Texas Instruments

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

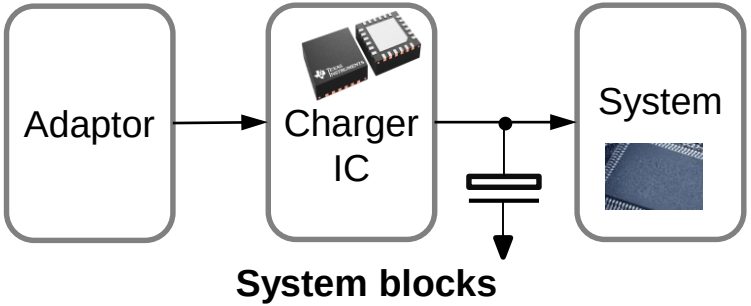
ERIC ZHAO

BATTERY CHARGER OVERVIEW – FROM THE FUNDAMENTAL TO THE SYSTEM CHALLENGES AND APPLICATION SOLUTIONS

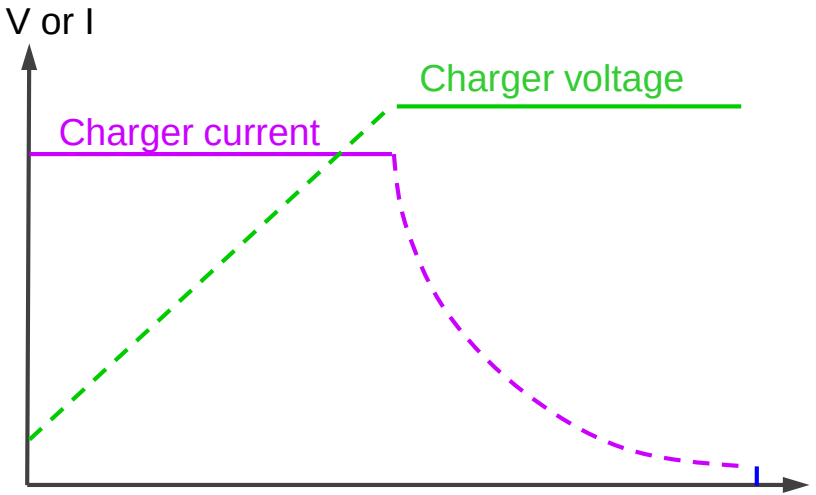
Agenda

- Battery charger fundamentals
  - The difference between a DC/DC converter and a battery charger
  - The system challenges and why
  - The solutions!
- How to find the right chargers for your applications
  - 5V input for 1S and 2S battery
  - Other inputs for multicell battery
  - Solar panel inputs
- Summary

What charger ICs do?



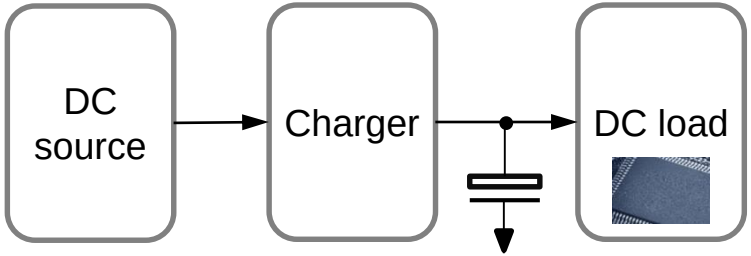
System blocks

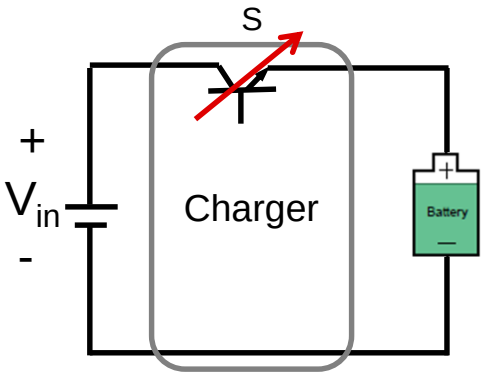


Simplified charging profile

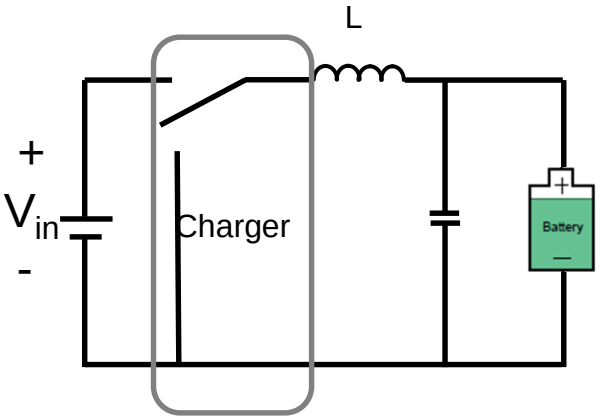
- **Charging functions:**
  - Regulate: constant current and constant voltage
  - Safety of charging: current, voltage and thermal protections
  - Status of charging: charging, charge full, abnormal state
  - Advanced features: dynamic power management, system and battery monitoring…

Charger topologies

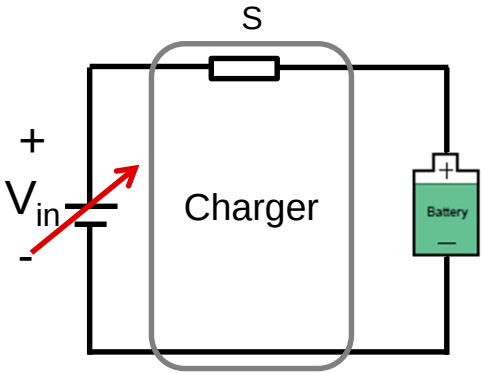




Linear charger

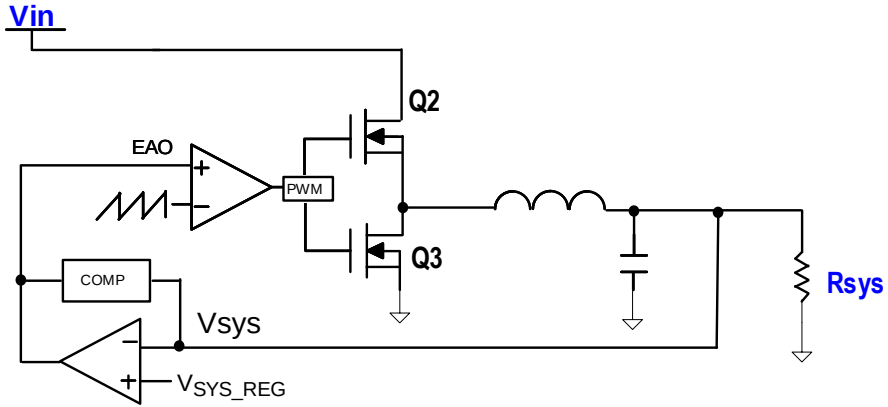


Switch-mode charger



Flash charger

DC/DC converter vs. charger – DC/DC source and load

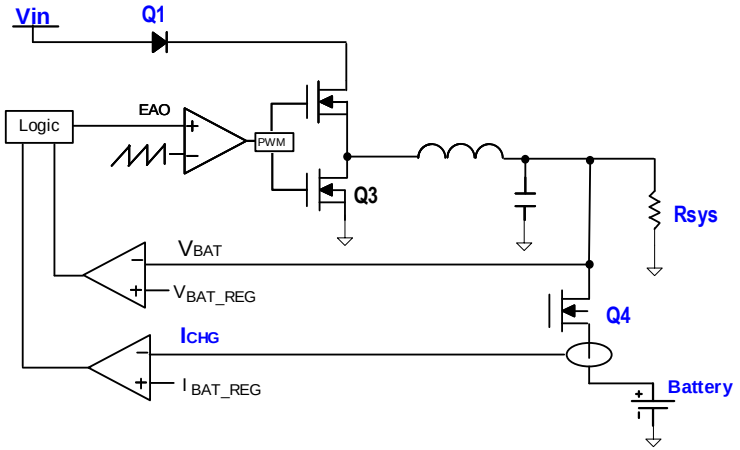


Vin	Rsys	Battery	Source	Load	Mode
Source	Load	NA	1	1	CV or CC

A DC/DC converter:

- *Single source* and *single load*
- One active switch and one syn rectifier switch for efficiency – *2 switches*
- Single loop to regulate the output voltage ***or*** current

DC/DC converter vs. charger – charger source and load



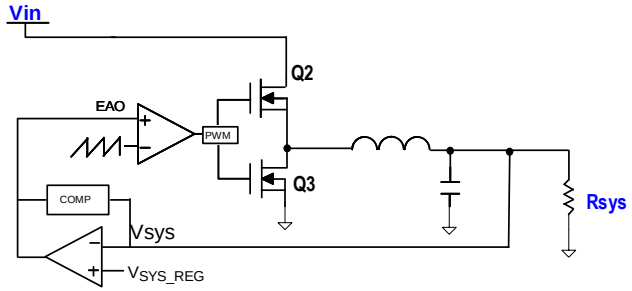
Vin	Rsys	Battery	Source	Load	Mode
S	L	Idle	1	1	Charge done
S	L	Load	1	2	CC and CV
S	L	**Source**	2	1	Supplement
L	L	**Source**	1	2	On-The-Go

A battery charger

- Different combinations – *1 or 2 source* and *1 or 2 load*
- Two loops to regulate the output voltage *and* current
- Buck converter (2) + reverse blocking *3 switches* + power path *4 switches*

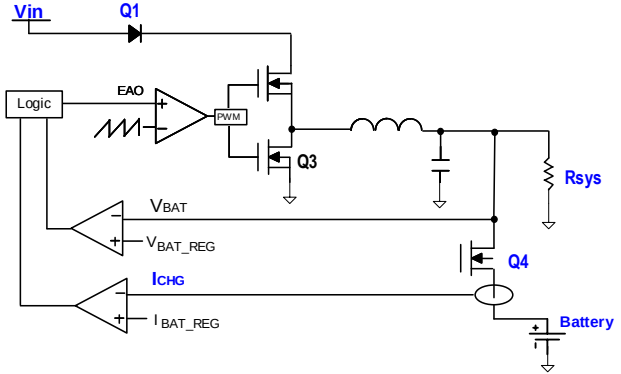
DC/DC converter vs. charger – source and load comparison

DC/DC



Vin	Rsys	Battery	Source	Load	Mode
Source	Load	NA	1	1	CV or CC

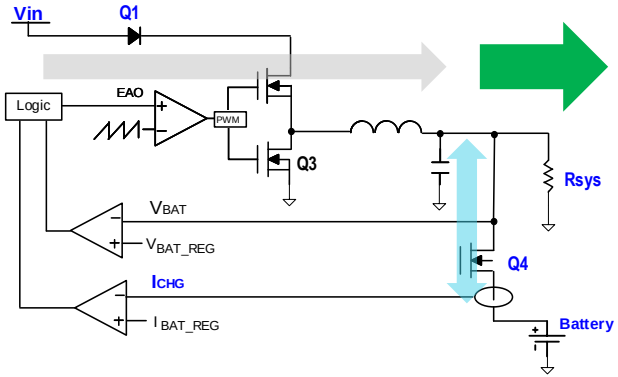
Charger



Vin	Rsys	Battery	Source	Load	Mode
S	L	Idle	1	1	Charge done
S	L	L	1	2	CC and CV
S	L	S	2	1	Supplement
L	L	S	1	2	On-The-Go

- Battery charger – multiple control loops (CC, CV)
- Battery is a source – reverse block FET/diode (Q1), power path (Q4)

The unique challenge for a charger - two sources/loads

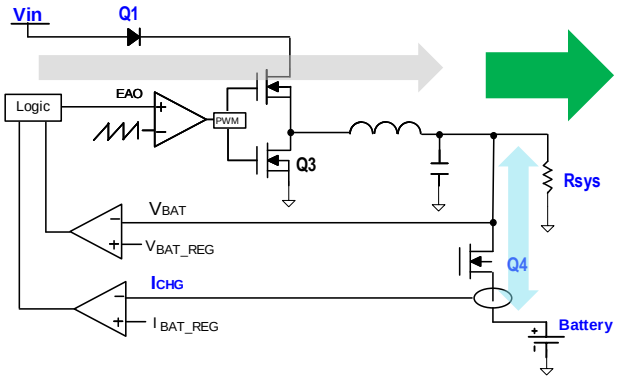


Vin	Rsys	Battery	Source	Load	Mode
S	L	Idle	1	1	Charge done
S	L	L	1	**2**	CC and CV
S	L	S	**2**	1	Supplement

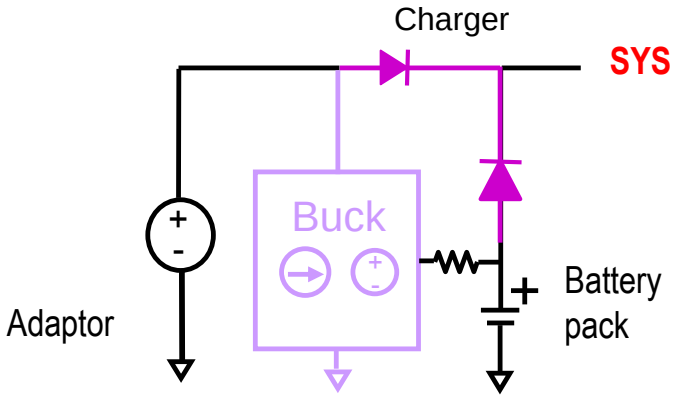
Input power = Battery power + Dynamic system power

- System power is dynamic depending on the system (applications)

Power path – prioritize SYS from the load perspective



Input power = Battery power + Dynamic system power



- System power is dynamic depending on the system (applications)
- Power path is to prioritize the SYS

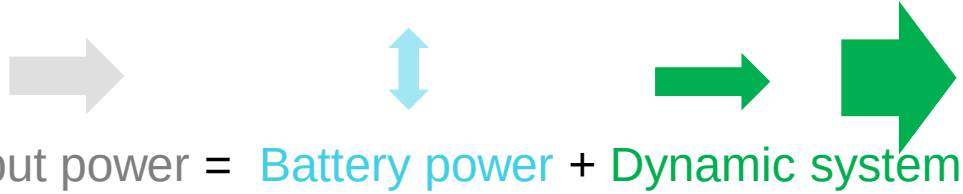
Input DPM – maximize the utilization of the input power

- 3 types of 5-V input sources

OEM

USB port

3rd party

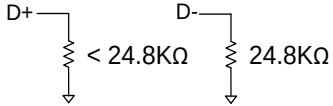


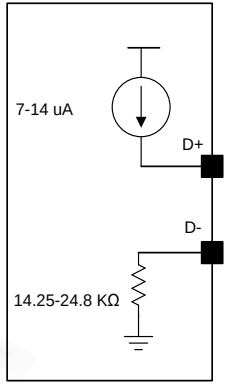
Input power = Battery power + Dynamic system power

- Detect the input power source maximum power capability
- Provide the end user the convenience to charge with different adaptors

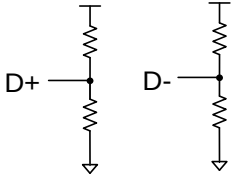
Input current dynamic for USB – USB detection

500mA SDP
(Standard Downstream Port)

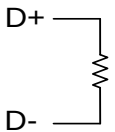




Non-Standard Adapter

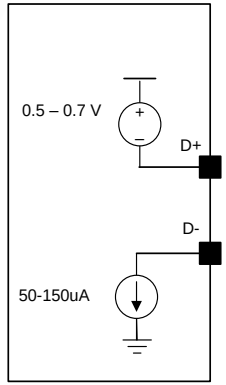


(DCP)
Dedicated Charging Port

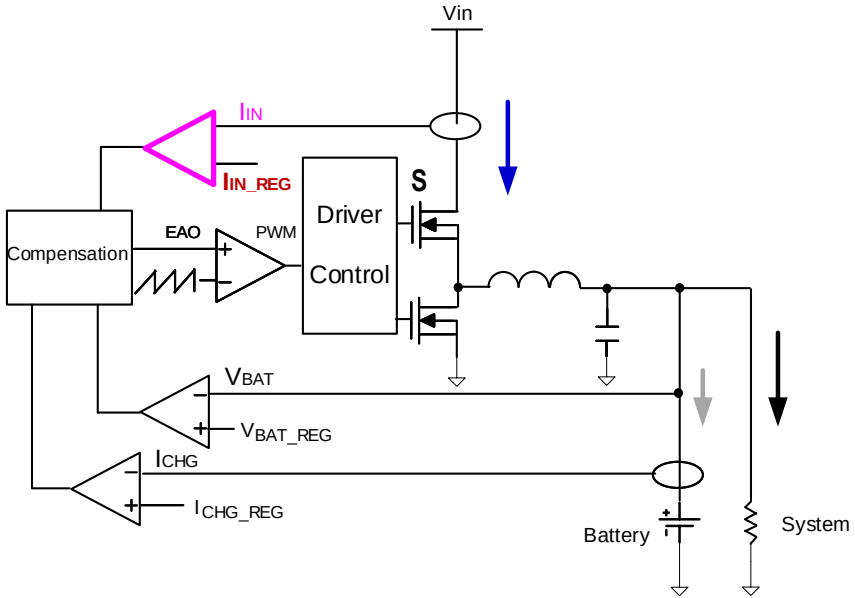


< 200Ω

*Use ILIM pin to set 1.5A limit if needed

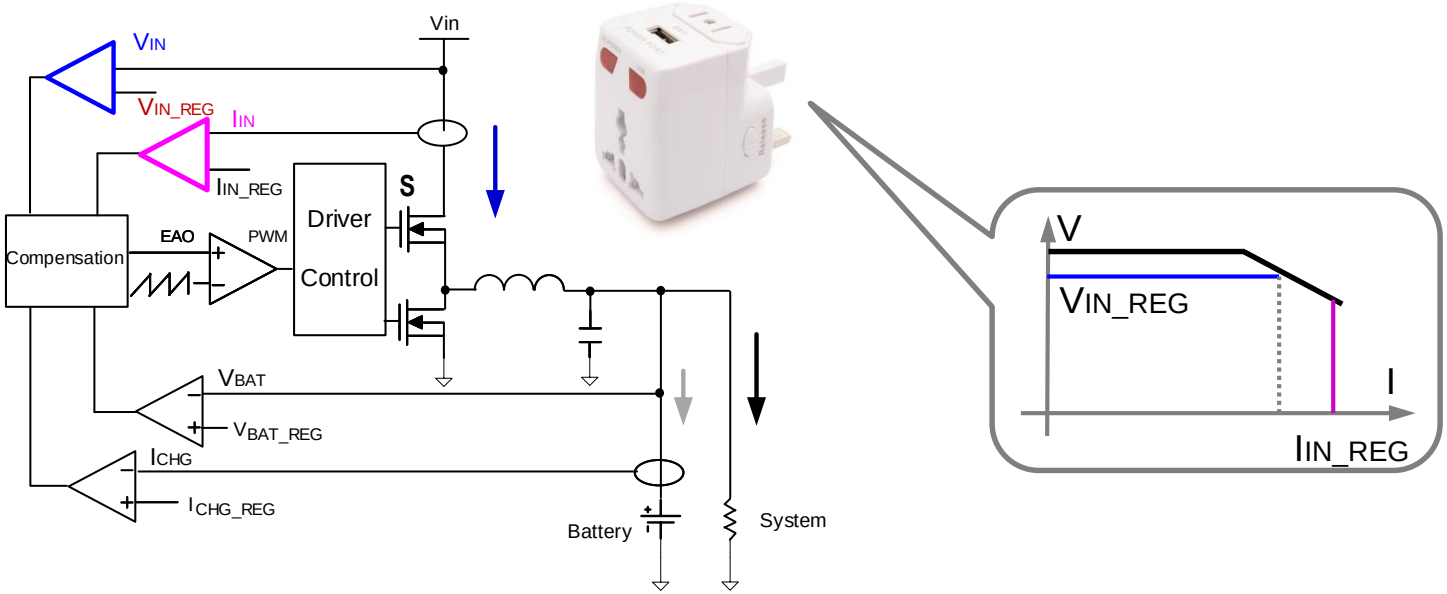


Input current dynamic power management



- Input current dynamic power management (I_{in} DPM)
  - Limit the input current with the system load as high priority
  - Current DPM: for OEM adaptor and OEM sets the current reference I_{IN_REG}

Input voltage dynamic power management



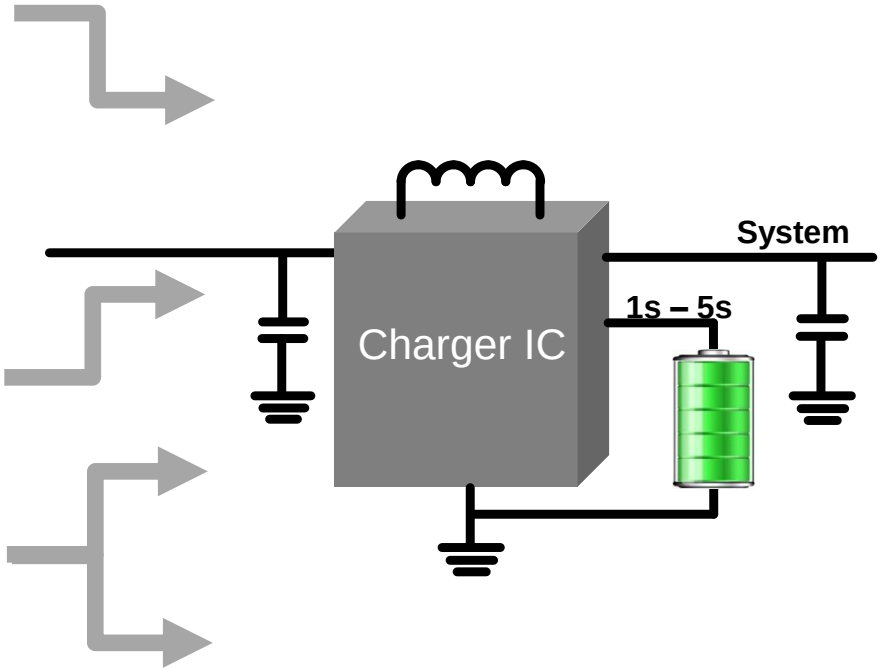
- Input voltage dynamic power management (V_{in} DPM)
  - Limit the input current with the system load as high priority
  - Voltage DPM: for using with the third party adaptor setting VIN_REG
  - Current DPM: for OEM adaptor and OEM sets the current reference

The challenge – universal charging

19-V adaptor

5-V USB

USB PD 3.0
5 V, 9 V, 15 V, 20 V



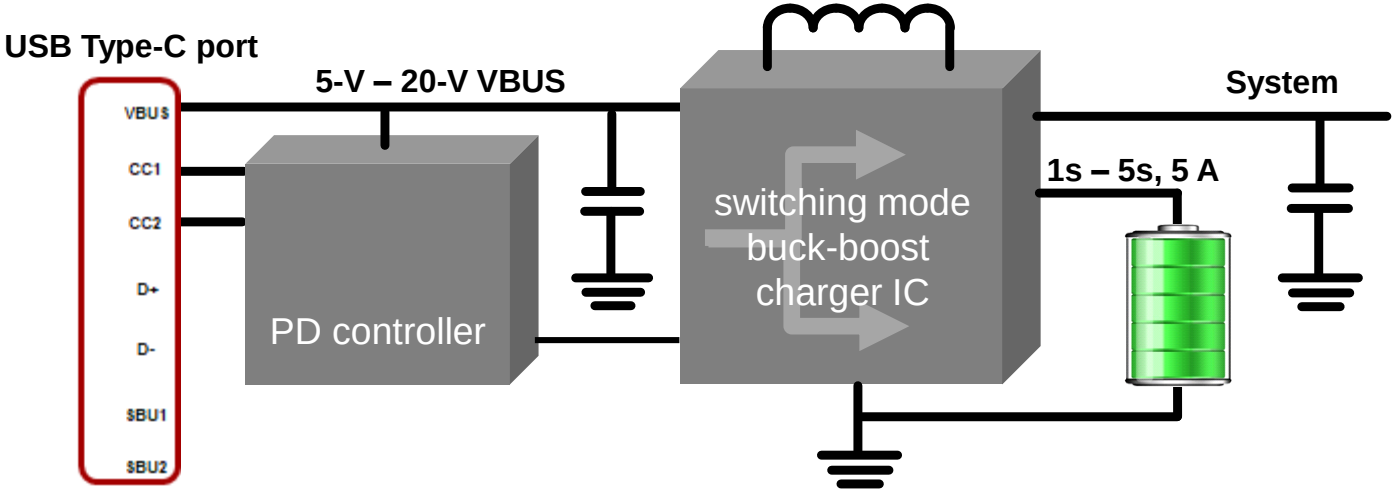
4 cells

2 cells

4 cells

- Charging voltage ratio change
  - Topology: buck, boost, buck-boost

USB-PD system with buck-boost charger



1 cell

2 cells

2~4 cells

4 cells

- With a buck-boost charger, the VIN and VOUT combination can be flexible
- Wide input voltage 5 V ~ 20 V to charge multi-cell battery 1S ~ 5S
- Support up to 100-W power delivery, 5 V/3 A, 9 V/3 A, 15 V/3 A, 20 V/3 A, 20 V/5 A

Agenda

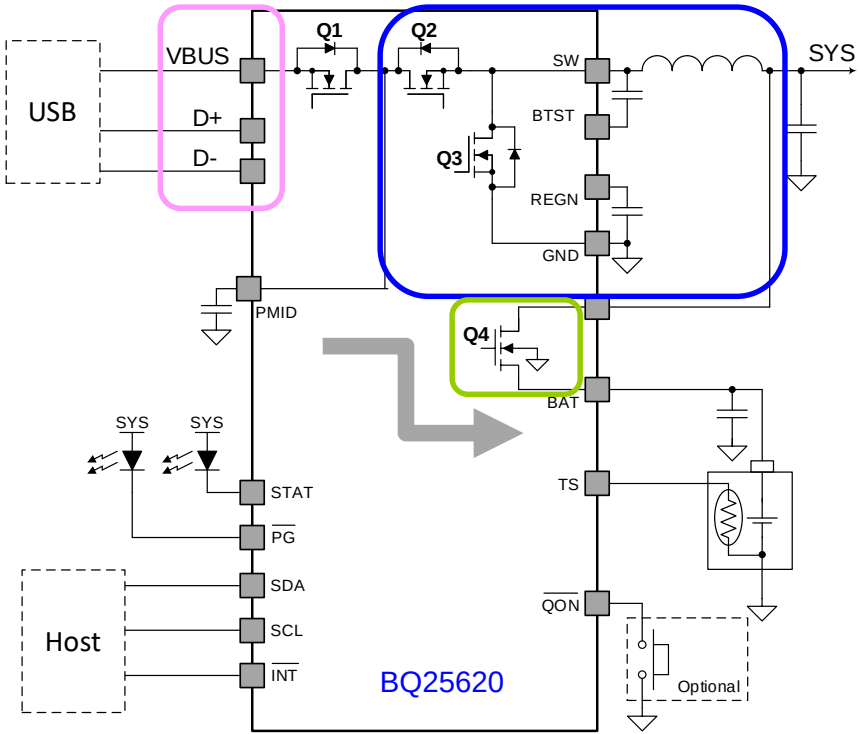
- Battery charger fundamentals
  - DC/DC converter vs. battery chargers
  - The system challenges for multiple sources
  - Battery charger key features
- Applications and TI charger ICs
  - 5V input for 1S and 2S
  - Other inputs for multicell battery
  - Solar panel input for charging
  - How to find the best solutions for your applications
- Summary

5-V input for 1S and 2S charging

- Why 5V is the most popular adapter?
  - USB 5V is the most easy to find and standard source
  - Cost effective than higher voltage adaptor
  - Good for relative low power and small battery
- Examples for 5V input
  - Personal electronics: smartphones, tablets, watches
  - Speaker: high quality class D amplifier – 1S or 2S battery
  - EPOS: thermal printing speed – 2S battery
- Key charging requirements
  - USB detection
  - Small size
  - System monitoring
  - Low Iq

Input	5V USB ports 5V adaptor
Battery	1S
I_{CHG} (A)	
Topology	
IIN DPM VIN DPM	
External FETs	
ADC bit	
Unique features	
Charger	

5V input for 1S charging



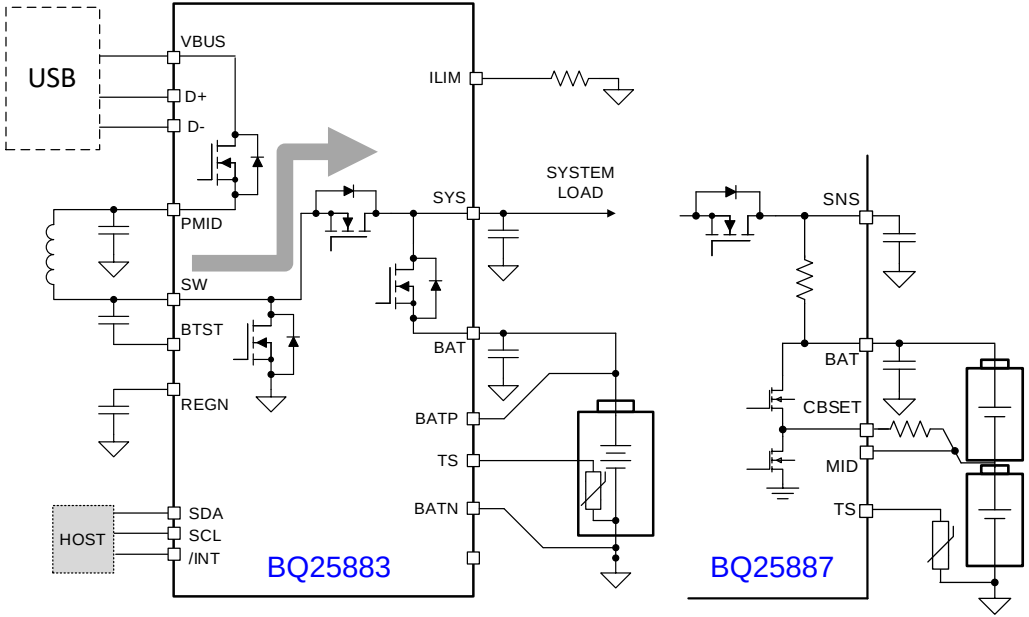
Input	5V USB ports 5V adaptor
Battery	1S
ICHG (A)	3.5
Topology	Buck
IIN DPM VIN DPM	D+D- Yes
External FETs	0 (integrated)
ADC bit	16
Unique features	SHIPMODE Iq=1.5 µA
Charger	BQ25620/2/8/9

5-V input for 2S charging

- Why 5V is the most popular adapter?
  - USB 5V is the most easy to find and standard source
  - Cost effective than higher voltage adaptor
  - Good for relative low power and small battery
- Examples of 2S applications
  - Speaker: high quality class D amplifier –2S battery
  - EPOS: thermal printing speed – 2S battery
- Key charging requirements
  - USB detection
  - Small size
  - System monitoring
  - Balancing

Input	5V USB ports 5V adaptor
Battery	2S
$I_{CHG\ (A)\_MAX}$	
Topology	
IIN DPM VIN DPM	
External FETs	
ADC bit	
Unique features	
Charger	

5-V input for 2S charging



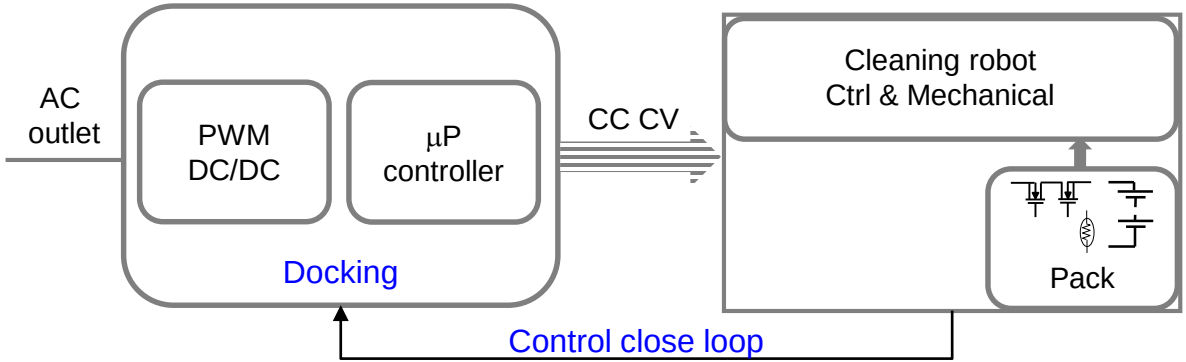
Input	5V USB ports 5V adaptor
Battery	2S
ICHG (A)_MAX	2.0
Topology	Boost
IIN DPM VIN DPM	D+D- or PSEL Yes
External FETs	0
ADC bit	16
Unique features	Cell Balance
Charger	BQ25887/3/6

Other inputs for multiple cell charging

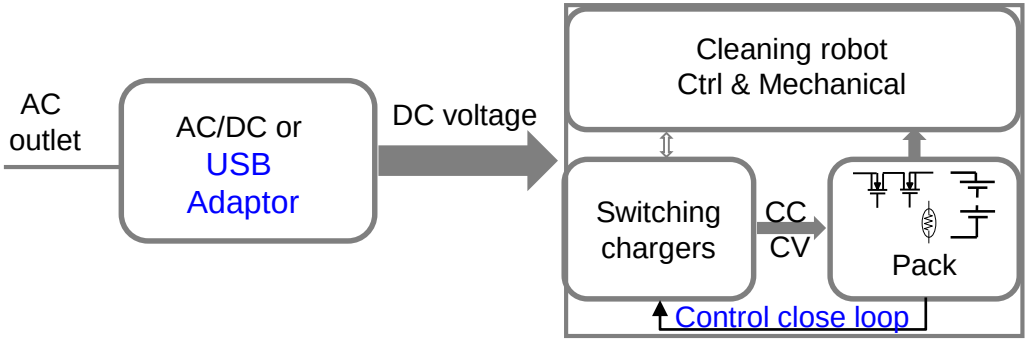
- Other input source – high voltage adaptor and USB
  - Deliver higher power, low cable loss
  - USB is the trend as the standard source
  - Good for relative high power and multi-cell battery
- Examples for high input voltage
  - Cleaning robots
  - Drone
  - Medical equipment
- Key charging requirements
  - Small size
  - Flexibility and low system cost
  - High efficiency / good thermal

Input	USB PD High-V adaptor
Battery	1S-5S
ICHG (A)_MAX	
Topology	
IIN DPM VIN DPM	
External FETs	
ADC bit	
Unique features	
Charger	

Charging solutions power tool and cleaning robots

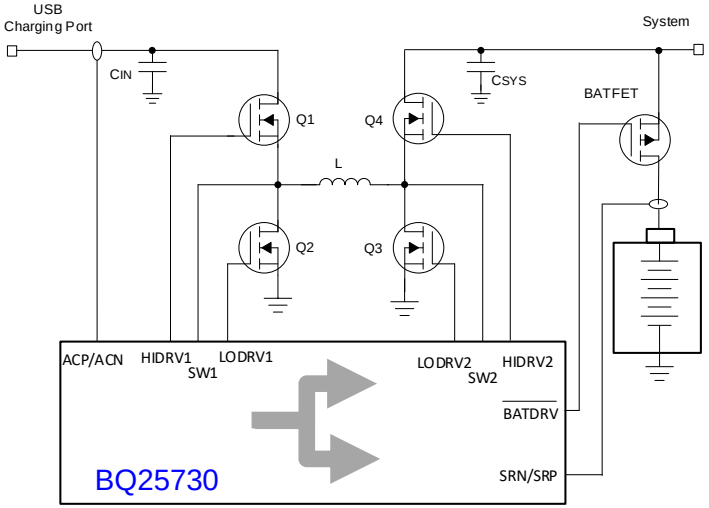


Solution 1:
- Single stage isolated AC-DC converter
- Bulky and relative low cost
- Low efficiency
- Low accuracy

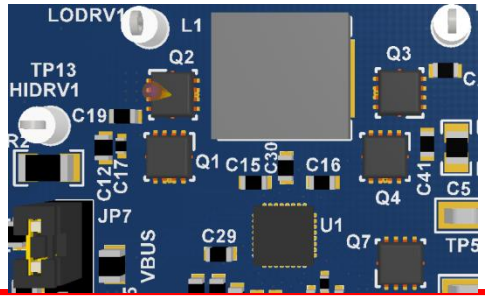


Solution 2:
- USB Type C PD charging
- Compact and light weight
- High efficiency
- Accurate

USB inputs for multiple cell charging



30 mm



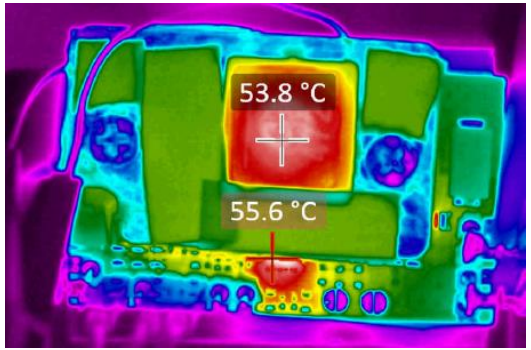
20 mm

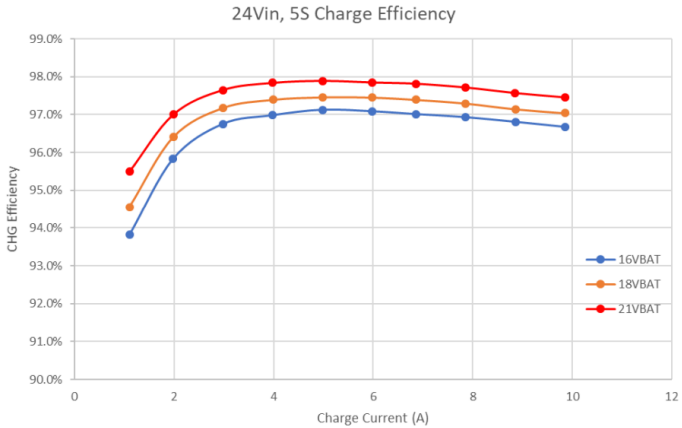
600-mm^2 PCB footprint

Input	USB PD High-V adaptor
Battery	1S-5S
ICHG (A)_MAX	16.2
Topology	Buck-boost
IIN DPM VIN DPM	+ PD Controller Yes
External FETs	5
ADC bit	8
Unique features	EMI reduction
Charger	BQ25730/1

A reference design

24-VIN, 240-W, 98% Efficient, BQ25731 5S Battery Charger with USB On-The-Go



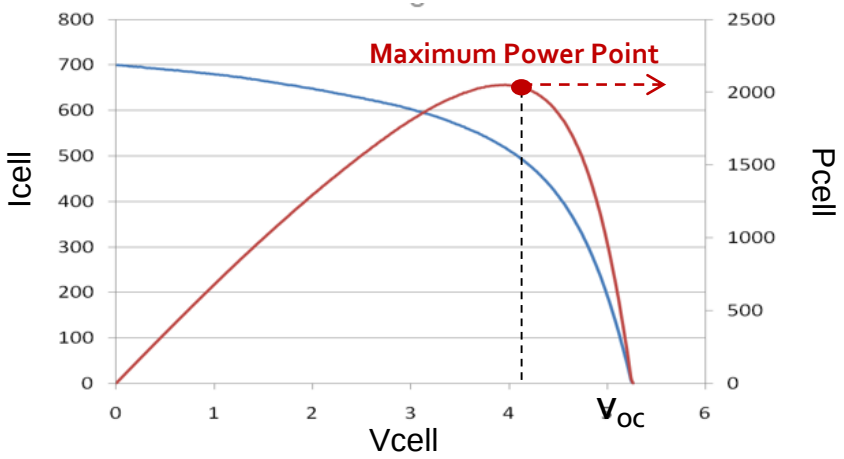


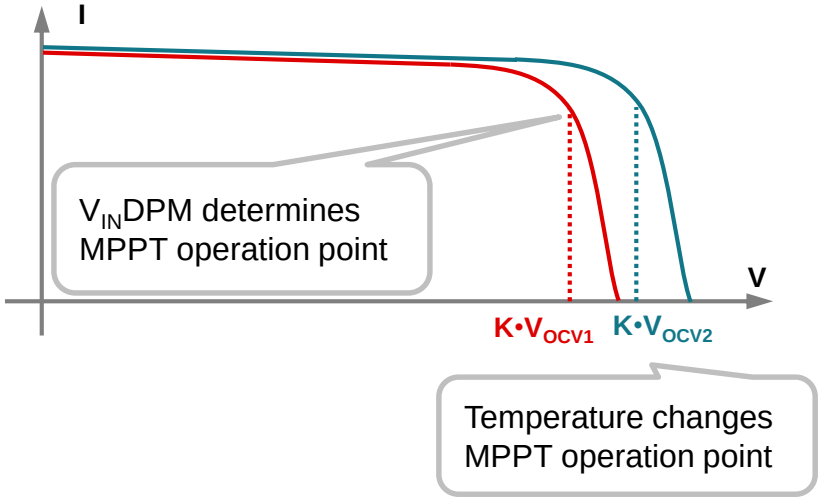
https://www.ti.com/tool/PMP22805

Features:

- High efficiency up to 98% with high power 5 to 24 V_{IN}, 240 W
- Supports 1-5S battery
- Compact size 1.08 in × 1.68 in
- Wide input range USB-Type C PD compliance, USB On-the-Go (OTG) power bank

Solar panel as the source - maximum power point





Autonomous MPPT implementation

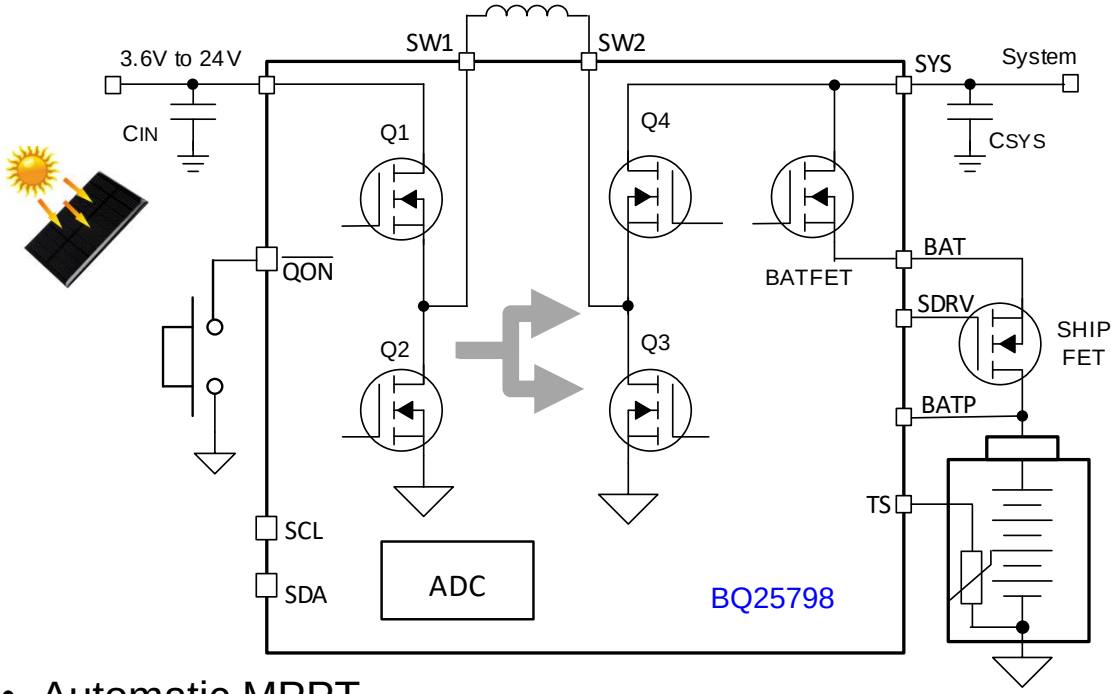
- Periodic measurement of OCV
- K factor determined
- **K** • **V_{OCV}** (V_{IN}DPM) determines the MPPT

Solar panel for charging

- Why solar panel?
  - No power grid
  - Green power and sustaining
  - Different power range
- Examples for solar panel applications
  - Remote sensing – 1S – 2S battery
  - Lawn mower – 4S and above
- Key charging requirements
  - Maximum power point
  - Small size
  - System monitoring
  - Low quiescent current

Input	Solar panel
Battery	1S-4S
I_{CHG} (A)_MAX	
Topology	
IIN DPM VIN DPM	
External FETs	
ADC bit	
Unique features	
Charger	

Solar Charging Features



- Automatic MPPT
  - Measures the open circuit voltage (VOC)
  - Charger VINDPM will be set to a programmable ratio of VOC with the K factor

Input	Solar panel
Battery	1S-4S
I_{CHG} (A)_MAX	5.0
Topology	Buck-boost
IIN DPM VIN DPM	+ PD controller Yes
External FETs	0 or 1 (SHIP)
ADC bit	16
Unique features	K•Voc for MPPT SHIP Iq= 11µA
Charger	BQ25798

Different combinations of the input and battery

Input	5V USB ports 5V adaptor	5V USB ports 5V adaptor	USB PD High-V adaptor	Solar panel
Battery	1S	2S	1S-5S	1S-4S
I_{CHG} (A)_MAX	3.5	2.0	16.2	5.0
Topology	Buck	Boost	Buck-boost	Buck-boost
IIN DPM VIN DPM	D+D- Yes	D+D- or PSEL Yes	+ PD Controller Yes	+ PD controller Yes
External FETs	0	0	5	0 or 1 (SHIP)
ADC bit	16	16	8	16
Unique features	SHIPMODE Iq=1.5uA	Cell Balance	EMI reduction	K•Voc for MPPT SHIP Iq=11µA
Charger	BQ25620/2/8/9	BQ25887/3/6	BQ25730/1	BQ25798/2

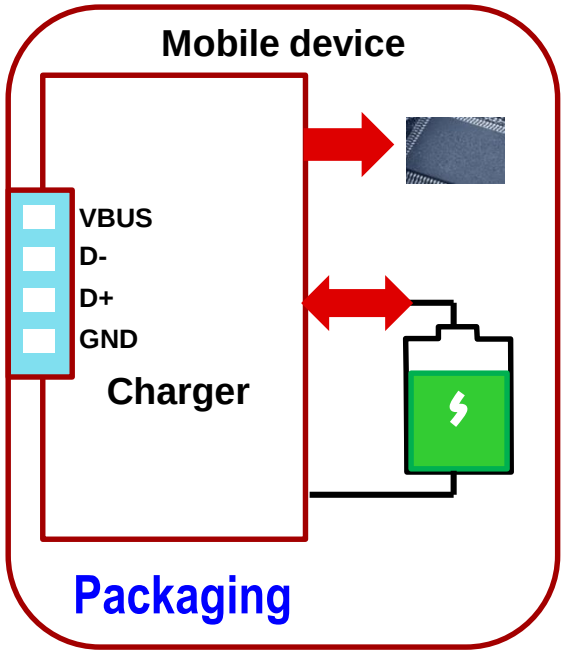
Finding the requirements

Input source

Adaptor or USB
Input current / Voltage

Control interface

Standalone
I2C
SMBus



System

Min Voltage
Current

Battery

Voltage, Charge Current
Chemistry Configuration
Capacity

Temperature profile

JEITA
COLD/HOT

Safety and Protection

Overvoltage/Overcurrent/
Over-temperature, etc

Summary

- Battery charger fundamentals
  - DC/DC converter with multiple loops including CC and CV
  - Challenges due to multiple sources and the solutions
  - DPM (input current or voltage) for the best utilization of the adaptor capacity
- How to select a charger for different input sources and battery configurations
  - Key parameters to identify
  - Unique features improving the system design and customer experience
- The comparisons of application cases

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