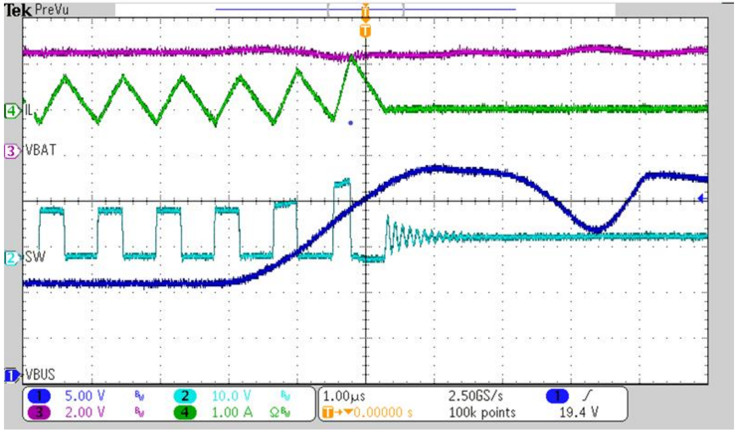


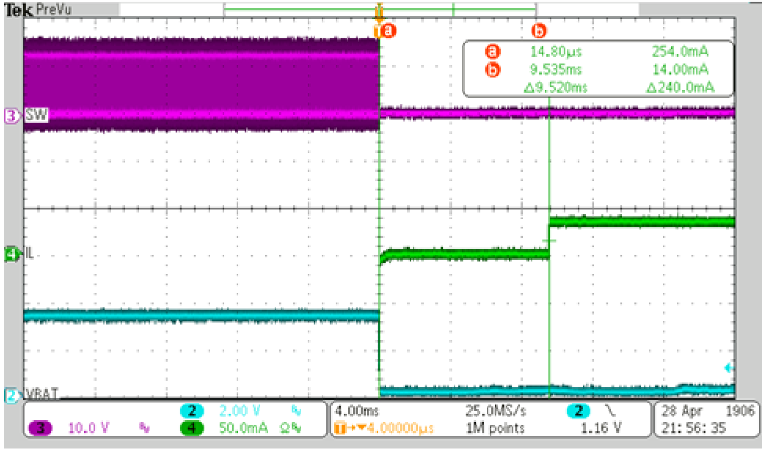
JEITA



Extensive fault reporting

- Protection
  - 200 ns V_{BUS} OVP response
  - Shorted battery insertion
    - Battery clamp / 30 mA charge current
- STAT fault indication
  - FB open/short
  - I_{CHG} open/short
- Manufacturing mistakes can result in
  - Adjacent pin short
  - Pin open





BMS safety initiative

- Provides designers with tools to design functionally safe systems
- Determines the effect of each failure based on:
  - Potential device damage that affects functionality
  - No device damage but loss of functionality
  - No device damage but performance degradation
  - No device damage, no impact to functionality or performance

BQ2404x 1A, Single-Input, Single Cell Li-Ion and Li-Pol Battery Charger With Auto Start

1 Features

- Charging
  - 1% Charge voltage accuracy
  - 10% Charge current accuracy
  - Pin selectable USB 100 mA and 500 mA maximum input current limit
  - Programmable termination and precharge threshold, BQ24040 and BQ24045
  - High voltage (4.35 V) chemistry support with BQ24045
- Protection
  - 30V Input rating; with 6.6 V or 7.1 V input overvoltage protection
  - Input voltage dynamic power management
  - 125°C thermal regulation; 150°C thermal shutdown protection
  - OUT Short-circuit protection and ISET short detection
  - Operation over JEITA range via battery NTC – 1/2 fast-charge-current at Cold, 4.06V at Hot, BQ24040 and BQ24045
  - Fixed 10 hour safety timer, BQ24040 and BQ24045
- System
  - Automatic termination and timer disable mode (TTDM) for absent battery pack with thermistor, BQ24040 and BQ24045
  - Status indication – charging and done
  - Available in small 2 × 2 mm^2 DFN-10 package
  - Integrated auto start function for production line testing, BQ24041
- Functional Safety-Capable (BQ24040)
  - Documentation available to aid functional safety system design

3 Description

The BQ2404x series of devices are highly integrated Li-Ion and Li-Pol linear chargers devices targeted at space-limited portable applications. The devices operate from either a USB port or AC adapter. The high input voltage range with input overvoltage protection supports low-cost unregulated adapters.

The BQ2404x has a single power output that charges the battery. A system load can be placed in parallel with the battery as long as the average system load does not keep the battery from charging fully during the 10 hour safety timer.

The battery is charged in three phases: conditioning, constant current and constant voltage. In all charge phases, an internal control loop monitors the IC junction temperature and reduces the charge current if an internal temperature threshold is exceeded.

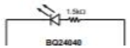
The charger power stage and charge current sense functions are fully integrated. The charger function has high accuracy current and voltage regulation loops, charge status display, and charge termination. The pre-charge current and termination current threshold are programmed through an external resistor on the BQ24040 and BQ24045. The fast charge current value is also programmable through an external resistor.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
BQ24040	WSON (10)	2.00 mm x 2.00 mm
BQ24041		
BQ24045		

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic



Summary

- Difference of a basic charger vs. a DC/DC converter
  - Current sensing loop for constant current
  - Reverse blocking capability
- How to customize a standalone switching charger
  - Different control approaches
  - Flexibility for different chemistry
  - Extending shelf lifetime
  - Maintain minimal BOM count
- Safety features of a charger
  - Temperature profile for battery
  - Thermal regulation
  - Functional safety

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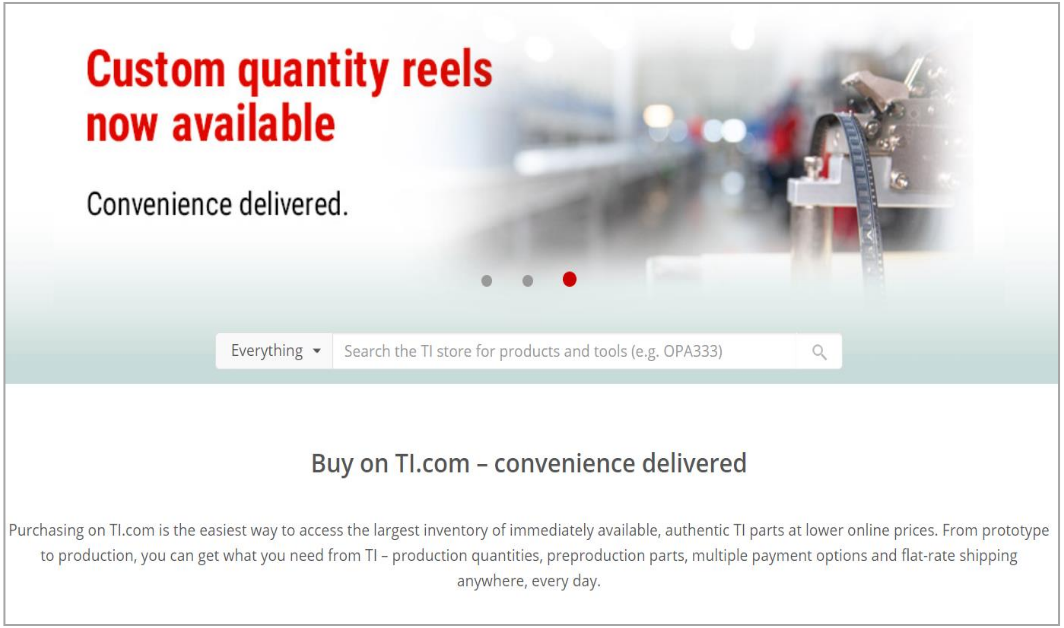

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