2007 Portable Power Design Seminar

Topic 3

Battery Charging Design Considerations

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Battery Management Applications

Technology for Innovators™ TEXAS INSTRUMENTS

Portable Power Device Market

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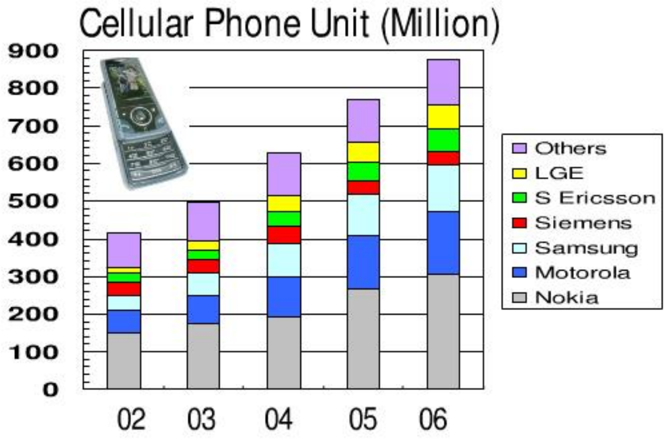
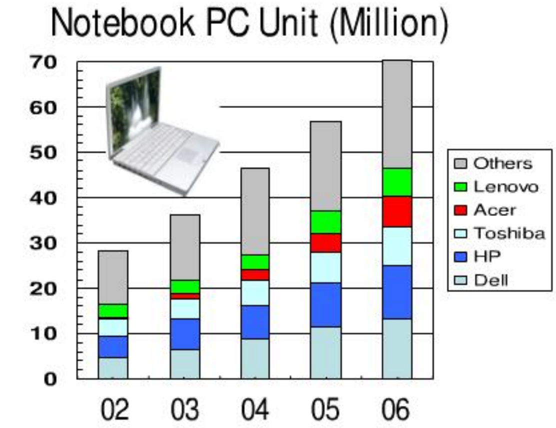
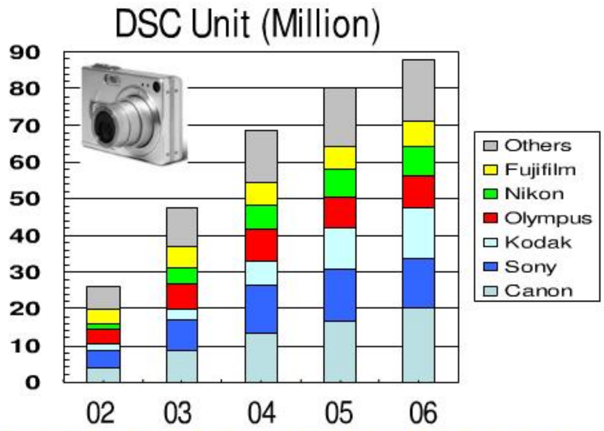
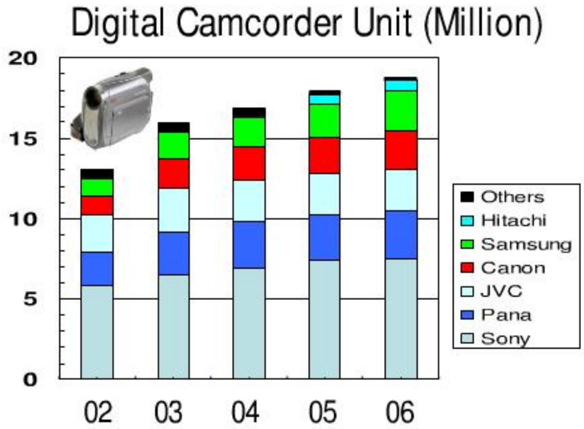
THE 23rd International battery seminar, 2006









Portable Power Management for Portable Electronics

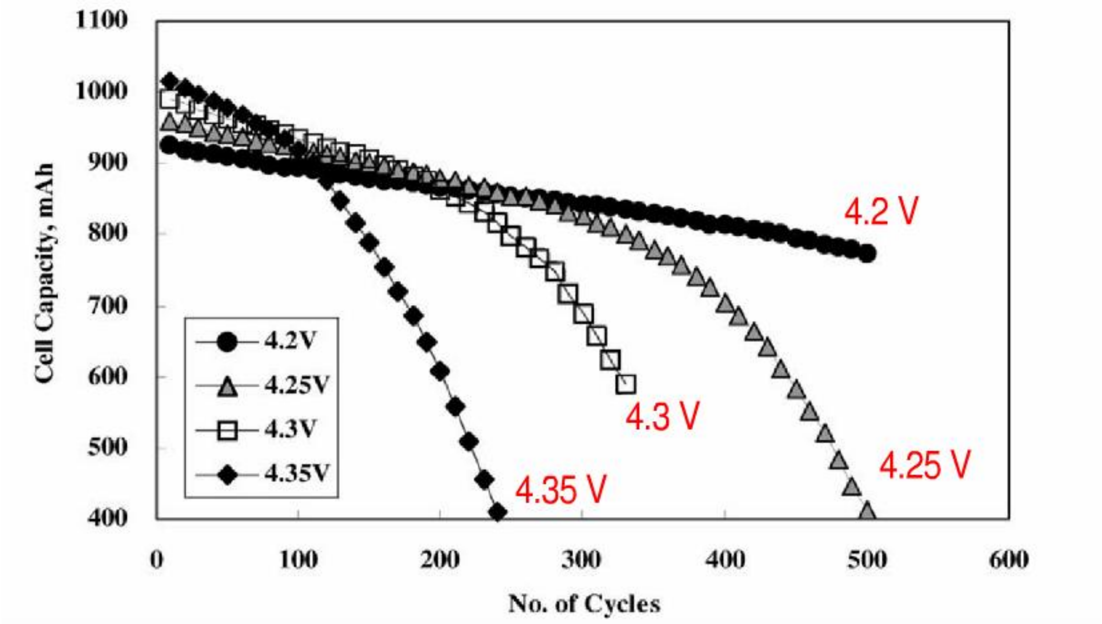
Battery Charging Management

- Safety
- Longer battery cycle life
- Longer battery usable time
- Shorter battery charge time
- Smaller size
- Lighter weight

Outline

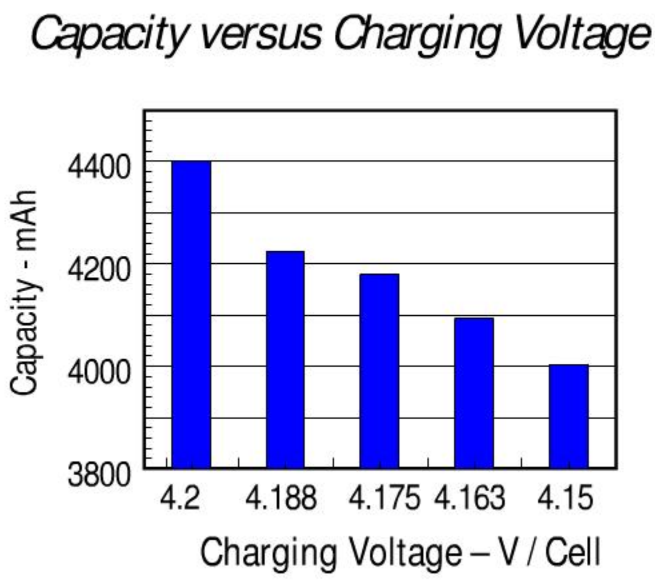
- Battery charging voltage vs. capacity and cycle life,
- Battery charge front end (CFE) safety protection
- Power path management battery charging
  - Voltage based DPPM
  - Input current based DPM

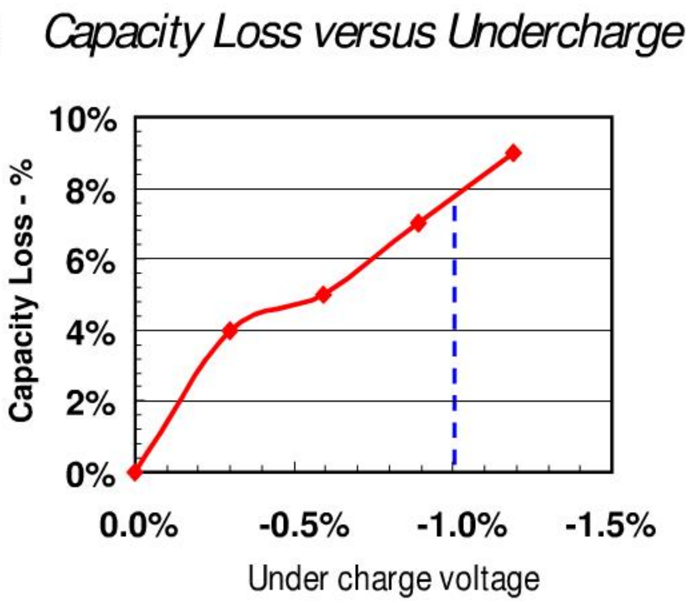
Charging Voltage versus Cycle Life



- Low Charging voltage accuracy: Over Charging
- Over charging get higher initial capacity
- Over charging shortens battery cycle life

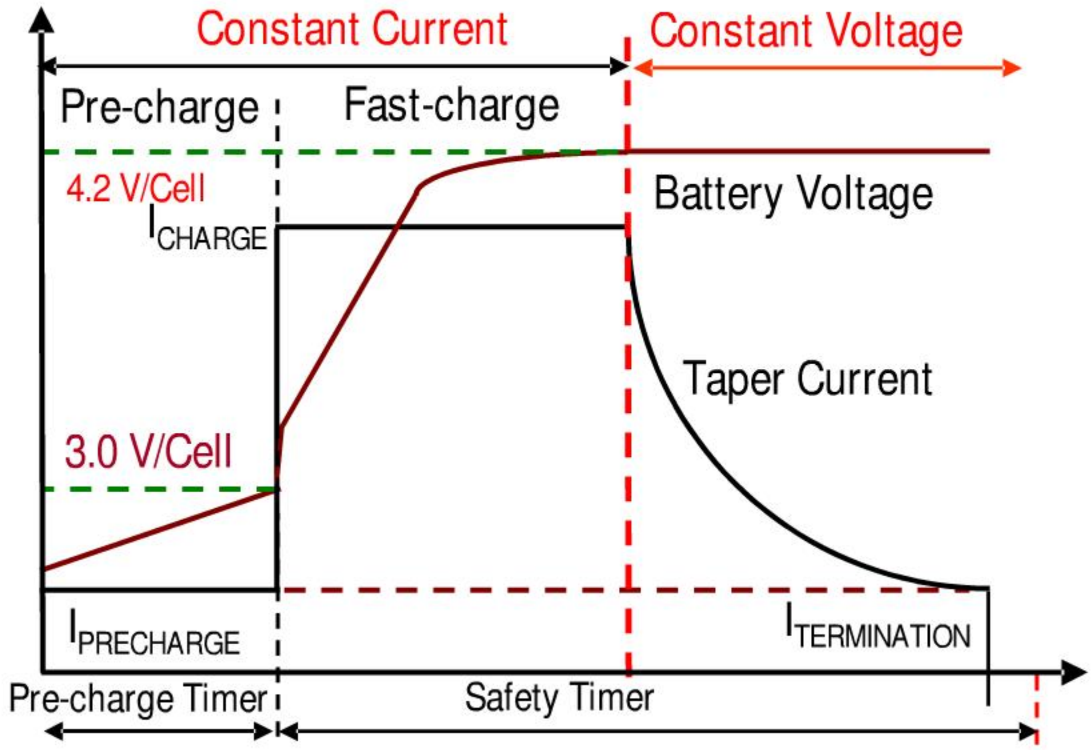
Capacity versus Battery Charging Voltage





- Under charge decrease battery capacity
- Charge voltage accuracy is very important

Li-Ion Charge CC-CV Profile



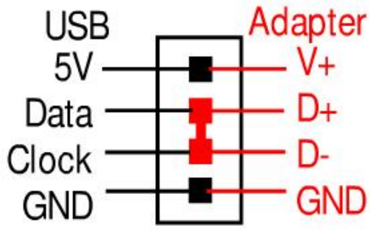
- Constant Current: 20-30% charging time, 70-80% capacity
- Constant Voltage: 70-80% charging time, 20-30% capacity

Battery Charging System Requirements

- Safety and Reliability
  - Adapter Hot Plug-in
  - Adapter Reverse Input to the charger
  - Short Circuit and Overcharging Protection

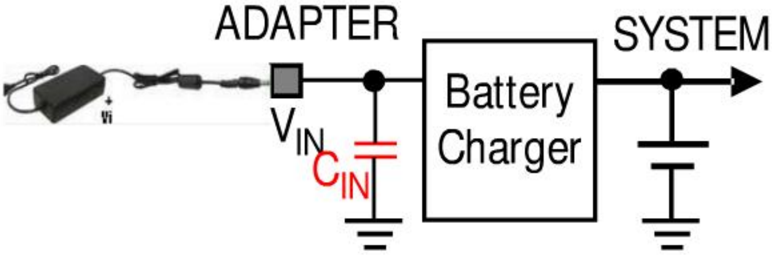
Cellular Phone Charger Interface

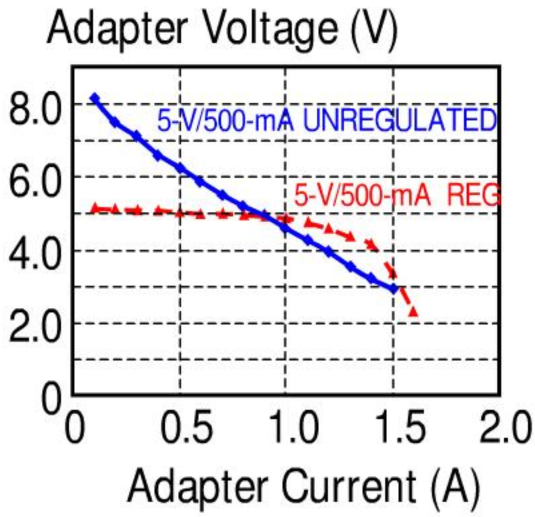
AC 100-240 V 50/60 Hz
DC 5 V, 0.31 A



- USB type A connector from adapter output
- Terminal to the portable device could be different

Causes of System Failure Due to Input Power

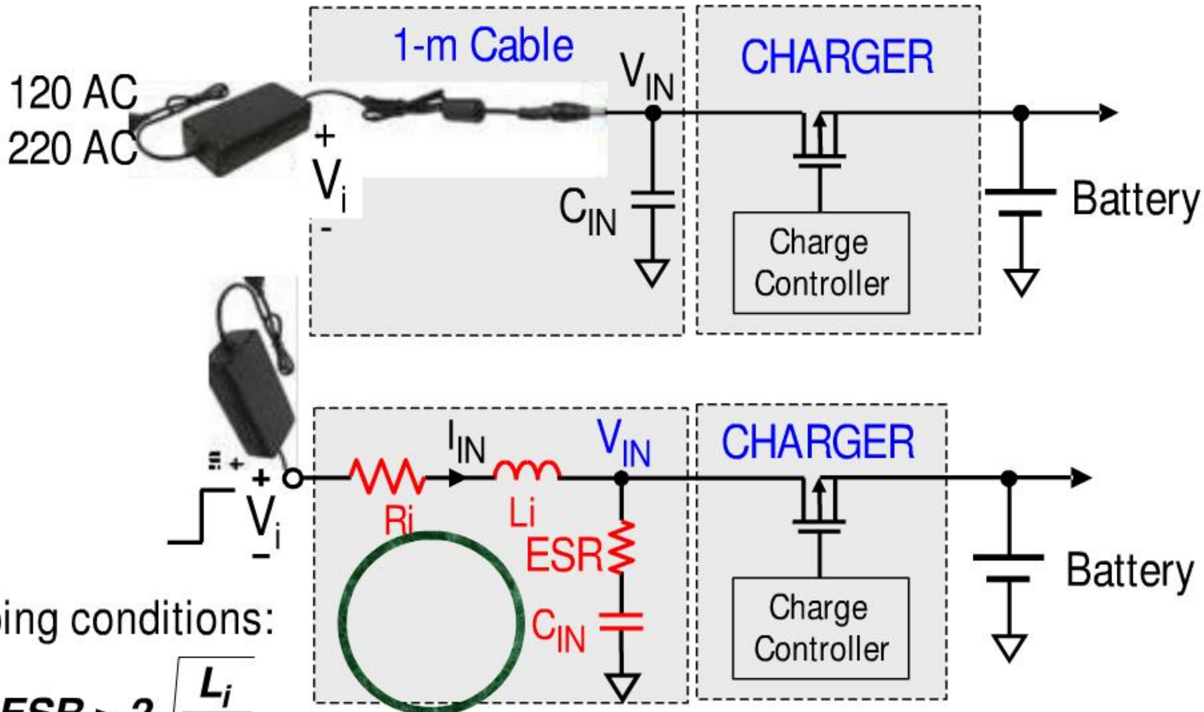




Input Over Voltage

- Wrong Adapter or After-Market Adapter
- Transformer–Rectifier Adapters (un-regulated)
- Hot Plug Event

Hot Plug In Test Setup and Equivalent Circuit

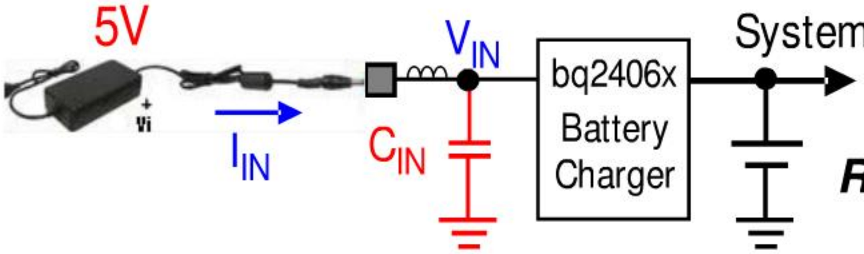


Damping conditions:

$$R_i + ESR > 2\sqrt{\frac{L_i}{C_{IN}}}$$

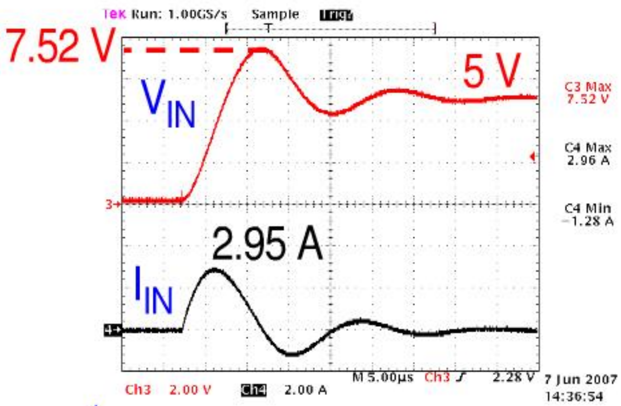
- How ESR and C_{IN} affect the Over-voltage?

Reducing Overshoot by Increasing C_{IN}

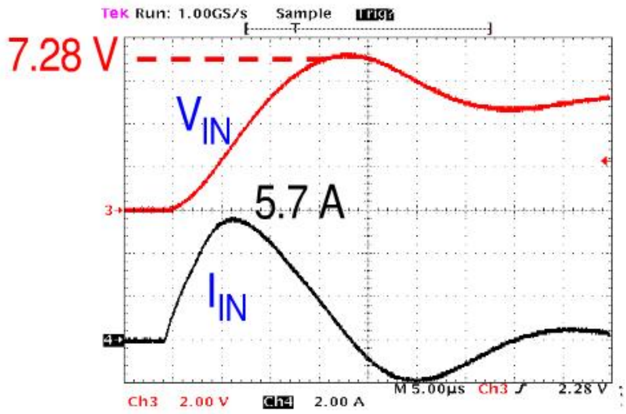


$$R_i + ESR > 2\sqrt{\frac{L_i}{C_{IN}}}$$

C_{IN} = 2×1 µF (0805, X7R)
Overshoot: 50.4% to 7.52 V

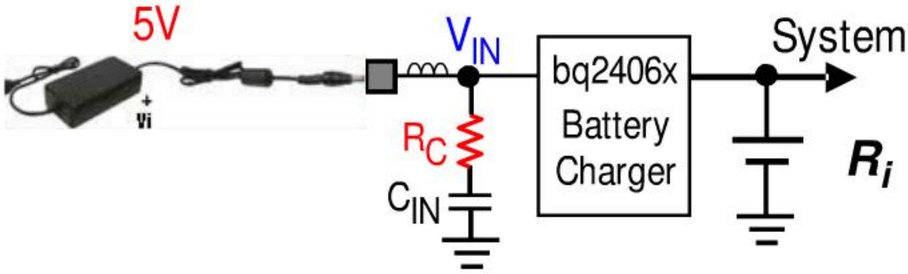


C_{IN} = 8×1 µF (0805, X7R)
Overshoot: 45.6%, 7.28 V



C_{IN}↑, Overshoot can not be reduced significantly.

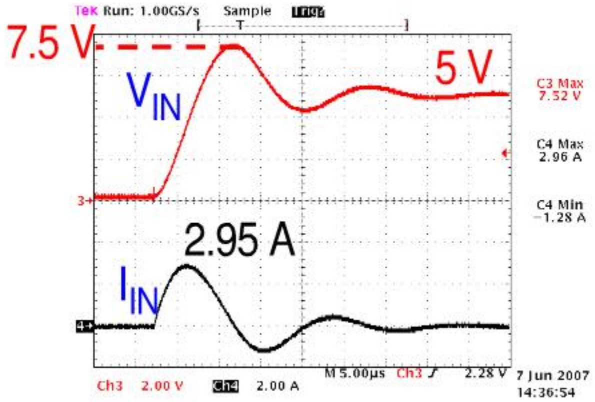
Reducing Overshoot by Increasing ESR

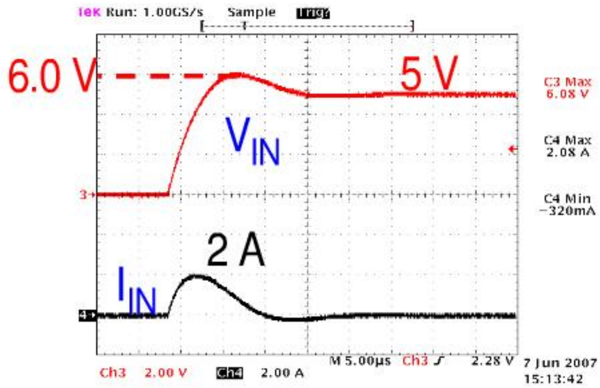


$$R_i + ESR > 2\sqrt{\frac{L_i}{C_{IN}}}$$

C_{IN} = 2×1 µF (0805, X7R)
Overshoot: 50 % to 7.5 V

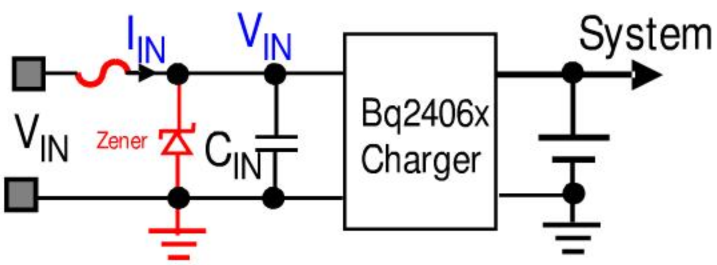
C_{IN} = 2×1 µF (0805,X7R) + 1 Ω
overshoot: 20%, 6.08 V

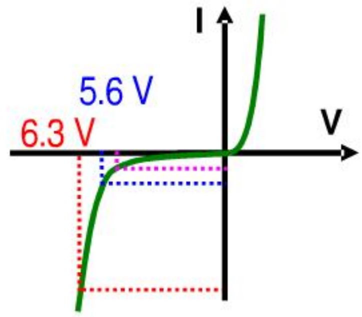




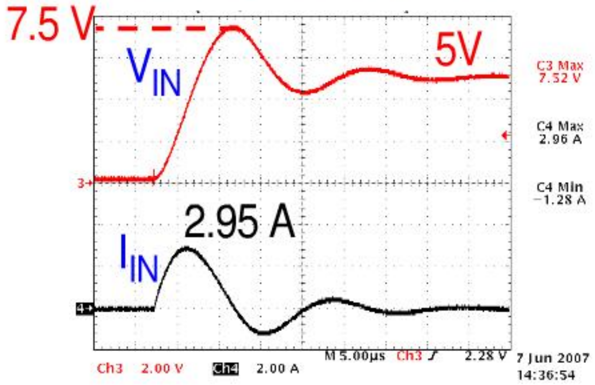
- High ESR or external resistor can help reduce voltage overshoot.

Reducing Overshoot by TVS Diode

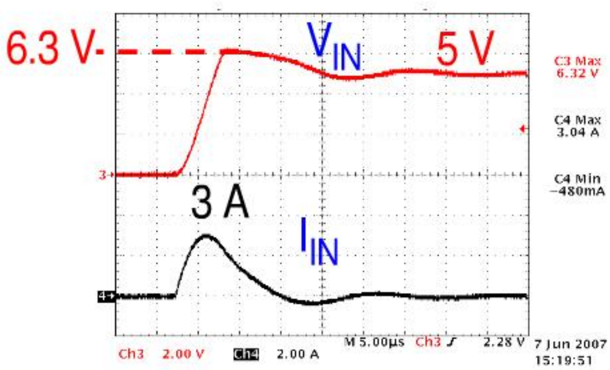




C_{IN} = 2×1 μF (0805, X7R)
Overshoot: 50 % to 7.5 V

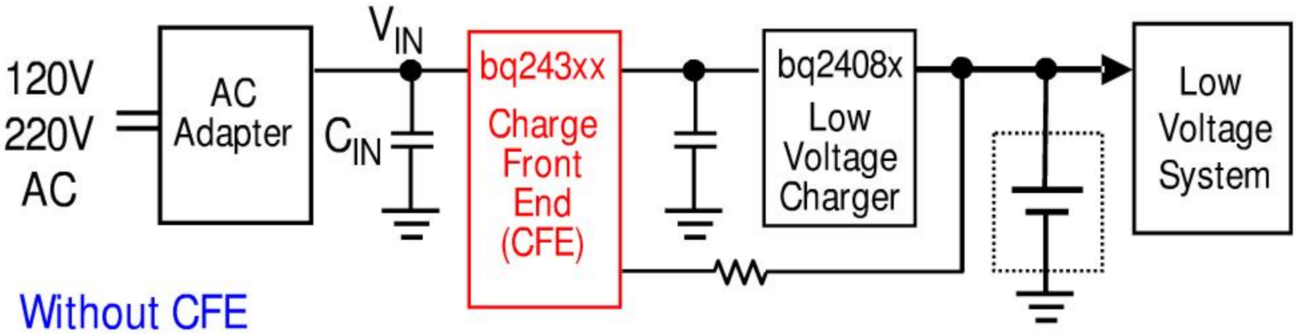


C_{IN} = 2×1 μF + 5.6-V TVS Zener
overshoot: 26%, 6.3 V



- TVS Zener diode can marginally clamp voltage spike

TI Solution: Charge Front End (CFE) Improves Safety



Without CFE

If Charger fails due to any reason

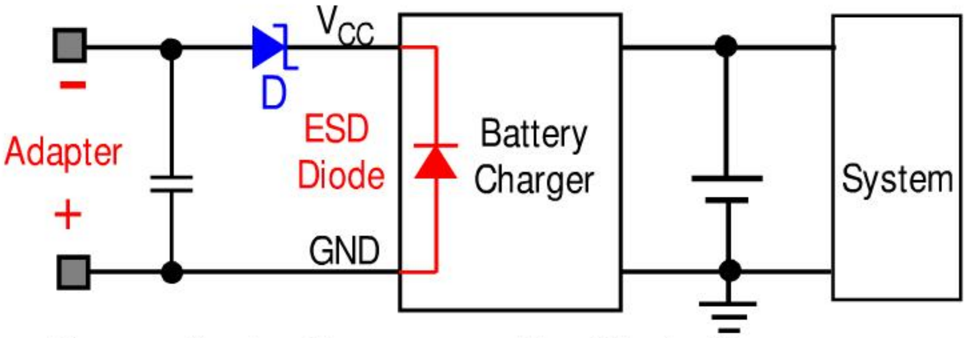
- System will be in over-voltage condition and Fail
- Battery will be over-charged, and may explode or burn

CFE Provide System Level Protections

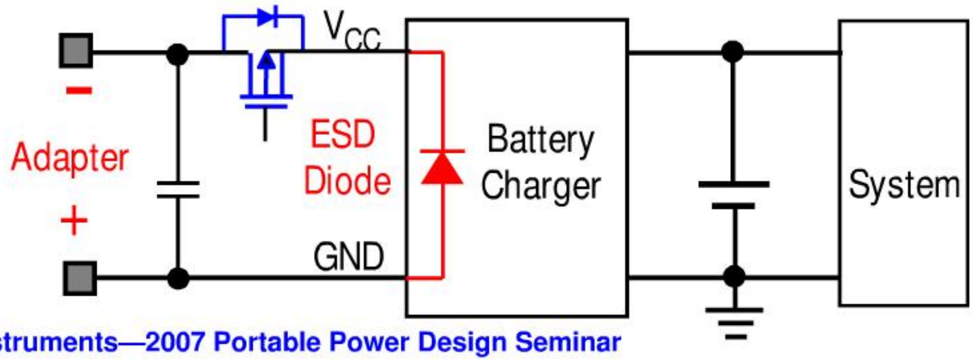
- Input Transient Over-Voltage
- Steady state over voltage
- Over-Current Protection, Latch or Hiccup
- Adapter Reverse Polarity
- Battery Over-voltage

Reverse Input Voltage to the System

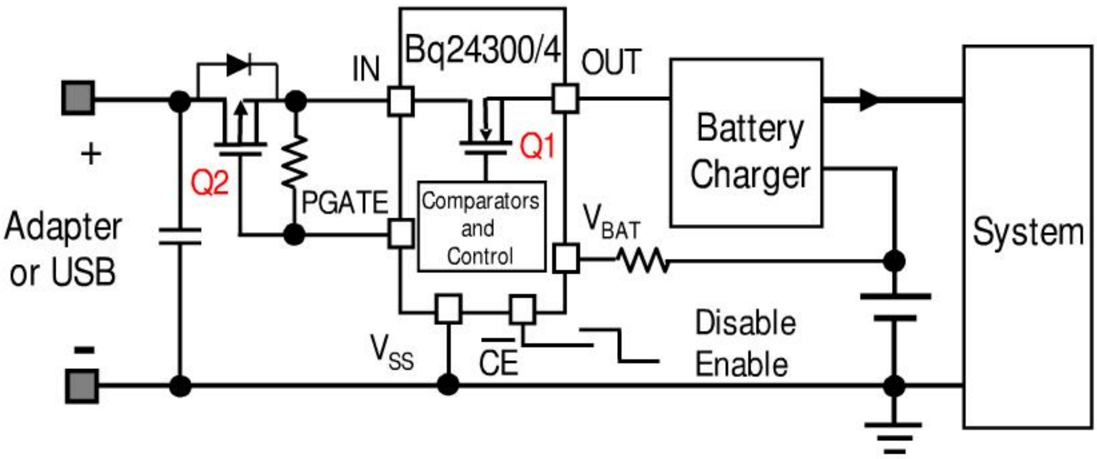
- Forward-biased ESD diode, short the adapter output
- High current injected into the substrate



- Power dissipation across the Diode D



TI Solution: Multiple Protection Levels

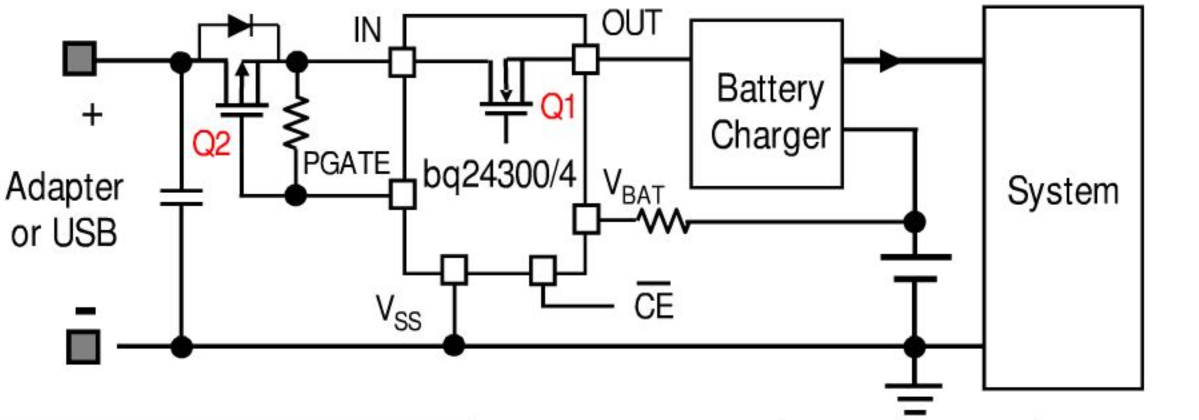


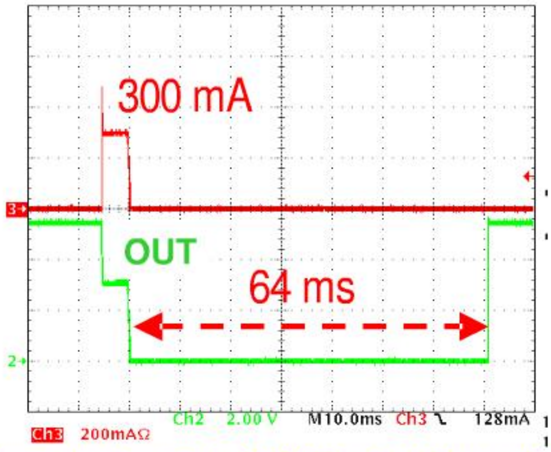
Protections

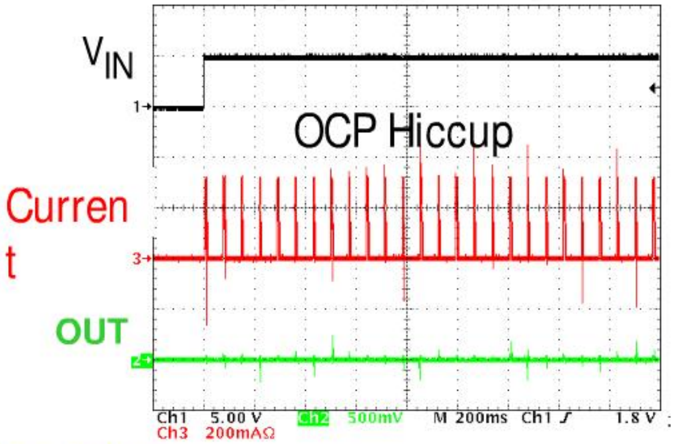
- Input Over-Voltage Protection
- Over-Current Protection: Hiccup or Latch
- Battery Over-Voltage Protection
- Reverse Input Voltage Protection

bq24300: $V_{O(REG)}$ = 5.5 V
2x2 8-pin DSG package
V_{OVP} = 10.5 V
OCP = 300 mA, current limiting
BATOVP = 4.35 V
bq24304: $V_{O(REG)}$ = 4.5 V

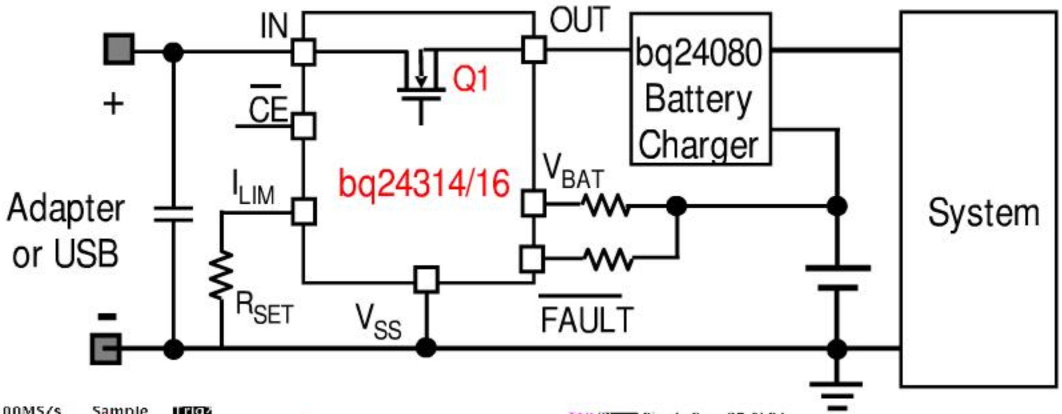
Bq2430x OCP Performance

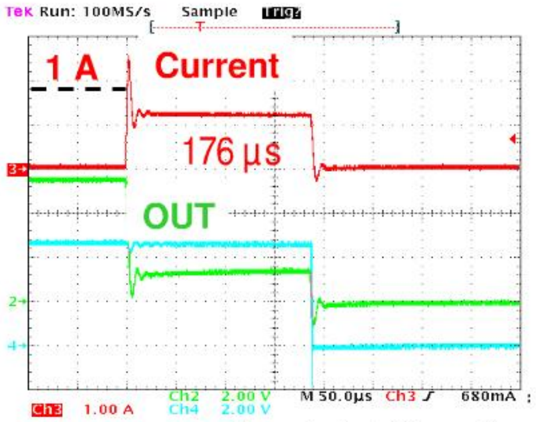


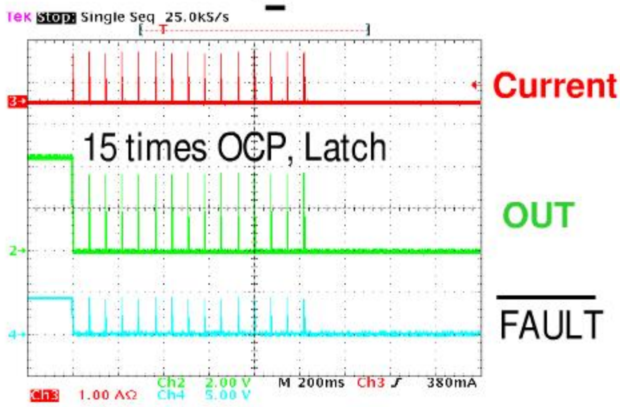




bq2431x OCP-Hiccup-Latch

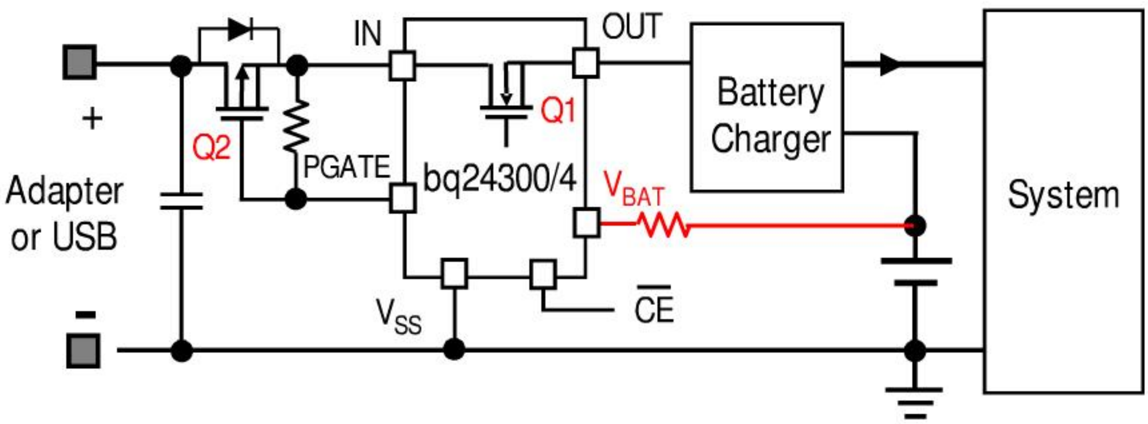


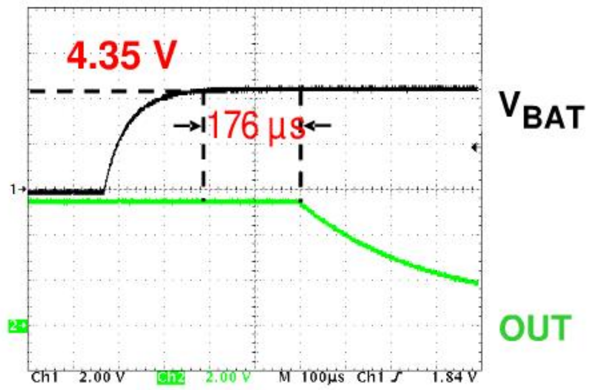


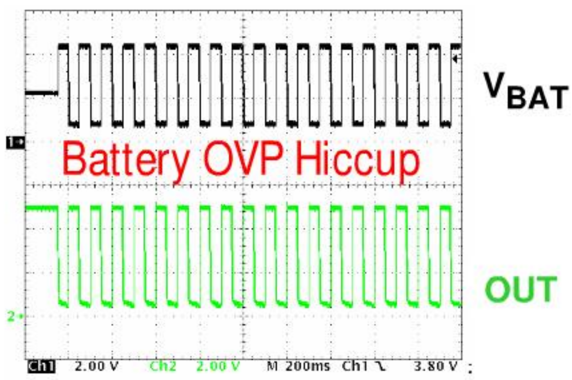


- Regulated Over-Current threshold for 176µs @OCP

Bq2430x Battery OVP (Hiccup)

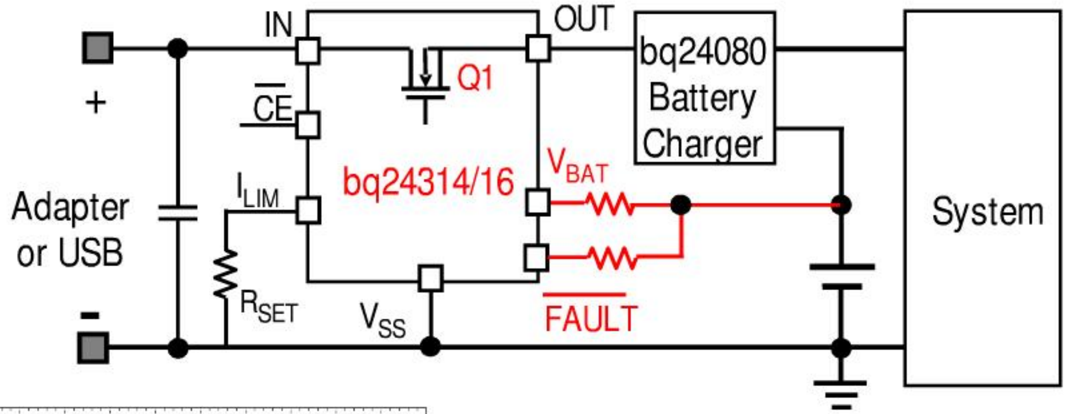


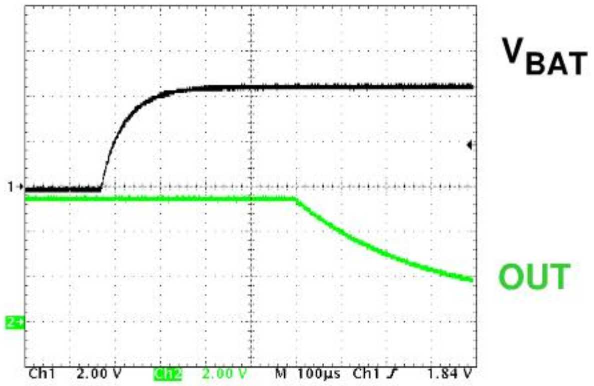


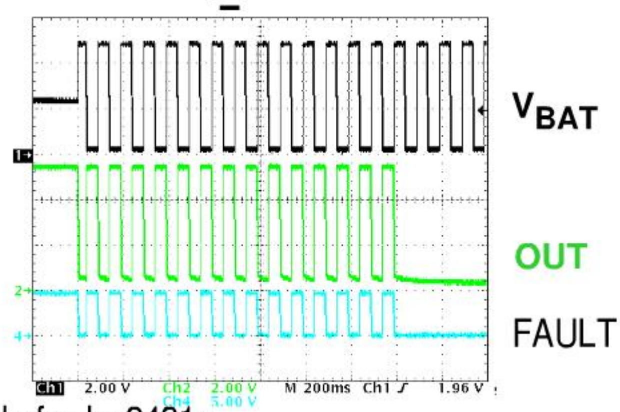


- Battery OVP is 4.35 V with 6% hysteresis

bq2431x Battery OVP (Latch)







- BOVP is hiccup 15 times and then latch mode for bq2431x
- POR or toggle /CE pin to reset BOVP latch

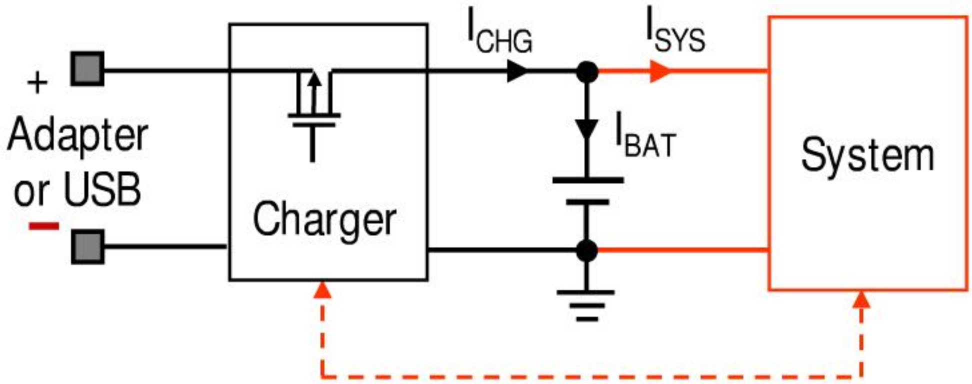
Summary of bqCFE Protection Features

		INPUT OVP			OCP		Battery OVP	
Part #	Package	V_{OVP}	$V_{O(REG)}$	$t_{BLANK(OVP)}$	I_{OCP}	$t_{BLANK(OCP)}$	BV_{OVP}	Counter
bq24300	2x2 mm	10.5	5.5	64 µs	300 mA	5 ms	4.35	HICCUP
bq24302	2x2 mm	10.5	5.5	64 µs	300 mA	5 ms	No	HICCUP
bq24304	2x2 mm	10.5	4.5	64 µs	300 mA	5 ms	4.35	HICCUP
bq24308	2x2 mm	10.5	PROG	64 µs	300 mA	5 ms	4.35	HICCUP
bq24310	2x2 mm	PROG		0	PROG	5 ms	4.35	LATCH
bq24312	2x2 mm	PROG		0	PROG	176 µs	4.35	LATCH
bq24314	2x2 mm 4x3 mm	5.85		0	PROG	176 µs	4.35	LATCH
bq24316	2x2 mm 4x3 mm	6.8		0	PROG	176 µs	4.35	LATCH

- Latch: After 15 times OCP or OVP, then latch

Power Path Management Charging

Charging with an Active System Load: Issues



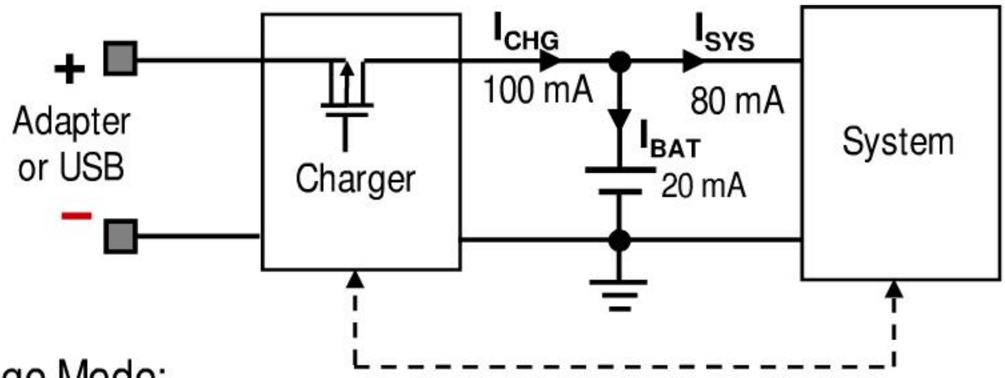
Charger output current is shared:

$I_{CHG} = I_{BAT} + I_{SYS}$

Issues:

- Safety Timer False Expiration
- Termination Detection

Issue 1: Pre-charge and Safety Timer Fault



Pre-Charge Mode:

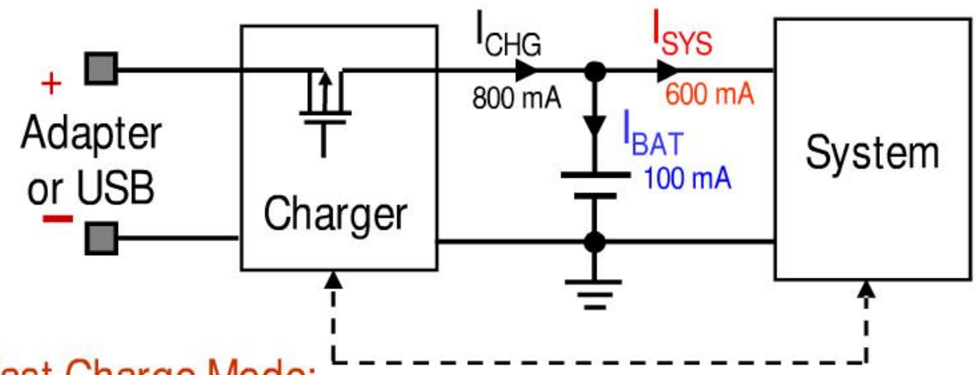
Battery voltage may not reach the fast charge voltage threshold

- Pre-charge timer may expire

Solution: keep system off or in low-power mode in pre-charge mode

Drawback: Can not operate the system while charging a deeply discharged battery simultaneously

Issue 2: Safety Timer Fault



When in Fast Charge Mode:

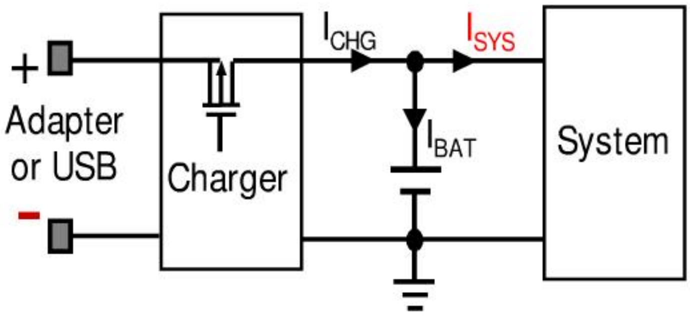
1. Charger output current is limited to fast charge current
2. System current "steals" charger output current
3. Battery is charged at a lower rate !

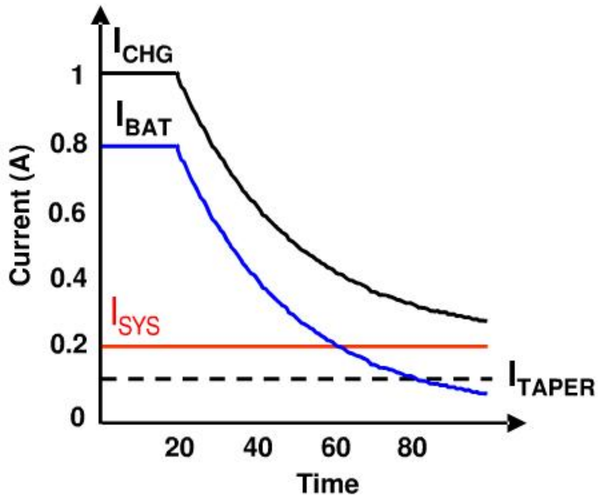
➢ Charge safety timer may expire, turning off the charger

Solution:

- Increase the safety timer timeout value
- Increase the fast charge current value

Issue 2: Charge Termination NOT Detected

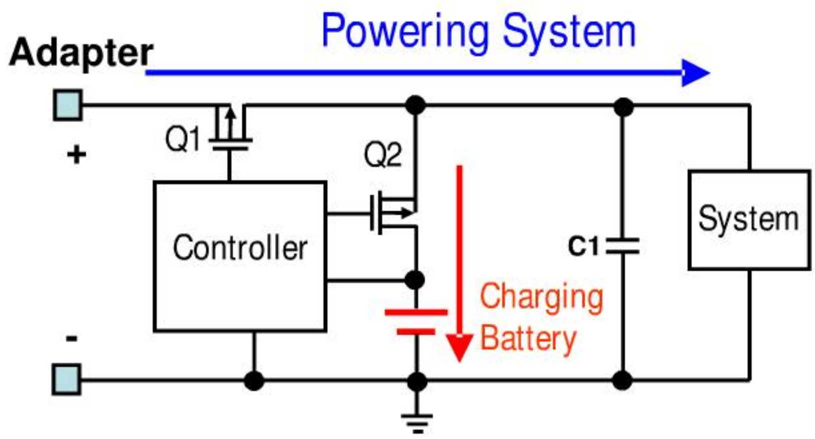




Voltage Regulation Mode:

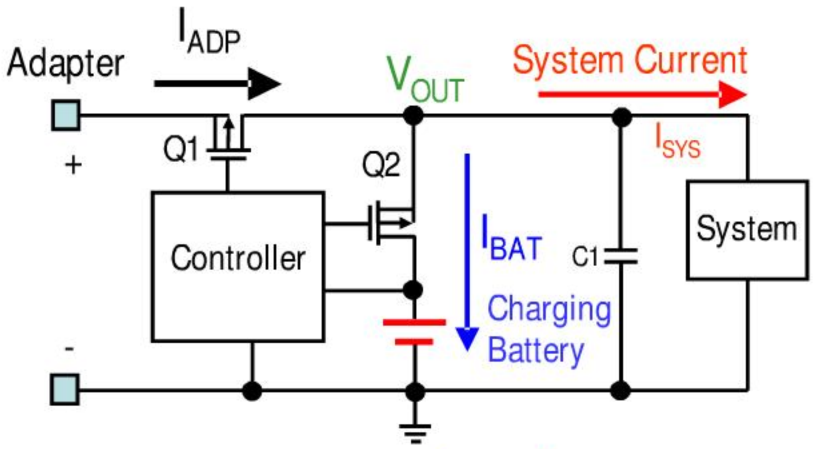
- If $I_{SYS} > I_{TAPER}$, Termination is never detected
  Solution: current supplement circuit

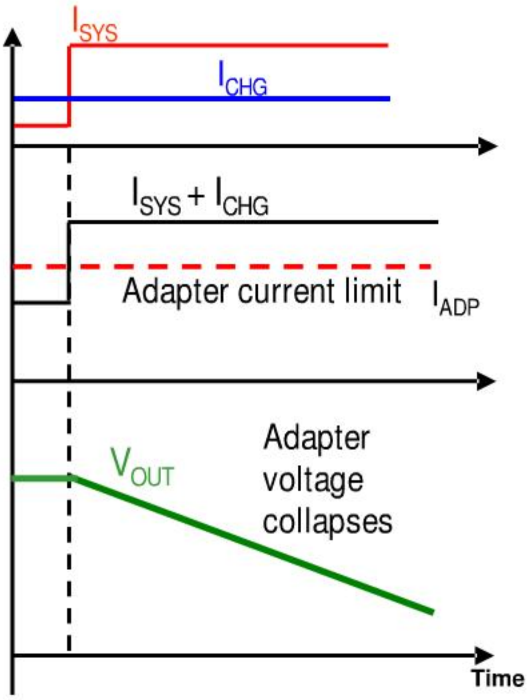
Power Path Management Battery Charger



- System power supplied from adapter through Q1
- Charge current controlled by Q2
- Ideal topology when powering system and charging battery simultaneously is a requirement
- Separates charge current path from system current path
- No interaction between charge current and system current

Power Path Management: Potential Issues





Input current : $I_{ADP} = I_{BAT} + I_{SYS}$

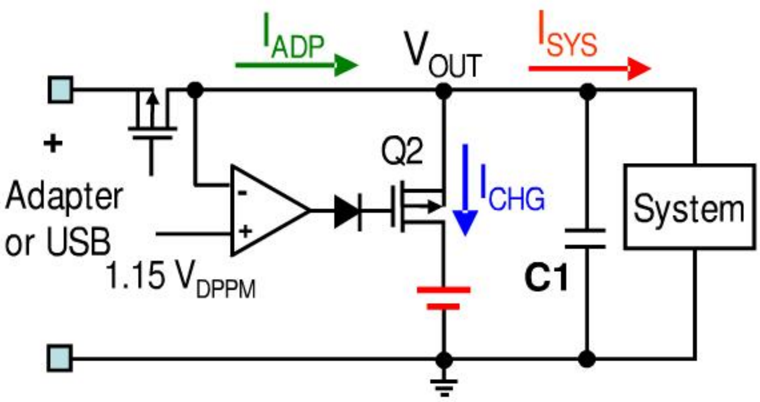
Issues:

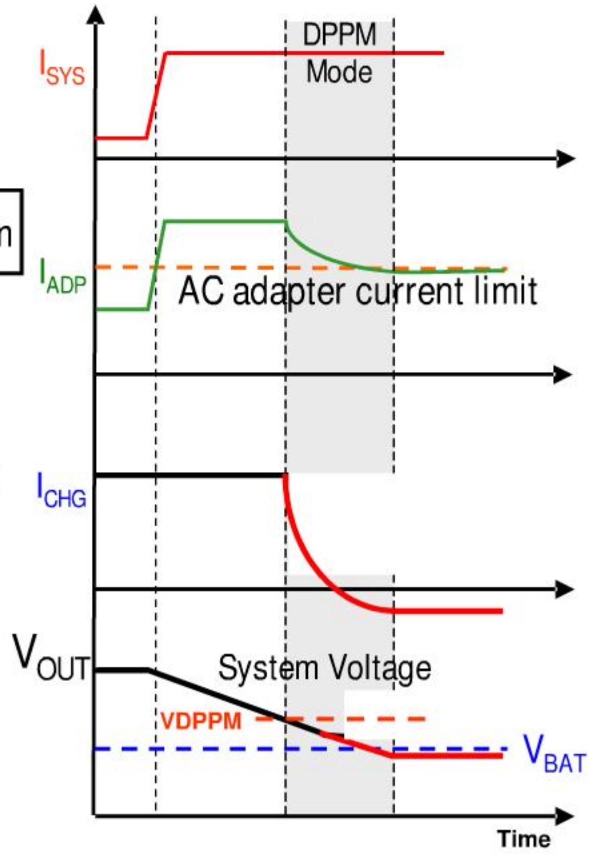
- Input voltage collapses

Solution 1:

Design the AC adapter at maximum $I_{SYS} + I_{CHG}$, HIGH COST

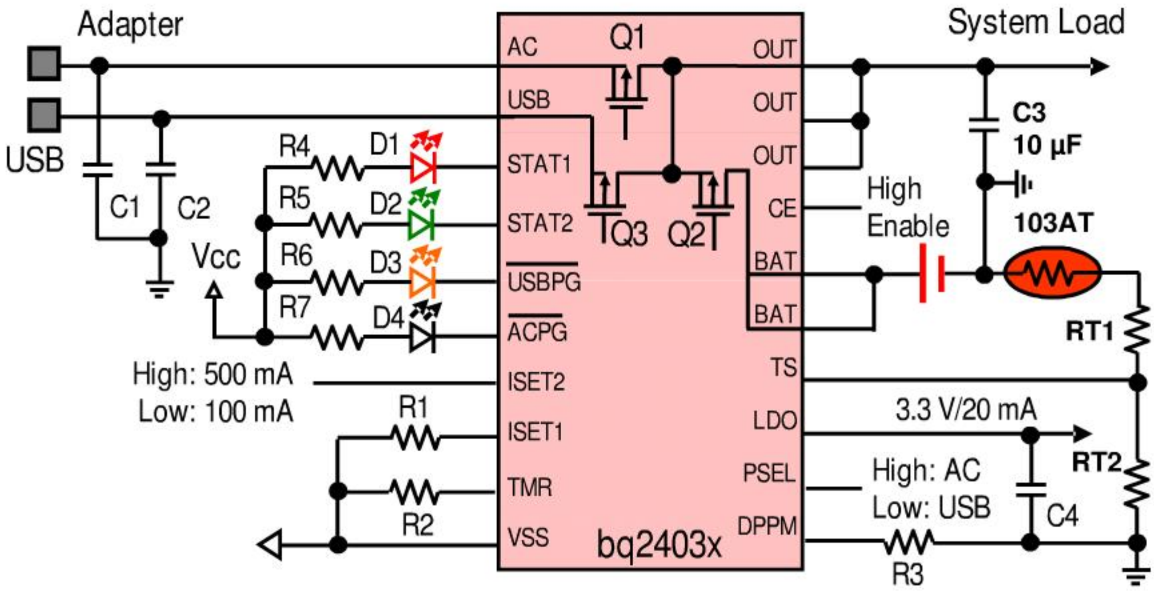
Voltage Based Dynamic Power Path Management (DPPM)





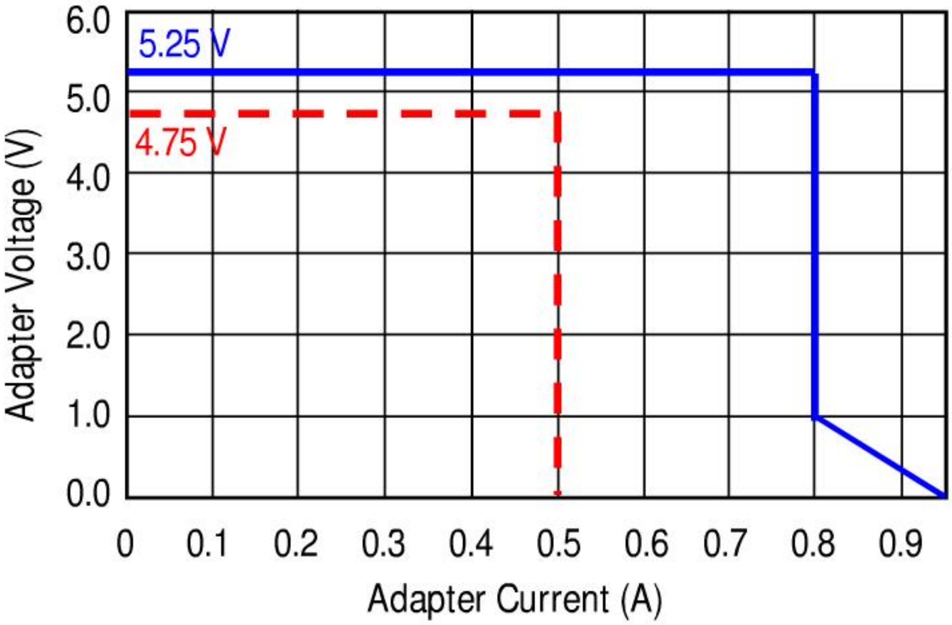
- Bus voltage drop causes system reset
- DPPM function :
  - Reduces the charge current when the system voltage is V_{DPPM}
  - "Finds" maximum adapter power
- Battery Supplement Mode

Voltage Based Dynamic Power-Path Management Charger



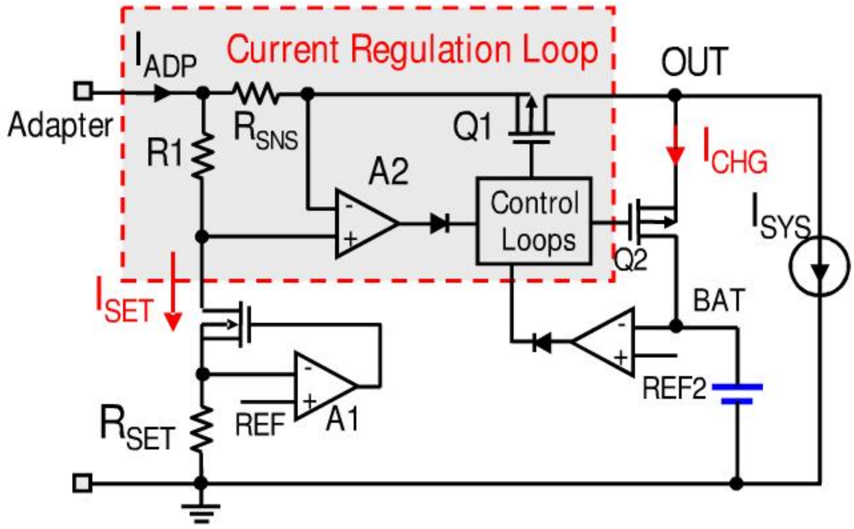
- OUT: 4.4 V for bq24032A; 6.0 V for bq24030
- Dynamically reduces the charge rate to maximize adapter to system current
- Regulate junction temperature at 125°C by reducing charge current
- Dynamically increase the safety timer based on real charge current

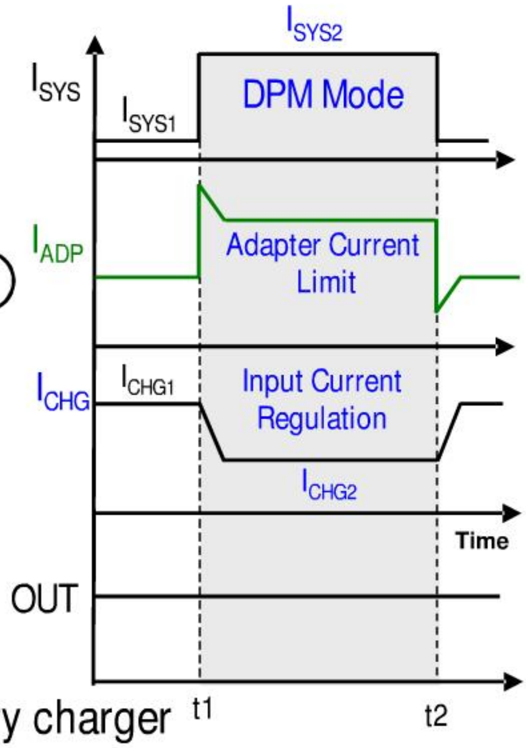
Typical Adapter Output Characteristics



- Current limited Voltage Source
- Ideal to use input current regulated battery charger

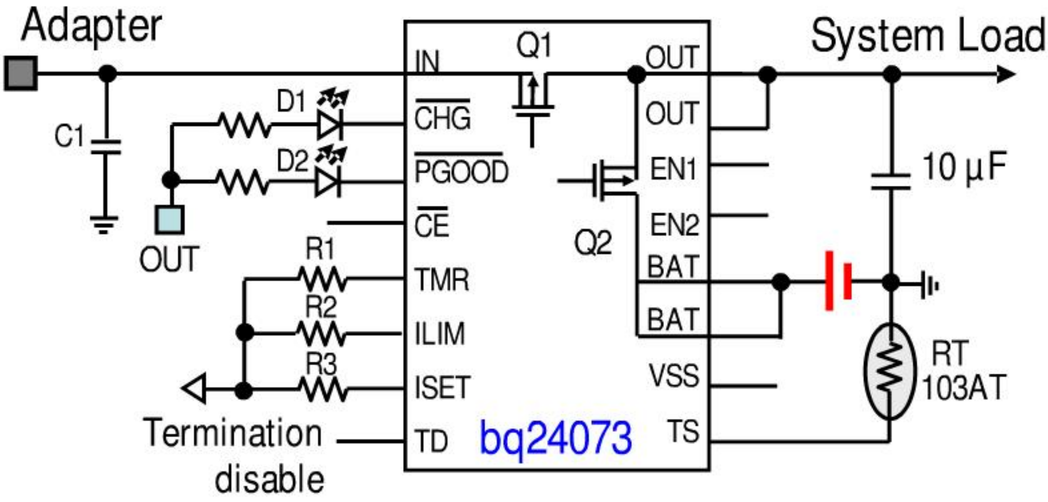
Input Current Regulated DPM Battery Charger





- Input current regulation to maximize use of the input current
- Current sharing between system and battery charger
- Minimize the AC adapter size and power rating
- Constant output voltage: Guarantee no system crash

Input Current Regulated DPM Charger Example



- Input current limiting
- Selectable charge termination
- Input over-voltage protection (6.6 V)
- Programmable charge current
- 3x3-mm QFN

EN1	EN2	Maxim Input Current
0	0	100 mA
0	1	500 mA
1	0	Set by R2
1	1	Stand-by (USB suspend)

Comparisons

	Charging & System Operation	Safety Timer	Termi Detection	Output Voltage	Thermal
Battery in system bus bq2401x,2x bq2406x	No	May false expiration	May Not	V_{BAT}	Regulated at 125°C for bq2406x
Voltage DPPM bq2403x	Yes	Dynamic	Yes	Pulsating VDPPM--4.4 V	Regulated at 125°C
Current DPM bq2407x	Yes	Dynamic	Yes	Fixed	Regulated at 125°C

Summary

- Battery Charging System Safety Protection
- Battery Charging Front End (CFE)
- Voltage based Dynamic Power Path Management Charging
- Input Current regulated Dynamic Power management charging