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MP2633

1.5A Single Cell Switch Mode Battery Charger with Power Path Management and Boost OTG

DESCRIPTION

The MP2633 is a highly-integrated, flexible, switch-mode battery charge management and system power path management device for a single-cell Li-ion and Li-Polymer battery used in a wide range of portable applications.

The MP2633 has two operating modes—charge mode and boost mode—to allow management of system and battery power based on the state of the input.

When input power is present, the device operates in charge mode. It automatically detects the battery voltage and charges the battery in the three phases: trickle current, constant current and constant voltage. Other features include charge termination and auto-recharge. This device also integrates both input-current limit and input-voltage regulation in order to manage input power and meet the priority of the system power demand. .

In the absence of an input source, the MP2633 switches to boost mode through the MODE pin to power the SYS pins from the battery. The OLIM pin programs the output current limit in boost mode. The MP2633 also allows an output short-circuit thanks to an output disconnect feature, and can auto-recover when the short circuit fault is removed.

The MP2633 provides full operating status indication to distinguish charge mode from boost mode.

The MP2633 achieves low EMI/EMC performance with well-controlled switching edges.

To guarantee safe operation, the MP2633 limits the die temperature to a preset value 120°C. Other safety features include input over-voltage protection, battery over-voltage protection, thermal shutdown, battery temperature monitoring, and a programmable timer to prevent prolonged charging of a dead battery.

FEATURES

- 4.5V-to-6V Operating Input Voltage Range
- Power Management Function Integrated Input-Current Limit and Input-Voltage Regulation
- Up to 1.5A Programmable Charge Current
- Trickle-Charge Function
- Selectable 3.6V/ 4.2V Charge Voltage with 0.5% Accuracy
- Negative Temperature Coefficient Pin for Battery Temperature Monitoring
- Programmable Timer Back-Up Protection
- Thermal Regulation and Thermal Shutdown
- Internal Battery Reverse Leakage Blocking
- Reverse Boost Operation Mode for System Power
- Up to 91% 5V Boost Mode Efficiency @ 1A
- Programmable Output Current Limit for Boost Mode
- Integrated Short Circuit Protection for Boost Mode

APPLICATIONS

- Sub-Battery Applications
- Power-Bank Applications for Smart-Phone Tablet and other Portable Device

TYPICAL APPLICATION

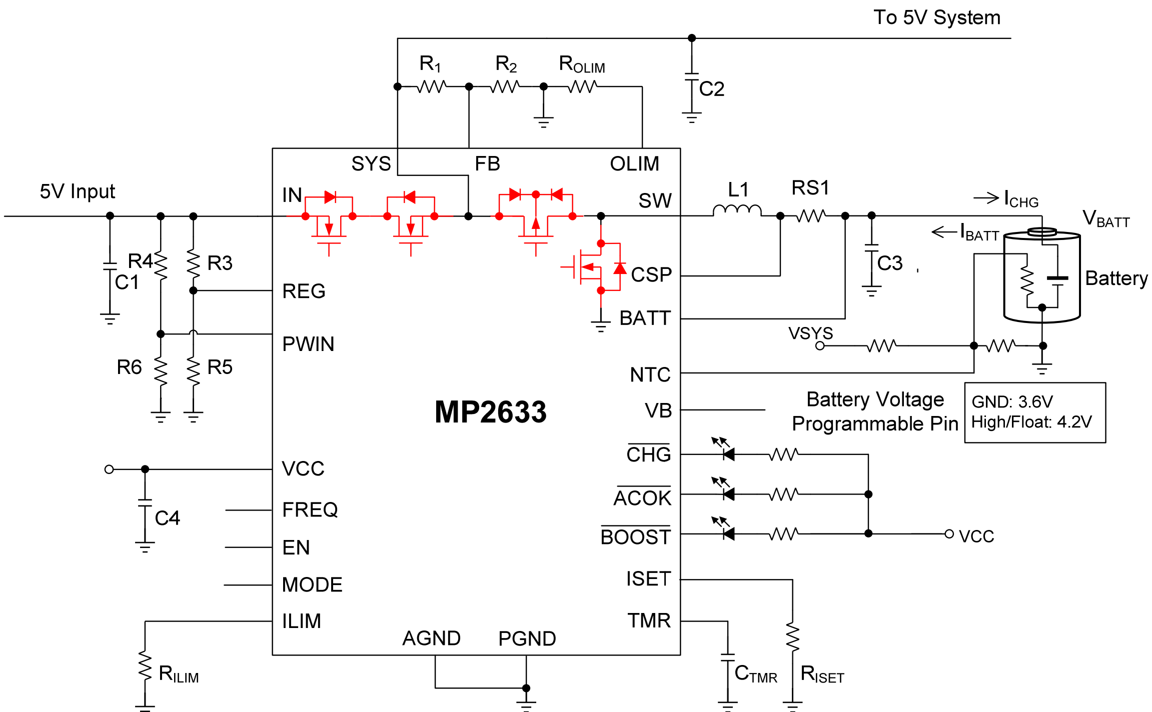


Table 1: Operation Mode

Power Source	$\overline{\text{ACOK}}$	EN	MODE	Operating Mode
0.8V<PWIN<1.15V & V_{IN}>V_{BATT}+300mV	Low	High	X	Charge Mode, Enable Charging
		Low		Charge Mode, Disable Charging
PWIN<0.8V or PWIN >1.15V or V_{IN}<V_{BATT}+300mV	High	X	High	Boost Mode
V_{IN}<2V	High	X	Low	Sleep Mode

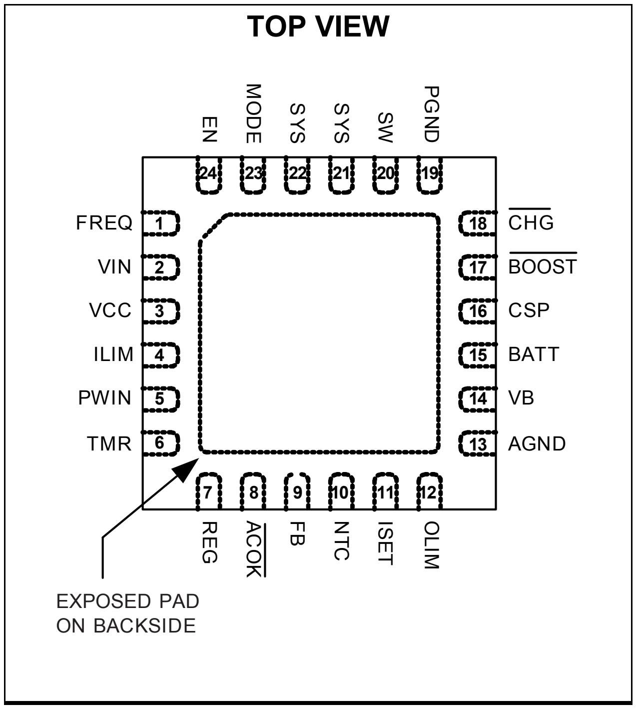
X=Don't Care.

ORDERING INFORMATION

Part Number*	Package	Top Marking
MP2633GR	QFN24 (4×4mm)	M2633E

* For Tape & Reel, add suffix –Z (e.g. MP2633GR–Z);

PACKAGE REFERENCE



ABSOLUTE MAXIMUM RATINGS (1)

VIN ....–0.3V to 20V
SYS ....–0.3V to 6.5V
SW ....
-0.3V (-2V for <20ns) to 6.5V (8.5V for <20ns)
BATT ....–0.3V to 6.5V
ACOK, CHG, BOOST ....–0.3V to 6.5V
All Other Pins ....–0.3V to 6.5V
Junction Temperature ....150°C
Lead Temperature ....260°C
Continuous Power Dissipation (T_A = +25°C) (2)
.... 2.97W
Junction Temperature ....150°C
Operating Temperature............. –20°C to +85°C

Recommended Operating Conditions (3)

Supply Voltage VIN............................4.5V to 6V
Battery Voltage V_{OUT} ....2.5V to 4.35V
Operating Junction Temp. (T_J).−40°C to +125°C

Thermal Resistance (4)	θ_{JA}	θ_{JC}	
QFN24 (4×4mm).....................	42	9	... °C/W

Notes:

1) Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature T_J (MAX), the junction-to-ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX)-T_A)/θ_{JA}. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
3) The device is not guaranteed to function outside of its operating conditions.
4) Measured on JESD51-7, 4-layer PCB.

ELECTRICAL CHARACTERISTICS

V_{IN} = 5.0V, T_A = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
IN to SYS NMOS ON Resistance	$R_{IN\ to\ SYS}$			100		mΩ
High-side PMOS ON Resistance	R_{H_DS}			72		mΩ
Low-side NMOS ON Resistance	R_{L_DS}			70		mΩ
High-Side PMOS Peak Current Limit	I_{PEAK_HS}	CC Charge Mode/Boost Mode		4		A
		TC Charge Mode		1.5		A
Low-Side NMOS Peak Current Limit	I_{PEAK_LS}			4.5		A
Switching Frequency	f_{SW}	FREQ = 0		600		kHz
		FREQ = Float/ High		1200		
VCC UVLO	V_{CC_UVLO}		2	2.2	2.4	V
VCC UVLO Hysteresis				100		mV
PWIN, Lower Threshold	V_{PWIN_L}		0.75	0.8	0.85	V
Lower Threshold Hysteresis				40		mV
PWIN, Upper Threshold	V_{PWIN_H}		1.1	1.15	1.2	V
Upper Threshold Hysteresis				65		mV
Charge Mode						
Input Quiescent Current	I_{IN}	EN = 5V, Battery Float			2.5	mA
		EN = 0			1.5	mA
Input Current Limit	I_{IN_LIMIT}	R_{ILIM} = 90.9k	400	450	500	mA
		R_{ILIM} = 49.9k	720	810	900	
		R_{ILIM} = 20k	1800	2000	2200	
Input Over-Current Threshold	$I_{IN(OCP)}$			3		A
Input Over-Current Blanking Time(5)	$\tau_{INOCBLK}$			120		µs
Input Over-Current Recovery Time(5)	$\tau_{INRECVR}$			100		ms
Terminal Battery Voltage	V_{BATT_FULL}	Connect VB to GND	3.582	3.6	3.618	V
		Leave VB floating or connect to logic HIGH	4.179	4.2	4.221	
Recharge Threshold	V_{RECH}	Connect to VB to GND	3.39	3.44	3.49	
		Leave VB floating or connect to logic HIGH	3.95	4.01	4.07	V
Recharge Threshold Hysteresis				200		mV
Battery Over Voltage Threshold				103.3%		V_{BATT_FULL}
Constant Charge (CC) Current	I_{CC}	RS1 = 40mΩ, R_{ISET} = 69.8k	900	1000	1100	mA
		RS1 = 40mΩ, R_{ISET} = 46.4k	1350	1500	1650	
Trickle-Charge Current	I_{TC}			230		mA

ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 5.0V, T_A = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Trickle-Charge Voltage Threshold	V_{BATT_TC}	Connect to VB to GND	2.47	2.57	2.67	V
		Leave VB floating or connect to high logic	2.9	3	3.1	
Trickle-Charge Hysteresis				200		mV
Termination Charge Current	I_{BF}	RS1=40m, R_{ISET}=69.8k	2.5%	10%	17.5%	I_{CC}
Input-Voltage-Regulation Reference	V_{REG}		1.18	1.2	1.22	V
Boost Mode						
SYS Voltage Range			4.2		6	V
Feedback Voltage			1.18	1.2	1.22	V
Feedback Input Current		V_{FB}=1V			200	nA
Boost SYS Over-Voltage Protection Threshold	$V_{SYS(OVP)}$)	Threshold over V_{SYS} to turn off the converter during boost mode	5.8	6	6.2	V
SYS Over-Voltage Protection Threshold Hysteresis		V_{SYS} falling from $V_{SYS(OVP)}$		125		mV
Boost Quiescent Current		I_{SYS} = 0, MODE = 5V			1.4	mA
Programmable Boost Output Current Limit Accuracy	I_{OLIM}	RS1 = 40mΩ, R_{OLIM} = 100k	1	1.2	1.44	A
Programmable Boost Output Current(5)		RS1 = 50mΩ, ROLIM=63.4k	1.5			A
SYS Over-Current Blanking Time(5)	$\tau_{SYSOCBLK}$			120		µs
SYS Over-Current Recovery Time(5)	$\tau_{SYSRECVR}$			1		ms
Weak-Battery Threshold	$V_{BATT(LOW)}$	During Boost mode		2.5		V
		Before Boost mode		2.9	3.05	V
Sleep Mode						
Battery Leakage Current	$I_{LEAKAGE}$	V_{BATT} = 4.2V, SYS Float, V_{IN} = 0V, MODE = 0V		15	30	µA
Indication and Logic						
$\overline{ACOK}$, $\overline{CHG}$, $\overline{BOOST}$ pin output low voltage		Sinking 1.5mA			400	mV
$\overline{ACOK}$, $\overline{CHG}$, $\overline{BOOST}$ pin leakage current		Connected to 5V			1	µA
NTC and Time-Out Fault Blinking Frequency(5)		C_{TMR}=0.1µF, I_{CHG}=1A		13.7		Hz
EN Input Logic LOW Voltage					0.4	V
EN Input High Voltage			1.4			V
Mode Input Logic LOW Voltage					0.4	V
Mode Input Logic HIGH Voltage			1.4			V

ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 5.0V, T_A = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Protection						
Trickle-Charge Time		C_{TMR}=0.1µF, remains in TC mode, I_{CHG}= 1A		60		Min
Total Charge Time		C_{TMR}=0.1µF, I_{CHG}= 1A		360		Min
NTC Low Temp, Rising Threshold		R_{NTC}=NCP18XH103(0°C)	65%	66%	67%	V_{SYS}
NTC Low Temp, Rising Threshold Hysteresis				1%		
NTC High Temp, Rising Threshold		R_{NTC}=NCP18XH103(50°C)	34%	35%	36%	
NTC High Temp, Rising Threshold Hysteresis				1%		
Charging Current Fold-back Threshold(5)		Charge Mode		120		°C
Thermal Shutdown Threshold(5)				150		°C

Notes:

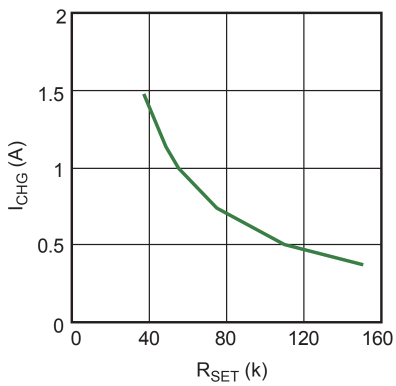
5) Guaranteed by design.

TYPICAL CHARACTERISTICS

C_{IN}=C_{BATT}=C_{SYS}=C3=22µF, C1=C2=1µF, L1=4.7µH, RS1=50mΩ, C4=C_{TMR}=0.1µF, Battery Simulator, unless otherwise noted.

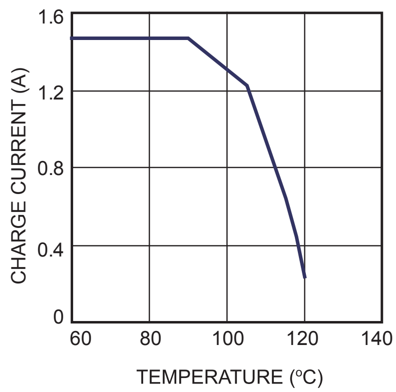
Charge Current vs. RISET,Charge Mode

V_{IN}=5V, V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, F_{SW}=1.2MHz



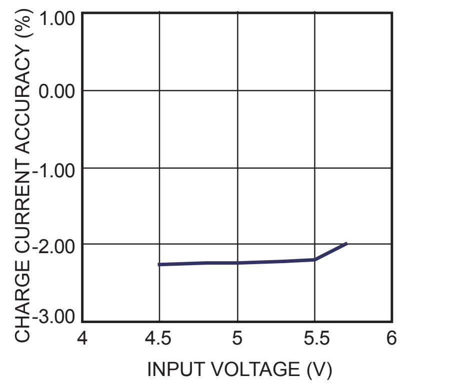
Charge Current vs. Temeprature, Charge Mode

V_{IN}=5V, V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A

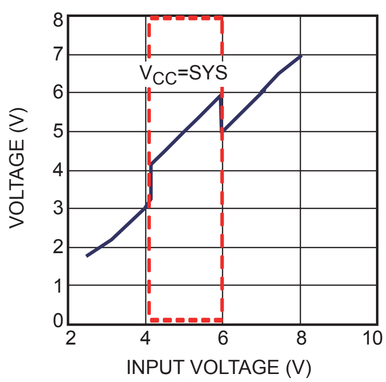


Charge Current vs. Input Voltage, Charge Mode

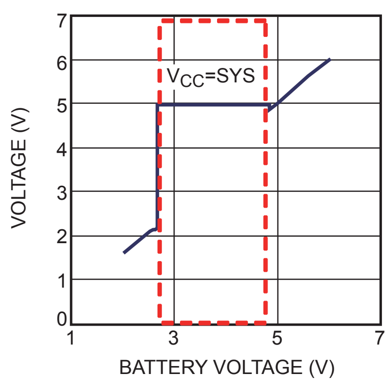
V_{IN}=5V, V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A, Temperature=25ºC



V_{CC} @ Charge Mode

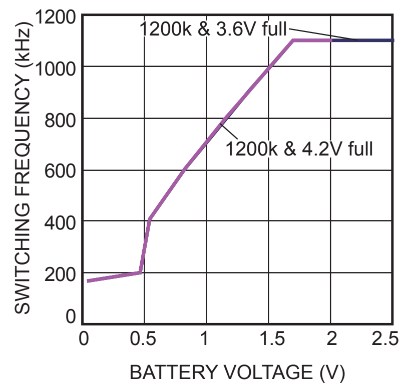


V_{CC} @ Boost Mode

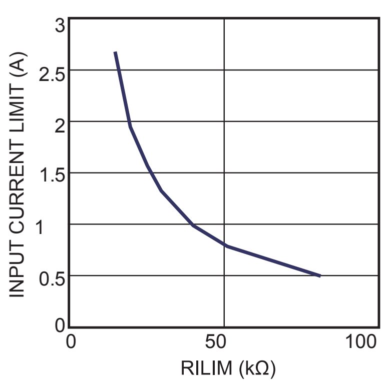


Switching Frequency vs. Battery Voltage, Charge Mode

V_{IN}=5V, V_{BATT_FULL}=4.2V, I_{CHG}=2A

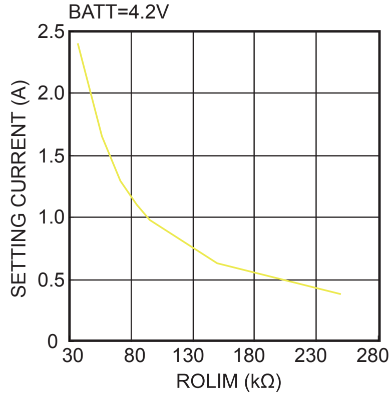


Input Current Limit Setting (Iin_lim vs. RILIM)



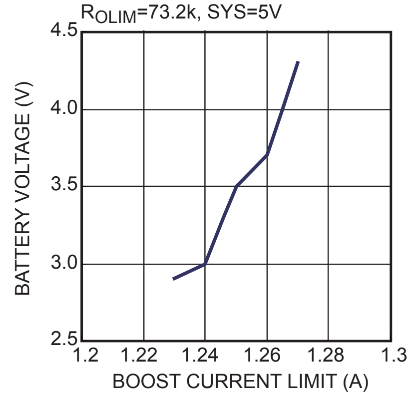
Programmable Output Current Limit (OLIM vs. ROLIM)

BATT=4.2V



Programmable Output Current Limit vs. Battery Voltage

R_{OLIM}=73.2k, SYS=5V

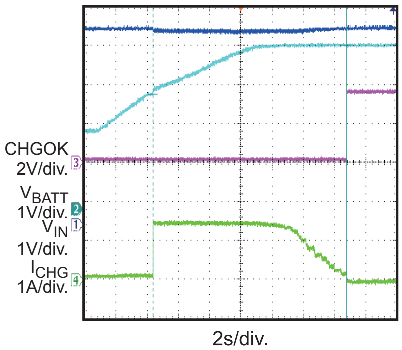


TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN}=5V, C_{IN}=C_{BATT}=C_{SYS}=C3=22μF, C1=C2=1μF, L1=2.2μH, RS1=50mΩ, C4=C_{TMR}=0.1μF, Battery Simulator, unless noted otherwise.

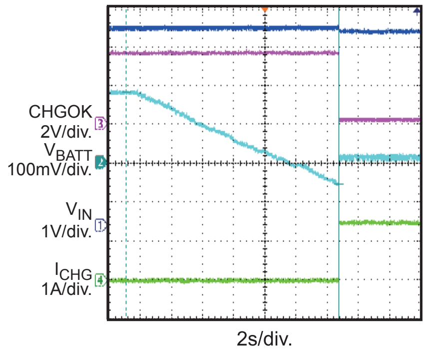
Battery Charge Curve

V_{BATT_FULL} = 4.2V



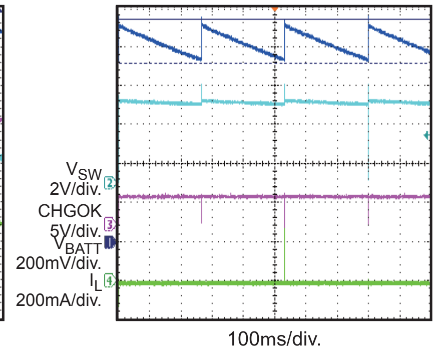
Auto Recharge

V_{BATT_FULL} = 4.2V



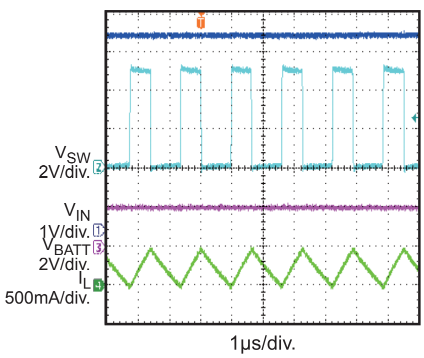
Battery Float Steady State

V_{BATT_FULL} = 4.2V



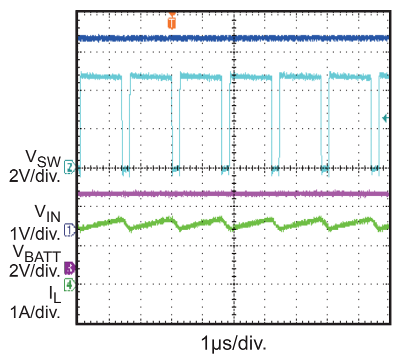
TC Charge Steady State

V_{BATT_FULL} = 4.2V, V_{BATT} = 2V, F_{SW} = 600kHz



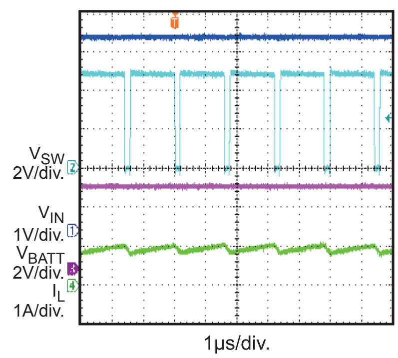
CC Charge Steady State

V_{BATT_FULL} = 4.2V, V_{BATT} = 3.7V, F_{SW} = 600kHz



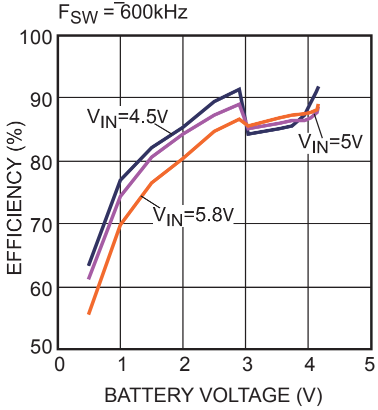
CV Charge Steady State

V_{BATT_FULL} = 4.2V, V_{BATT} = 4.2V, F_{SW} = 600kHz



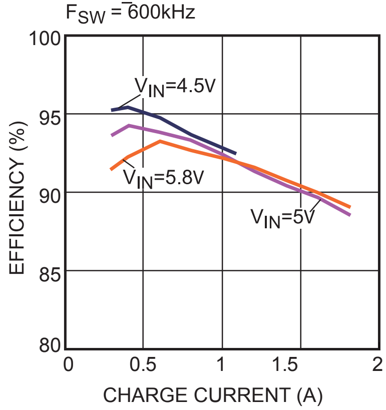
Constant Current Charge Efficiency

V_{BATT_FULL} = 4.2V, V_{BATT} = 0.5-4.2V, F_{SW} = 600kHz



Constant Voltage Charge Efficiency

V_{BATT_FULL} = 4.2V, V_{BATT} = 4.2V, F_{SW} = 600kHz

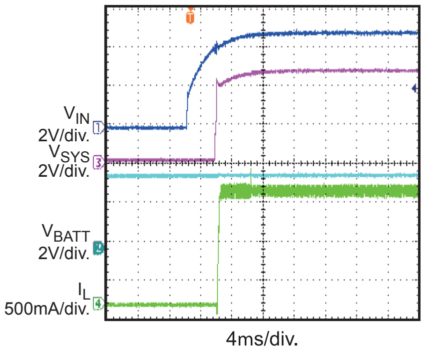


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN}=5V, C_{IN}=C_{BATT}=C_{SYS}=C3=22µF, C1=C2=1µF, L1=2.2µH, RS1=50mΩ, C4=C_{TMR}=0.1µF, Battery Simulator, unless otherwise noted.

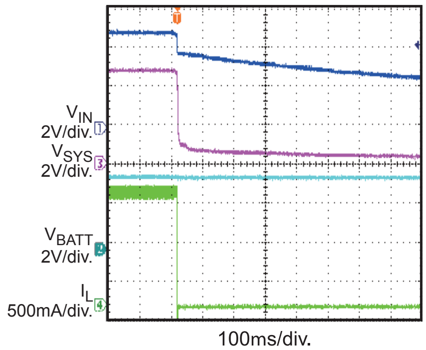
Power On, Charge Mode

V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A



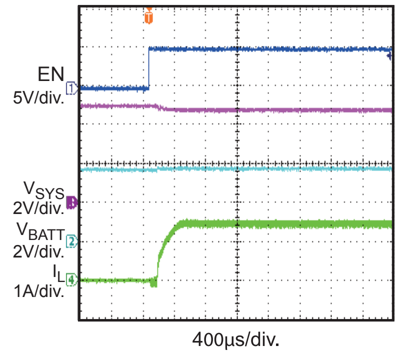
Power Off, Charge Mode

V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A



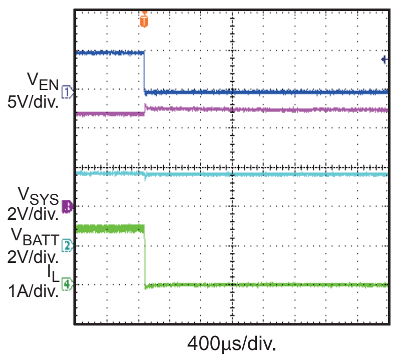
En On, Charge Mode

V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A



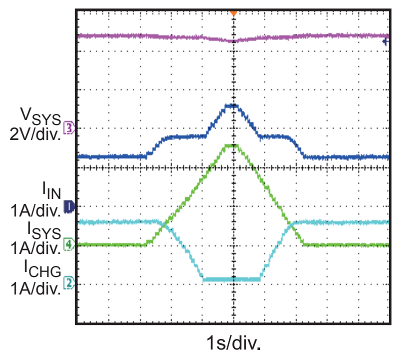
En Off, Charge Mode

V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A



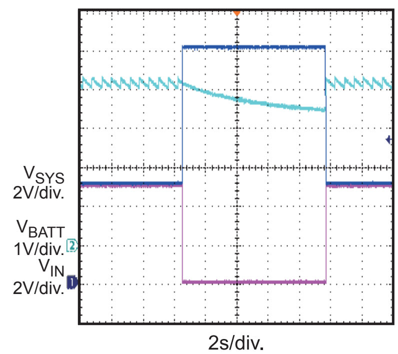
Input Current Limit

V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A



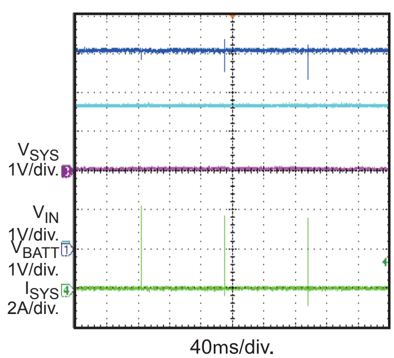
Input Over Voltage Protection

V_{IN}=5V to 12V, R_{SYS_LOAD}=25Ω, Battery Float, Enabled Charge



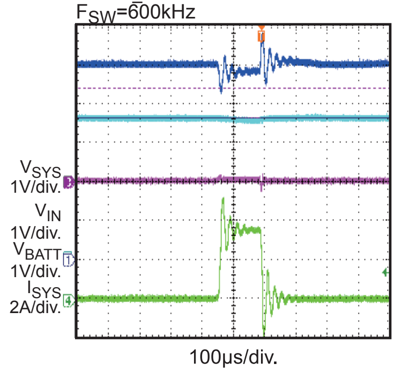
System Short Protection

V_{BATT_FULL}=4.2V, V_{BATT}=2V, F_{SW}=600kHz



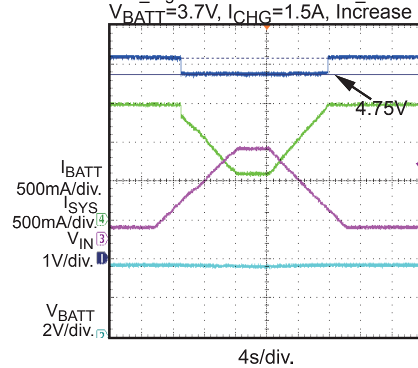
System Short Protection Zoom In

V_{BATT_FULL}=4.2V, V_{BATT}=2V, F_{SW}=600kHz



Input Voltage Clamp @ 4.75V Charge Mode

$V_{IN\_regulation}$=4.75V, V_{BATT_FULL}=4.2V, V_{BATT}=3.7V, I_{CHG}=1.5A, Increase Isys

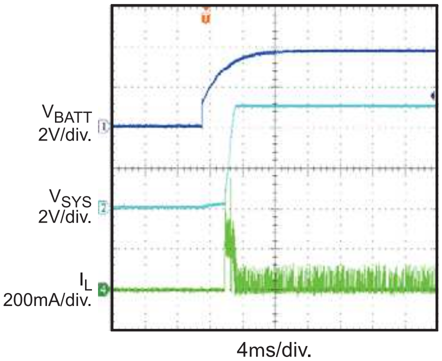


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN}=5V, C_{IN}=C_{BATT}=C_{SYS}=C3=22µF, C1=C2=1µF, L1=2.2µH, RS1=50mΩ, C4=C_{TMR}=0.1µF, Battery Simulator, unless otherwise noted.

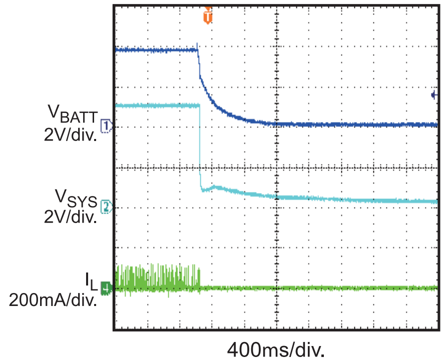
Power On, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
No SYS Load



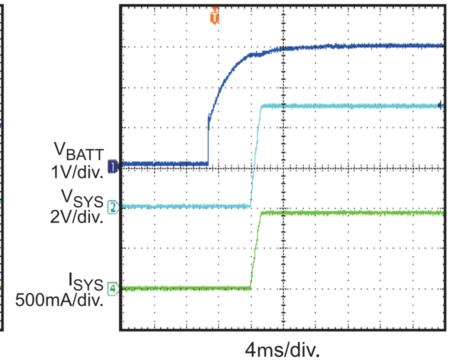
Power Off, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
No SYS Load



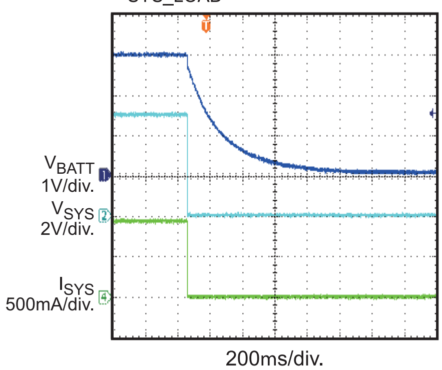
Power On, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3V,
R_{SYS_LOAD}=5Ω



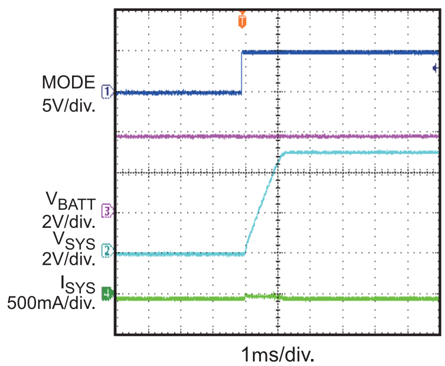
Power Off, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3V,
R_{SYS_LOAD}=5Ω



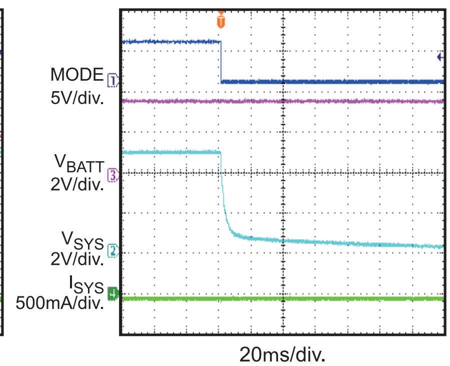
Mode On, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
No SYS Load



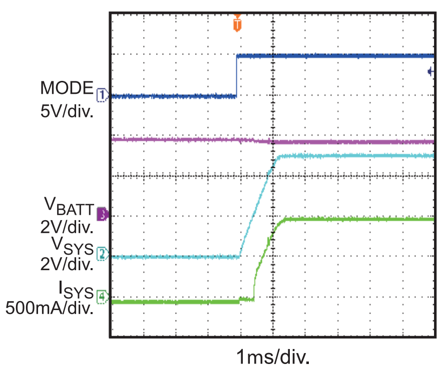
Mode Off, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
No SYS Load



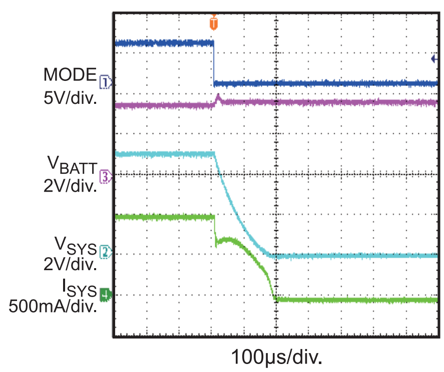
Mode On, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
R_{SYS_LOAD}=5Ω



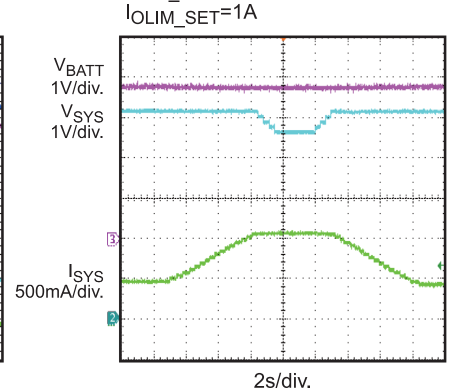
Mode Off, Boost Mode

V_{SYS_SET}=5V, V_{BATT}=3.7V,
R_{SYS_LOAD}=5Ω



SYS Output Current Limit, Boost Mode

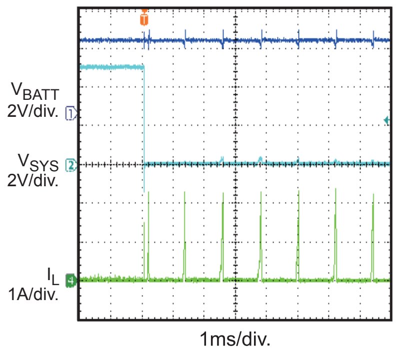
V_{SYS_SET}=5V, V_{BATT}=3.7V,
I_{OLIM_SET}=1A



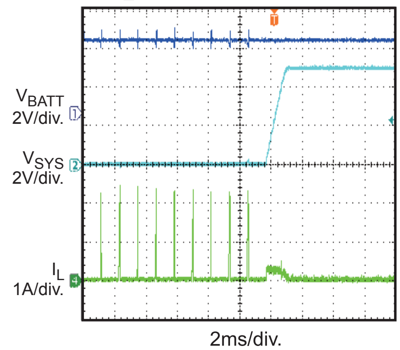
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN}=5V, C_{IN}=C_{BATT}=C_{SYS}=C3=22µF, C1=C2=1µF, L1=2.2µH, RS1=50mΩ, C4=C_{TMR}=0.1µF, Battery Simulator, unless otherwise noted.

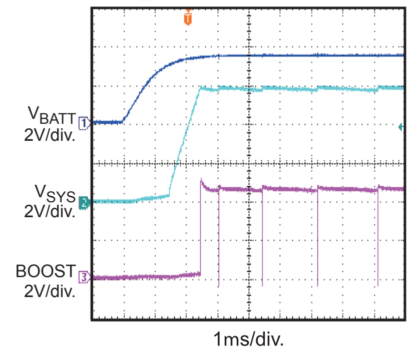
SYS short Entry
Boost Mode
V_{SYS_SET}=5V, V_{BATT}=3.7V



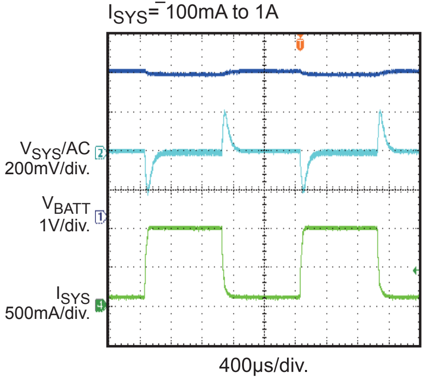
SYS Short Recovery
Boost Mode
V_{SYS_SET}=5V, V_{BATT}=3.7V



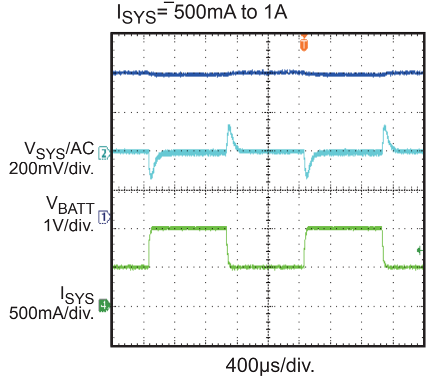
SYS Over Voltage Protection,
Boost Mode
V_{SYS_SET}=6.5V, V_{BATT}=3.7V



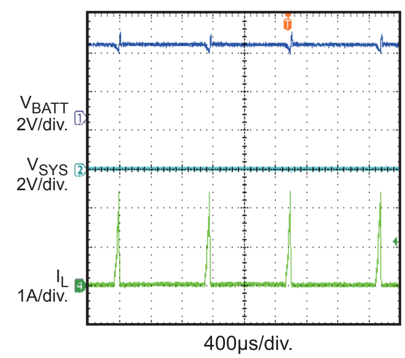
SYS Load Transient,
Boost Mode
V_{SYS_SET}=5V, V_{BATT}=3.7V,
I_{SYS}= 100mA to 1A



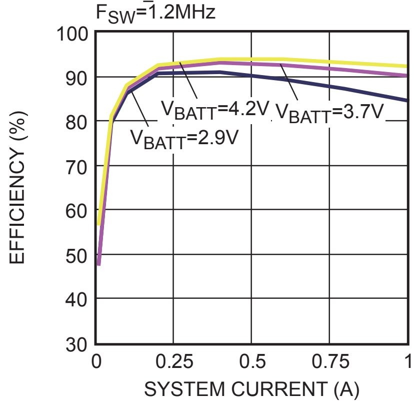
SYS Load Transient,
Boost Mode
V_{SYS_SET}=5V, V_{BATT}=3.7V,
I_{SYS}= 500mA to 1A



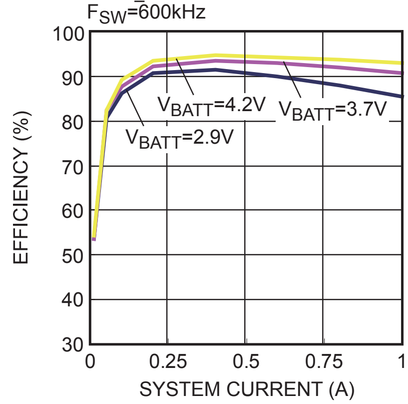
SYS Short Steady State
Boost Mode
V_{SYS_SET}=5V, V_{BATT}=3.7V



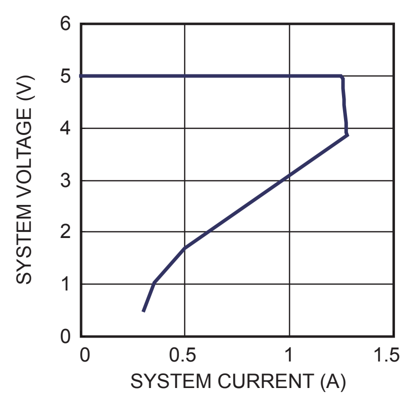
Efficiency, Boost Mode
V_{SYS_SET}=5V, V_{SYS}=5V,
F_{SW}=1.2MHz



Efficiency, Boost Mode
V_{SYS_SET}=5V, V_{SYS}=5V,
F_{SW}=600kHz



Boost Output V-I Curve
BATT=3.7V, SYS=5V



PIN FUNCTIONS

Pin #	Name	Description
1	FREQ	Connect to GND to program the operating frequency to 600kHz. Leave floating or connect to HIGH to program the operating frequency to 1.2MHz.
2	VIN	Adapter Input. Place a bypass capacitor close to this pin to prevent large input voltage spikes.
3	VCC	Internal Circuit Power Supply. Bypass to GND with a 100nF ceramic capacitor. This pin can not carry external load higher than 5mA.
4	ILIM	Input Current Set. Connect to GND with an external resistor to program input current limit in charge mode.
5	PWIN	AC Input Detect. Detect the presence of valid input power.
6	TMR	Oscillator Period Timer. Connect a timing capacitor between this pin and GND to set the oscillator period. Short to GND to disable the Timer function.
7	REG	Input Voltage Feedback for input voltage regulation loop. Connect to tap of an external resistor divider from VIN to GND to program the input voltage regulation. Once the voltage at REG pin drops to the inner threshold, the charge current is reduced to maintain the input voltage at the regulation value.
8	$\overline{ACOK}$	Valid Input Supply Indicator. Logic LOW indicates the presence of a valid power supply.
9	FB	System Voltage Feedback.
10	NTC	Negative Temperature Coefficient (NTC) Thermistor.
11	ISET	Charge Current Set. Connect an external resistor to GND to program the charge current.
12	OLIM	Boost-Output-Current Limit Set. Connect an external resistor to GND to program the system current in boost mode.
13	AGND	Analog Ground
14	VB	Programmable Battery-Full Voltage. Connect to GND for 3.6V. Leave floating or connect to logic HIGH for 4.2V.
15	BATT	Positive Battery Terminal / Battery Charge Current Sense Negative Input.
16	CSP	Battery Charge Current Sense, Positive Input.
17	$\overline{BOOST}$	Boost Mode Indicator. Logic LOW indicates boost mode in operation. This pin becomes an open drain when the part operates in charge mode or sleep mode.
18	$\overline{CHG}$	Charge Completion indicator. Logic LOW indicates charge mode. The pin becomes an open drain once the charging has completed or is suspended.
19	PGND, Exposed Pad	Power Ground. Connect the exposed pad and GND pin to the same ground plane.
20	SW	Switch Output Node.
21, 22	SYS	System Output. **Please make sure the enough bulk capacitors from SYS to GND. Suggest 4.7uF at least.**
23	MODE	Mode Select. Logic HIGH→boost mode. Logic LOW→sleep mode. Active only when $\overline{ACOK}$ is HIGH (input power is not available).
24	EN	Charge Control Input. Logic HIGH enables charging. Logic LOW disables charging. Active only when $\overline{ACOK}$ is low (input power is OK)

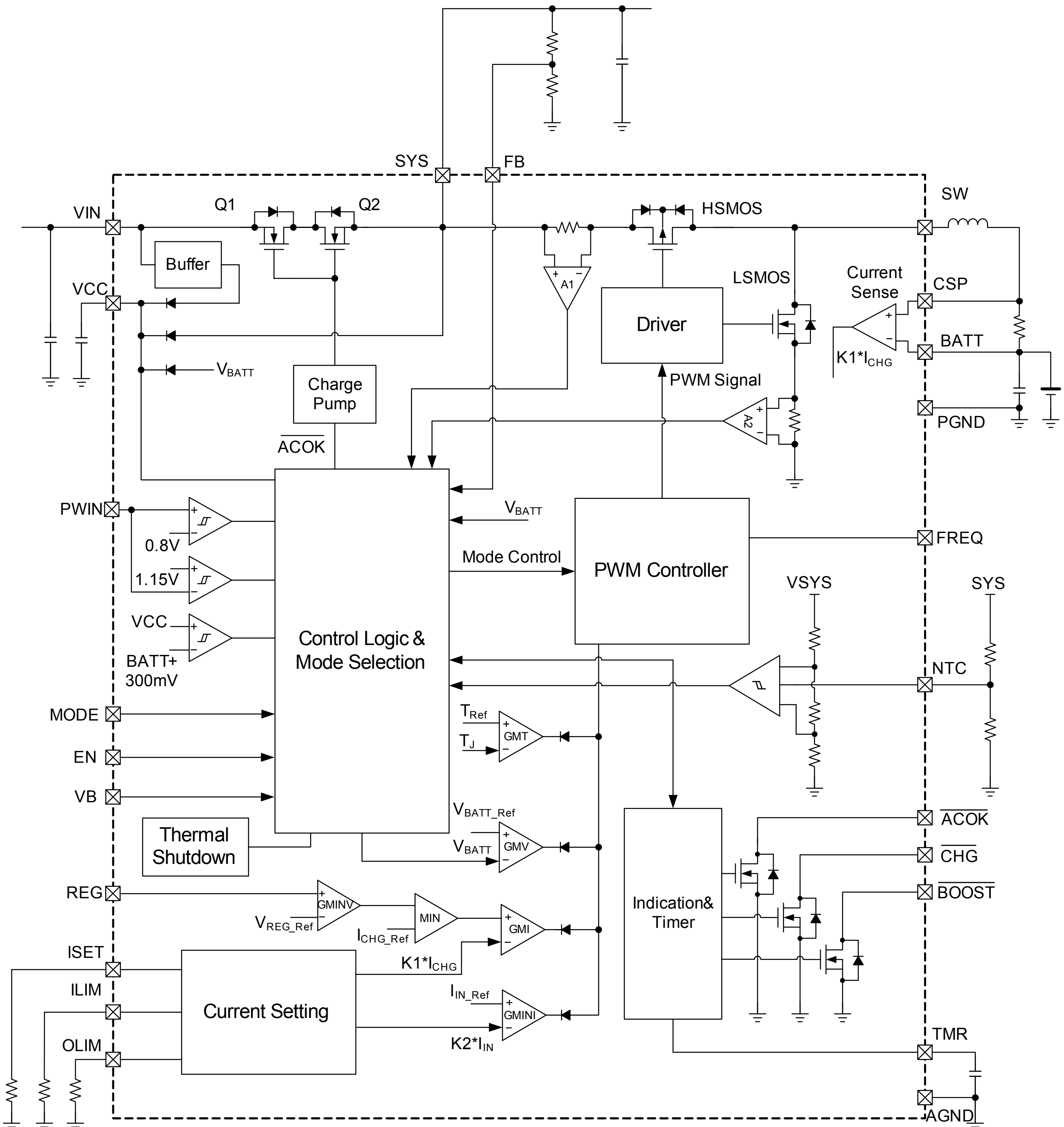


Figure 1: Functional Block Diagram in Charge Mode

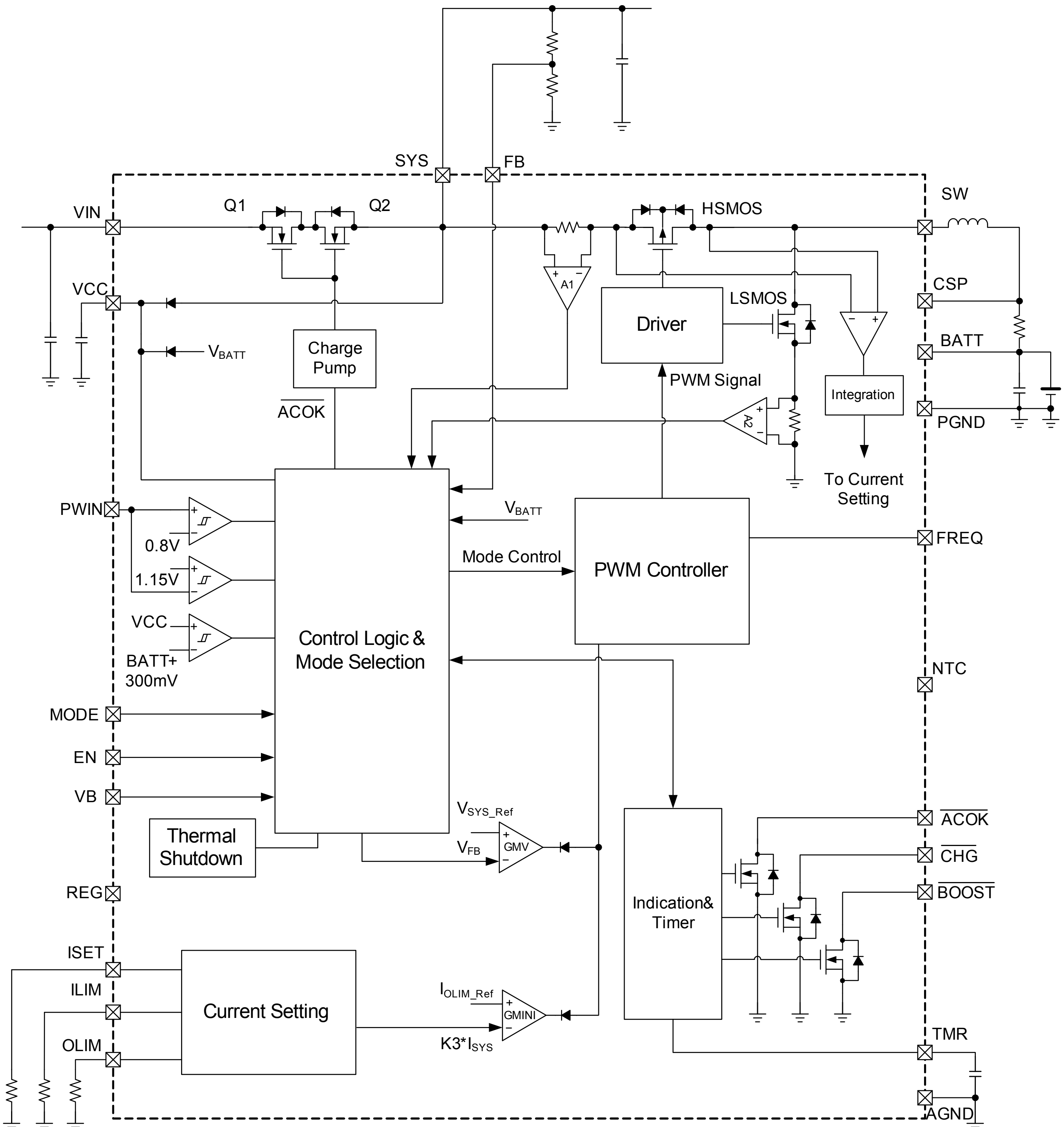


Figure 2: Functional Block Diagram in Boost Mode

OPERATION FLOW CHART

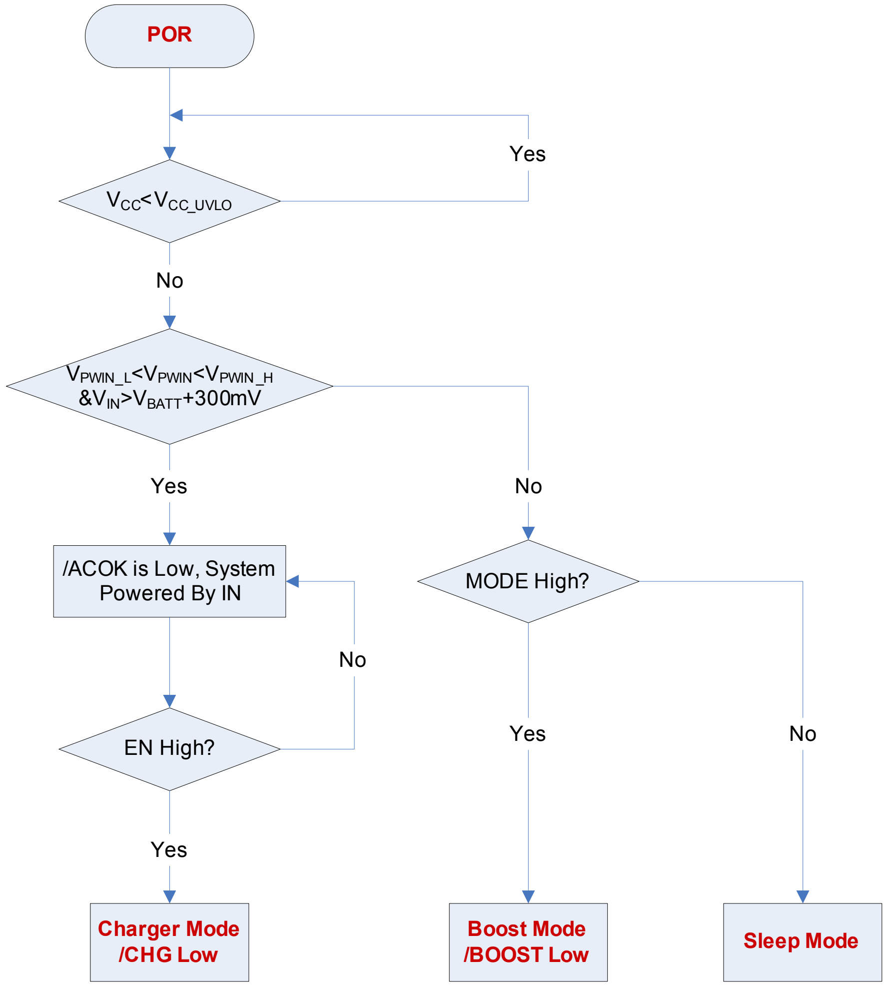


Figure 3: Mode Selection Flow Chart

OPERATION FLOW CHART *(continued)*

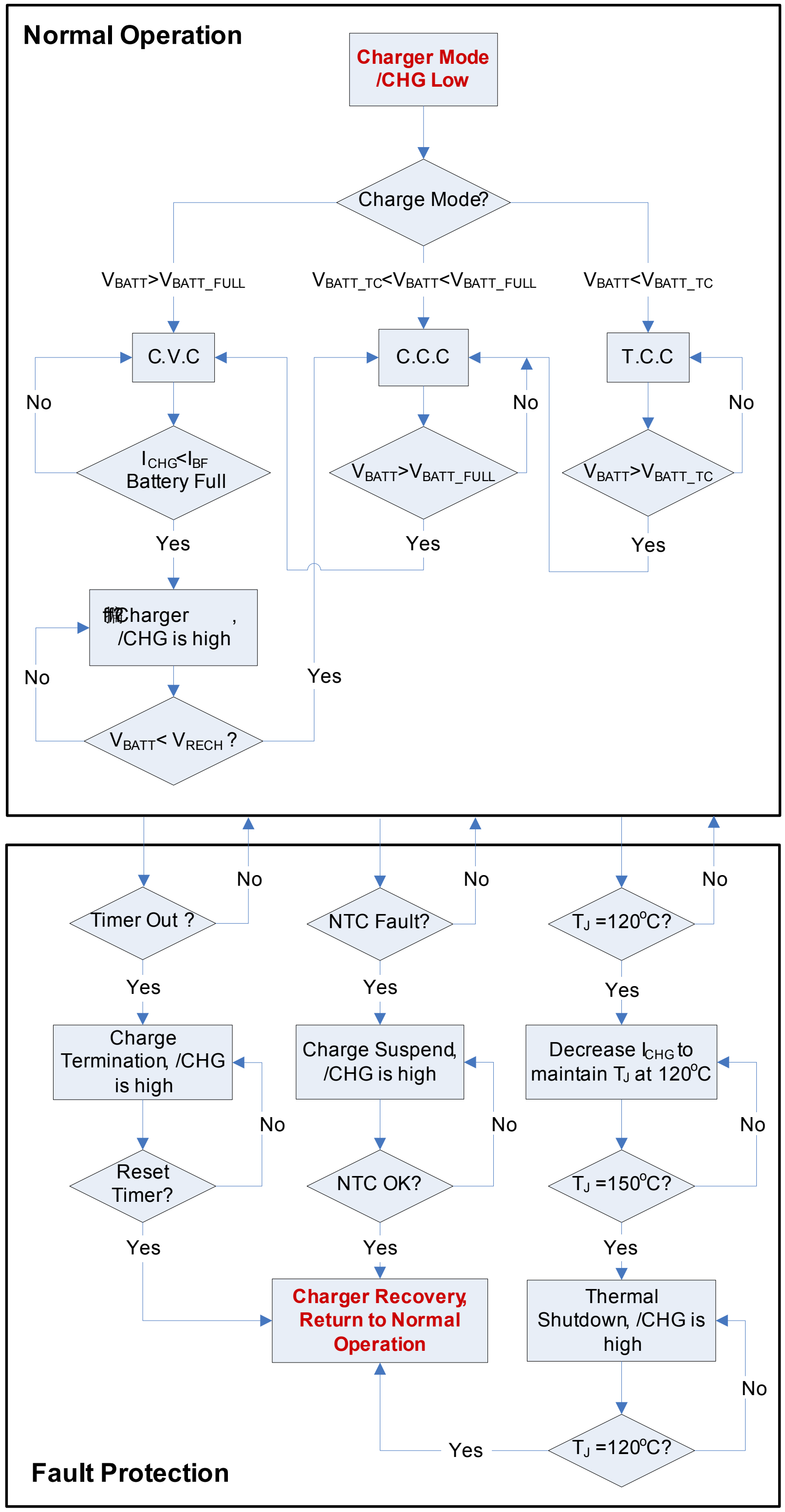


Figure 4: Normal Operation and Fault Protection in Charge Mode

OPERATION FLOW CHART *(continued)*

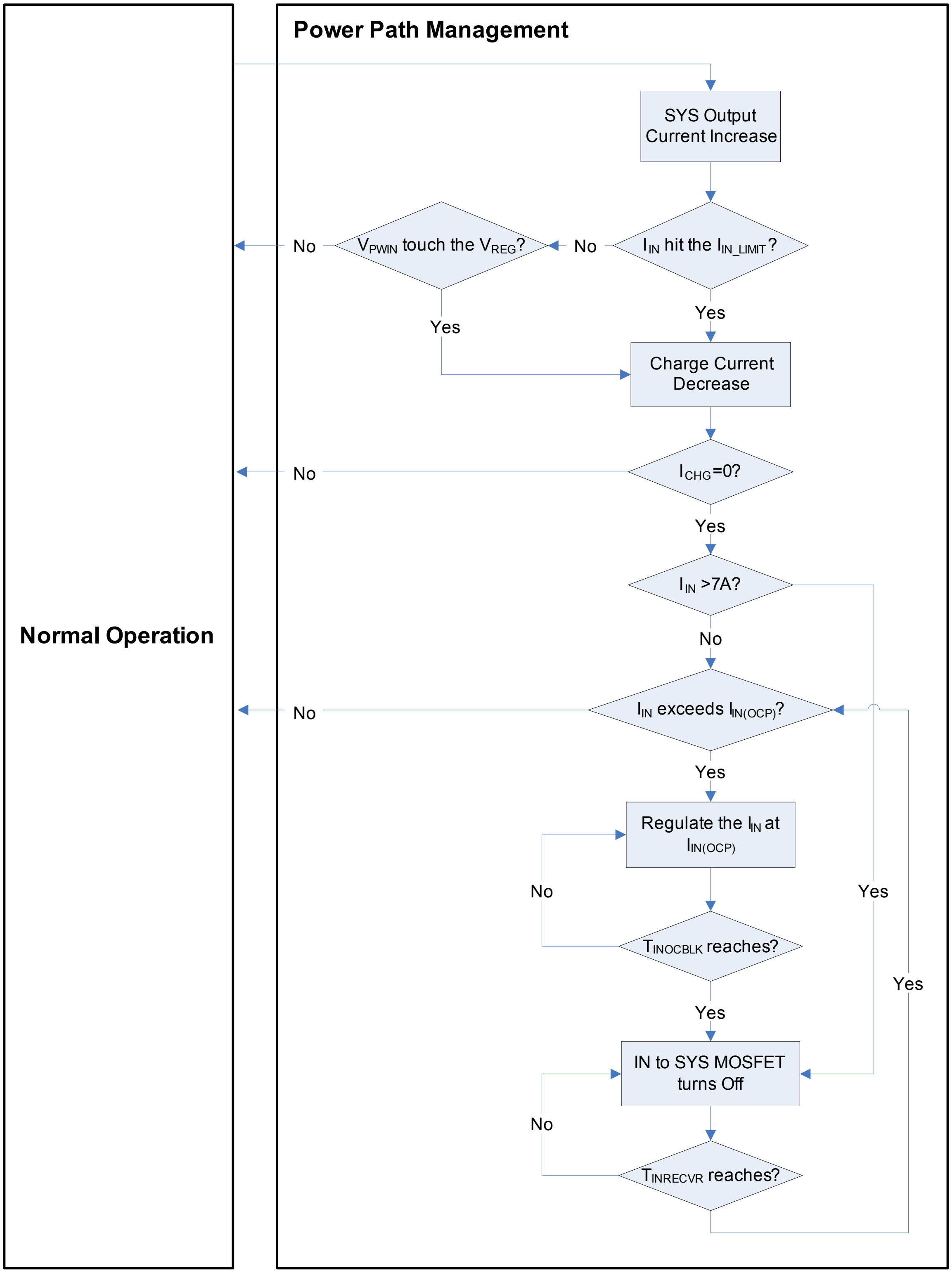


Figure 5: Power-Path Management in Charge Mode

OPERATION FLOW CHART *(continued)*

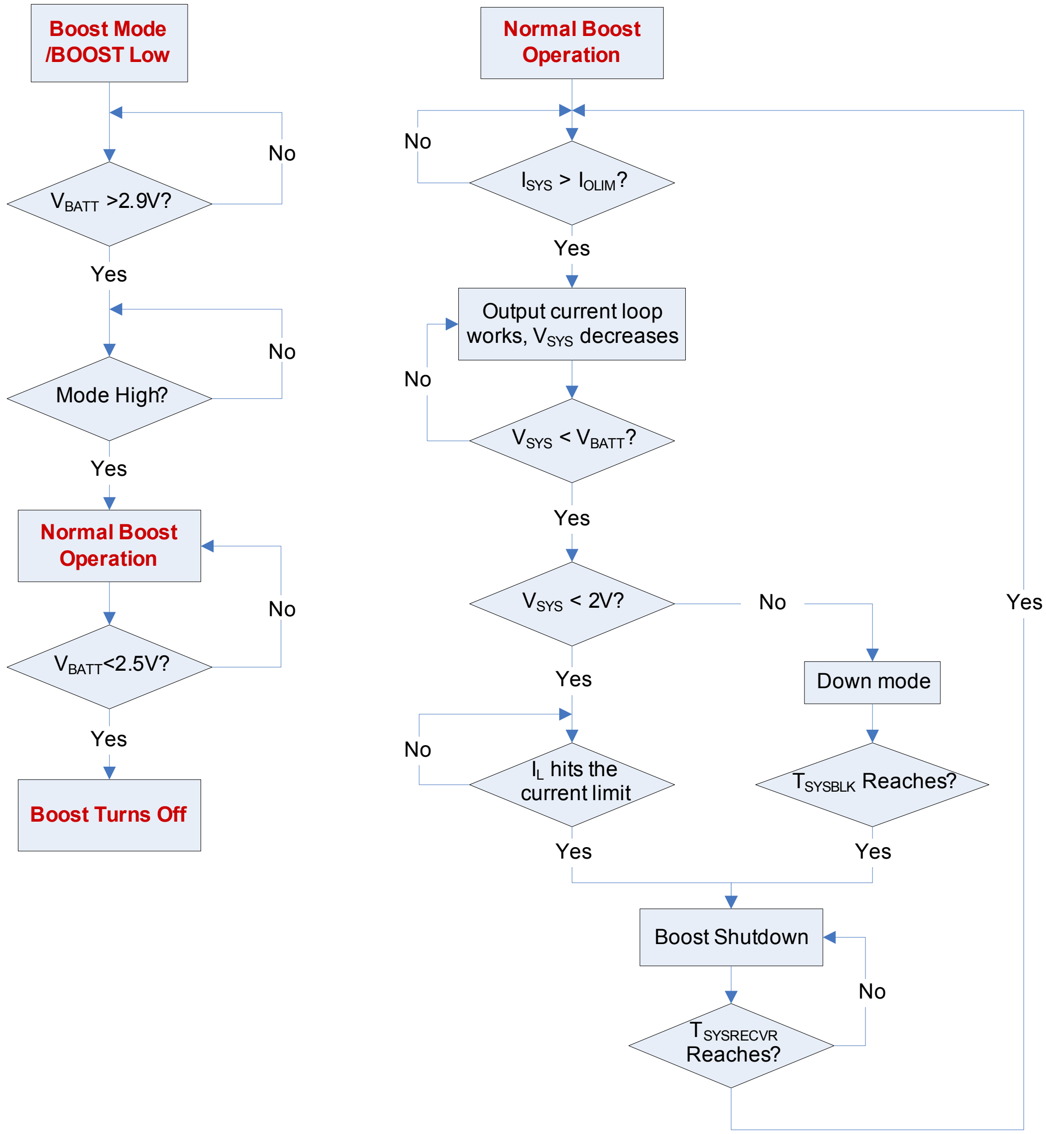


Figure 6: Operation Flow Chart in Boost Mode

START UP TIME FLOW IN CHARGE MODE

Condition: EN = 5V, Mode = 0V, /ACOK and /CHG are always pulled up to an external constant 5V

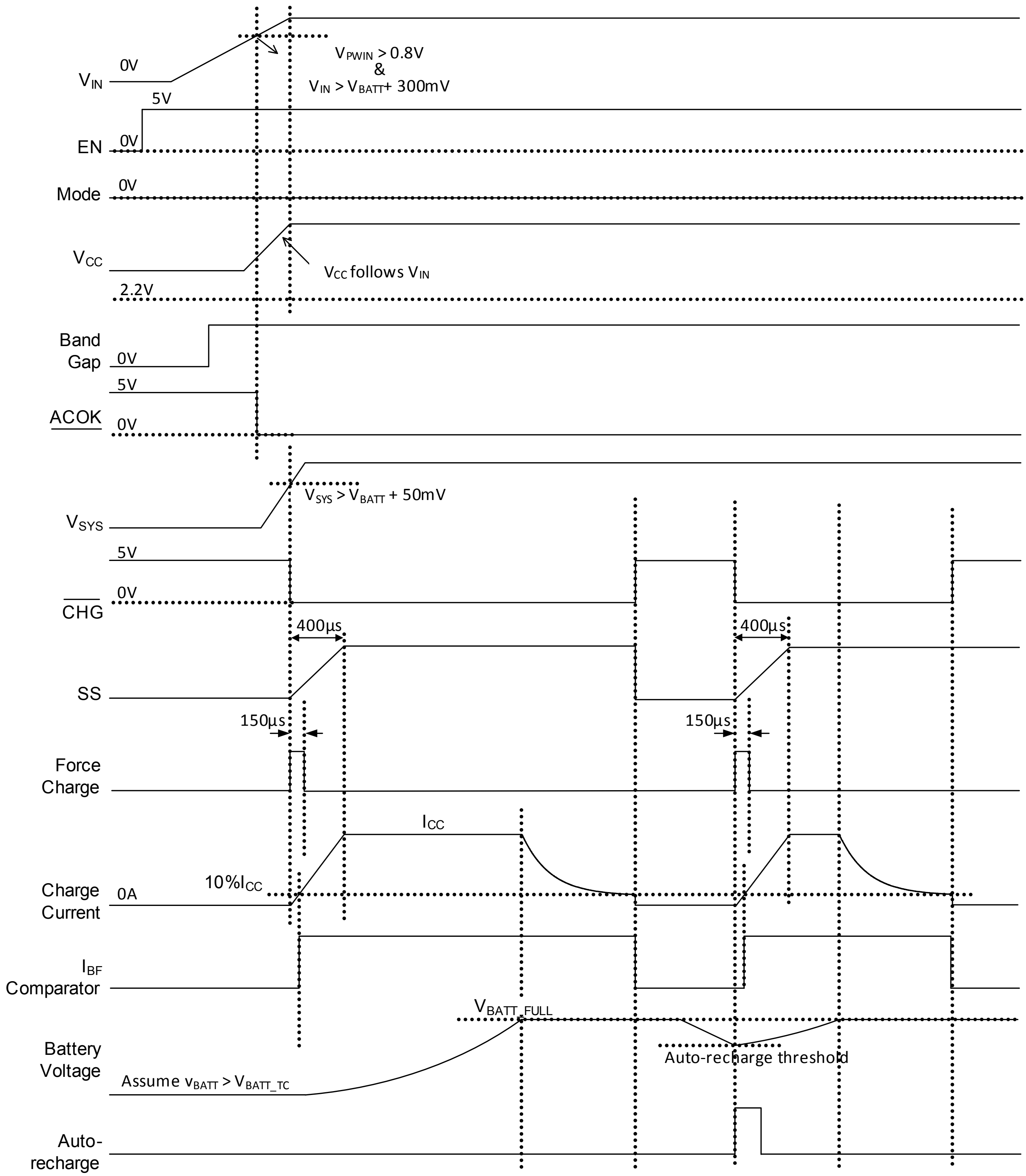


Figure 7: Input Power Start-Up Time Flow in Charge Mode

START UP TIME FLOW IN CHARGE MODE

Condition: V_{IN} = 5V, Mode = 0V, /ACOK and /CHG are always pulled up to an external constant 5V.

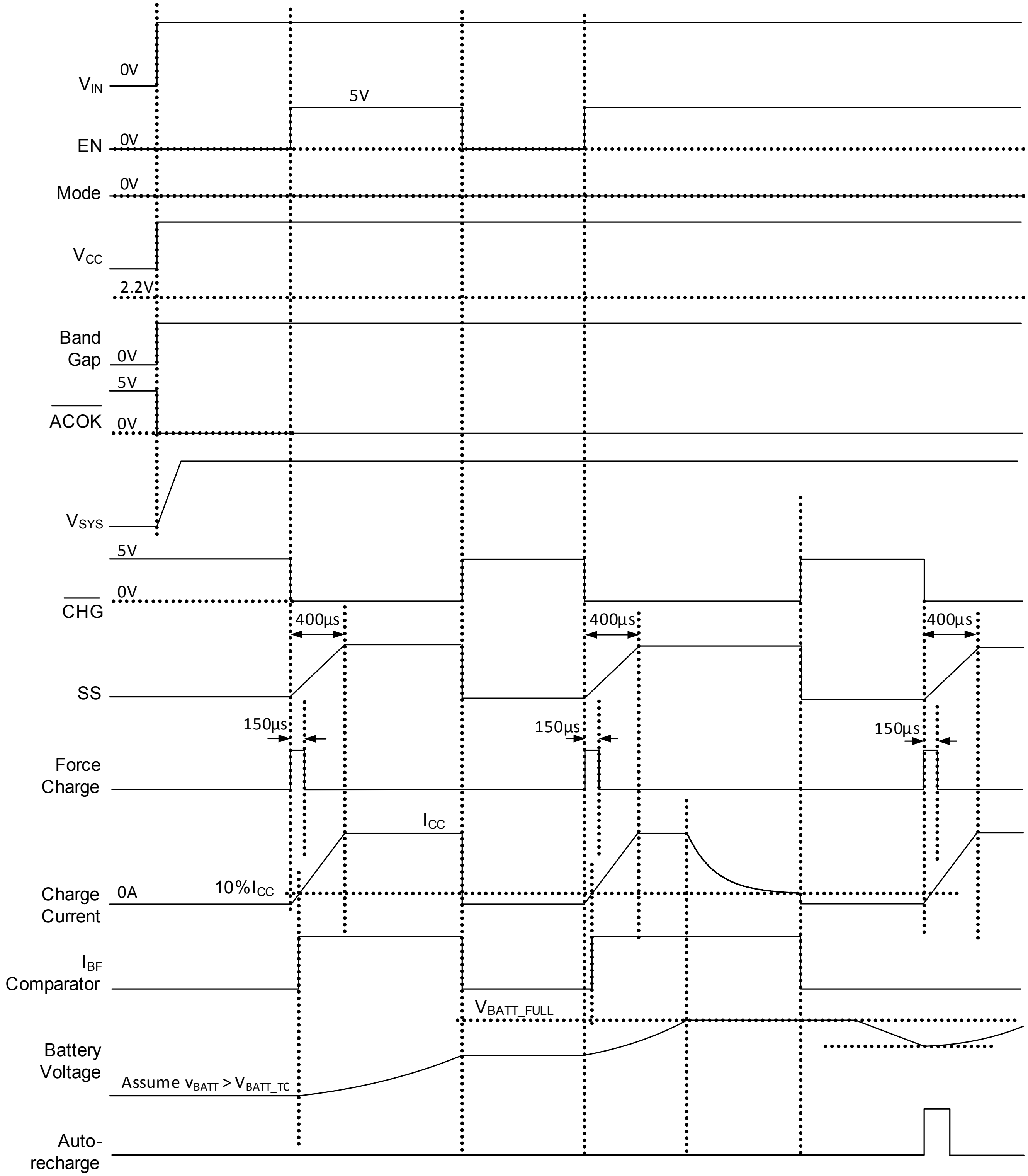


Figure 8: EN Start-Up Time Flow in Charge Mode

START UP TIME FLOW IN BOOST MODE

Condition: V_{IN} = 0V, Mode = 5V, /Boost is always pulled up to an external constant 5V.

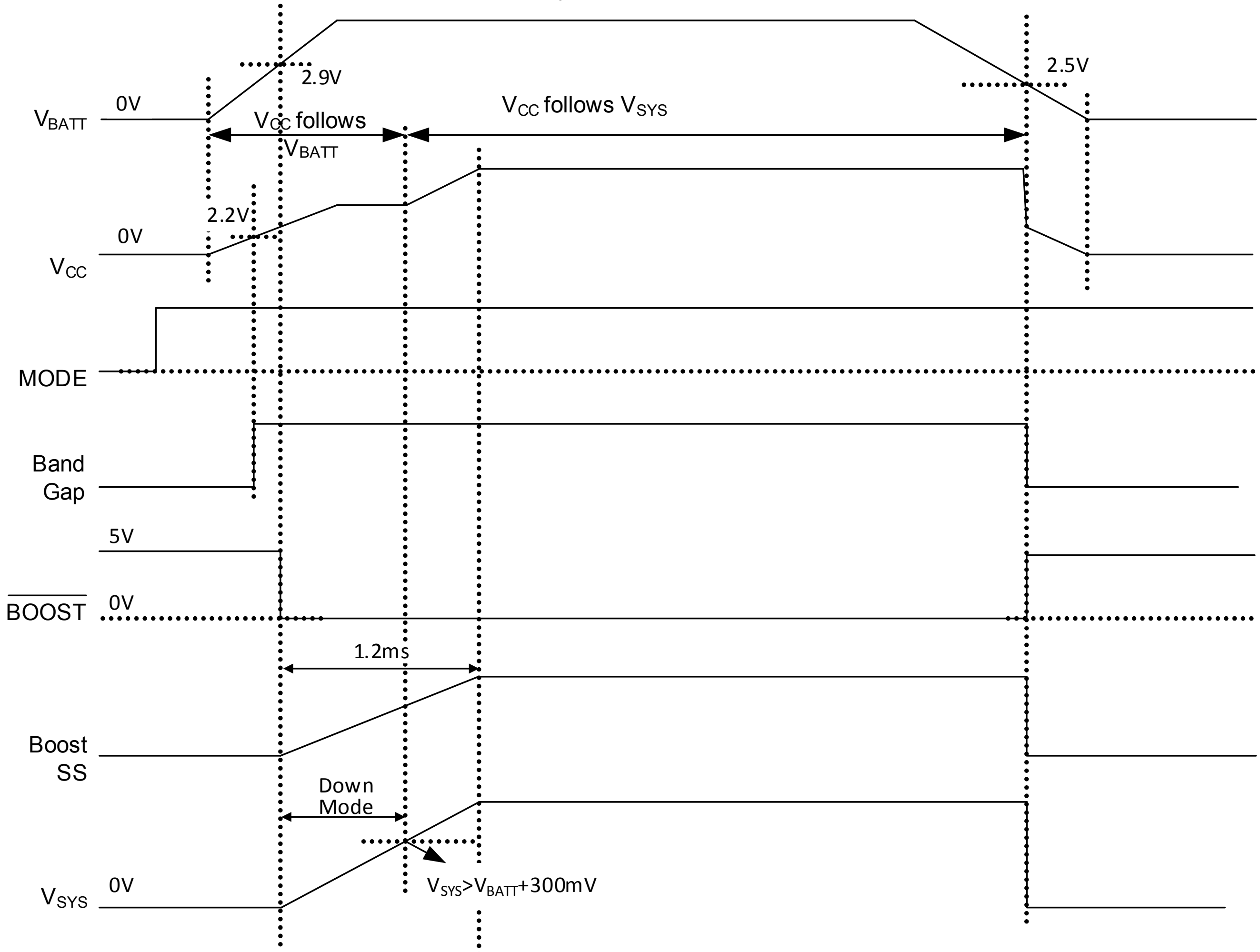


Figure 9: Battery Power Start-Up Time Flow in Boost Mode

START UP TIME FLOW IN BOOST MODE

Condition: V_{IN} = 0V, /Boost is always pulled up to an external constant 5V.

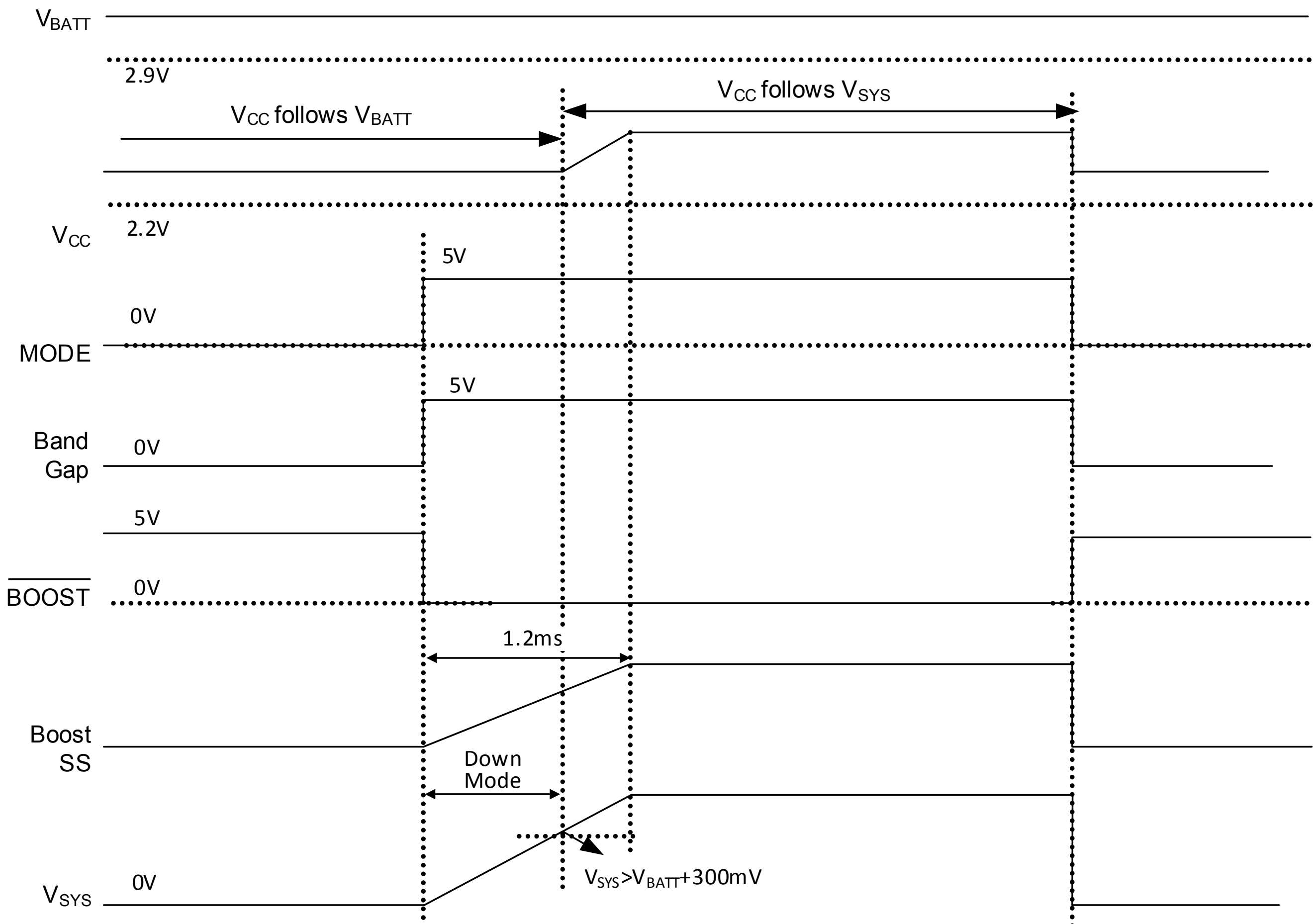


Figure 10: Mode Start-Up Time Flow in Boost Mode

OPERATION

INTRODUCTION

The MP2633 is a highly-integrated, synchronous, switching charger with bi-directional operation for a boost function that can step-up the battery voltage to power the system. Depending on the VIN value, it operates in one of three modes: charge mode, boost mode and sleep mode. In charge mode, the MP2633 supports a precision Li-ion or Li-polymer charging system for single-cell applications. In boost mode, MP2633 boosts the battery voltage to V_{SYS} to power higher-voltage systems. In sleep mode, the MP2633 stops charging or boosting and operates at a low current from the input or the battery to reduce power consumption when the IC isn't operating. The MP2633 monitors VIN to allow smooth transition between different modes of operation.

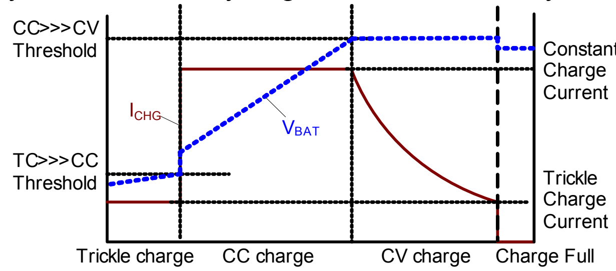
CHARGE MODE OPERATION

Charge Cycle (Trickle Charge→CC Charge→CV Charge)

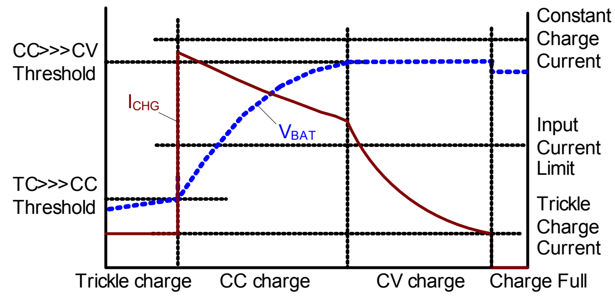
In charge mode, the MP2633 has five control loops to regulate the input current, input voltage, charge current, charge voltage, and device junction temperature. It charges the battery in three phases: trickle current (TC), constant current (CC), and constant voltage (CV). While charging, all four loops are active but only one determines the IC behavior. Figure 11(a) shows a typical battery charge profile. The charger stays in TC charge mode until the battery voltage reaches a TC-to-CC threshold. Otherwise the charger enters CC charge mode. When the battery voltage rises to the CV-mode threshold, the charger operates in constant voltage mode. Figure 11 (b) shows a typical charge profile when the input-current-limit loop dominates during the CC charge mode, and in this case the charge current exceeds the input current, resulting in faster charging than a traditional linear solution that is well-suited for USB applications.

Auto-Recharge

Once the battery charge cycle completes, the charger remains off. During this process, the system load may consume battery power, or the battery may self discharge. To ensure that the battery will not go into depletion, a new charge cycle automatically begins when the battery



a) Without input current limit



b) With input current limit

Figure 11: Typical Battery Chargenging Profile

voltage falls below the auto-recharge threshold and the input power is present. The timer resets when the auto-recharge cycle begins.

During the off state after the battery is fully charged, if the input power re-starts or the EN signal refreshes, the charge cycle will start and the timer will reset no matter what the battery voltage is.

Battery Over-Voltage Protection

The MP2633 has battery over-voltage protection. If the battery voltage exceeds the battery over-voltage threshold, (103.3% of the battery-full voltage), charging is disabled. Under this condition, an internal current source draws a current from the BATT pin to decrease the battery voltage and protect the battery.

Timer Operation in Charge Mode

The MP2633 uses an internal timer to terminate the charging. The timer remains active during the charging process. An external capacitor between TMR and GND programs the charge cycle duration.

If charging remains in TC mode beyond the trickle-charge time τ_{TOTAL_TMR}, charging will terminate. The following determines the length of the trickle-charge period:

$$\tau_{TRICKLE\_TMR} = 60\,\text{mins} \times \frac{C_{TMR}(\mu F)}{0.1\mu F} \times \frac{1A}{I_{CHG}(A)} \quad \textbf{(1)}$$

The maximum total charge time is:

$$\tau_{TOTAL\_TMR} = 6\text{Hours} \times \frac{C_{TMR}(\mu F)}{0.1\mu F} \times \frac{1A}{I_{CHG}(A)} \quad \textbf{(2)}$$

Negative Temperature Coefficient (NTC) Input for Battery Temperature Monitoring

The MP2633 has a built-in NTC resistance window comparator, which allows the MP2633 to monitor the battery temperature via the battery-integrated thermistor. Connect an appropriate resistor from V_{SYS} to the NTC pin and connect the thermistor from the NTC pin to GND. The resistor divider determines the NTC voltage depending on the battery temperature. If the NTC voltage falls outside of the NTC window, the MP2633 stops charging. The charger will then restart if the temperature goes back into NTC window range.

Input-Current Limiting in Charge Mode

The MP2633 has a dedicated pin that programs the input-current limit. The current at ILIM is a fraction of the input current; the voltage at ILIM indicates the average input current of the switching regulator as determined by the resistor value between ILIM and GND. As the input current approaches the programmed input current limit, charge current is reduced to allow priority to system power.

Use the following equation to determine the input current limit threshold,

$$I_{ILIM} = \frac{40.5(k\Omega)}{R_{ILIM}(k\Omega)}(A) \quad \textbf{(3)}$$

Input Over-Current Protection

The MP2633 features input over-current protection (OCP): when the input current exceeds 3A, Q2 is controlled linearly to regulate the current. If the current still exceeds 3A after a 120µs blanking time, Q2 will turn off. A fast off function turns off Q2 quickly when the input current exceeds 7A to protect both Q1 and Q2.

Input Voltage Regulation in Charge Mode

In charge mode, if the input power source is not sufficient to support both the charge current and system load current, the input voltage will decrease. As the input voltage approaches the programmed input voltage regulation value, charge current is reduced to allow priority of system power and maintain the input voltage avoid dropping further.

The input voltage can be regulated by a resistor divider from VIN pin to REG pin to AGND according to the following expression:

$$V_{IN\_R} = V_{REG} \times \frac{R3 + R5}{R5} \quad (4)$$

Where: the VREG is the internal voltage reference, 1.2V.

Setting the Charge Current

The external sense resistors, RS1 and R_{ISET}, program the battery charge current, I_{CHG}. Select R_{ISET} based on RS1:

$$I_{CHG}(A) = \frac{70(k\Omega)}{R_{ISET}(k\Omega)} \times \frac{40(mV)}{RS1(m\Omega)} \quad \textbf{(5)}$$

Where: the 40mV is the charge current limit reference.

Battery Short Protection

The MP2633 has two current limit thresholds. CC and CV modes have a peak current limit threshold of 3A, while TC mode has a current limit threshold of 1.5A. Therefore, the current limit threshold decreases to 1.5A when the battery voltage drops below the TC threshold. Moreover, the switching frequency also decreases when the BATT voltage drops to 40% of the charge-full voltage.

Thermal Foldback Function

The MP2633 implements thermal protection to prevent thermal damage to the IC and the surrounding components. An internal thermal sense and feedback loop automatically decreases the programmed charge current when the die temperature reaches 120°C. This function is called the charge-current-thermal foldback. Not only does this function protect against thermal damage, it can also set the charge current based on requirements rather than worst-case conditions while ensuring safe operation. Furthermore, the part includes thermal shutdown protection where the ceases charging if the junction temperature rises to 150°C.

Fully Operation Indication

The MP2633 integrates indicators for the following conditions as shown in Table 2.

Table 2: Indicator for Each Operation Mode

Operation		$\overline{\text{ACOK}}$	$\overline{\text{CHG}}$	$\overline{\text{BOOST}}$
Charge Mode	Charging	Low	Low	High
	End of Charge, charging disabled		High	
	NTC Fault, Timer Out		Blinking	
Boost Mode		High	High	Low
Sleep Mode, VCC absent		High	High	High

BOOST MODE OPERATION

Low-Voltage Start-Up

The minimum battery voltage required to start up the circuit in boost mode is 2.9V. Initially, when V_{SYS} < V_{BATT}, the MP2633 works in down mode. In this mode, the synchronous P-MOSFET stops switching and its gate connects to V_{BATT} statically. The P_MOSFET keeps off as long as the voltage across the parasitic C_{DS} (V_{SW}) is lower than V_{BATT}. When the voltage across C_{DS} exceeds V_{BATT}, the synchronous P-MOSFET enters a linear mode allowing the inductor current to decrease and flowing into the SYS pin. Once V_{SYS} exceeds V_{BATT}, the P-MOSFET gate is released and normal closed-loop PWM operation is initiated. In boost mode, the battery voltage can drop to as low as 2.5V without affecting circuit operation.

SYS Disconnect and Inrush Limiting

The MP2633 allows for true output disconnect by eliminating body diode conduction of the internal P-MOSFET rectifier. V_{SYS} can go to 0V during shutdown, drawing no current from the input source. It also allows for inrush current limiting at start-up, minimizing surge currents from the input supply. To optimize the benefits of output disconnect, avoid connecting an external Schottky diode between the SW and SYS pins.

Board layout is extremely critical to minimize voltage overshoot at the SW pin due to stray inductance. Keep the output filter capacitor as close as possible to the SYS pin and use very low ESR/ESL ceramic capacitors tied to a good ground plane.

Boost Output Voltage

In the boost mode, the MP2633 programs the output voltage via the external resistor divider at FB pin, and provides built-in output over-voltage protection (OVP) to protect the device and other components against damage when V_{SYS} goes beyond 6V. Should output over-voltage occur, the MP2633 turns off the boost converter. Once V_{SYS} drops to a normal level, the boost converter restarts again as long as the MODE pin remains in active status.

Boost Output-Current Limiting

The MP2633 integrates a programmable output current limit function in boost mode. If the boost output current exceeds this programmable limit threshold, the output current will be limited at this level and the SYS voltage will start to drop down. The OLIM pin programs the current limit threshold up to 1.5A as per the following equation:

$$I_{OLIM}(A) = \frac{70(k\Omega)}{R_{OLIM}(k\Omega)} \times \frac{40(mV)}{RS1((m\Omega)} \times 1.7 \quad \textbf{(6)}$$

Where: the 40mV is the charge current limiting reference.

SYS Output Over Current Protection

The MP2633 integrates three-phase output over-current protection.

Phase one (boost mode): when the output current exceeds the output current limit, the