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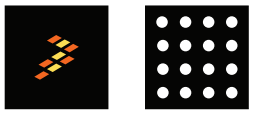
Document Number: MC32BC3770
Rev. 1.0, 7/2016

2.0 A switch-mode charger with intelligent power-path for 1-cell li-ion battery

BC3770

BATTERY CHARGER



CS SUFFIX
98ASA00848D
25 WLCSP

The BC3770 is a fully programmable switching charger with dual-path output for single-cell Li-Ion and Li-Polymer battery. This dual-path output allows mobile applications with fully discharged battery or dead battery to boot up the system. High-efficiency and switch-mode operation of the BC3770 reduce heat dissipation and allow for higher current capability for a given package size. In addition, the BC3770 features single input with a 20 V withstanding input and charges the battery with the current up to 2.0 A. The charging parameters and operating modes are fully programmable over an I^2C Interface that operates up to 400 kHz.

The BC3770 is a highly integrated synchronous switch-mode charger, featuring integrated OVP and Power FETs. The charger and boost regulator circuits switch at 1.5 MHz to minimize the size of external passive components. The BC3770 is able to operate as a boost regulator for USB-OTG function via either I^2C command or an external pin from the host/processor. The BC3770 is available in a 25-bump, 2.27 mm x 2.17 mm, WLCSP package.

Features

- Dual-path output to power-up system in dead battery
- Single input for USB/TA
- High-efficiency synchronous switching regulator
- 20 V maximum withstanding input voltage
- Minimize the charging time with remote sense
- Up to 2.0 A load current for system or battery
- Programmable charge parameters via I^2C compatible interface
- 400 kHz full-speed I^2C interface
- 1.5 MHz switching frequency
- Charge reduction mode for maximizing charging efficiency

Applications

- Internet of things (IoT)
- Handheld consumer devices
- Wearable application
- mPOS terminals
- Medical portable equipment
- Consumer tablets

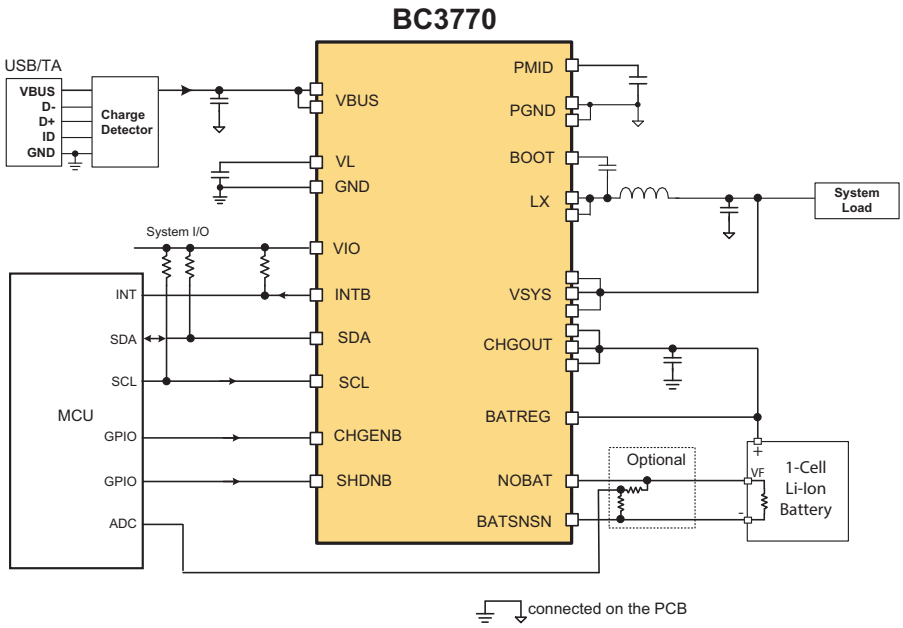


Figure 1. BC3770 simplified application diagram

* This document contains certain information on a new product.
Specifications and information herein are subject to change without notice.

1 Orderable parts

Table 1. Orderable part variations

Part number	Temperature (T_A)	Package
MC32BC3770CSR2	-40 °C to 85 °C	25 WLCSP, 2.27 mm x 2.17 mm, 0.4 pitch

2 Internal block diagram

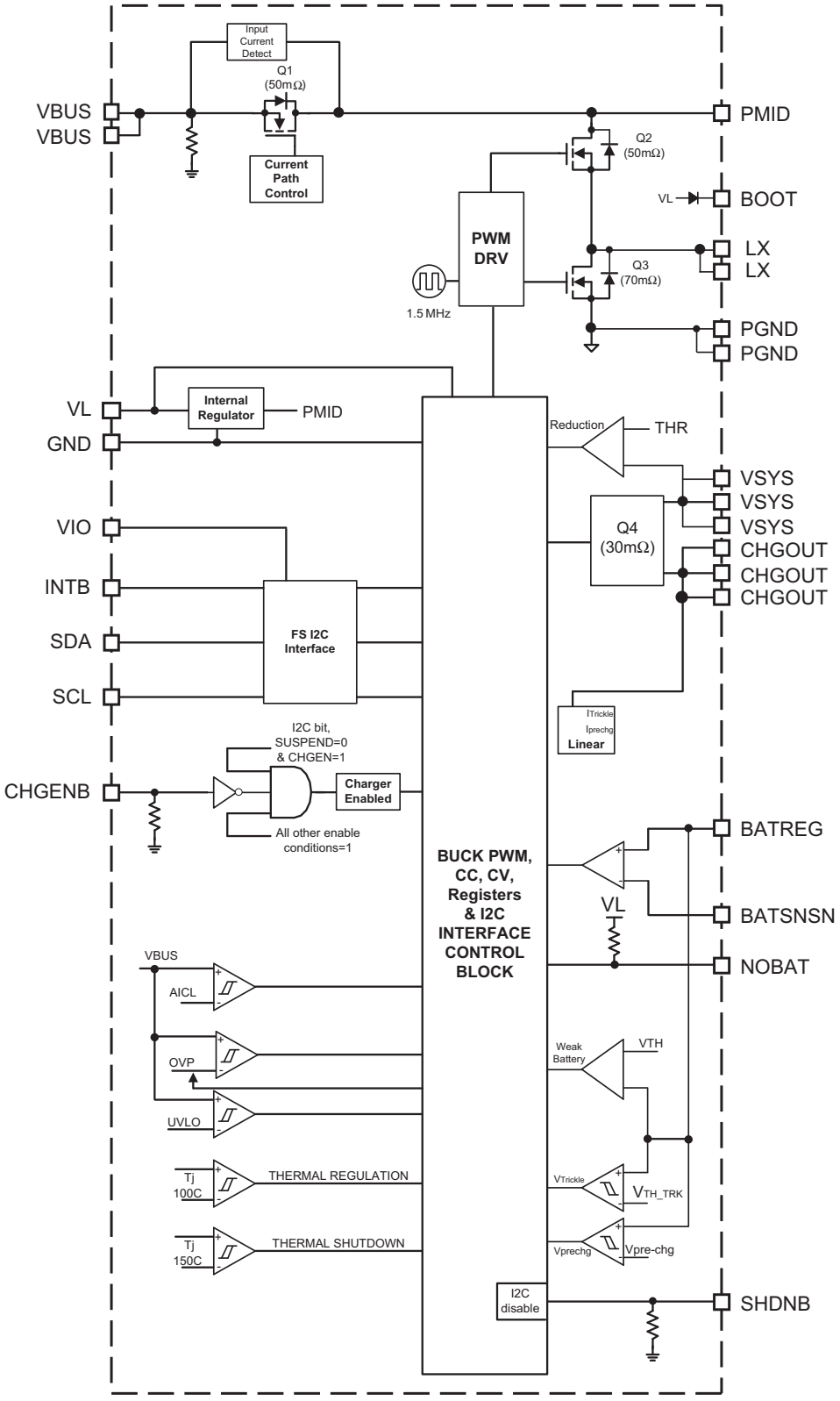


Figure 2. BC3770 simplified internal block diagram

3 Pin connections

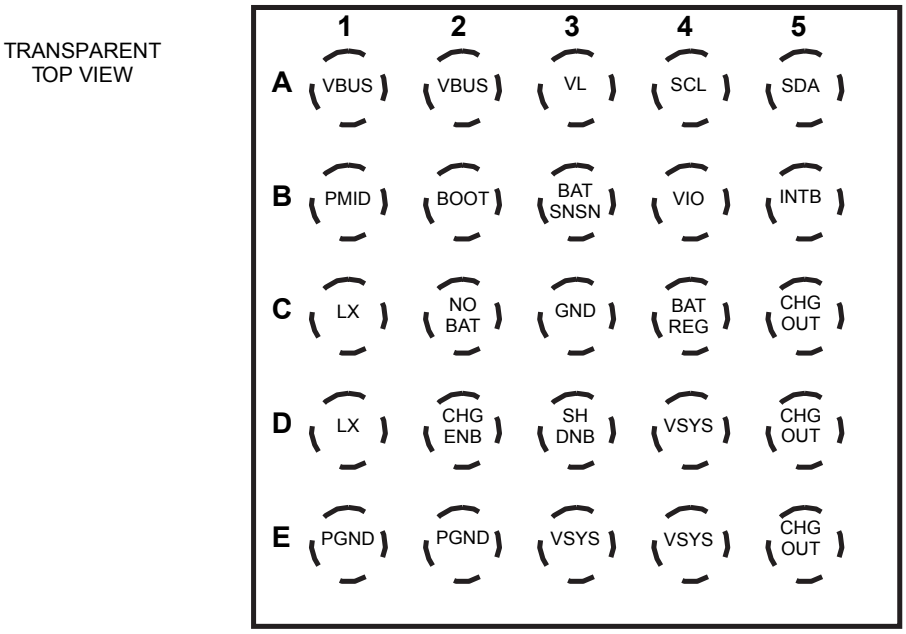


Figure 3. BC3770 pin connections (transparent top view)

Functional descriptions of many of these pins can be found in the Functional Pin Description section beginning on page 13.

Table 2. BC3770 pin definitions

Pin	Pin name	Pin function	Formal name	Definition
A1, A2	VBUS	Input	USB/DCP Adapter Input	Connect the pins to the output of USB or DCP (dedicated Charging Port) adapter. Bypass with a 2.2 µF/10 V ceramic capacitor to the ground, in case the peak voltage on the pins is always below 10 V due to a clamp device. Otherwise, a 2.2 µF/25 V or higher rating capacitor is recommended. The two VBUS pins must be connected together externally. These pins are used as an output in OTG mode. An embedded 100 kΩ discharge resistance is enabled in Charge mode. It is disconnected in the Boost mode.
A3	VL	Output	Internal Regulator Output	The analog output for internal reference, bandgap and so on. DO NOT LOAD. Bypass with a 1.0 µF/10 V to ground.
A4	SCL	Input	Clock Input for FS I^2C Serial Interface with the Processor	Use a pull-up resistor, 1.5 kΩ to 2.2 kΩ, to the VIO.
A5	SDA	Input/ Output	Data I/O for FS I^2C Serial Interface with the Processor	Use a pull-up resistor, 1.5 kΩ to 2.2 kΩ, to the VIO.
B1	PMID	Output	VBUS Bypass Output	High-side MOSFET connection node and VBUS bypass output. Bypass with a 2.2 µF ceramic capacitor to PGND pins as close as possible. Do NOT LOAD any external applications.
B2	BOOT		High-side MOSFET Driver Supply	Bypass BOOT to LX with a 22 nF/10 V ceramic capacitor.
B3	BATSNSN		Battery - Terminal Sensing	Connect to negative terminal of battery cell as close as possible. If a sense resistor is used for a fuel gauge, connect the pin to the ground terminal of the sense resistor.
B4	VIO		Supply for Internal Buffer	Connect to the system I/O supply voltage rail.

Table 2. BC3770 pin definitions (continued)

Pin	Pin name	Pin function	Formal name	Definition
B5	INTB	Output	Logic Output for Interrupt	An open-drain output with an external pull-up resistor, 200 kΩ, to the system I/O supply. Active-low when status change on interrupt registers occurs.
C1, D1	LX		Switching Node	Connect a 1.0 μH inductor. The two LX pins must be connected together externally.
C2	NOBAT	Input	Logic Input for Battery Presence Detection	Connect the pin to VF or ID pin on the battery cell. It has an internal pull-up resistance, 300 kΩ typ, to the VL. If a logic-high threshold is detected on the pin, the charging is suspended immediately. If this pin is not used, connect it to ground.
C3	GND	Ground	Device Ground	Must be connected to the system ground.
C4	BATREG		Battery + Terminal Sensing	Connect to positive terminal of battery cell as close as possible.
C5, D5, E5	CHGOUT	Output	Battery Charger Output	These pins must be connected together externally. Bypass with a 4.7 μF/10 V or higher to ground.
D2	CHGENB	Input	Charger Enable Logic Input	Logic-low to enable charger. Logic-high to disable the charger, not to disable buck converter. It has an internal 300 kΩ resistance to ground. If this pin is not used, leave it open or connect it to ground. The serial interface, I^2C, is still available in CHGENB = High.
D3	SHDNB	Input	Logic Input for Disabling I^2C Interface	If there is no valid input source, logic-low is to put the I^2C interface into Disabled mode to reduce the idle current as low as possible. In the Shutdown mode, I^2C interface is not available but the Q4 FET is kept ON. A valid power source on VBUS is able to overwrite to wake-up the device for Charge mode even in SHDNB = Low. This pin is not effective as long as a valid input power source is present. This pin has an internal pull-down resistance, 300 kΩ typ. If this pin is not used, tie it to the system I/O supply rail or an appropriate rail to reduce idle current as low as possible.
D4, E3, E4	VSYS	Output	System Supply Output	VSYS is the power supply for the system load. When a valid power source at VBUS is attached, VSYS is regulated at 3.6 V until the BATREG hits the threshold of V_{SYS_MIN} x $R_{DS(on)\_Q4}$. When the +Terminal on the battery cell is regulated at VBATREG, the VSYS output is regulated to the I_{FAST_CHG} x $R_{DS(on)\_Q4}$ above BATREG. Bypass with a 10 μF/10 V ceramic capacitor to ground.
E1, E2	PGND	Ground	Power Ground for the Buck Converter	The two PGND pins must be connected together externally.

4 Electrical characteristics

4.1 Maximum ratings

Stress(es) beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the following operational sections of the specifications is not implied. Exposure to absolute maximum rating condition(s) for extended periods may affect device reliability.

Table 3. Maximum ratings

All voltages are with respect to ground unless otherwise noted.

Symbol	Rating	Min.	Max.	Unit	Notes
Electrical ratings					
	VBUS, PMID to GND	-0.3	20	V	(1)
	LX to GN	-0.3	20	V	(1)
	BOOT to LX	-0.3	5.5	V	(1)
	BOOT to GND	-0.3	25.5	V	
	PGND, BATSNSN to GND	-0.3	0.3	V	(1)
	VL to GND	-0.3	5.5	V	
	VSYS, CHGOUT, BATREG to GND	-0.3	Continuous 6.0	V	
	PGND to GND	-0.3	0.3	V	(1)
	All Other Pins to GND	-0.3	5.5		(1)
V_{ESD1} V_{ESD3}	ESD Voltage • Human Body Model (HBM) • Machine Model	 — —	 2000 200	V	 (2) (3)
Thermal ratings					
	Continuous Power Dissipation • $T_A \leq 25$ °C • $T_A \leq 70$ °C • $T_A \leq 85$ °C	 — — —	 2.08 1.14 0.832	W	
T_A	Operating Temperature • Ambient	-40	85	°C	
T_J	Maximum Temperature • Junction	—	150	°C	
T_{STG}	Storage Ambient Temperature	-65	150	°C	
T_{SOLDER}	Lead Soldering Temperature (within 10 s)	—	300	°C	
$T_{\theta JA}$	Thermal Resistance Junction to Ambient	—	48	°C/W	(4), (5)

Notes

1. GND: all of the PGND and GND should be within the limit.
2. Human Body Model (HBM) per JESD22-A114 for all pins
3. Highly depends on the PCB heat dissipation. Tested with the Thermal Characteristics test condition below.
4. T_A = 70 °C
5. Measured in still air, free convection condition (conforms to EIA/JESD51-2) on high effective thermal conductivity JESD51-7 test board.

4.2 Electrical characteristics

Table 4. BC3770 electrical characteristics

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
VBUS supply						
V_{BUS_OP} V_{VIO_OP}	Operating Range • On VBUS • On VIO	 4.0 1.6	 — —	 6.2 3.3	 V	
V_{BUS_UVLO}	UVLO Threshold • VBUS rising, 200 mV Hysteresis, VBUSOK bit set to 1	3.6	3.8	4.0	V	
V_{BUS_OVP}	OVP Threshold • VBUS rising to turn off converter, 200 mV Hysteresis	6.3	6.5	6.7	V	(7)
V_{AICL_TH}	Adaptive-Input Current Limit (AICL) Threshold Range • VBUS falling, Programmable in 100 mV steps, 4.5 V Default	4.3	—	4.9	V	
I_{VBUS_OP}	Adaptive-Input Current Limit (AICL) Threshold Range • In charger enabled, I_{FAST_CHG} = I_{SYS} = 0 mA, SHDNB = H, SUSPEN = 0 LX No switching, V_{VSYS} = V_{BATREG} = 4.4 V override LX switching w/VSYS = 3.7 V in PWM • USB suspended mode in SUSPEN=1	 — — —	 2.0 15 —	 — — 1.0	 mA	
I_{IN_LIM}	Input Current Limit Programmable Range • 500 mA default, test 100 mA, 500 mA, 900 mA and 1.9 A only in production	100	—	2050	mA	
	IIN_LIM Accuracy • With respect to I_{IN_LIM} = 100 mA • With respect to I_{IN_LIM} = 500 mA • With respect to I_{IN_LIM} = 900 mA • With respect to I_{IN_LIM} = 2000 mA	 70 70 84 93	 85 85 92 100	 100 100 100 107	 %	(7)
	VBUS Pull-down Resistance • Off in BOOST Mode	—	100	—	kΩ	
VL LDO regulator						
V_{OUT_VLLDO}	Output Voltage • V_{PMID} = 5.0 V, I_{LOAD} = 30 mA	4.65	4.8	—	V	
I_{LOAD_LIM}	Current Limit • V_{VLLDO} = 3.8 V	50	—	—	mA	(7)
Switching regulator						
f_{SW}	Switching Frequency • In PWM mode	1.35	1.5	1.65	MHz	(7)
D_{MAX}	Maximum Duty Cycle	—	—	99	%	
D_{MIN}	Minimum Duty Cycle	0.0	—	—	%	
I_{LIM_CHG}	Cycle-by-cycle Current Limit for Charger Mode • For high-side MOSFET in charger mode	—	3.5	4.7	A	(7)
	Minimum Output Capacitance • For stability	-30%	10	—	µF	(7)

Notes

6. Specifications over the T_A range are assured by design, characterized, and correlated with process control.
7. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.

Table 4. BC3770 electrical characteristics (continued)

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
Power switches						
$R_{DS(on)\_Q1}$	Reverse Blocking MOSFET On-resistance • Q1 FET	—	50	—	mΩ	
$R_{DS(on)\_Q2}$	Internal High-side MOSFET On-resistance • Q2 FET	—	50	—	mΩ	
$R_{DS(on)\_Q3}$	Internal Low-side MOSFET On-resistance • Q3 FET	—	70	—	mΩ	
$R_{DS(on)\_Q4}$	CHGOUT to VSYS MOSFET On-resistance • Q4 FET	—	30	—	mΩ	
VSYS output						
V_{VSYS_MIN}	VSYS Min. Regulation Voltage in $I_{IN\_LIM} \geq I_{VSYS}$ • In both Trickle and pre-charge mode ($V_{BATREG} < V_{VSYS\_MIN}$), I_{SYS} = 500 mA	3.5	3.6	3.71	V	
$V_{VSYS\_MIN\_OLP}$	VSYS Min Regulation Voltage in $I_{IN\_LIM} < I_{VSYS}$ (VSYS overloaded) • VSYS falling in VSYS overloaded in VBUSOK = 1	3.3	3.4	—	V	
V_{VSYS_MAX}	SYS Max Regulation Voltage • In VBUSOK = 1, I_{SYS_LOAD} = 0 mA, I_{CHG} = 1.5 A	—	V_{BATREG} + I_{CHG} * R_{DSON_Q4}	V_{BATREG} + 0.1 V	V	
	VSYSOK Threshold • VSYS rising in VBUSOK = 1, VSYSOK bit set to 1	3.4	3.5	3.61	V	(8)
	VSYSNG Threshold • VSYS falling, VSYSNG bit set to 1	3.2	3.3	—	V	(8)
$V_{SYS\_REVERSE}$	Ideal Diode Regulation Voltage • VSYS falling below BATREG, I_{SYS_LOAD} = 3.0 A	—	V_{BATREG} - 50 mV	V_{BATREG} - 75 mV	V	(8)
$\Delta_{VSYSLOAD}$	Load Regulation in Transition • I_{SYS} = 1.0 mA to 1.0 A in t_R = 20 µs	V_{BATREG} - 0.2	V_{BATREG} - 0.1	—	V	(8)
V_{SYS_UVLO}	VSYS Undervoltage Lockout Threshold • VSYS falling, 200 mV Hysteresis	2.3	2.4	2.5	V	
$t_{DIODE-ON}$	Ideal Diode Turn-on Time	—	10	—	µs	
t_{DIODE_OFF}	Ideal Diode Turn-off Time	—	10	—	µs	
Battery charger						
V_{BATREG_RNG}	BATREG Programmable Voltage Range • Programmable in 25 mV steps	4.1	—	4.475	V	
V_{BAT_REG}	Voltage Accuracy • I_{FAST_CHG} = 0 mA, set to 4.2 V and 4.35 V at V_{BATREG} T_A = 25 °C T_A = -40 to 85≥	 -0.5 -1.0	 — —	 0.5 1.0	%	
V_{RCH}	Recharge Threshold • V_{BATREG} - V_{BAT_REG}	—	-100	—	mV	

Notes

8. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.
9. Designed and simulated according to I^2C specifications except general call support.
10. The regulation in boost is only guaranteed in the operation range.

Table 4. BC3770 electrical characteristics (continued)

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
Battery charger (continued)						
I_{BAT_STD}	Stand-By Current • No VBUS, V_{BATREG} = 4.2 V, I_{SYS} = 0 mA, SHDNB = H(I^2C active), Q4 = On with OCP enabled, ENCOMPARATOR bit reset to 0, others with default	—	60	—	µA	
I_{BAT_SHDN}	Shutdown Current • No VBUS, V_{BATREG} = 4.2 V, charger disabled, Q4 = On with OCP disabled, SHDNB = L (I^2C inactive), ENCOMPARATOR bit reset to 0, others with default	—	—	20	µA	
V_{CHGEN_ON} V_{CHGEN_OFF}	Charger Enable Threshold • V_{BUS} - V_{BATREG}, rising, valid VBUS detected to enable buck & charging • V_{BUS} - V_{BATREG}, falling, invalid VBUS detection to disable buck & charging	100 0.0	150 50	200 —	mV	(11)
$V_{TRICKLE}$	Trickle to Pre-charge Mode Change Threshold • V_{BATREG} rising, 100 mV Hysteresis	2.4	2.5	2.7	V	(11)
$I_{TRICKLE}$	Trickle Charge Current • Fixed, V_{BATREG} = 2.3 V, V_{SYS} = 3.6 V	—	90	—	mA	
I_{PRECHG}	Pre-charge Current Programmable Range • 450 mA default and test in production	150	—	450	mA	
I_{FAST_CHG}	Fast-charge Current Programmable Range • 500 mA default, test 500 mA, 1.0 A only in production	100	—	2000	mA	
I_{TOPOFF}	Top-off Current Programmable Range • I_{FAST_CHG} falling, 100 mA default, in 50 mA steps, test 100 mA and 300 mA only in production	100	—	65	mA	
V_{BAT_OVP}	Overvoltage Protection Threshold • BATREG rising	—	V_{BAT_REG} + 0.1	—	V	
	Soft-start Slope Time • In fast charge mode	—	1.17	—	mA/µs	
	Minimum Output Capacitance • On CHGOUT, For stability	-30%	4.7	—	µF	(11)
	Charge Current Accuracy • Pre-charge current at 150 mA • Top-off current at 100 mA • I_{FAST_CHG} = 1000mA • I_{FAST_CHG} = 2000mA	 -20 -20 -7.0 -7.0	 — — — —	 20 20 7.0 7.0	%	(11)
Thermal protection						
T_{SD}	Thermal Shutdown Temperature • Temperature rising to shutdown with 20 °C hysteresis	—	150	—	°C	(11)
T_{CF}	Thermal Regulation Threshold • Rising, charge current starts to reduce and the Interrupt triggered	—	100	—	°C	
	Thermal Regulation Gain • To have no charge current with respect to I_{FAST_CHG}, $T_J \geq 100$ °C	—	3.33	—	%/°C	

Notes

11. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.

Table 4. BC3770 electrical characteristics (continued)

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
Safety timer						
t_{PRECHG_TMR}	Pre-charge Timer • Time for BAT from $V_{TRICKLE}$ to V_{SYS_MIN}	—	45	—	min.	
	Timer Accuracy	-10	—	10	%	(12)
t_{TOPOFF_TMR}	Top-off Timer • Programmable	10	—	45	min.	
t_{FAST_TMR}	Fast Charge Timer • This timer is automatically disabled when the input current limit is set to 100 mA FASTTIME = 00 FASTTIME = 01 FASTTIME = 10 FASTTIME = 11 (default)	 — — — —	 3.5 4.5 5.5 disabled	 — — — —	hrs.	
Deglitch timer (12)						
t_{VBUS_OVP}	VBUS Supply OVP Release Deglitch Time • Duration VBUS stays below falling OVP before VSYS/Charger/OTG is enabled	—	0.426	—	ms	
t_{NOBAT}	NOBAT Release Deglitch Time • Duration V_{NOBAT} stays logic low to enable the charger	—	1.0	—	ms	
t_{BATOVP}	BATREG OVP Release Deglitch Time • Duration BATREG stays below falling OVP level to enable charger/OTG	—	7.0	—	ms	
$t_{TRICKLE}$	Trickle to Pre-charge Release Deglitch Time • Duration BATREG stays above trickle charge level to enable pre-charge	—	7.0	—	ms	
t_{PRCHG}	Pre-charge to Fast Charge Release Deglitch Time • Duration BATREG stays above pre-charge level to enable fast charge	—	7.0	—	ms	
$t_{ITOPOFF}$	Top-Off Deglitch Time • Duration I_{FAST_CHG} stays below Top-off level to generate an interrupt	—	7.0	—	ms	
t_{BAT_RECHG}	Recharge Deglitch Time • Duration V_{BATREG} stays below the V_{RCH} Threshold	—	27	—	ms	
t_{WAIT}	Waiting Time to Initiate Trickle Charge Mode • From t_{START_VSYS} expire to initiate trickle charge	—	27	—	ms	(12)
t_{WEAK_DEB}	Weak Battery Deglitch Time • Duration V_{BATREG} stays below V_{WEAK_HYS} in ENCOMPARATOR bit = 1	—	27	—	ms	
t_{START_VSYS}	VSYS Start-up Time • From VBUS stays above UVLO to VSYS start-up	—	220	—	ms	
t_{INT_MASK}	Interrupt Mask Time	—	10	—	µs	
$t_{ITOPOFF}$	Overcurrent Discharge Deglitch Time • Duration I_{FAST_DISCHG} stays above the overcurrent threshold in Discharge mode to generate an interrupt	—	7.0	—	ms	

Notes

12. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.

Table 4. BC3770 electrical characteristics (continued)

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
Deglitch timer (12) (continued)						
t_{VSYSOK_DEB}	VSYSOK Deglitch Time • Duration VSYS stays above 3.6 V to set the VSYSOK interrupt bit = 1 and pull the INTB pin Low in VBUSOK = ENCOMPARATOR = 1	—	27	—	ms	
t_{VSYSNG_DEB}	VSYSNG Deglitch Time • Duration VSYS stays at/below the $V_{VSYS\_MIN\_OLP}$ threshold to set the VSYSNG interrupt bit = 1 and pull the INTB pin Low in Discharge mode and ENCOMPARATOR = 1	—	27	—	ms	
$t_{VSYSOLP\_DEB}$	VSYSOLP Deglitch Time • Duration VSYS stays at/below the $V_{VSYS\_MIN\_OLP}$ threshold to set the VSYSOLP interrupt bit = 1 and pull the INTB pin Low in Overload mode and VBUSOK = 1	—	27	—	ms	
Boost converter						
I_{S_OTG}	Boost Supply Current • In OTG enabled with no load	—	3.0	—	mA	
	Output Regulation Voltage Range • Programmable at PMID	5.0	—	5.2	V	
I_{LIM_OTG}	Cycle-by-Cycle Current Limit	—	2.4	—	A	
V_{BO_REG}	Boost Output Regulation Voltage at VBUS • 3.0 V ≤ V_{BATREG} ≤ 4.45 V, set to 5.1 V at PMID, 0 mA ≤ I_{LOAD} ≤ 900 mA	4.75	5.0	5.25	V	(13), (14)
I_{BO_MAX}	Maximum Continuous Output Current at VBUS • 3.0 V ≤ V_{BATREG} ≤ 4.45 V	0.9	—	—	A	(13)
$V_{BAT\_MAX\_BO}$	Battery Operation Voltage Range • For the regulated output	3.0	—	4.45	V	(13)
V_{START_BO}	BATREG Start Threshold Voltage for Boost • V_{BATREG} rising	—	2.9	—	V	
V_{STOP_BO}	BATREG Stop Threshold Voltage for Boost • V_{BATREG} falling	—	2.5	—	V	
$V_{BUS\_OVP\_H}$	Overvoltage Protection at VBUS • VBUS rising, 400 mV Hysteresis	—	5.4	—	V	
INTB						
	Output Low Voltage • I_{SINK} = 5.0 mA	—	—	0.4	V	
Logic inputs (CHGENB, SHDNB, and NOBAT)						
V_{IH}	Logic Input High Voltage	1.2	—	—	V	
V_{IL}	Logic Input Low Voltage	—	—	0.4	V	
R_{PD}	Pull-down Resistance to GND • On CHGENB & SHDNB pin	—	300	—	kΩ	
R_{PU}	Pull-up Resistance to VL • On NOBAT pin	—	300	—	kΩ	

Notes

13. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.
14. The regulation in boost is only guaranteed in the operation range.

Table 4. BC3770 electrical characteristics (continued)

Characteristics noted under conditions: V_{VBUS} = 5.0 V, V_{BATREG} = 3.7 V, V_{VIO} = 1.8 V, C_{VBUS} = C_{PMID} = 2.2 µF, C_{VSYS} = 10 µF, C_{CHGOUT} = 4.7 µF, C_{VL} = 1.0 µF, L = 1.0 µH, T_A = - 40 °C to 85 °C *). Typical values are at T_A = 25°C, unless otherwise noted. (6)

Symbol	Characteristic	Min.	Typ.	Max.	Unit	Notes
Weak battery detection						
V_{WEAK_L}	Weak Battery Programmable Range • BATREG falling, programmable in 50 mV steps	3.0	—	3.75	V	
	Weak Battery Threshold Accuracy	-5.0	—	0.4	%	(15)
V_{WEAK_HYS}	Weak Battery Voltage Hysteresis • BATREG rising	—	100	—	mV	
I^2C interface (15), (16)						
V_{IH_I2C}	I^2C Logic Input High Threshold Voltage • SDA, SCL	1.2	—	—	V	
V_{IL_I2C}	I^2C Logic Input Low Threshold Voltage • SDA, SCL	—	—	0.4	V	
V_{OL_I2C}	I^2C Logic Output Low Voltage • SDA at 3.0 mA sink current	—	—	0.4	V	
f_{SCL}	SCL Clock Frequency	0.0	—	400	kHz	

Notes

15. Guaranteed by design, characterization, and correlation with process controls. Not fully tested in production.
16. The regulation in boost is only guaranteed in the operation range.

5 Functional device operation

5.1 Introduction

The BC3770 is a fully programmable switching charger with a single-input for USB/DCP adapter and a dual-path output for single-cell Li-Ion and Li-Polymer batteries. The dual-path output allows mobile applications with a fully discharged or dead battery to boot up the system through the VSYS output. High-efficiency and switch-mode operation of the BC3770 reduce thermal dissipation and allows the battery to charge faster with a higher current capability. The BC3770 supports single input up to 20 V max. absolute voltage and charges the battery with the current up to 2.0 A. Owing to a high-efficiency in a wide range of input voltages and charging currents, the switch mode charger is a good choice for fast charging with less power loss and better thermal management than a linear charger. The charging parameters and operating modes are fully programmable over an I^2C interface that operates up to 400 kHz in full speed. The BC3770 features a highly integrated synchronous switch-mode charger, intelligent power-path, VSYS stable control scheme in overload condition, and an automatic battery detection function. The charger and boost regulator circuit switches at 1.5 MHz, to minimize the size of external passive components.

To ensure USB compliance and minimize charging time, the input current is able to be limited to the value set through the I^2C. The setting of charge top-off current is also programmable over I^2C.

The BC3770 provides battery charging in four modes: trickle, pre-charge, fast charge (constant current), and full-charge (constant voltage). The charging restart circuit automatically restarts the fast-charge cycle in full-charge mode when the battery falls below an internal threshold over the deglitch time and detected top-off threshold. Input and charge status are reported to the processors through the interrupt pin, INTB. Charge current is reduced when the die temperature reaches 100 °C, while the system current is maintained. The BC3770 is able to operate as a boost regulator for USB-OTG devices over I^2C.

5.2 Features

- Dual-path output to power-up system in dead battery
- Single Input for USB/TA
- High-efficiency synchronous switching regulator
- 20 V maximum withstanding input voltage
- Minimize the charging time with remote sense
- Up to 2.0 A load current for system or battery
- Programmable charge parameters via I^2C compatible interface
  - Fast charge current
  - Charge termination current
  - Battery regulation voltage
  - Pre-charge current
  - Fast charge threshold voltage
  - Charge reduction threshold voltage
- 400 kHz full-speed I^2C interface
- 1.5 MHz switching frequency
- Charge reduction mode for maximizing charging efficiency
- Protection
  - Thermal protection
  - Thermal regulation
  - Input/output overvoltage protection
  - Adaptive input current limit protection (AICL)
  - Reverse leakage protection
  - No battery detection over pin detection
  - Battery OVP protection
  - Overcurrent protection in discharge mode
- Boost mode operation for USB OTG
  - Output voltage: 5.0 V to 5.2 V, programmable at 900 mA

5.3 Operational modes

5.3.1 Undervoltage lockout (UVLO)

The BC3770 has a typical undervoltage lockout threshold of 3.8 V, with a 200 mV hysteresis, rising on VBUS. VSYS also has a falling 2.5 V typical with 200 mV hysteresis. When the input supply voltage is below the 3.6 V typical UVLO falling level, the PWM buck converter turns off.

5.3.2 Registers reset

All programmable registers in the device are reset to the default values when the following condition is met.

- Reset Condition: VSYS ≤ V_{SYS_UVLO}

5.3.3 Q4 FET on in no valid VBUS

If the battery is connected with the voltage above a typical of 2.4 V and no any valid input power source is attached, the Q4 FET between VSYS and CHGOUT turns On and connects the Battery to the system, regardless of status of SHDNB. The VL regulator stays off.

5.3.4 Charge mode

The BC3770 performs the following pre-qualification process before initiating the Charging mode:

1. Input Voltage: Detect the validation of VBUS power source, charger enable threshold, and Adaptive-Input Current Limit (AICL) threshold. If the falling VBUS hits the AICL threshold, the charging current is reduced to limit the amount of drop on VBUS power source. In addition, the device senses the input voltage is at least above BATREG + 150 mV.
2. Battery Presence Detection: Detect the status of battery presence through the NOBAT pin. If the voltage on the NOBAT pin is above the logic high threshold, the charging is suspended (Internal Q4 FET is open). However, VSYS is regulated at VVSYS_MAX as long as a valid input source is attached.
3. Battery Voltage: Sense the battery voltage if it is less than the BAT OVP threshold.
4. Die Temperature: If the die temperature is above 130 °C or less than 150 °C, charging is suspended.
5. Overvoltage Detection (OVP): Sense if the VBUS is less than the OVP threshold. If the OVP condition is detected, the PWM converter is immediately shut off.
6. Validation of Software and Hardware Enable signals: Detect the status of software enable bit, CHGEN=1, SUSPEN=0, and hardware pin of CHGENB=LOW.

This pre-qualification process is continuously monitored and charging is suspended until all conditions are met.

5.3.5 Charging profile

5.3.5.1 Trickle-charge mode

Trickle-charge mode is automatically enabled in 27 ms after the VSYS start-up time expires. The battery is charged with a fixed 90 mA charge current until the battery voltage reaches the threshold, 2.5 V typical in rising. This threshold is not programmable over I^2C. As soon as the battery voltage crosses over the threshold, a pre-charge mode is activated automatically after the fixed deglitch time. This allows the protection circuit in the battery pack to be reset with no damage, and brings the battery voltage to a higher level.

5.3.5.2 Pre-charge mode

The Pre-charge mode is enabled in $t_{TRICKLE}$ when the battery voltage crosses over a typical 2.5 V. The safety timer called pre-charge timer, t_{PRECHG_TMR}, 45-minute counts at the same time as well. This timer is reset as soon as the Fast-charge mode is initiated. This allows a deeply discharged battery to charge safely. The pre-charge current is programmable from 150 mA to 450 mA in 100 mA steps over I^2C. If the battery voltage does not exceed the V_{VSYS_MIN} threshold before the timer expires, charging is suspended and a fault signal is asserted via the INTB pin. If the VSYS voltage drops due to the limited input power source during the mode, the charge current is automatically reduce to maintain the VSYS as low as at 3.4 V. If the load is still overloaded, even in no charge current and limited input current, the VSYS can't help the collapse.

5.3.5.3 Fast-charge mode (constant-current mode)

The Fast-charge mode is entered in t_{PRECHG} when the battery voltage exceeds the V_{VSYS_MIN} threshold of a typical 3.6 V. During this mode, the battery is charged with a programmable fast-charge current. The fast-charge current is programmable from 100 mA to 2000 mA with a 500 mA default. Fast-charge current is always limited by the input current limit setting. As soon as the battery voltage reaches the V_{VSYS_MIN} threshold, VSYS tracks the battery voltage through the Q4. This is called 'tracking mode". In tracking mode, power dissipation is minimized by RDSON_Q4 x IFAST_CHG. However, if the VSYS voltage drops during the fast-charge mode, the charge current is automatically reduce to keep the dropout voltage, to ensure proper operation of charging circuitry. During this fast-charge mode, the safety timer called fast charge timer, t_{FAST_TMR}, counts. If the battery voltage does not reach the V_{BAT_REG} threshold before the timer expires, charging is suspended and a fault signal is asserted via the INTB pin. This timer is programmable and is disabled by default. This timer is automatically disabled when the input current limit is set to 100 mA.

5.3.5.4 Full-charge mode (constant-voltage mode)

As soon as the BATREG voltage reaches the V_{BAT_REG} threshold, the fast-charge current is reduced to a programmable top-off current. The V_{BAT_REG} regulation threshold is programmable from 4.1 V to 4.475 V in 25 mV steps.

5.3.5.5 Top-off mode (constant-voltage mode)

If the charge current down to a pre-programmed top-off current threshold is sensed over $t_{ITOPOFF}$, the safety timer called top-off timer, t_{TOPOFF_TMR}, 45-minute by default, automatically counts. The top-off interrupt event is reported to the processor via the INTB. As soon as the processor reads the interrupt registers, the processor is able to turn off the charger by either CHGENB = H, CHGEN = 0, or wait until the timer expires in AUTOSTOP=1. The top-off current is programmable from 100 mA to 650 mA in 50 mA steps. 100 mA is the default.

5.3.5.6 Done mode (constant-voltage mode)

After the top-off timer expires, the charger is Off automatically in AUTOSTOP=1. However, the charger stays at CV (Constant-voltage mode) in AUTOSTOP=0 even though the top-off timer expires. The interrupt signal of Done is reported to the processors via the INTB pin, regardless of the AUTOSTOP status.

5.3.6 Boost (OTG) mode

Similar to Charge mode operation, in OTG mode enabled by I^2C control bit, ENBOOST = 1, the device provides a regulated output voltage to VBUS from the battery. In Boost mode, the device first converts the battery voltage to a target voltage at PMID, then bypasses it to the VBUS pin with load current up to 900 mA to support USB OTG devices. In order to have a final regulated output at VBUS, the minimum input at BATREG should be at least or above 3.0 V. To activate Boost mode, all of the following conditions should be met in advance.

1. Either the CHGEN bit resets to “0” or CHGENB = HIGH (meaning for “charger disabled”)
2. The VBUS voltage must be less than the UVLO falling threshold
3. No Fault Conditions
4. SUSPEN bit reset to “0”

Then set the ENBOOST bit to “1”. In this Boost mode, the following functions are consequently disabled.

- AICL
- Charging

5.3.6.1 Soft-start in Boost mode

When Boost mode is enabled, the PMID is regulated to a pre-programmed voltage. After PMID reaches a preset target regulation voltage, the FET between PMID and VBUS turns On slowly to minimize the inrush current. The output current limit is ramped up to the boost output current limit. This soft-start counter is not initialized when one of next conditions occur.

1. Die temperature exceeds T_{SD}
2. No battery detection (NOBAT = H) on NOBAT
3. Voltage on VBUS rises over V_{BUS_OVP}
4. Voltage on the BATREG pin rises over $V_{BAT\_MAX\_BO}$
5. Voltage on the BATREG pin falls below V_{STOP_BO}

5.3.7 Battery recharge

Regardless of the AUTOSTOP bit status, the re-charge of the battery is able to be performed in two ways.

1. Automatic Enable

After a top-off threshold or Done is detected and the battery voltage drops below the recharge threshold, V_{RCH}, over the deglitch time, a typical of 27 ms, the charger automatically resumes the charging. In this mode, the interrupt signal of “recharge” is reported to a processor via the INTB pin. However if the battery voltage recovers above the threshold within 27 ms, the charging restart is not resumed and an interrupt event is not reported. The threshold is a fixed value of -100 mV.

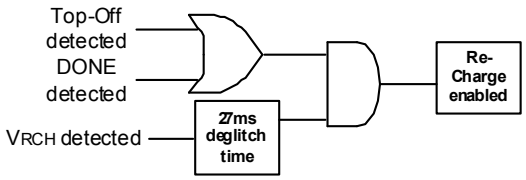


Figure 4. Re-charge enabled in the automatic way

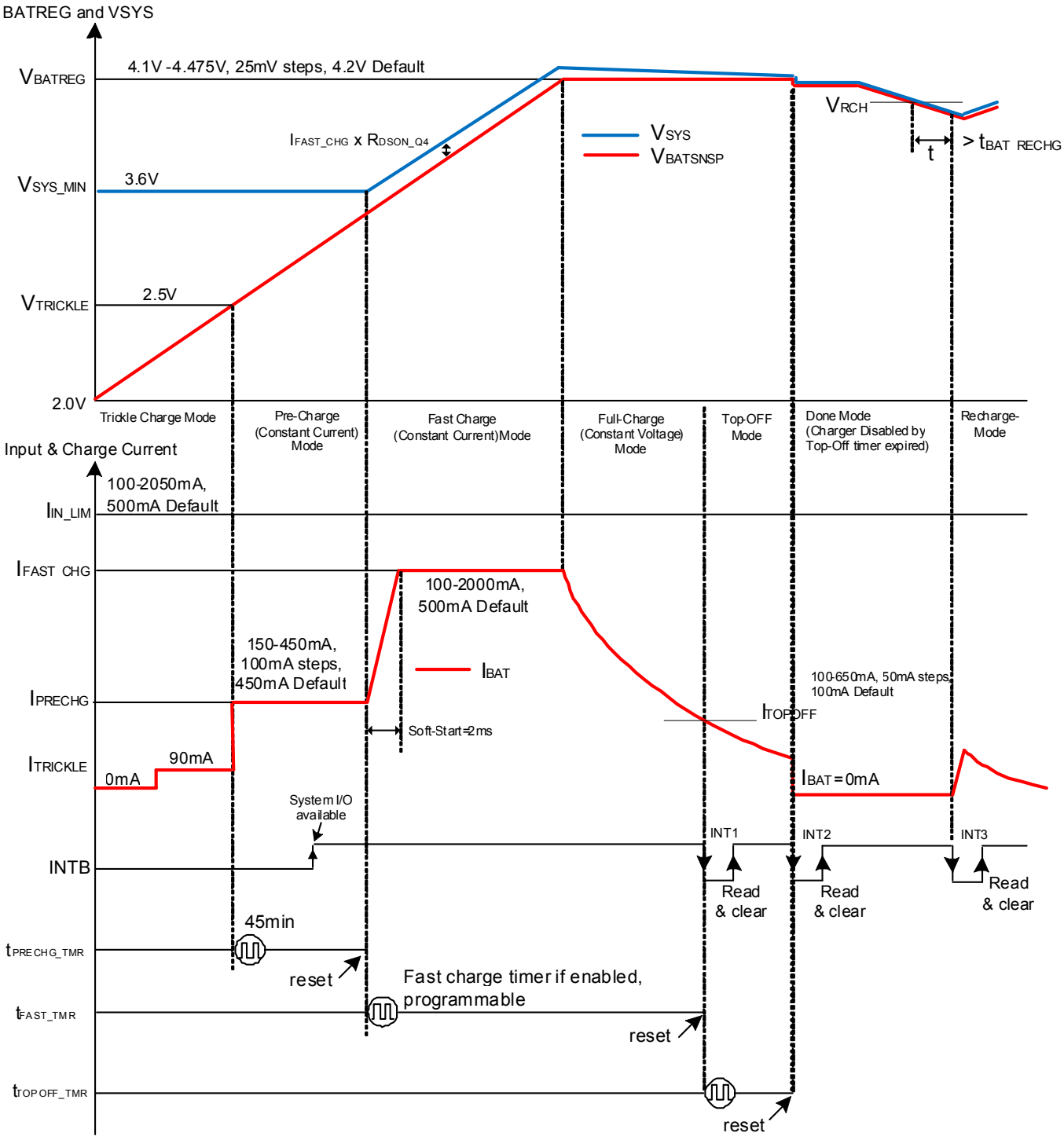
2. Manual Enable

The Application Processor (AP) is able to turn off the charger after the top-off or Done state is detected. Once the charger is enabled by the processor and if the recharge conditions are met, the charger automatically charges the battery.

5.3.8 Soft-start

The BC3770 provides a soft-start in the transition from Pre-charge to Fast-charge mode to allow for a smaller voltage drop on VSYS and to prevent input current and voltage transients. However, there is no soft-start in recharge mode. In summary, the following is the typical charging profile where the following conditions are met in advance.

- A valid input is detected
- No AICL threshold detected
- All timers reset
- Input current limit > fast-charge current
- No SYS current
- Input current limit not detected
- No status changes on CHGEN = 1, CHGENB = LOW, SUSPEND = 0 and AUTOSTOP = 1
- V_{RCH} = -100 mV
- Related interrupt bits not masked
- Deep battery with 2.0 V attached in advance
- Deglitch time excluded



Note 1: INT1 for Top-Off Interrupt, INT2 for Done Interrupt, INT3 for Recharge Interrupt
Note 2: The time of Read &Clear depends on the processor.
Note 3: Each deglitch time is not included.
Note 4; Charger restart condition is made on purpose to show the behavior.

Figure 5. Typical charging profile in no fault condition

Figure 6. Charger state diagram

5.3.9 Safety timer

There are three safety timers on the device: a pre-charge timer, a fast charge timer, and a top-off timer. The pre-charge is fixed at 45 minutes, and the fast charge and the top-off timer are programmable over I^2C. The reset conditions for each timer are described with the following.

1. Pre-charge timer is reset in one or more of the following ways:
- BATREG crosses over the VSYS minimum threshold of 3.6 V
- Falling VBUS UVLO detected
- CHGENB = HIGH

2. Fast-charge timer is reset in one or more of the following ways:
- BATREG hits the regulation voltage V_{BAT_REG} and the charge current hits the top-off current threshold
- Falling VBUS UVLO detected
- CHGENB=HIGH or CHGEN reset to “0” before expiration

3. Top-off timer is reset in one or more of the following ways:
- BATREG hits the regulation voltage V_{BAT_REG}, the charge current hits the top-off current threshold, and the timer expires in AUTOSTOP = 1
- Falling VBUS UVLO detected
- CHGENB = HIGH or CHGEN reset to “0” before expiration

However, all safety timers are reset commonly in the following fault conditions:

- BAT OVP detected
- VBUS OVP detected
- Thermal shutdown

If all fault conditions are released, the timer resumes to start.

5.3.10 VSYS

When being charged from VBUS, if the battery voltage becomes close to the minimum system voltage threshold, V_{VSYS_MIN} (3.6 V), VSYS tracks the battery voltage up to a preset V_{BAT_REG}. A load current from an input is provided to both VSYS and the battery with up to a maximum input limit programmed value.

The device regulates the system supply voltage, VSYS (3.6 V), in Trickle and Pre-charge mode, which allow the application system to be booted up even in dead or deeply discharged battery. The device has the system output, VSYS, priority over charge current, which gives the required load for the system while reducing the charge current, if the input current is limited. System path also allows accurate charge cycle since it allows the system to know precisely when the charging current has hit the current termination threshold vs. implementations, where the battery and the system are connected to the same node. When the battery voltage crosses the minimum system voltage threshold, V_{VSYS_MIN}, the VSYS tracks the battery voltage with an appropriate voltage differential by R_{DS_ONQ4} x charge current. This insures the minimum power dissipation on the device comes true. When the battery charging is completed, the system node, VSYS, is regulated to V_{BAT_REG} + R_{DS_ON} x charge current (if available). If the charge current becomes truly 0 mA, the VSYS is technically equal to the battery voltage.

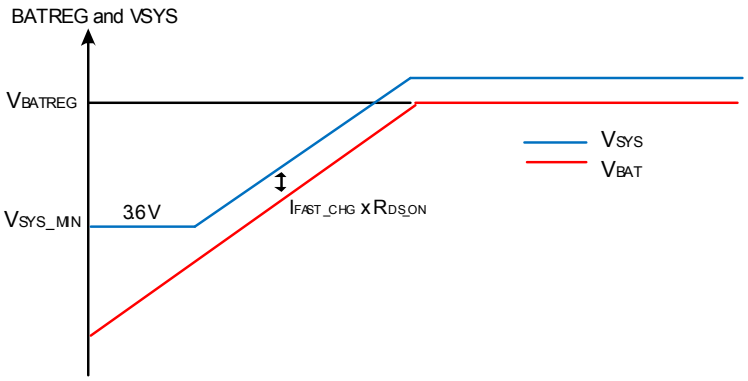


Figure 7. VSYS tracking BATREG

5.3.10.1 Charger enable control

The CHGEN bit in the control register and CHGENB pin are used to enable or disable the charging process.

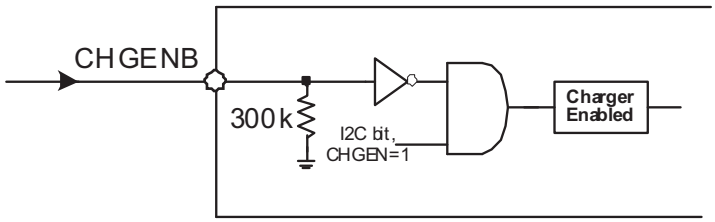


Figure 8. Charger enable

If the CHGENB pin is not used in the application, leave the pin float since CHGENB has an internal 300 kΩ pull-down resistance to ground.

5.3.10.2 Battery presence detection

The BC3770 monitors battery presence via the NOBAT pin in any condition. This function utilizes the pull-down resistor on VF in the battery pack. If no battery is detected, the charging is suspended immediately and the corresponding interrupt event is reported to the processor via the INTB pin. If the NOBAT pin needs to be connected to an ADC input on the main processor, a resistor-divided configuration in fig should be done to lower the voltage rating to 1.8 V.

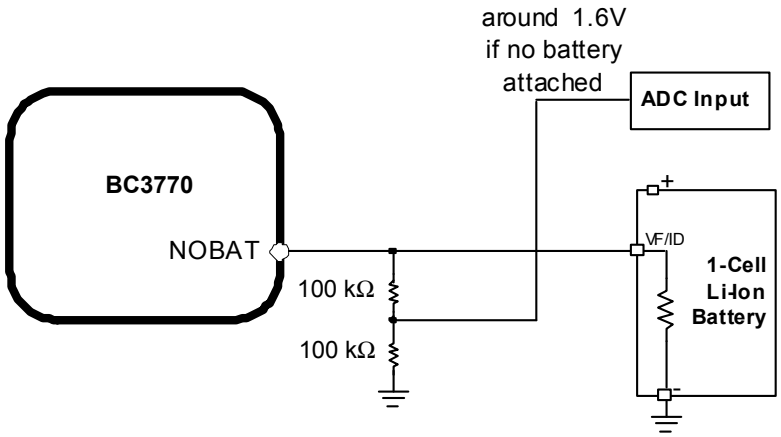


Figure 9. Resister divided network

If NOBAT is not used as a battery presence indicator, the following configuration is also possible.

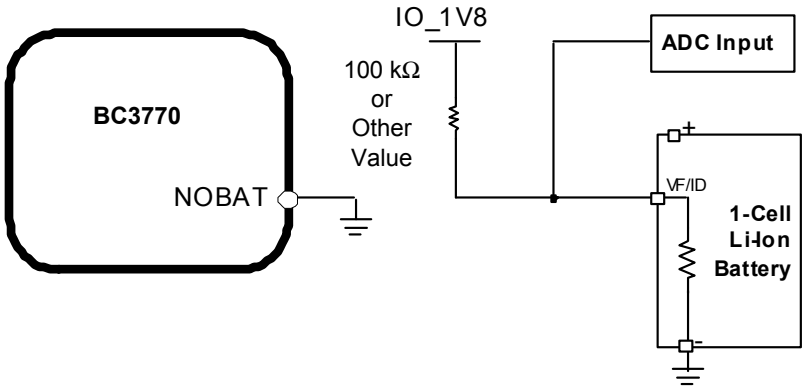


Figure 10. Resister divided network option

5.3.10.3 Battery remote sensing

In order for the device to exactly regulate the + terminal on the battery cell as close to a preset V_{BAT_REG} as possible, the BATREG and BATSNSN pins are used. In the real application, there may be some voltage drop between the CHGOUT pin and the + terminal, which comes from parasitic resistance, due to the PCB trace and a charge current. This voltage drop makes the VBAT_REG not regulate at the target regulation voltage. To reduce the charging time, place those two pins, BATREG and BATSNSN, as close to each + and - terminal on the battery pack as possible.

5.3.10.4 Adaptive-input current limit (AICL)

The AICL function prevents the current limited input supply voltage from sagging below a certain preset AICL threshold voltage (V_{AICL_TH}). If the required input current of device for a certain programmed value of I_{IN_LIM} exceeds the maximum input current of the VBUS supply, then the VBUS supply will collapse and the device won't function properly under these conditions. To keep the device functional with a current and voltage limited VBUS source, the device in Start-up mode automatically starts incrementing the input current limit to either the default or pre-programmed value until either the input current limit is detected or the VBUS voltage detects the AICL threshold, to keep input supply voltage as a valid power source to provide the load for the application. The device allows the maximum current the input supply can possibly provide without severely collapsing.

In general, the AICL function is enabled whenever the input current tries to exceed the input current limit, while charging the battery and/or providing the system load. At the beginning of the charge cycle with discharged battery, the required input current could be lower than the VBUS current limit. The input current increases as the battery voltage increases. Eventually, the input current may exceed the VBUS input current limit. If this happens, the AICL function takes over and lowers the charge current below the programmed value to keep VBUS around VAICL_TH.

Most of the time charge reduction occurs at the beginning of charge cycle when a low current limited AC adapter or USB port is connected as a valid input source. During start-up the device detects the current limited supply by slowly stepping up the input current with a programmable soft-start clock period. Each current step is around 25 mA. As the charge and system current are stepped up, the input current also steps up in staircase fashion. Eventually, the input current will hit the current limit. The input falls to or below V_{AICH_TH}. When this happens, the device steps down the input current by 25 mA at the next clock rising edge. This allows the input supply voltage to rise above V_{AICL_TH} at the next soft start clock cycle. The charge current is stepped up again by 25 mA. This again allows the input current to be exceed. The input reduction continues to step up and down the input current by 25 mA to maintain the input supply voltage as close to V_{AICL_TH} as possible.

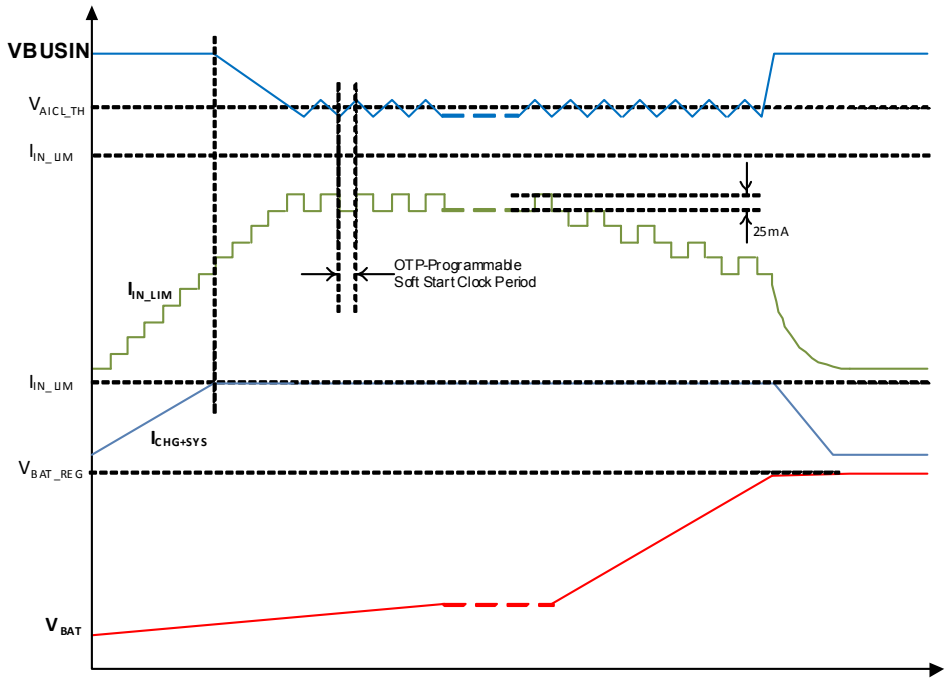


Figure 11. AICL operation

5.3.10.5 Supplement mode

When the VSYS voltage falls below the battery voltage while a valid input is attached, the Q4 FET turns On and the Q4 FET gate regulates the gate drive of Q4 so the minimum VSYS stays at 50 mV below BATREG in the Supplement mode. This prevents oscillation from entering and exiting Supplement mode. As the discharge current increases, the Q4 gate is regulated with a higher voltage, to reduce $R_{DS(on)}$ until Q4 is full conduction.

5.3.10.6 Charging current reduction in VSYS overload

When the input current limit is detected in Charge mode by either a system overload or a programmed value is lower than the sum of load current and charge current, the device reduces the charge current until the limited input current falls below the preset current limit threshold, and the input voltage rises above the input voltage limit while maintaining the VSYS voltage at 3.4 V.

Although the charge current is reduced to 0 mA, the input power source is still overloaded, and the system voltage starts to drop. Once the system voltage falls 50 mV below the battery voltage, the device automatically enters the Supplement mode and the battery starts discharging so the system is supported from the both the input supply and battery. An corresponding interrupt for VSYS overload triggers via the INTB pin.

5.4 Protection and diagnosis features

5.4.1 Input overvoltage protection

When the input voltage exceeds the overvoltage protection (OVP) threshold, internal switches immediately turn off and disconnect the load and the charger from the power source, preventing damage to any downstream components. Simultaneously, the fault flag is triggered, alerting the system. As soon as the OVP event stays over the deglitch time, t_{INPUT_OVP}, the converter resumes.

5.4.2 Battery (BAT) overvoltage protection

When the BATREG voltage exceeds the battery overvoltage protection threshold, V_{BAT_OVP} (typ. V_{BAT_REG}+ 0.1 V), the device turns off the PWM converter and sets the fault status bit. Simultaneously, the fault flag is asserted, alerting the system. There is a 0.1 V hysteresis in the internal threshold voltage. If the OVP event over the deglitch time is released, the converter and charging resume.

5.4.3 Reverse blocking

In the reverse blocking mode (V_{BUS} - V_{BATREG}) ≤ 50 mV (typ.), charging is disabled and the device is entered into Charger-suspended mode to minimize current drain from BATREG.

5.4.4 Thermal regulation and protection

When the device's die temperature reaches T_{CF} (around 100 °C), the device reduces the charge current by around 3.33% of the fast-charge current per °C. This drives the charge current down to 0 mA at 130 °C. Since the system load has priority over the battery charging, the battery charge current is reduced to 0 mA before the input limiter drops the system load current. If the junction temperature rises beyond 130 °C and then hits 150 °C, the PWM switcher shuts down to allow no input current from the input source. This prevents further die heating. In this condition, the system output voltage is regulated at BATREG. This internal thermal protection helps to improve device reliability. The device automatically goes back to normal operation when the die temperature cools down below 130 °C. In these thermal regulation and shutdown modes, I^2C access is still active.

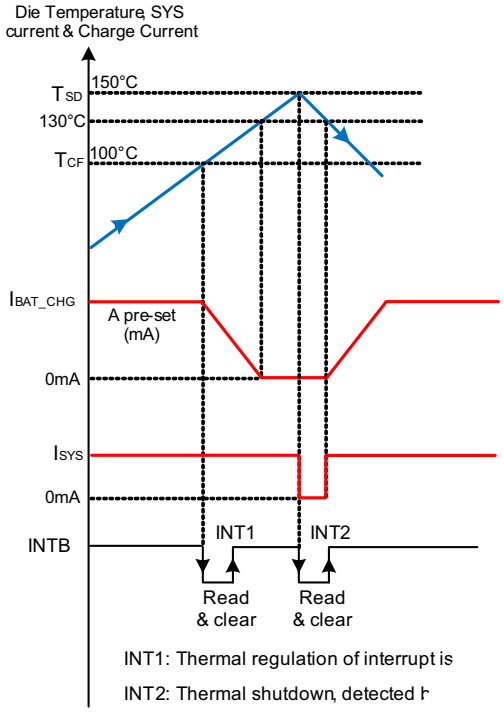


Figure 12. Thermal regulation

5.4.5 Weak battery detection

A weak battery detection function allows the processor to acknowledge the low-battery condition. To prevent false voltage transients from interrupting the processor unnecessarily, the out-of-range condition must stay at least for the deglitch time of 27 ms, before an interrupt is generated. If the battery voltage goes back in range before the deglitch time, no corresponding interrupt is generated.

5.4.6 DC-DC PWM converter

The device features an integrated fixed 1.5 MHz frequency. The device uses a peak current mode PWM controller to regulate the output voltage and battery charge current. The low-side FET (Q3) also has a current limit that decides if the PWM controller can operate in boost mode. The threshold is set to 100 mA and turns off the high-side N-channel FET (Q2) before the current reverses, preventing the battery from discharging.

5.4.7 Interrupt

The device uses the Interrupt pin, INTB, to indicate if the status on the device has changed. The Interrupt is asserted whenever one or more interrupt events are detected in its operation. The processor reads the interrupt registers to see the source of interrupt event(s). Interrupt bit(s) is (are) only cleared by reading all or some corresponding bits in the interrupt registers. If an interrupt bit is masked in an interrupt event, the corresponding interrupt bit is still set to 1 in the corresponding register. However, the INTB interrupt pin is not asserted to low. When the corresponding mask bit is set to “0” because of an earlier interrupt event, the interrupt pin for the corresponding interrupt event is asserted low to alert the processor after the t_{INT_MASK} delay time, typically 10 µs. If the abnormal condition continues after the processor reads a corresponding interrupt bit, the corresponding interrupt bit is no longer set to “1”.

5.4.7.1 Comparators for interrupt events

To save the idle current in Stand-by or Shutdown mode, the internal comparators that detects “Weak Battery” status, “VSYSOK or NG” status, the “Battery OVP” status and “Discharge Limit” status are capable of being disabled over the I^2C interface by resetting the “ENCOMPARATOR” bit 6 to 0 in the 07h register. The comparators are enabled by default.

If the comparators are disabled in “no valid supply” on VBUS, the VBUSOK signal overrides the bit set to 1 by force, to detect weak battery detection, VSYSOK or NG detection, and BATOVP detection. This wakes up the comparators to notify the application processor of these interrupt events.

5.5 Logic commands and registers

5.5.1 Serial interface

I^2C is a two-wire serial interface developed by Phillips Semiconductor. The bus consists of a data line, SDA, and a clock line, SCL, with pull-up structures. When the bus is idle, both the SDA and SCL lines are pulled high. All the I^2C compatible devices connect to the I^2C bus through open drain I/O pins, SDA, and SCL. A master generates the clock signal and device addresses. The master also generates specific conditions that indicate the START and STOP of data transfer. A slave device receives and/or transmits data on the bus under the master device.

The device works as a slave and is compatible with the following data transfer modes, as defined in the I^2C-Bus Specification: Standard mode (100 kbps) and Fast mode (400 kbps). The interface adds flexibility to all necessary control options of the program, and enables most functions to be programmed to the new values, depending on the instantaneous application requirements. I^2C is asynchronous, which means that it runs off of SCL.The data transfer protocol for Standard and Fast modes is exactly the same.

5.5.1.1 Bus speed

The device I^2C interface supports bus SCL clock speeds up to 400 kbps for Full-speed mode. The SCL and SDA input buffers incorporate spike suppression and Schmitt triggers to reject short glitches, as required by the I^2C specifications.

5.5.1.2 Data validity

During all transmissions, the master ensures the data is valid. A valid data condition requires the SDA line to be stable during the High period of the clock (see Figure 13). The High or Low state of the data line can only change when the clock signal on the SCL line is Low (see Figure 1). One clock pulse is generated for each data bit transferred.

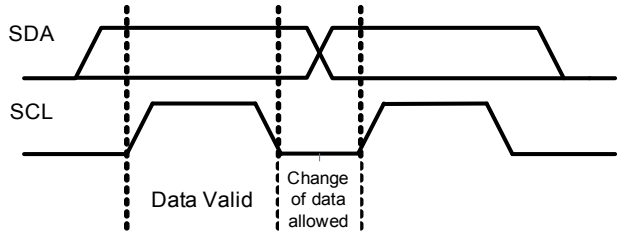


Figure 13. Bit transfer on the I^2C bus

5.5.1.3 Start and stop condition

All transactions begin with a START (S) and can be terminated by a STOP (P) (see Figure 2). A High to Low transition on the SDA line while SCL is High defines a START condition. A Low to High transition on the SDA line while SCL is High defines a STOP condition.

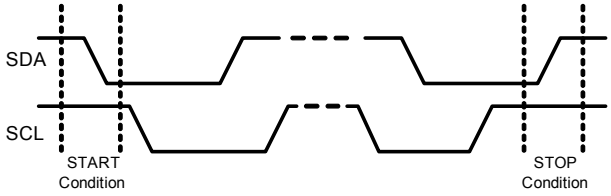


Figure 14. START and STOP conditions

START and STOP conditions are always generated by the master. The bus is considered to be busy after a START condition. The bus is considered to be free again a certain time after the STOP condition.

5.5.1.4 Byte format

Every byte put on the SDA line must be eight bits long. The number of bytes that can be transmitted per transfer is unrestricted. Each byte has to be followed by an acknowledge bit. Data is transferred with the Most Significant Bit (MSB) first. If a slave cannot receive or transmit by servicing an internal interrupt, it can hold the clock line SCL Low to force the master into a wait state. Data transfer then continues when the slave is ready for another byte of data and releases clock line SCL.

5.5.1.5 Acknowledge (ACK) and not acknowledge (NACK)

The acknowledge bit is used for handshaking purpose between the master and slave. The master and slave both can either receive or send eight bits of serial data, depending on whether the master sends device's read address or write address at the beginning of the data transfer sequence. In either case, the receiver must send an acknowledge bit to the transmitter to complete transmission of one data byte without any errors. When the device is written to, it acknowledges its write address as well as the following data bytes. When it is read from, device only acknowledges its read address.

The device generates an acknowledge bit, right after receiving eight bits of data, by pulling SDA Low during the INTB clock pulse's entire High period. The master generates a similar acknowledge byte when it reads from device. The transmitter must let go of SDA during the ninth clock cycle's high period, to allow the receiver to generate an acknowledge bit. The generation of the acknowledge bit is shown in Figure 15.

When SDA remains High during this 9th clock pulse, this is defined as the Not Acknowledge signal. The master can then generate either a STOP condition to abort the transfer, or a repeated START condition to start a new transfer. There are five conditions that lead to the generation of a NACK:

1. No receiver is present on the bus with the transmitted address, so there is no device to respond with an acknowledge.
2. The receiver is unable to receive or transmit, because it is performing some real-time function and is not ready to start communication with the master.
3. During the transfer the receiver gets data or commands it does not understand.
4. During the transfer, the receiver cannot receive any more data bytes.
5. A master-receiver needs to signal the end of the transfer to the slave transmitter.

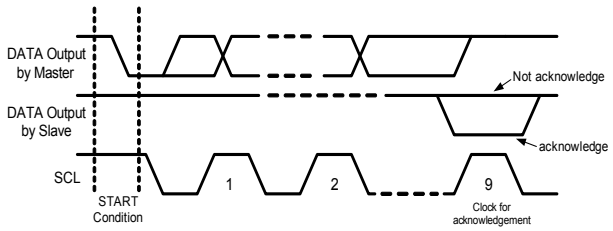


Figure 15. BUS acknowledge cycle