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Battery charger Introduction

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2017 4Q

Your Integral Component to Success

Agenda

- Battery charger
- Battery charger Key parameter
- TI battery charger solution
- eFuse
- eFuse solution



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Battery charger

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Switching Charger Solutions

Switching chargers with integrated FETs and high efficiency for handheld single-cell applications:

- Faster, Cooler
- Smarter and Safer
- High efficiency
- Excellent Thermal Performance



Multi-Cell and Linear Charger

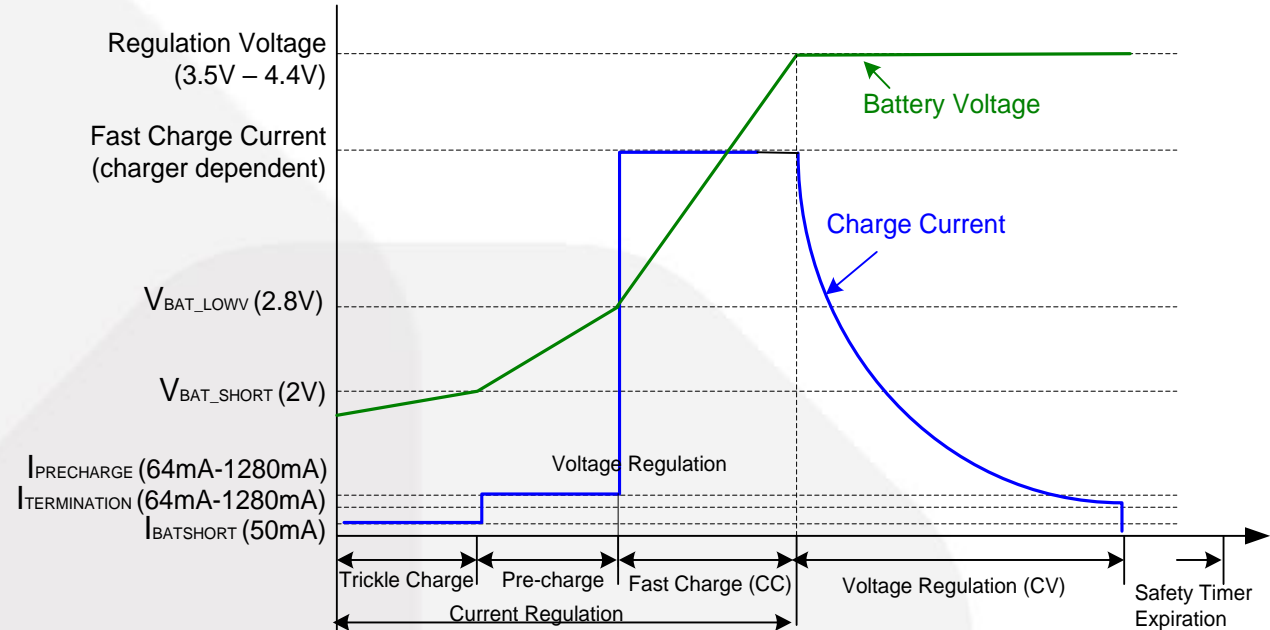
Linear and switching chargers for diversified applications, providing high performance and low-cost solutions:

- Flexibility
- Small and highly integrated
- Low power and high power
- Industrial and Automotive ready



What does a charger do?

- Charge battery from adaptor: pre-charge, CC / CV charge and termination
- Safety of charging: temperature profile, timer (precharge and fast-charging)
- Indicator of charging: charging state or fault
- Advanced Features: USB detection; power path; DPM; turbo boost; supplement mode



(1S Li-Ion battery example)

Which charger do I need for my application?

Linear charger

Low charge current < 1.0 or 1.5A

Thermal performance depends on $V_{OUT} - V_{IN}$ and PCB layout / copper area

No EMI concern

Simple

Lower cost

Switching charger

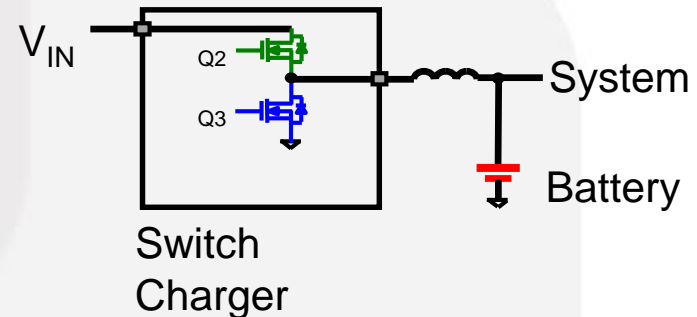
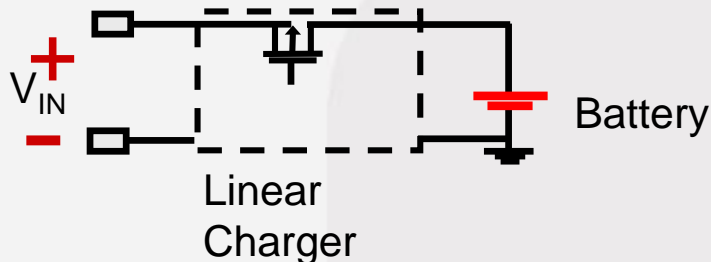
Higher charge current > 1.5A

Good thermal performance across wider $V_{OUT} - V_{IN}$ range

Proper layout needed for best EMI performance

High efficiency

Higher cost





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Battery charger Key parameter

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Key Charger Parameters to Consider

Inputs:

- Min/Max Voltage
- Current



Control Interface

- Standalone
- I2C
- SMBus



Architecture

- Traditional
- NVDC
- Turbo Boost

Solution

- Controller
- Integrated FET

Charging

- Voltage
- Current

Battery

- Chemistry
- Configuration (?S?P)
- Capacity

Temperature Profile

- Standard Cold/Hot
- JEITA

Safety and Protection

- OVP (Input, BAT and OTG)
- OCP/UCP...
- Thermal Regulation

System:

- Min Voltage
- Current

Key Information on Page 1



bq24170
bq24172

Device Name

www.ti.com

SLUSAD2B – NOVEMBER 2010 – REVISED APRIL 2011

1.6-MHz Synchronous Switch-Mode Li-Ion and Li-Polymer Stand-Alone Battery Charger with Integrated MOSFETs and Power Path Selector

Check for Samples: bq24170, bq24172

Charging

Inputs

Series Cells

Integration

Safety

Packaging

FEATURES

- 1.6MHz Synchronous Switch-Mode Charger with 4A Integrated N-MOSFETs
- Up to 94% Efficiency
- 30V Input Rating with Adjustable Over-Voltage Protection
 - 4.5V to 17V Input Operating Voltage Range
- Battery Charge Voltage
 - bq24170: 1, 2, or 3-Cell with 4.2V/Cell
 - bq24172: Adjustable Charge Voltage
- High Integration
 - Automatic Power Path Selector Between Adapter and Battery
 - Dynamic Power Management
 - Integrated 20-V Switching MOSFETs
 - Integrated Bootstrap Diode
 - Internal Loop Compensation
 - Internal Digital Soft Start
- Safety
 - Thermal Regulation Loop Throttles Back Current to Limit $T_j = 120^{\circ}\text{C}$
 - Thermal Shutdown
 - Battery Thermistor Sense Hot/Cold Charge Suspend & Battery Detect
 - Input Over-Voltage Protection with Programmable Threshold
 - Cycle-by-Cycle Current Limit
- Accuracy
 - $\pm 0.5\%$ Charge Voltage Regulation
 - $\pm 4\%$ Charge Current Regulation
 - $\pm 4\%$ Input Current Regulation
- Less than 15 μA Battery Current with Adapter Removed
- Less than 1.5mA Input Current with Adapter Present and Charge Disabled
- Small QFN Package
 - 3.5mm \times 5.5mm QFN-24 Pin

APPLICATIONS

- Tablet PC
- Netbook and Ultra-Mobile Computers
- Portable Data Capture Terminals
- Portable Printers
- Medical Diagnostics Equipment
- Battery Bay Chargers
- Battery Back-Up Systems

DESCRIPTION

The bq24170/172 is highly integrated stand-alone Li-ion and Li-polymer switch-mode battery charger with two integrated N-channel power MOSFETs. It offers a constant-frequency synchronous PWM controller with high accuracy regulation of input current, charge current, and voltage. It closely monitors the battery pack temperature to allow charge only in a preset temperature window. It also provides battery detection, pre-conditioning, charge termination, and charge status monitoring. The thermal regulation loop reduces charge current to maintain the junction temperature of 120°C during operation.

The bq24170/172 charges the battery in three phases: preconditioning, constant current, and constant voltage. The bq24170 charges one, two, or three cells (selected by CELL pin), and the bq24172 is adjustable for up to three series Li+ cells.

Charge is terminated when the current reaches 10% of the fast charge rate. A programmable charge timer offers a safety back up. The bq24170/172 automatically restarts the charge cycle if the battery voltage falls below an internal threshold, and enters a low-quiescent current sleep mode when the input voltage falls below the battery voltage.

The bq24170/172 features Dynamic Power Management (DPM) to reduce the charge current when the input power limit is reached to avoid over-loading the adapter. A highly-accurate current-sense amplifier enables precise measurement of input current from adapter to monitor overall system power.

Application Targets

Descriptions

- Recommended vs. Absolute Maximum Rating

RECOMMENDED OPERATING CONDITIONS

	PARAMETER	MIN	MAX	UNIT
V_{IN}	Input Voltage	3.9V	17V ⁽¹⁾	V

(1) The inherent switching noise voltage spikes should not exceed the absolute maximum rating on either the BTST or SW pins. A tight layout minimizes switching noise.

ABSOLUTE MAXIMUM RATINGS

Parameter	Pin Name	VALUE
Voltage Range (with respect to GND)	VBUS	-2V – 20V

} bq2419x

RECOMMENDED OPERATING CONDITIONS

	PARAMETER	MIN	MAX	UNIT
V_{IN}	Input Voltage	3.9V	6.2V ⁽¹⁾	V

ABSOLUTE MAXIMUM RATINGS

Parameter	Pin Name	VALUE
Voltage Range (with respect to GND)	VBUS (converter not switching)	-2V – 15V ⁽²⁾

} bq2429x

(2) VBUS is specified up to 16V for a maximum of 24 hours under no load conditions..

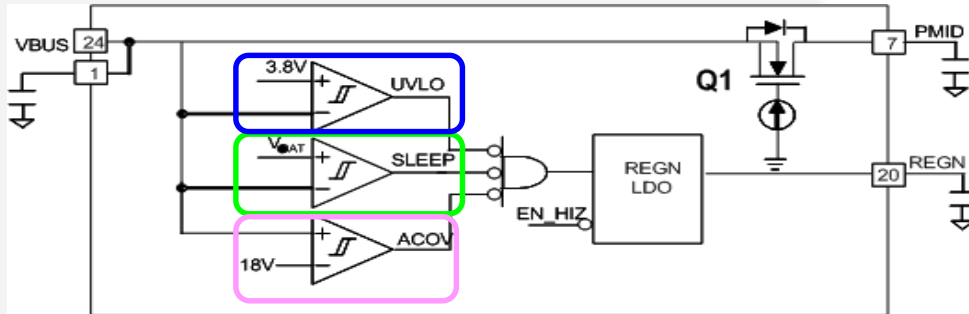
ELECTRICAL CHARACTERISTICS

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{ACOV}	VBUS over-voltage rising threshold	V_{VBUS} Rising	6.2V		6.7V	V

- The no-operation maximum voltage is much higher for bq24295
- Prevents damage from accidental plug-in of 12V adaptor.

Adaptor Plug in and Sleep Mode

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
VBUS/BAT Power Up						
V_{VBUS_UVLO}	VBUS for active I2C, no battery	V_{VBUS} rising	3.6	3.8		V
V_{SLEEP}	Sleep Mode falling threshold	V_{VBUS} falling, $V_{VBUS} - V_{BAT}$	35	80	120	mV
V_{SLEEPZ}	Sleep Mode exit rising threshold	V_{VBUS} rising, $V_{VBUS} - V_{BAT}$	170	250	300	mV
V_{ACOV}	VBUS over-voltage rising threshold	V_{VBUS} rising	17.4	18		V
V_{ACOV_HYST}	VBUS over-voltage falling hysteresis	V_{VBUS} falling		700		mV



- Adaptor Plug in
 - Input source qualification
 - Keep Sleep Mode or Exit
- Exit Sleep Mode
 - REGN is powered up
 - Q1 will be fully ON

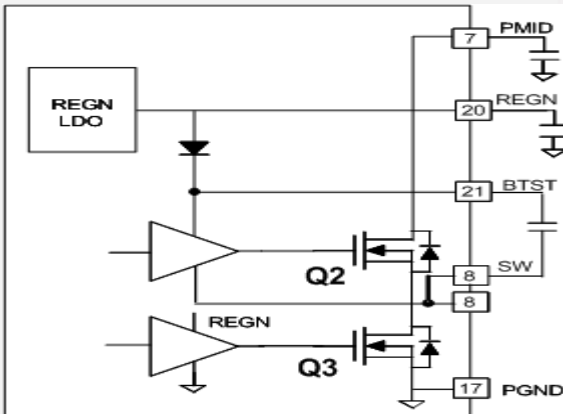
	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
QUIESCENT CURRENTS						
I_{BAT}	Battery discharging current	High-Z mode, or no VBUS, Q4 on		32	55	μ A
I_{VBUS}	Input supply current	$V_{VBUS} > V_{UVLO}$; $V_{VBUS} > V_{BAT}$; Converter not switching		1.5	3	mA

REGN Voltage and Function

- REGN Specifications

- Could be in LDO mode or drop-out mode. For VBUS above 6V, connect 1- μ F ceramic capacitor. For VBUS below 6V, connect a 4.7- μ F ceramic capacitor. This is due to the low PSRR when the LDO is drop-out mode.
- Voltage rating at drop-out or regulation mode is specified
- The current capability is specified

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
REGN LDO						
V_{REGN}	REGN LDO output voltage	$V_{VBUS} = 10V, I_{REGN} = 40mA$	5.6	6	6.4	V
		$V_{VBUS} = 5V, I_{REGN} = 20mA$	4.75	4.8	4.85	V
V_{REGN}	REGN LDO current limit	$V_{VBUS} = 10V, V_{REGN} = 3.8V$	50			mA

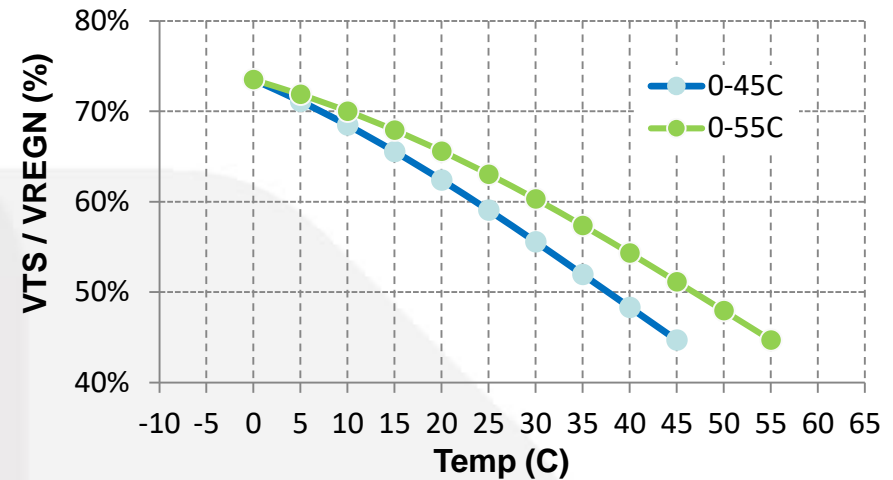
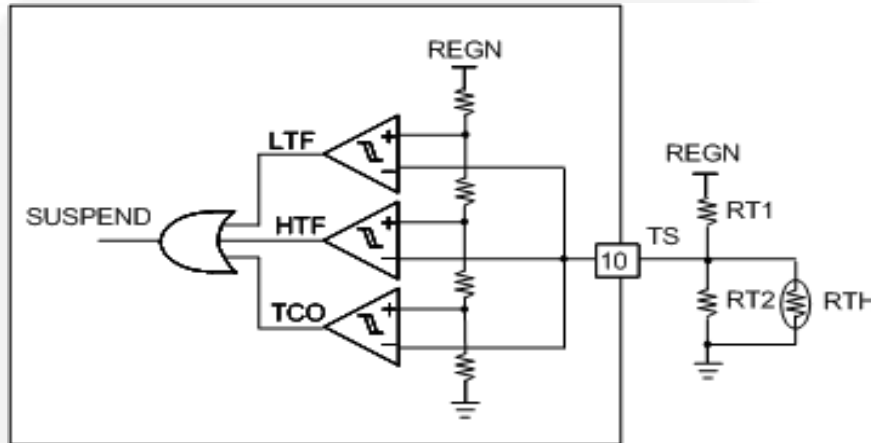


- REGN functions:

- driver voltage of Buck regulator Top and Bottom Fet
- bias voltage for thermistor network

Thermistor

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
COLD/HOT THERMISTOR COMPARATOR						
V_{LTF}	Cold temp threshold, TS pin Vrising	As percentage to VREGN	73	73.5	74	%
V_{TCO}	Cutoff temp threshold, TS pin Vfalling	As percentage to VREGN	44.2	44.7	45.2	%
V_{HTF}	Hot temp threshold, Ts pin Vfalling	As percentage to VREGN	46.6	47.2	48.8	%

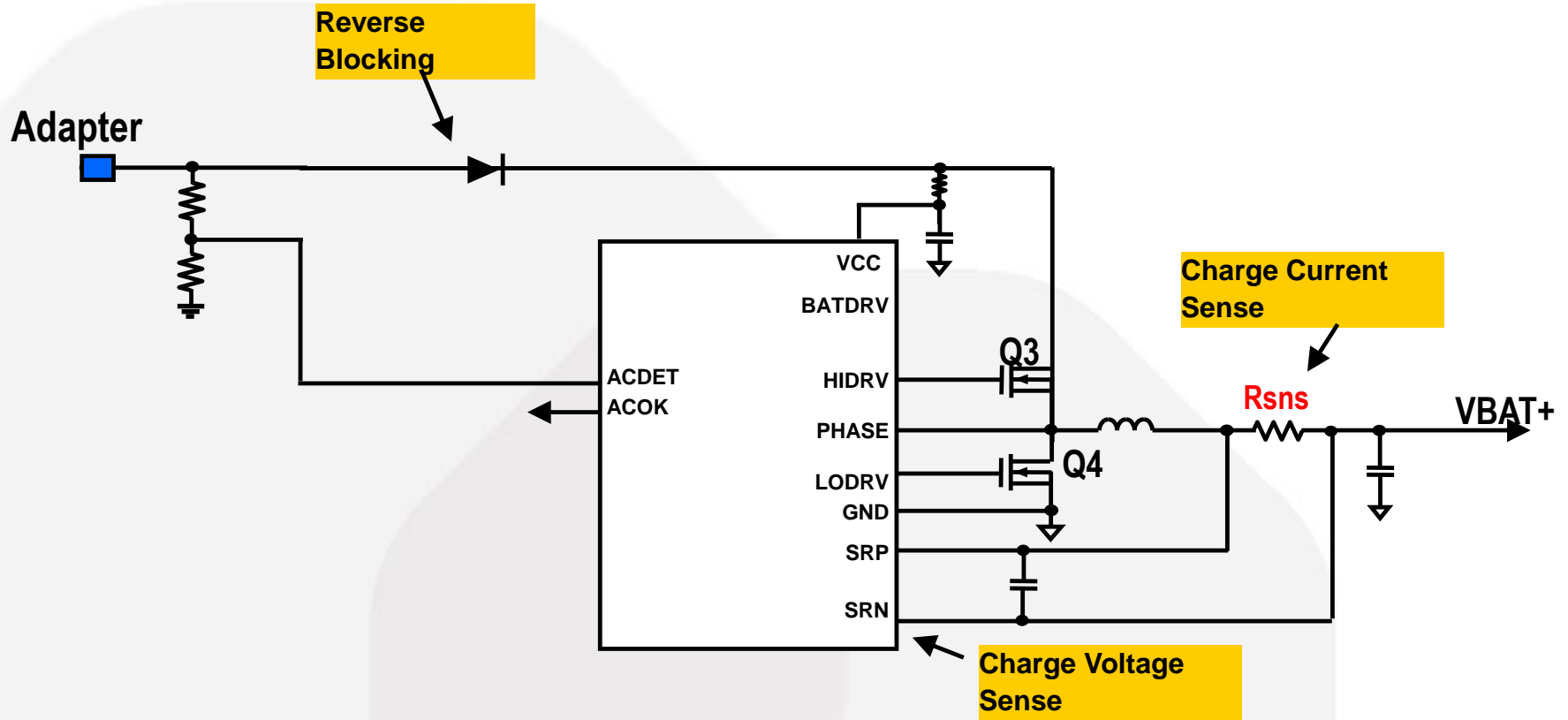


- REGN also provides bias to thermistor network
 - Both internal network and external network are biased with REGN
 - The REGN value does not affect temperature sensing accuracy
 - The temperature range can be modified based on the requirements

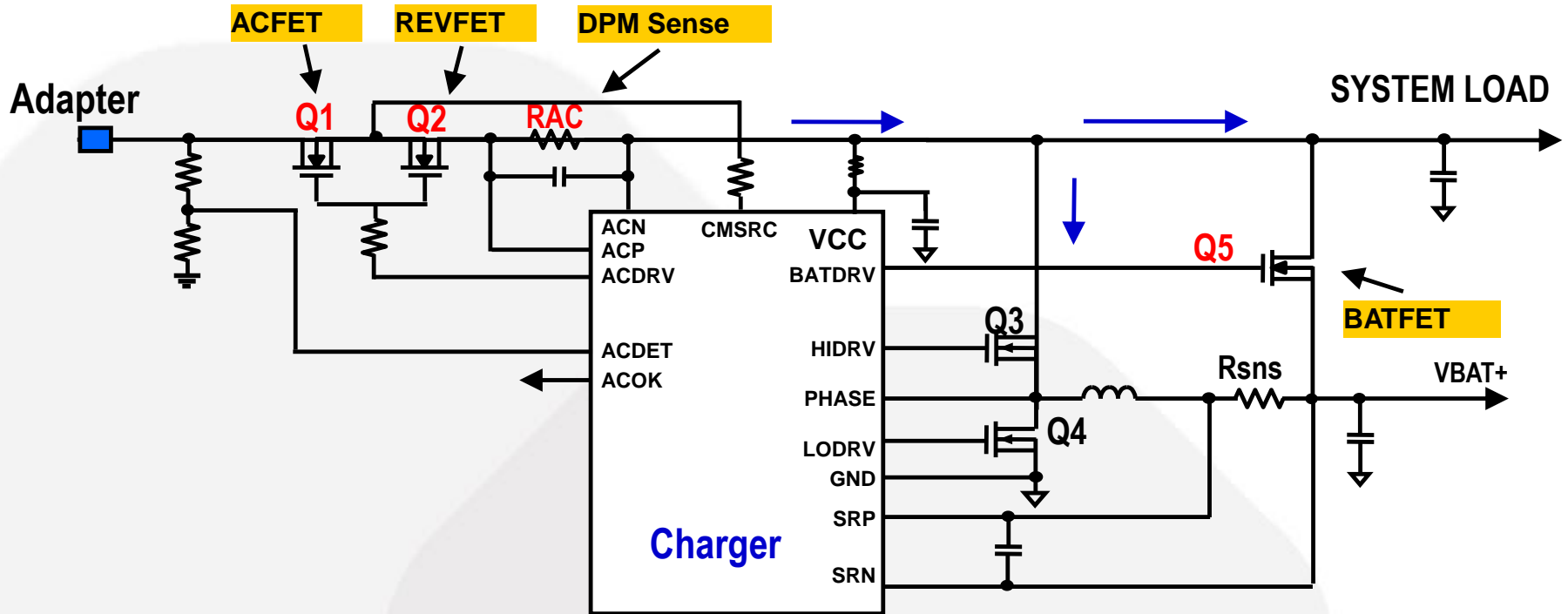
Traditional vs NVDC power path

- **“Power Path” architecture is a critical feature for any applications that require simultaneous system operation and battery charging**
- **Simple applications can reduce cost by using non-power-path chargers if the battery is charged only when the system is turned off**
- **Traditional power path has been used for many years (1990s and before)**
- **Most of our recent chargers support “NVDC” power path architecture**

A Simple Charger without Power Path

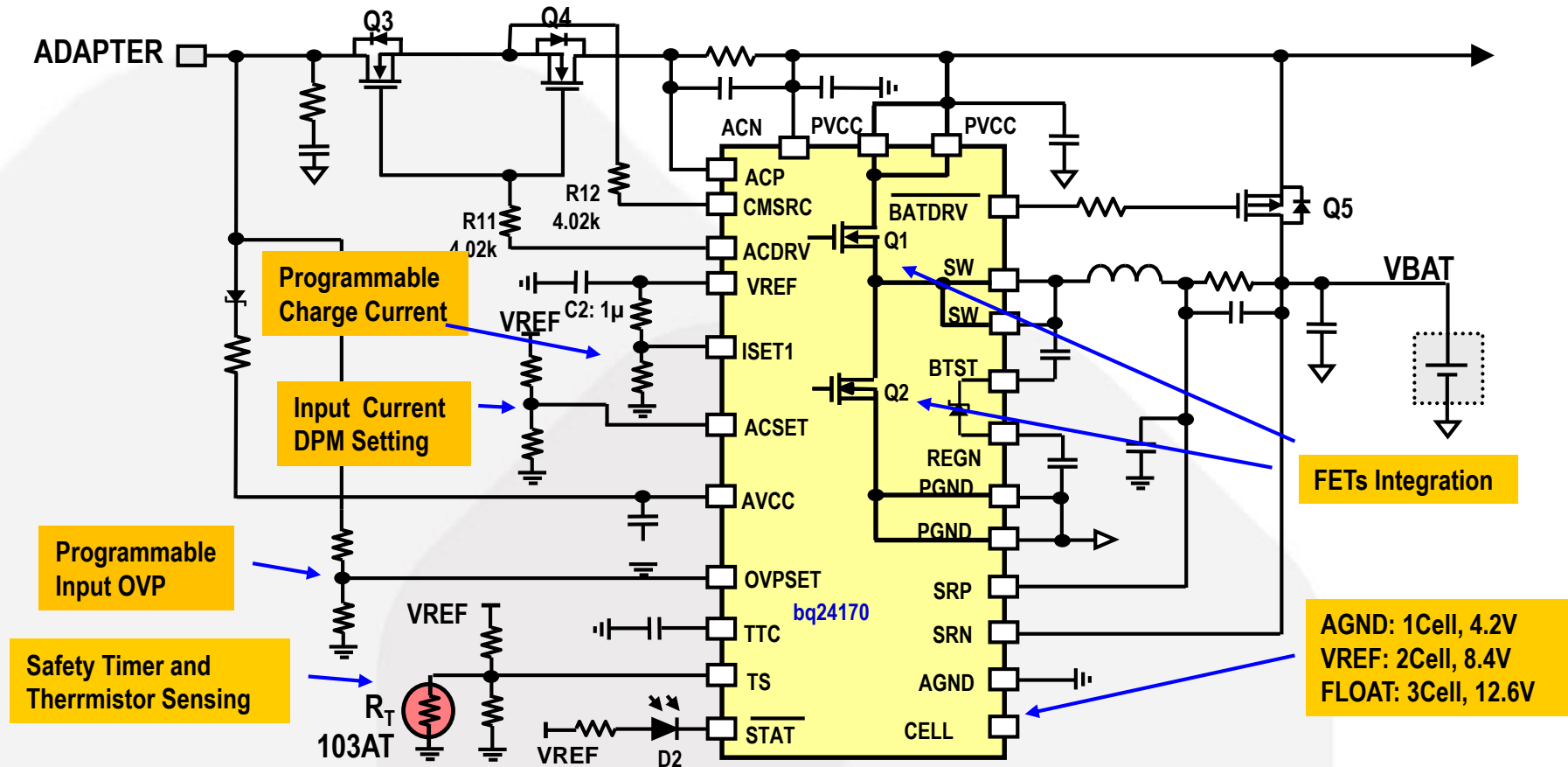


Typical Charger with Power Path



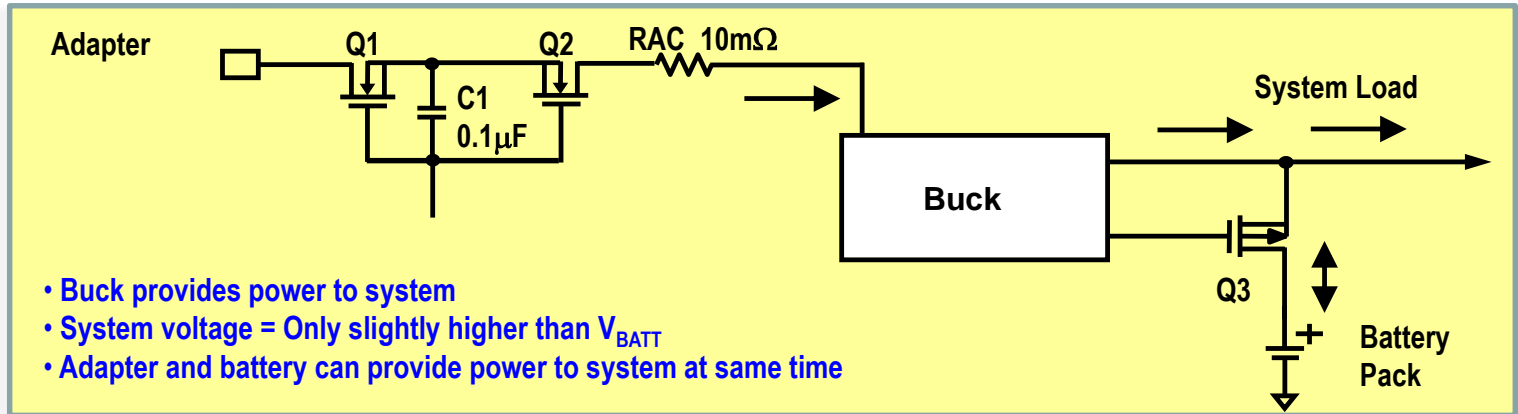
System Voltage ranges from V_{BATT_MIN} to $V_{ADAPTER_MAX}$
Input current DPM is usually required for system with power path

Power Path Charger Application Example

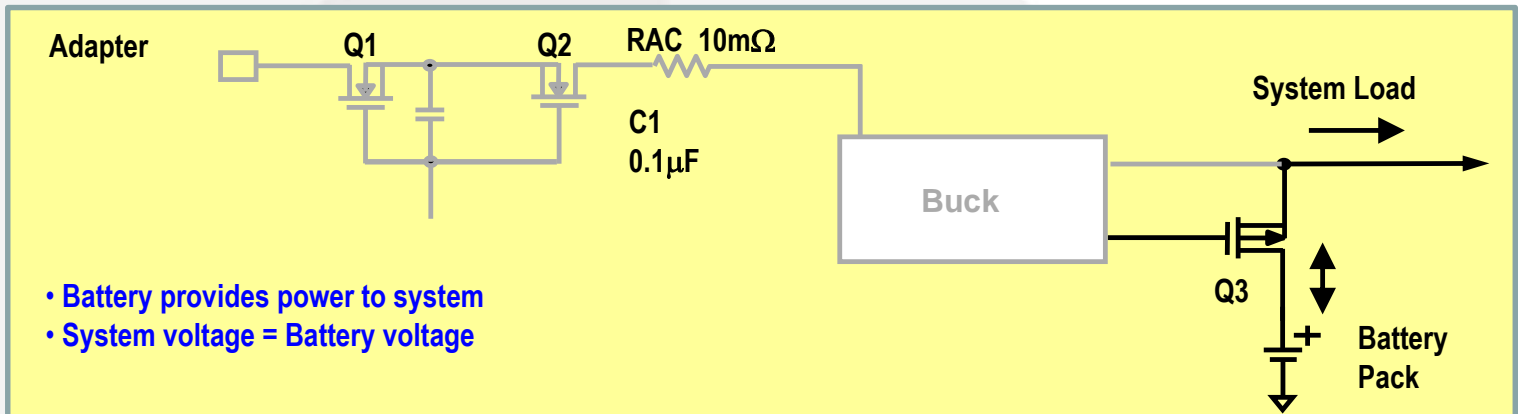


NVDC Charger Topology

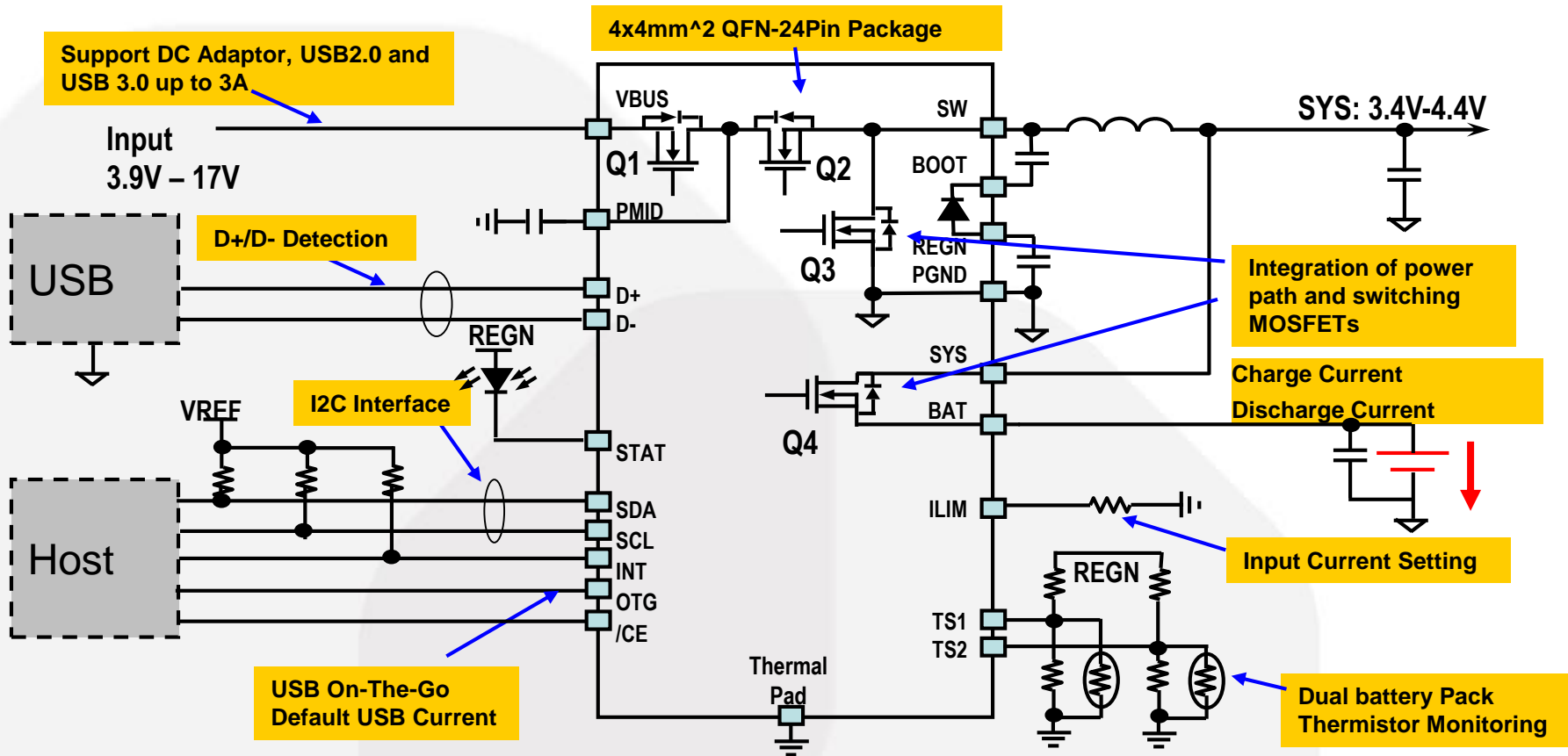
Adapter Mode



Battery Mode

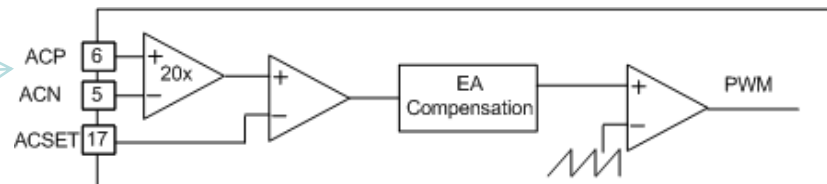


Integrated NVDC Charger Application



Input Current Dynamic Power Management

- External current sensing



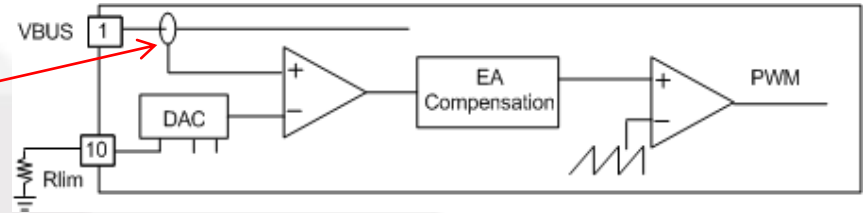
	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
INPUT CURRENT REGULATION						
K_{DMP}	Input DPM current set factor	$R_{sense} = 10\text{mohm}$		5		A/V
	Accuracy	$V_{ACP} - V_{ACN} = 2.5\text{mV}$	-40		40	%
		$V_{ACP} - V_{ACN} = 80\text{mV}$	-4		4	%

- Input current DPM prevents the adaptor with known current capability from hitting the “brown-out” condition
- The input current limit accuracy is lower at low current than at high current
 - One of the source of the low accuracy is the offset.

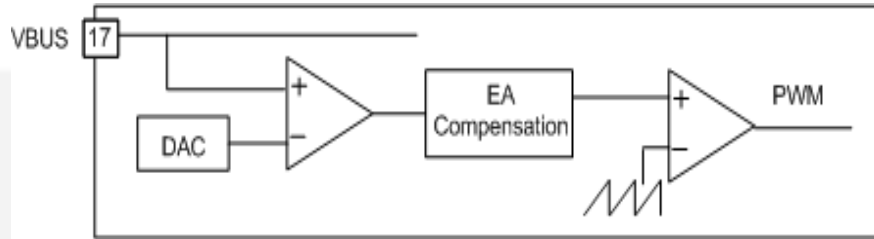
I (mA)	R (mΩ)	Voltage (mV)	Offset (mV)	Measured	Error
256	10	2.56	0.5	2.06	20%

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
INPUT CURRENT REGULATION						
K_{DILIM}	K_{DILIM}	$I_{IN}=K_{ILIM} / R_{ILIM}$	440	485	530	$A \times \Omega$
I_{ADP_DPM}	Input current regulation accuracy	Input current regulation accuracy	1.4	1.5	1.6	A

Integrated current sensing



- Host controlled (I2C programmable) charger may also have hardware-setting (R_{ILIM})
 - Register has the flexibility to set the input current
 - The external ILIM pin serves as the hardware limit for the input current
 - The actual input current limit is the lower of the pin setting and the register setting



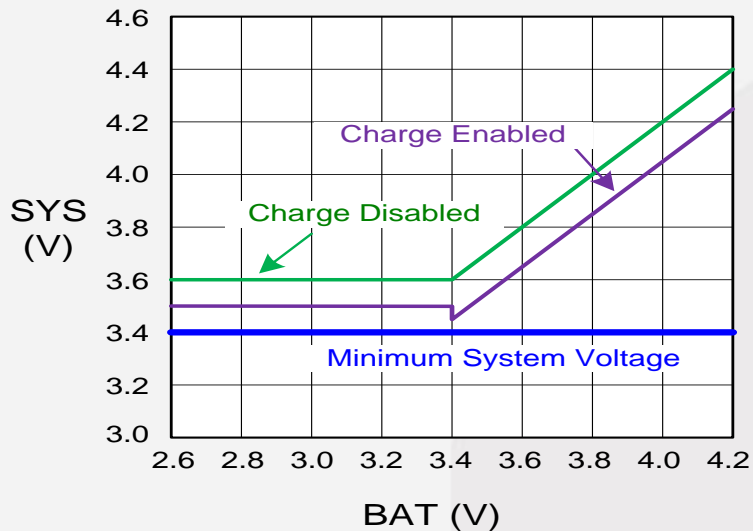
Input Source Control Register REG00

BIT		Description	
Input Voltage Limit			
Bit 6	VINDPM[3]	640mV	Offset 3.88V, Range: 3.88V-5.08V Default: 4.36V (0110)
Bit 5	VINDPM[2]	320mV	
Bit 4	VINDPM[1]	160mV	
Bit 3	VINDPM[0]	80mV	

- Input voltage DPM prevents the adaptor with unknown current capability from hitting the “brown-out” condition.
- Input Voltage DPM provides the flexibility to use the third party adaptor with unknown current capability
 - Better resolution compared to input current DPM
 - Input voltage min limit can go from 3.88V to 5.08V in ~ 80mV steps

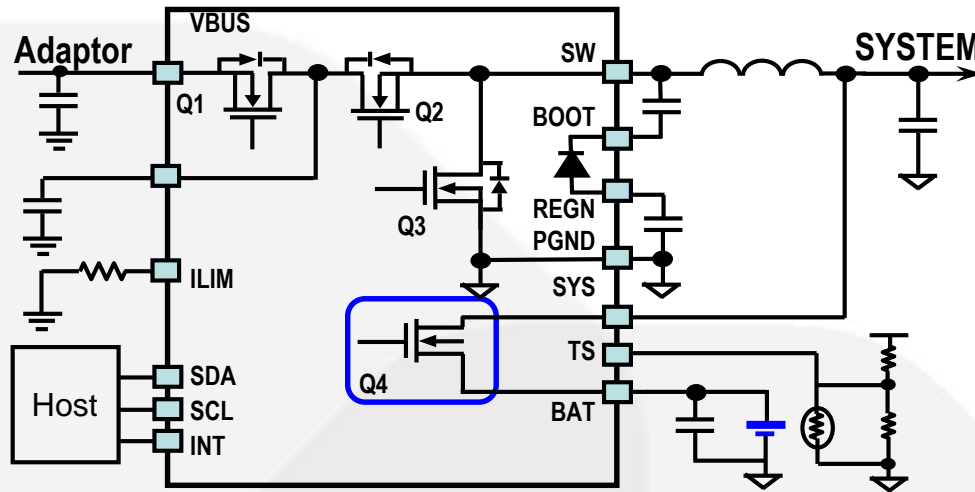
System voltage

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Power Path Management						
V_{SYS_RANGE}	Typical System Regulation Voltage	$I_{sys}=0A$, Q4 off, V_{BAT} up to 4.2V, REG01[3:1]=101, $V_{SYSMIN}=3.5V$	3.5		4.35	V
V_{SYS_MIN}	System Voltage Output	REG01[3:1]=101, $V_{SYSMIN}=3.5V$	3.55	3.65		V



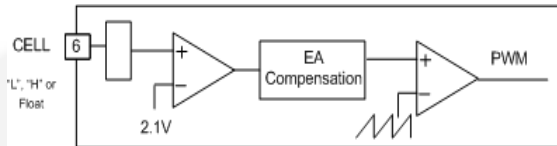
- Minimum system voltage:
 - Allows the “instant ON” for system with deeply discharged battery
- The minimum system voltage is 150mV higher than register setting when charge disabled to maintain load regulation during transients

Precharge and Thermal Regulation

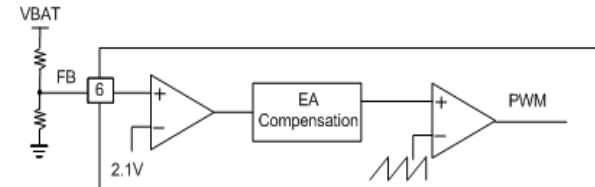


- When the battery voltage is lower than the V_{sys_min} , the battery Fet Q4 is in linear mode. The voltage $V_{sys_min} - V_{bat}$ drops on Q4
- To limit the power dissipation on Q4 during the linear charging mode, while still maintain high precharge current, the thermal regulation loop can be utilized

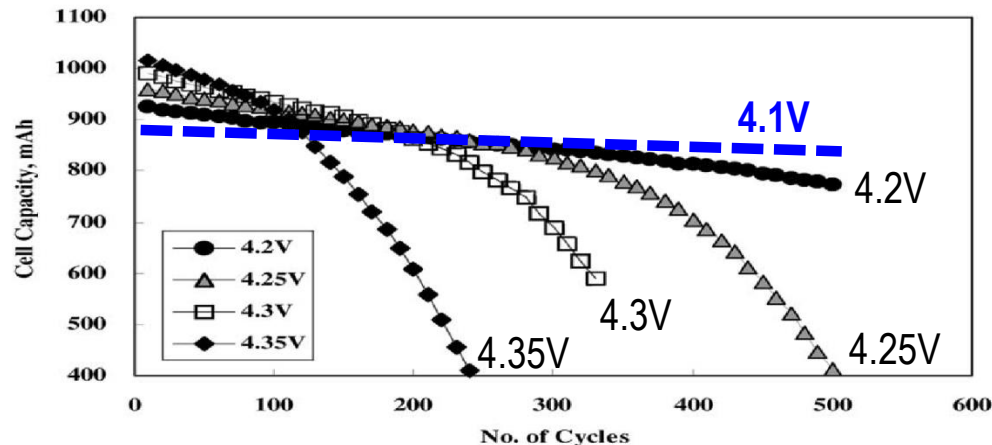
Charging Voltage



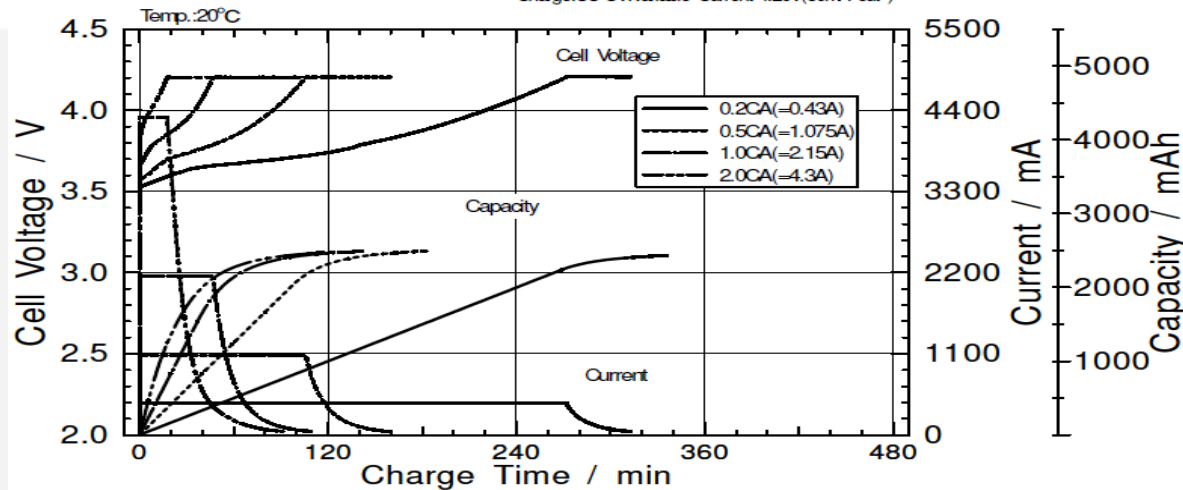
Standalone Fixed 4.2V/cell



Standalone adjustable

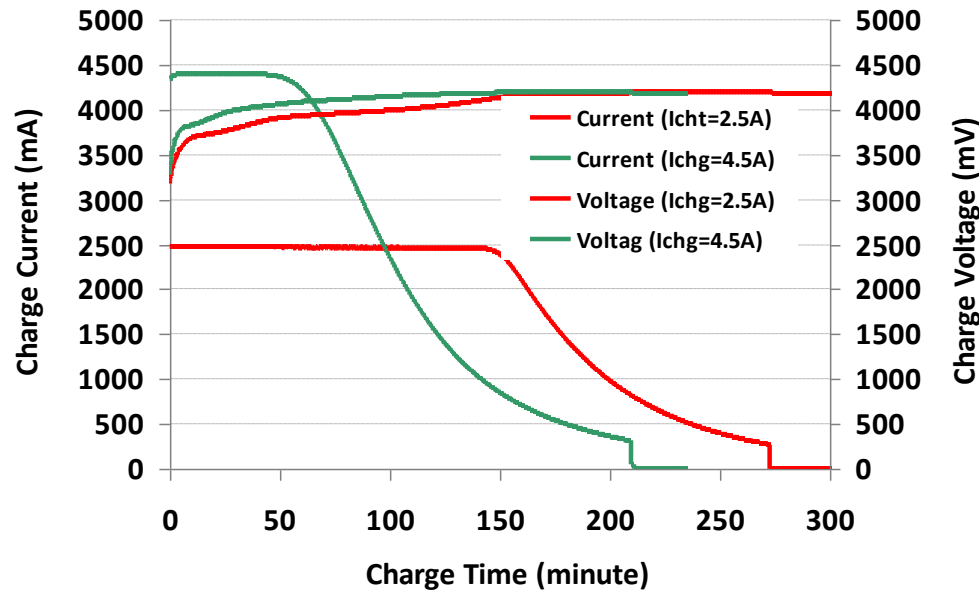


- Charging voltage
 - Fixed vs. Adjustable
 - Backup applications typically charge the battery to 4.1V, expecting longer battery service life
 - The regulation accuracy matters!



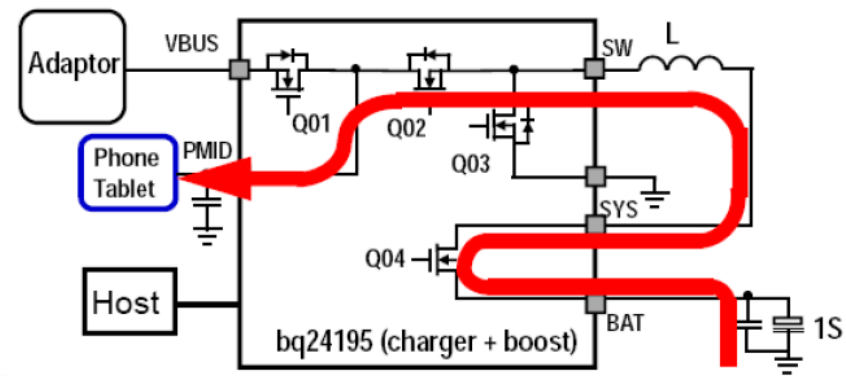
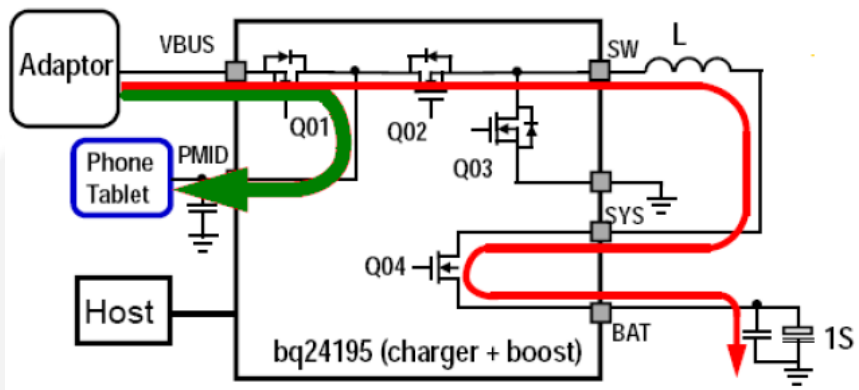
- Charging Current
 - The normal charge rate is 0.2C to 1C; Large current reduces the CC area
 - When the charging rate is above 1C, there is no big difference for total charging time to 100%
 - Manufacturer specified “charge current must be below xC”

Charging Current



- Charging Current is a trade off of battery capacity and charging time
- “Time to full” is not always a linear function of charge rate

Boost OTG operation



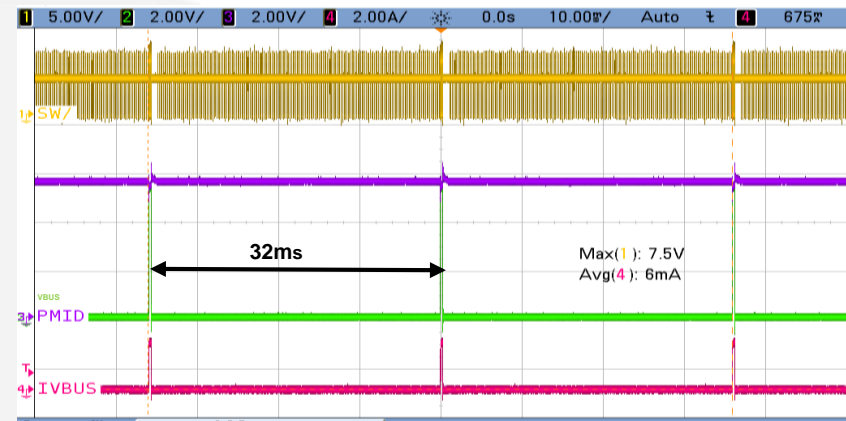
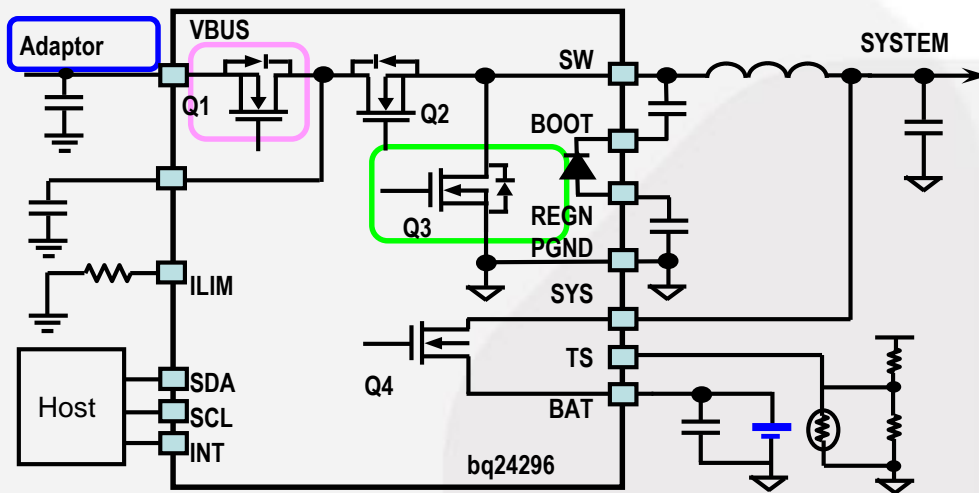
- Adaptor in, Charging and Bypass mode

- Boost OTG(on-to-go) Mode

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNITS
Boost Mode Operation						
V_{OTG_REG}	Boost mode output voltage	$I(PMID) = 0$		5.12		V
$V_{OTG_REG_ACC}$	Boost mode output voltage accuracy	$I(PMID) = 0$	-2%		2%	
I_{OTG}	Boost mode output current on PMID		2.1			mA
V_{OTG_BAT}	Battery operating voltage for boost mode		3.2			ms
V_{OTG_ILIM}	LSFET cycle-by-cycle current limit			6.5		us

Protection – Boost OTG

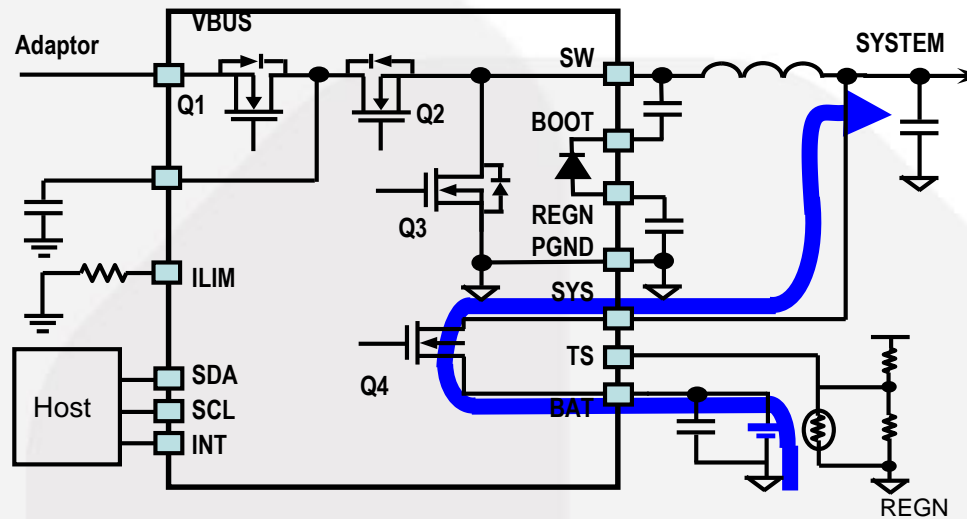
	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
BATTERY Mode Operation						
V_{OTG_OVP}	OTG over voltage threshold		5.8	6		V
V_{OTG_LSOCP}	LSFET cycle-by-cycle current limit		5.0			A
I_{RBFET_OCP}	RBFET over-current threshold	OTG=1.0A	1.0	1.15	1.3	A
$t_{OTG_OCP_OFF}$	OTG over current Off cycle time	OTG=1.0A		32		ms
$t_{OTG_OCP_ON}$	OTG over current on cycle time	OTG=1.0A		260		us



Protection – Battery Safety

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
BATTERY OVERVOLTAGE PROTECTION						
$V_{BATOV P}$	Battery over-voltage threshold		5.5	6.6		A
$V_{BATOV P \text{ HYST}}$	Battery over-voltage threshold	V_{BAT} rising, as percentage of V_{BAT_REG}		2		%
$t_{BATOV P}$	Battery over-voltage deglitch time			1		us

	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
SYSTEM OVER-CURRENT COMPARATOR						
$I_{BATFETOV P}$	System over load threshold		9			A



- BATOVP results in charge disable, INT and fault register bit set
- Q4 protects system overload or short conditions



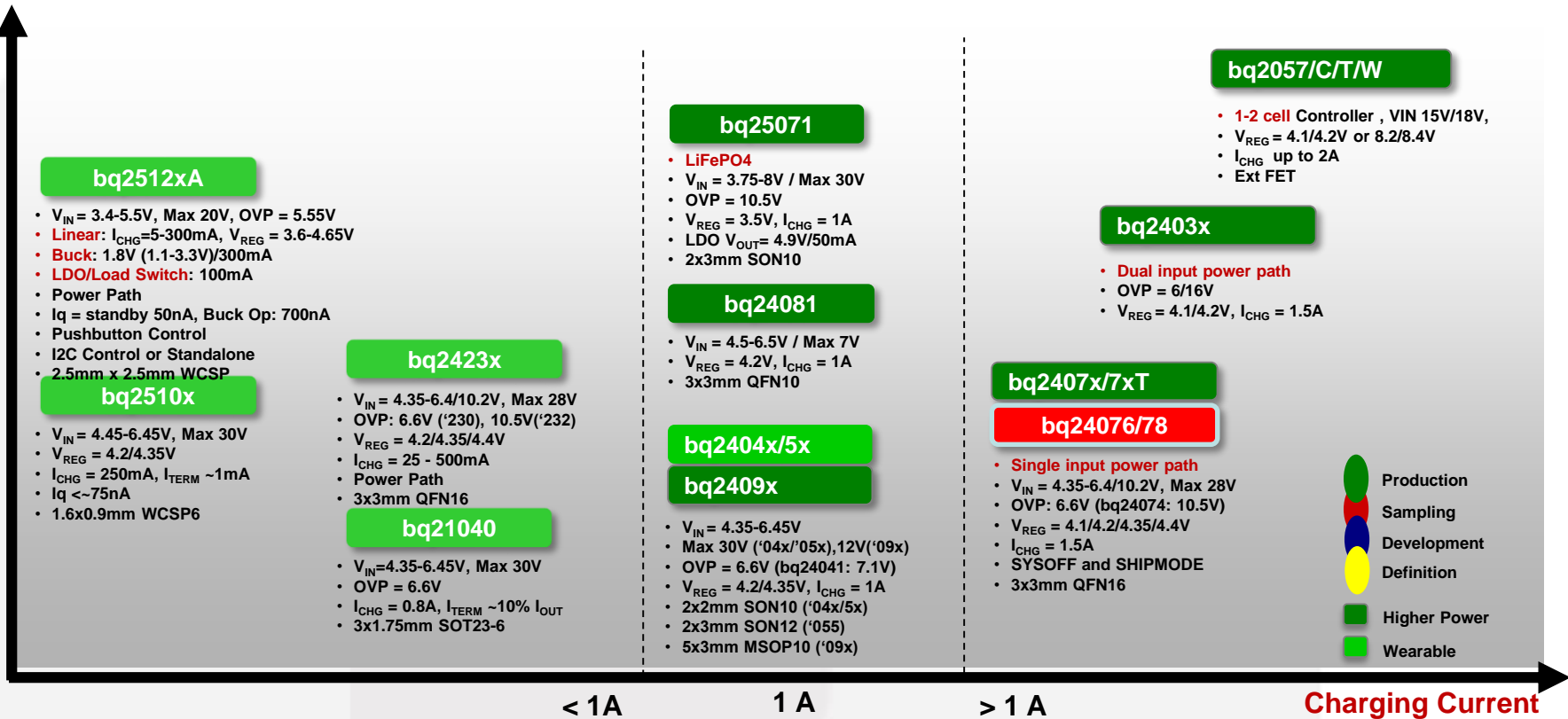
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TI battery charger solution

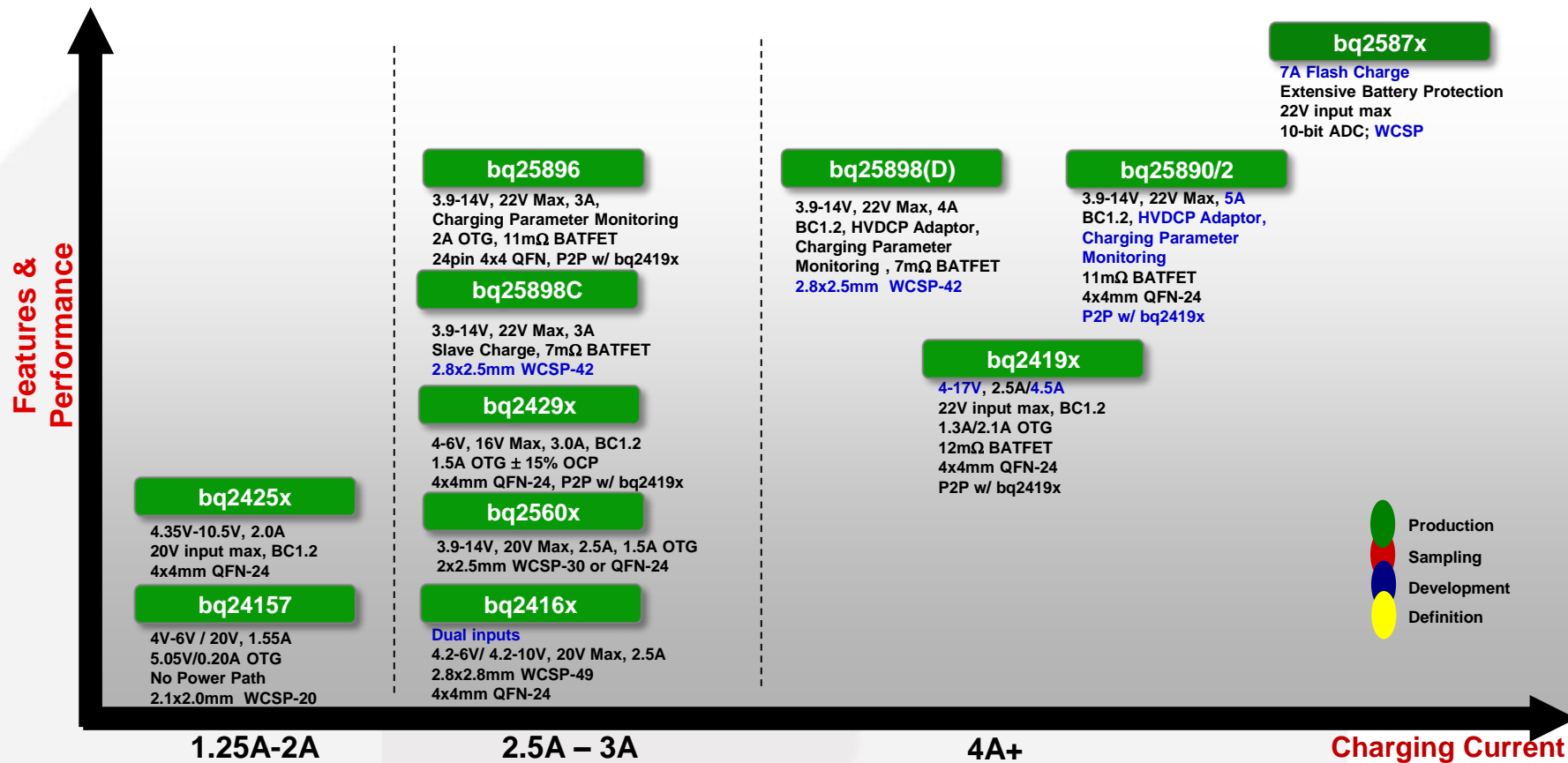
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Linear Chargers Portfolio

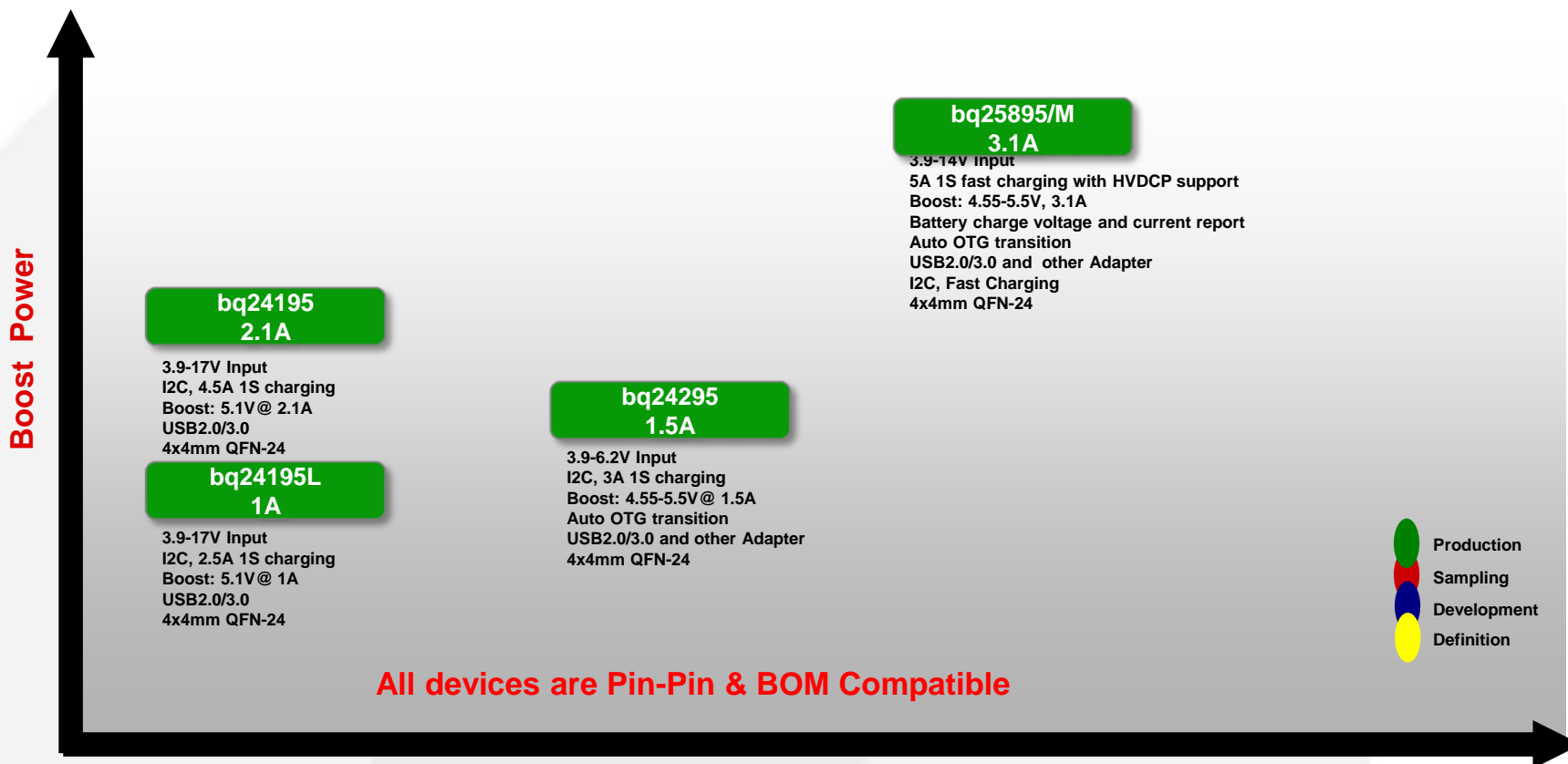
Features & Performance



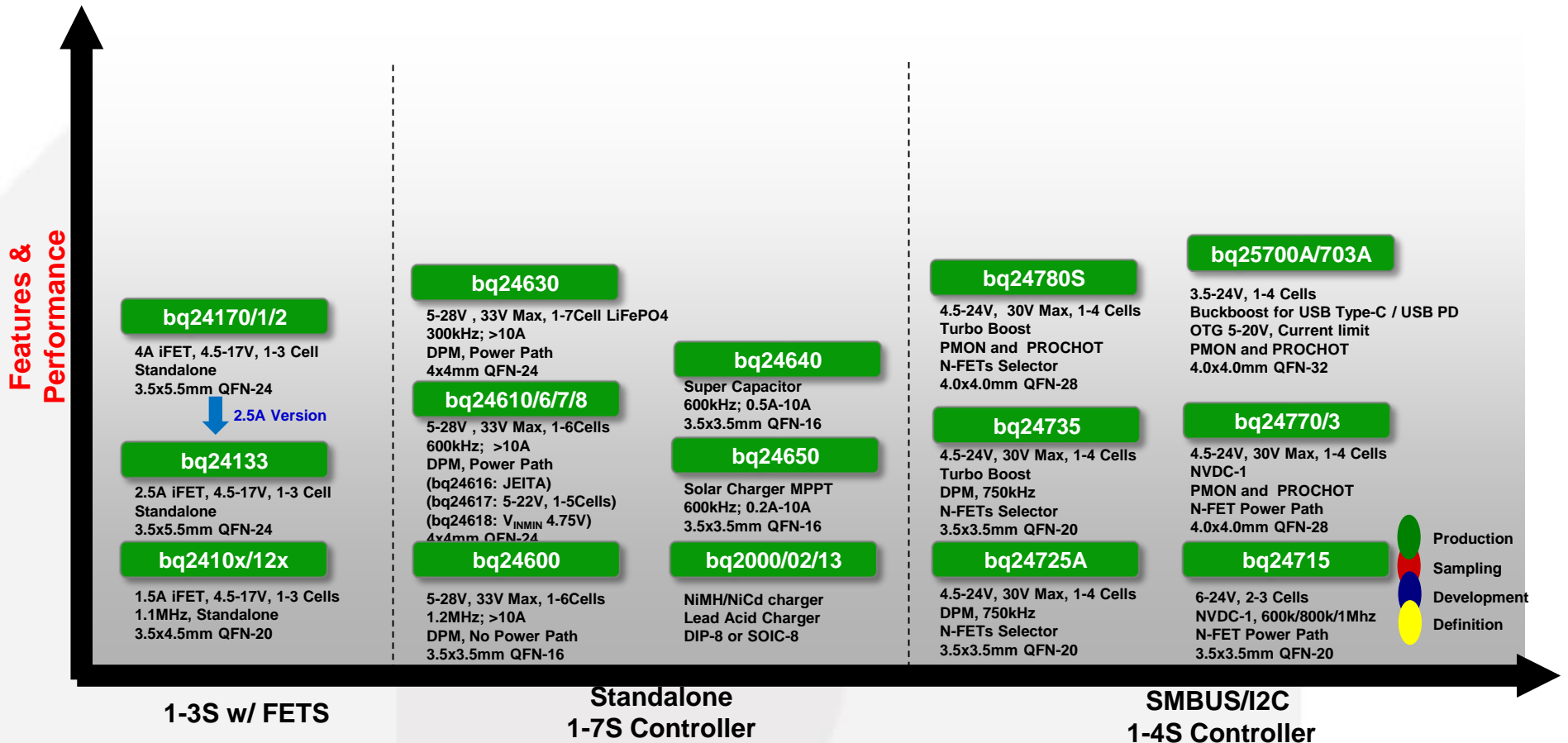
Single Cell Switch-Mode Charger Portfolio



Single Cell Switch-Mode Charger for Power Bank



Multi-Cell Switch-Mode Charger Portfolio





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eFuse

A Quick Comparison to eFuses

Your Integral Component to Success

Circuit Protection – What is it ?

Circuits designed specifically to....

- Prevent Fire ! --*“Keep the smoke in!”*
- Keep small problems from growing big
 - Minimize damage by quickly isolating failures
- Prevent potentially disruptive power bus disturbances
 - One small transient can take down/reset an entire system

What Gets Protected ?

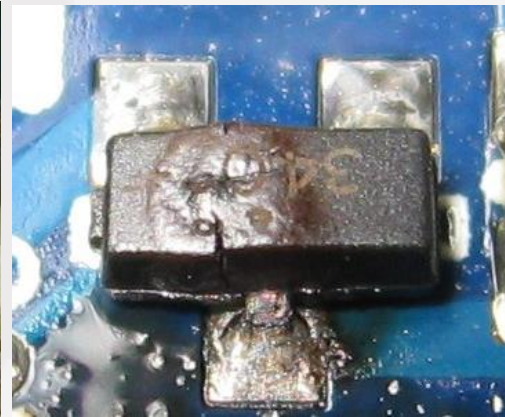
SUPPLY



CONNECTORS



POWER FET



LOAD



Circuit Protection – What is it ?

Many things with many names

- Inrush Control
- Hotswap
- Hotplug
- Current Limiting
- Electronic Circuit Breaker
- Short Circuit Protection
- Soft Start
- **eFuse**
- Over Voltage Protection (OVP)
- Load Power Limiting
- FET SOA Limiting (Protecting the Protector !)
- Reverse Current Protection (ORing)

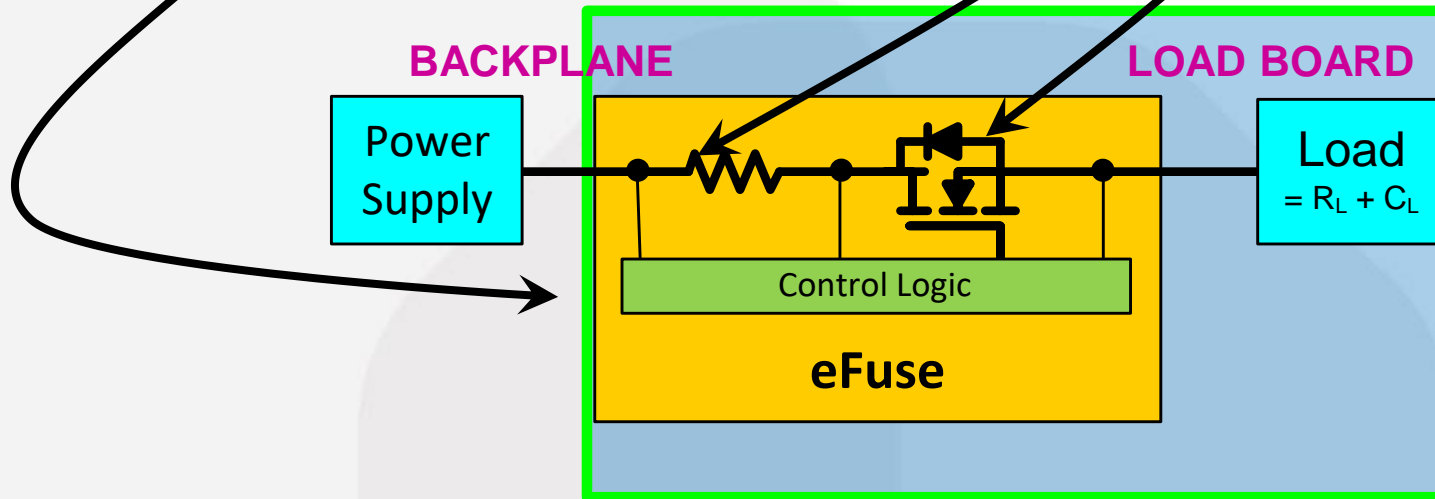
Similar functions

Often Required for Agency Rating – (IEC/UL60950, IEC/UL60730, etc.)

- UL, CSA – North America
- TUV, EN, IEC, (CENELEC) – Europe
- CCC Mark (CNCA) - China

Most Common Elements

- Element for modulating current
- Element for sensing current
 - (RSENSE is shown, but typically a senseFET)
- Element for controlling the FET



Location..

- Sometimes on the Load Side of the Connector
- Sometimes on the Supply Side of the Connector

Slow

Lossy

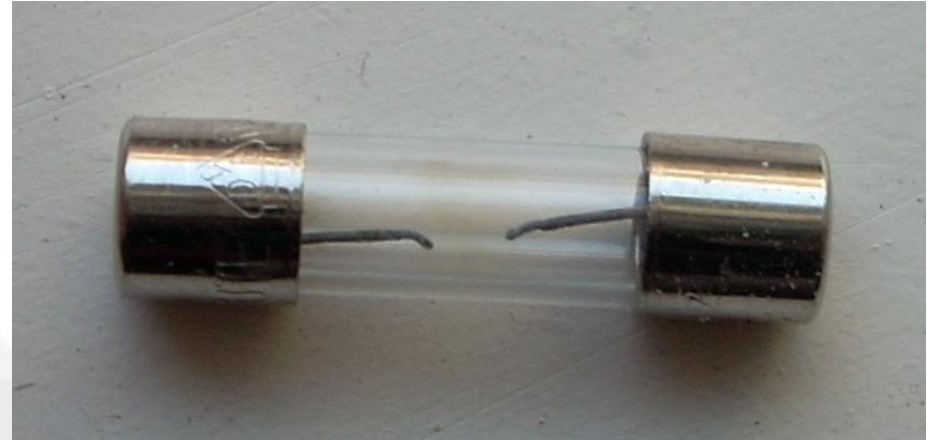
Inaccurate

Load unpowered after event

Low Cost

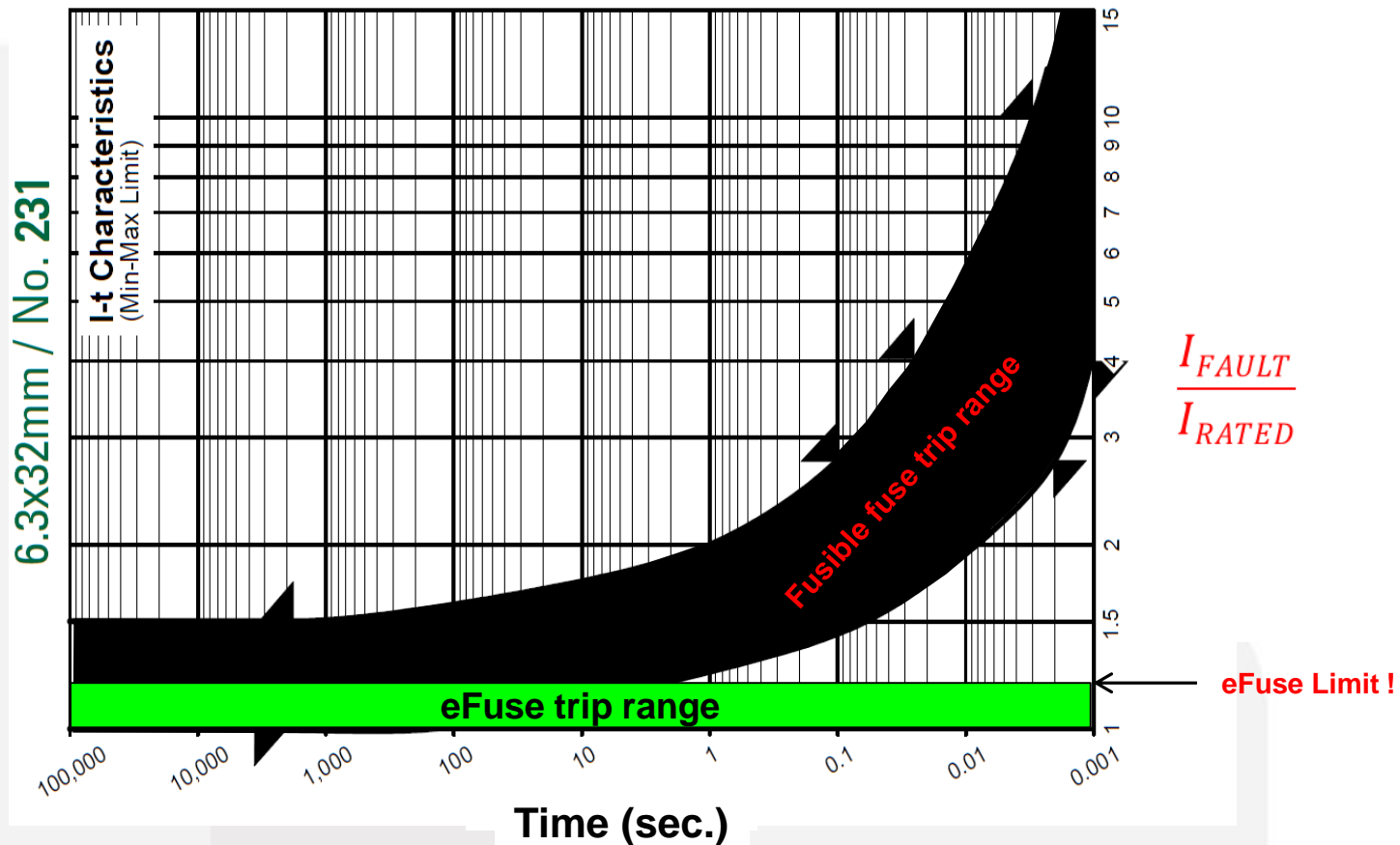
Can provide Safety Compliance

– UL, IEC, CSA



“Fast Blo fuse ” Trip time vs Current

eFuse vs fuse



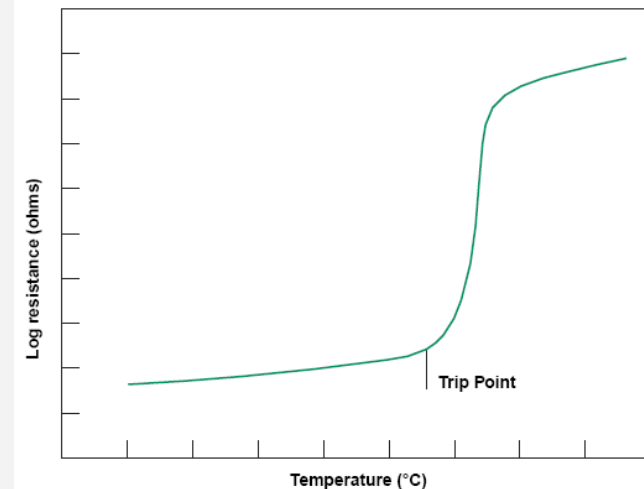
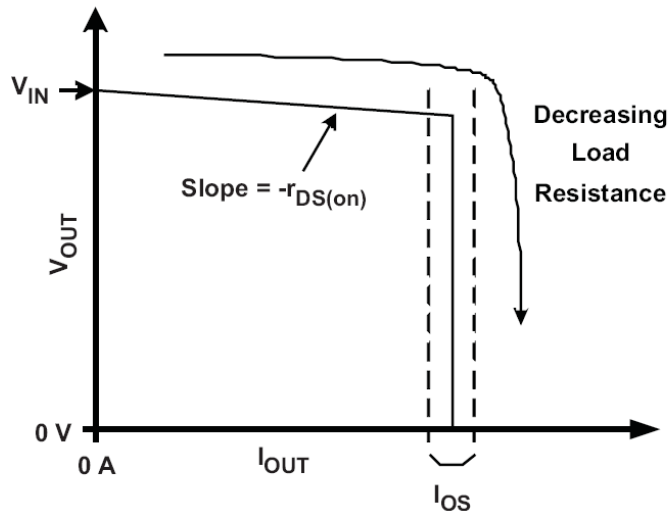
Time and trip limit inaccuracies mean bigger power supplies

eFuse (USB power switch)

- **Current based I_{LIMIT}**
- **Stable, accurate (20% - 30%) I_{LIMIT}**
- **Fixed or Programmable I_{LIMIT}**
- **Repeatable I_{LIMIT}**
- **Fast ($< 1.5 \mu s$ typ)**
- **Wide temp range**
 - **-40° to $+125^{\circ} C^{\circ}$**

Polyfuse

- **Temp based I_{LIMIT}**
- **Sloppy, variable I_{LIMIT}**
- **No Programmable I_{LIMIT}**
- **R_{ON} Increases with each event**
- **Slow to trip (several ms)**
- **Not usable above $85^{\circ} C^{\circ}$**
- **Auto –resets after trip event**





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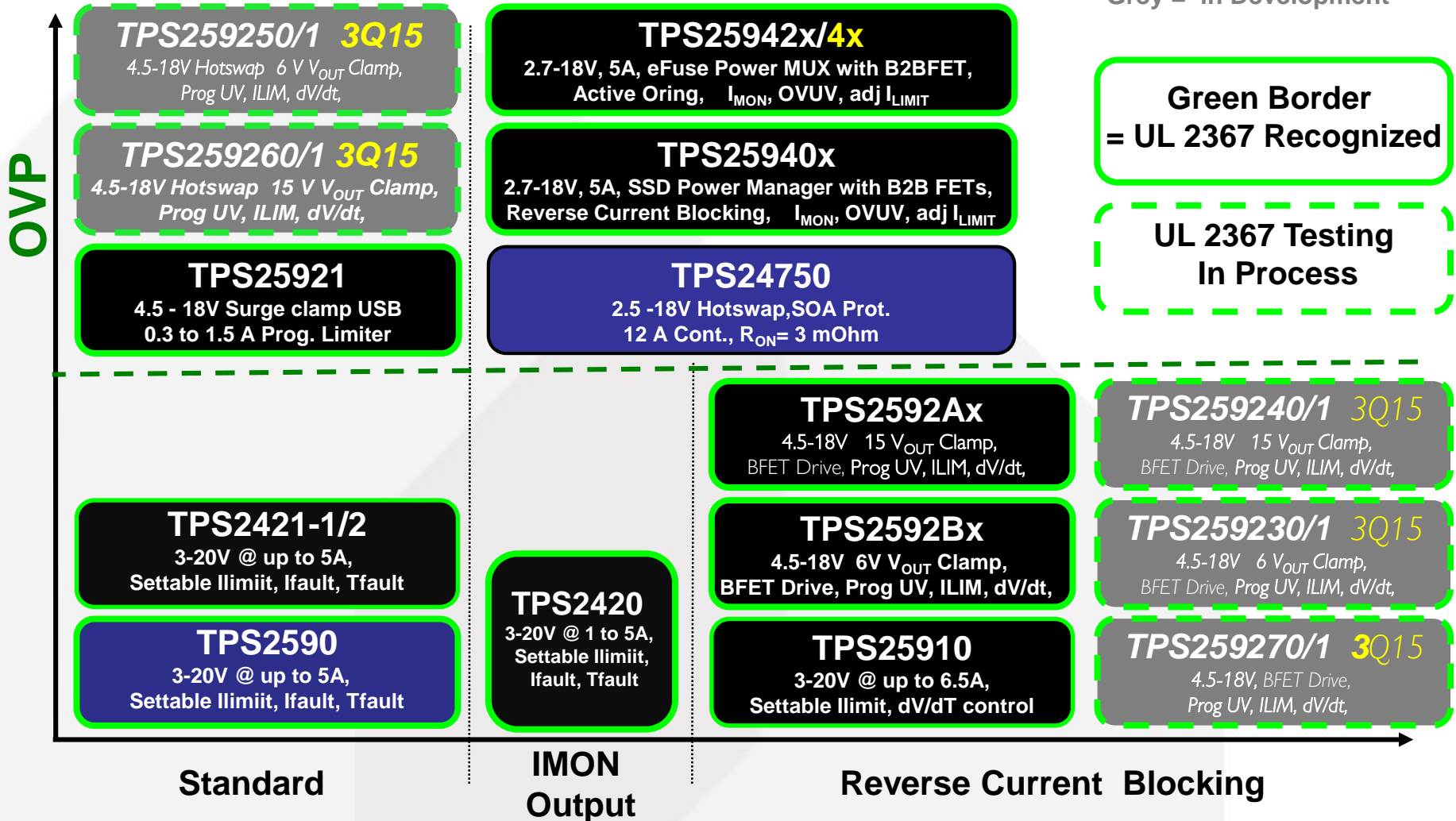
TI eFuse solution

Your Integral Component to Success

eFuse – Internal FET, Positive LV Current Limiting

Internal FET Devices

Red = New Release
Grey = in Development





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Thank you

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2017 4Q

Your Integral Component to Success