

LM3658

Dual Source USB/AC Li Chemistry Charger IC for Portable Applications

General Description

The LM3658 is a single chip charger IC designed for hand-held applications. It can safely charge and maintain a single cell Li-Ion/Polymer battery operating from an AC wall adapter or USB power source. Input power source selection of USB/AC is automatic. With both power sources present, the AC power source has priority. Charge current is programmed through an external resistor when operating from an AC wall adapter allowing charge currents from 50 mA to 1000 mA. When the battery is charged using USB power, charge currents of 100 mA or 500 mA are pin-selectable. The termination voltage is controlled to within $\pm 0.35\%$ of 4.2V.

The LM3658 requires few external components and integrates internal power FETs, reverse current protection and current sensing. The internal power FETs are thermally regulated to obtain the most efficient charging rate for a given ambient temperature.

The LM3658 operates in five modes: pre-qualification mode, constant-current mode, constant-voltage mode, top-off mode and maintenance mode. Optimal battery management is obtained through thermal regulation, battery temperature measurement and multiple safety timers. The LM3658 provides two open-drain outputs for LED status indication or connection to GPIOs.

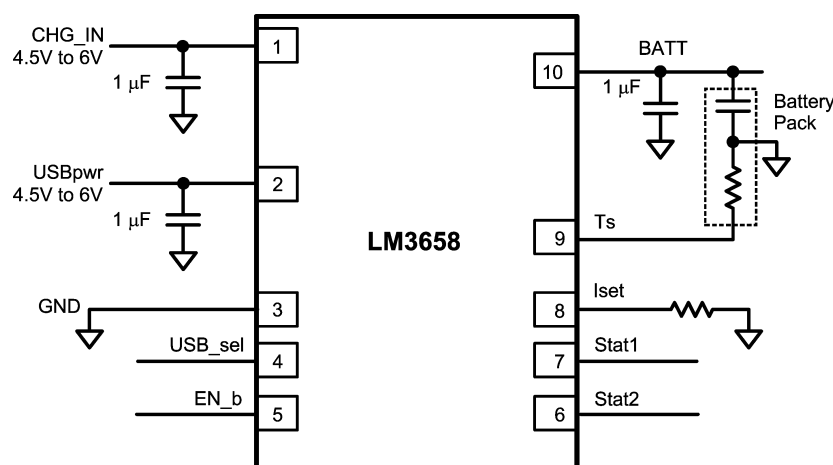
Features

- Integrated power FETs with thermal regulation
- Charges from either an AC wall adapter or USB power source with automatic source selection
- 50 mA to 1000 mA charge currents using AC wall adapter
- Pin-selectable USB charge currents of 100 mA or 500 mA
- Continuous battery temperature monitoring
- Built-in multiple safety timers
- Charge status indication
- Continuous over-current and temperature protection
- Near-depleted battery pre-conditioning
- Sleep mode with ultra low quiescent current
- On-board Kelvin-sensing achieves $\pm 0.35\%$ termination accuracy
- Maintenance mode with automatic recharge
- Thermally enhanced 3 mm x 3 mm LLP package

Applications

- Smartphones
- Digital still cameras
- PDAs
- Hard Drive and flash-based MP3 players
- USB-powered devices

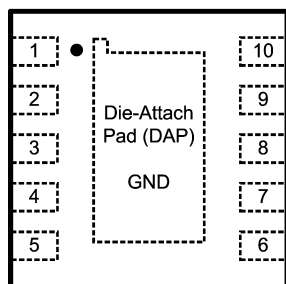
Typical Application



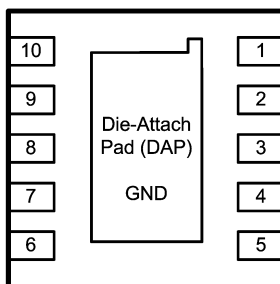
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Connection Diagram and Package Mark Information

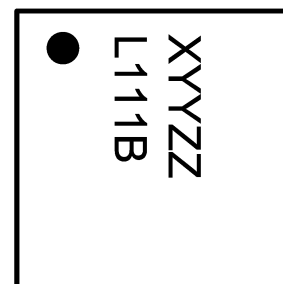
LLP10 Package Drawing



Top View



Bottom View



Package Marking
Top View

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Note: The actual physical placement of the package marking will vary from part to part. The package marking "X" is the manufacturing plant code. "YY" is a 2-digit date code, and "ZZ" for die traceability. These codes will vary considerably. "L111B" identifies the device (part number, option, etc.).

TABLE 1. LM3658 Pin Description

Pin #	Name	Description
1	CHG_IN	AC wall adapter input pin.
2	USBpwr	USB power input pin.
3	GND	Power and signal ground pin.
4	USB_sel	Pulling this pin low limits the USB charge current to 100 mA. Pulling this pin high limits the USB charge current to 500 mA.
5	EN_b	Pulling this pin low enables the charger. Pulling this pin high disables the charger.
6	STAT2	Active low open-drain output. Indicates charger status. This pin is capable of driving an LED as well as GPIOs. See Operation Description section for more detail.
7	STAT1	Active low open-drain output. Indicates charger status. This pin is capable of driving an LED as well as GPIO. See Operation Description section for more detail.
8	I _{SET}	A resistor is connected between this pin and GND. The resistor value determines the full-rate charge current when using the AC source.
9	T _S	Battery temperature sense pin. This pin must be connected to battery pack's temperature sense output pin. See Operation Description section for more detail.
10	BATT	Positive battery terminal connection.

TABLE 2. Ordering Information

Order Number	Package Marking	Supplied As
LM3658SD	L111B	1000 units, Tape-and-Reel
LM3658SDX	L111B	4500 units, Tape-and-Reel

For more information on the various options, please refer to Operation Description section.

Absolute Maximum Ratings (Notes 1,

2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

CHG_IN, USBpwr (V_{CC})	-0.3V to +6.5V
All other pins except GND	-0.3V to CHG_IN or USBpwr
Power Dissipation (Note 3)	Internally Limited
Junction Temperature (T_{J-MAX})	+150°C
Storage Temperature Range	-65°C to +150°C
ESD Rating (Note 4)	
Human Body Model:	2.0 kV
Machine Model:	200V

Operating Ratings (Notes 1, 2)

Input Voltage Range for CHG_IN	4.5V to 6.0V
Input Voltage Range for USB_pwr	4.35V to 6.0V
Recommended Load Current	0 to 1000 mA
Power Dissipation(Note 3)	Internally Limited
Junction Temperature (T_J) Range	-40°C to +125°C
Ambient Temperature (T_A) Range	-40°C to +85°C

Thermal Properties

θ_{JA} , Junction-to-Ambient Thermal Resistance (Note 5)	54°C/W
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Electrical Characteristics

Unless otherwise noted, V_{CC} (V_{CHG_IN} and/or V_{USBpwr}) = 5V, V_{BATT} = 3.5V. C_{CHG_IN} = 1 μ F, C_{USBpwr} = 1 μ F, C_{BATT} = 1 μ F. Typical values and limits appearing in normal type apply for T_J = 25°C. Limits appearing in **boldface** type apply over T_J = 0°C to +85°C. (Notes 2, 6, 7)

Symbol	Parameter	Conditions	Typ	Limit		Units
				Min	Max	
CHARGER						
V _{CHG_IN}	AC Wall Adapter Input Voltage Range			4.5	6.0	V
V _{USBpwr}	USB Input Voltage Range			4.35	6.0	V
I _{CC_PD}	Quiescent Current in Power Down Mode	V _{BATT} > V _{CC} –V _{OK_CHG}	1		5	μA
I _{CC_STBY}	Quiescent Current in Standby Mode	V _{BATT} < V _{CC} – V _{OK_CHG} V _{CC} > V _{POR} EN_b = High	400		600	μA
I _{BATT_PD}	Battery Leakage Current in Power Down Mode	V _{BATT} > V _{CC} + V _{OK_CHG}	0.01		2.0	μA
I _{BATT_MAINT}	Battery Leakage Current in Maintenance Mode	STAT1 = off, STAT2 = on, adapter or USB connected, V _{BATT} = 4.2V	7		15	μA
V _{OK_CHG}	CHG_IN or USBpwr OK Trip-Point	V _{CC} – V _{BATT} (Rising) V _{CC} – V _{BATT} (Falling)	200 50			mV
V _{POR}	V _{CC} POR Trip-Point	V _{CC} (Rising) V _{BATT} < V _{CC} – V _{OK_CHG} V _{FULL_RATE} < V _{BATT} < V _{TERM}	3.0			V
V _{TERM}	Battery Charge Termination Voltage	I _{CHG} = 10% of its value when V _{BATT} = 3.5V	4.2			V
	Battery Charge Termination Voltage Tolerance	T _A = 25°C		–0.35	+0.35	%
		T _A = 0°C to 85°C		–1.5	+1.5	
V _{CHG_DO}	CHG_IN Drop-Out Voltage	V _{BATT} = V _{TERM} , I _{CHG} = 1A V _{CC} > V _{BATT} + V _{CHG_DO_MAX}	500			mV
V _{USB_DO}	USBpwr Drop-Out Voltage	V _{BATT} = V _{TERM} , USB_sel = high V _{CC} > V _{BATT} + V _{USB_DO_MAX}	250			mV
I _{CHG}	CHG_IN Full-Rate Charge Current Range (see full-rate charge mode description)	6V ≥ V _{CC} ≥ 4.5V V _{BATT} < V _{CC} – V _{OK_CHG} V _{FULL_RATE} < V _{BATT} < V _{TERM} I _{CHG} = K _{ISET} /R _{ISET}		50	1000	mA

Electrical Characteristics

Unless otherwise noted, V_{CC} (V_{CHG_IN} and/or V_{USBpwr}) = 5V, V_{BATT} = 3.5V. C_{CHG_IN} = 1 μ F, C_{USBpwr} = 1 μ F, C_{BATT} = 1 μ F. Typical values and limits appearing in normal type apply for T_J = 25°C. Limits appearing in **boldface** type apply over T_J = 0°C to +85°C. (Notes 2, 6, 7) (Continued)

Symbol	Parameter	Conditions	Typ	Limit		Units
				Min	Max	
CHARGER						
I _{CHG}	CHG_IN Full Rate Charge Current	R _{ISET} = 10kΩ	245	220	270	mA
		R _{ISET} = 5 kΩ	500	465	535	
		R _{ISET} = 3.3kΩ	760	700	820	
K _{ISET}	Charge Current Set Coefficient I _{CHG} = K _{ISET} /R _{ISET} (see full-rate charge mode description)	6V ≥ V _{CC} ≥ 4.5V V _{BATT} < V _{CC} – V _{OK_CHG} V _{FULL_RATE} < V _{BATT} < V _{TERM}	2500			AΩ
V _{ISET}	Charge Current Set Voltage	6V ≥ V _{CC} ≥ 4.5V V _{BATT} < V _{CC} – V _{OK_CHG} V _{FULL_RATE} < V _{BATT} < V _{TERM}	2.5			V
I _{USB_L}	USB Full-Rate Charge Low Current		90	80	100	mA
I _{USB_H}	USB Full-Rate Charge High Current		450	400	500	mA
I _{PREQUAL}	Pre-Qualification Current	V _{BATT} = 2V, for both AC adapter and USB	45	35	55	mA
V _{FULL_RATE}	Full-Rate Qualification Threshold	V _{BATT} rising, transition from pre-qualification to full-rate charging	3.0	2.9	3.1	V
	Full Rate Hysteresis	V _{BATT} falling	60	50	70	mV
I _{EOC}	End-of-Charge Current, Percent from Full-Range Current	6V ≥ V _{CC} ≥ 4.5V V _{BATT} < V _{CC} – V _{OK_CHG} V _{FULL_RATE} < V _{BATT} < V _{TERM}	9	7	11	%
I _{TOPOFF}	Minimum Top-Off Charge Current	6V ≥ V _{CC} ≥ 4.5V V _{BATT} < V _{CC} – V _{OK_CHG} V _{BATT} = V _{TERM}	2.5	1.25	3.75	%
V _{RESTART}	Restart Threshold Voltage	V _{BATT} falling, transition from EOC to pre-qualification mode	4.0	3.94	4.07	V
V _{TL}	Battery Temperature Sense Comparator Low-Voltage Threshold		0.49	0.46	0.52	V
V _{TH}	Battery Temperature Sense Comparator High-Voltage Threshold		2.49	2.44	2.54	V
I _{TSENSE}	Battery Temperature Sense Current		100	94	106	μA
T _{REG}	Regulated Junction Temperature		120			°C
T _{SD}	Thermal Shutdown Temperature		165			°C
DETECTION AND TIMING						
T _{POK}	Power OK Deglitch Time	V _{BATT} < V _{CC} – V _{OK_CHG}	60	40	100	ms
T _{PREQUAL}	Pre-Qualification Timer		30	27	33	mins

Electrical Characteristics

Unless otherwise noted, V_{CC} (V_{CHG_IN} and/or V_{USBpwr}) = 5V, V_{BATT} = 3.5V.

C_{CHG_IN} = 1 μ F, C_{USBpwr} = 1 μ F, C_{BATT} = 1 μ F. Typical values and limits appearing in normal type apply for T_J = 25°C. Limits appearing in **boldface** type apply over T_J = 0°C to +85°C. (Notes 2, 6, 7) (Continued)

Symbol	Parameter	Conditions	Typ	Limit		Units
				Min	Max	
DETECTION AND TIMING						
T _{PQ_FULL}	Deglitch Time for Pre-Qualification to Full-Rate Charge Transition		300	270	330	ms
T _{FULL_PQ}	Deglitch Time for Full-Rate to Pre-Qualification Transition		300	270	330	ms
T _{CHG}	Charge Timer		300	270	330	min
T _{EOC}	Deglitch Time for End-of-Charge Transition		300	270	330	ms
T _{BATTEMP}	Deglitch Time for Battery Temperature Fault		40	20	80	ms
T _{DGL}	Deglitch Time for EN_b and USB_sel Pins		40	20	80	ms
T _{ITOPOFF}	Deglitch Time for I _{TOPOFF}		300	270	330	ms
T _{TOPOFF}	Top-Off Charging Timer		30	27	33	min
I/O						
V _{IL}	Low-Level Input Voltage	EN_b		0	0.7	V
		USB_sel			1.5	
V _{IH}	High-Level Input Voltage	EN_b		1.4		V
		USB_sel		2.5		
I _{OL}	Low-Level Output Current	STAT1, STAT2, output voltage = 0.25V	25	10		mA
I _{OH}	High-Level Output Current	STAT1, STAT2, output voltage = 6.0V	0.01		1	μA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

Note 2: All voltages are with respect to the potential at the GND pin.

Note 3: The LM3658 has built-in thermal regulation to regulate the die temperature to 120°C. See Operation Description section for more detail.

Note 4: The Human body model is a 100 pF capacitor discharged through a 1.5 k Ω resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin. MIL-STD-883 3015.7

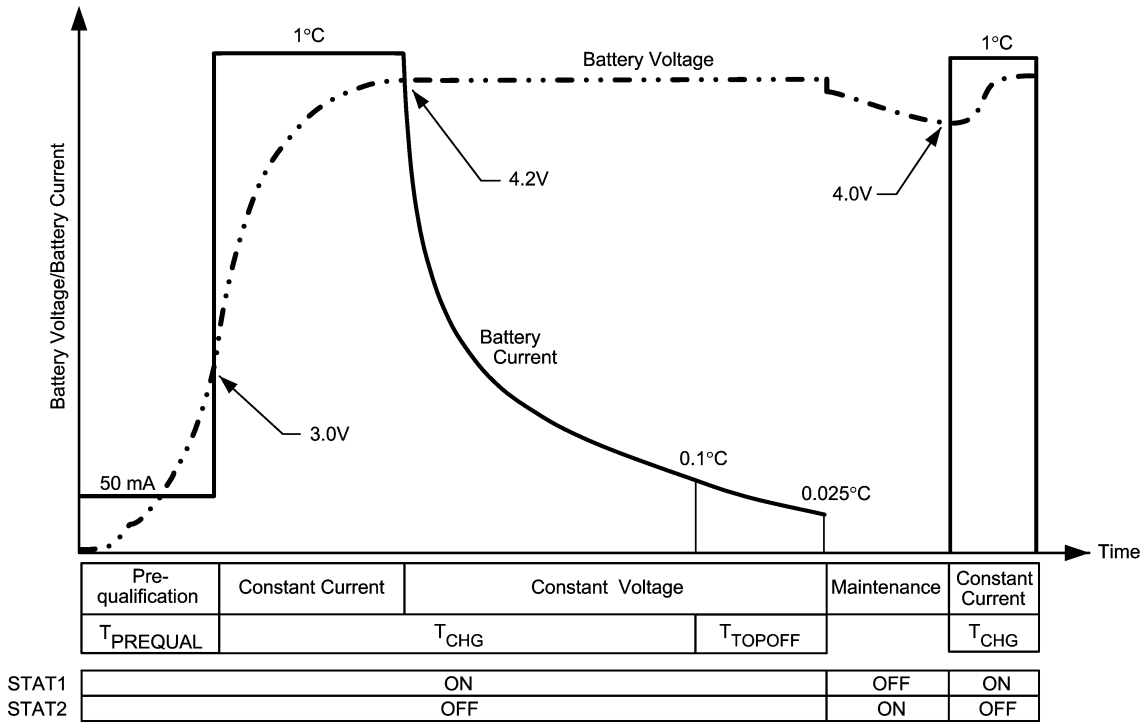
Note 5: Junction-to-ambient thermal resistance is highly application and board-layout dependent. In applications where high maximum power dissipation exists, special care must be paid to thermal dissipation issues in board design. Please refer to application note AN1187 for more detail.

Note 6: Min and Max limits are guaranteed by design, test, or statistical analysis. Typical numbers are not guaranteed, but do represent the most likely norm.

Note 7: LM3658 is not intended as a Li-Ion battery protection device; battery used in this application should have an adequate internal protection.



Li-Ion Charging Profile



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LM3658 Operation Description

POWER-DOWN MODE

The LM3658 will power down automatically when the voltage on the USBpwr or CHG_IN pin drops below the battery voltage with an amount that is equal to V_{OK_CHG} ($V_{BATT} > V_{CC} - V_{OK_CHG}$). Power-Down mode shuts off the internal power FETs as well as the open-drain pull-down transistors on the status pins STAT1 and STAT2. The only current consumed by the LM3658 is an ultra-low quiescent current of 1 μ A typical.

POWER-ON RESET

As soon as the voltage of one of the power sources rises above $V_{BATT} + V_{OK_CHG}$, the charger will wake up. However, charging will not be initiated unless the supply voltage source exceeds the V_{POR} .

AUTOMATIC POWER SOURCE DETECTION

When the voltage of one of the power sources exceeds the V_{POR} threshold, the LM3658 detects which power source is a valid charge supply. When both supply voltages are valid and present, CHG_IN will automatically be selected over USBpwr. The USBpwr will be the designated power source only if no CHG_IN is present or when the voltage on the CHG_IN pin is less than the battery voltage.

THERMAL POWER FET REGULATION

The internal power FETs are thermally regulated to the junction temperature of 120°C to guarantee optimal charging of the battery. At all times is the charge current limited by the I_{SET} resistor setting, the USB 100 mA/500 mA selection, or the 100°C junction temperature of the LM3658. The charge current is therefore a function of the charge current settings, the thermal conductivity of the package and the ambient temperature as described in the following equation:

$$I_{CHG} = \min \left[\frac{K_{ISET}}{R_{ISET}} \text{ or } \text{USB_sel or } \frac{120^\circ\text{C} - T_A}{\theta_{JA}(V_{CC} - V_{BATT})} \right]$$

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Where T_A is the ambient temperature and θ_{JA} is the thermal resistance of the package. Thermal regulation guarantees maximum charge current and superior charge rate without exceeding the power dissipation limits of the LM3658.

PRE-QUALIFICATION MODE

During pre-qualification, STAT1 is on and STAT2 is off, and the charger supplies a constant current of 50 mA to the battery. When the battery voltage reaches V_{FULL_RATE} , the charger transitions from pre-qualification to full-rate charging. The pre-qualification mode aborts when the battery doesn't reach V_{FULL_RATE} within the time allowed in $T_{PREQUAL}$ timer. In this event, charging stops and STAT1 and STAT2 will both be on, indicating a bad battery condition.

CHG_IN FULL-RATE CHARGING MODE

The full-rate charge cycle is initiated following the successful completion of the pre-qualification mode. Timer T_{CHG} starts to count when the charger enters full-rate charging, with STAT1 on and STAT2 off. When charging with an AC wall adapter, the full-rate charge current is proportional to the value of the resistor that is connected to the I_{SET} pin as described in the following equation:

$$I_{CHG} = \frac{K_{ISET}}{R_{ISET}}$$

It is recommended to charge Li-Ion batteries at 1C rate, where "C" is the capacity of the battery. As an example, it is recommended to charge a 750 mAh battery at 750 mA, or 1C. Charging at a higher rate can cause damage to the battery.

USBpwr FULL-RATE CHARGING MODE

The full-rate charge cycle is initiated following the successful completion of the pre-qualification mode. Timer T_{CHG} starts to count when the charger enters full-rate charging, with STAT1 on and STAT2 off. If the USB bus provides the charger supply, then the default full-rate charge current is 100 mA max unless the USB_sel pin is pulled high, which sets the charge current to 500 mA max.

CONSTANT-VOLTAGE CHARGING MODE AND END-OF-CHARGE (EOC) DETECTION

The battery voltage increases rapidly as a result of full-rate charging and will reach the 4.2V termination voltage, triggering the constant-voltage charge cycle. Timer T_{CHG} continues to count in this cycle. STAT1 is on and STAT2 is off. The charge current gradually decreases during constant-voltage charging until it reaches the End-Of-Charge (EOC), which is equal to 10% of the full-rate current set either by the resistor connected to the I_{SET} pin or the USB_sel pin. If Timer T_{CHG} times out before EOC is reached, charging stops and STAT1 and STAT2 will both be on, indicating a bad battery condition.

TOP-OFF CHARGING MODE

Once EOC has been reached, a top-off cycle continues to charge the battery. Timed top-off cycle provides optimal battery capacity following a complete charge cycle. During this cycle, charging terminates when I_{CHG} reaches 2.5% of the full-rate charge current or when T_{TOPOFF} times out, whichever occurs first. STAT1 will turn off and STAT2 will turn on once the top-off cycle completes successfully, indicating that charging is done.

MAINTENANCE MODE

Maintenance mode begins immediately after the charger successfully finishes the top-off cycle. In the maintenance mode, the battery voltage is being monitored by the LM3658 continuously. If the battery voltage drops 200 mV below V_{TERM} , a new full-rate charge cycle starts to replenish the battery. As this new full-rate charge cycle begins, STAT1 will turn on and STAT2 will turn off, and all the timers will reset. Refer to the LM3658 Flowchart.

CHARGE STATUS OUTPUTS

The LM3658 provides two open-drain outputs STAT1 and STAT2 that can be connected to external LEDs or to General Purpose I/O's (GPIO) of a peripheral IC. All charge status of the LM3658 is illustrated in Table 3. "ON" means that STATx pin is pulled low as its pull-down transistor is turned on, representing a logic 0.

LM3658 Operation Description

(Continued)

TABLE 3. Status Pins Summary

STAT1	STAT2	Condition
OFF	OFF	Power-Down, charging is suspended or interrupted
ON	OFF	Pre-qualification mode, CC and CV charging, Top-off mode
OFF	ON	Charge is completed
ON	ON	Bad battery (Safety timer expired), or LDO mode

SAFETY TIMERS

In order to prevent endless charging of the battery, which can cause damage to the battery, there are three safety timers that forcefully terminate charging if the charging mode is not completed within the time allowed.

Pre-Qualification Timer ($T_{PREQUAL}$)

The pre-qualification timer starts with the initiation of the pre-qualification mode and allows 30 minutes to transition from pre-qualification to full rate charging. If the battery voltage does not reach V_{FULL_RATE} in 30 minutes, charging stops and status pins STAT1 and STAT2 both turn on to indicate a bad battery status.

Charger Timer (T_{CHG})

The charge timer starts with the initiation of full-rate charging and has a duration of 5 hours for the LM3658. If the charge current does not reach EOC, charging stops and STAT1 and STAT2 both turn on to indicate a bad battery status. Once the charge control declares a bad battery, removing the input source is the only means to clear the bad battery status.

Top-Off Timer (T_{TOPOFF})

Once the charger successfully completes constant current constant voltage charging, it enters top-off mode and starts T_{TOPOFF} timer. Topoff lasts 30 minutes for the LM3658. During top-off, charging stops when T_{TOPOFF} reaches its count or when I_{CHG} reaches 2.5% of the full-rate charge current. There is no time-out condition in top-off mode.

When charging is interrupted either by battery temperature out of range or disabling the LM3658, the applicable safety timer will store its count value for the duration of the interruption and subsequently resumes counting from its stored count value when charging continues, only if the charger resumes to the same operation mode it was in before the interrupt.

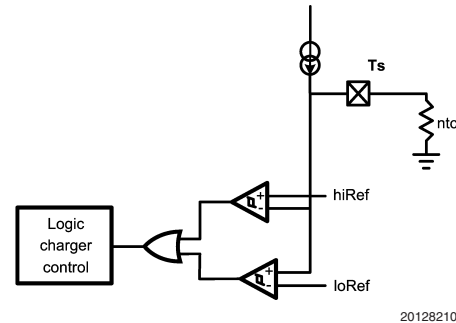
BATTERY TEMPERATURE MONITORING (Suspend Mode)

The LM3658 is equipped with a battery thermistor interface to continuously monitor the battery temperature by measuring the voltage between the T_S pin and ground. Charging is allowed only if the battery temperature is within the acceptable temperature range set by a pair of internal comparators inside the LM3658. If the battery temperature is out of range, STAT1 and STAT2 both turn off and charging is suspended. Timer holds its count value.

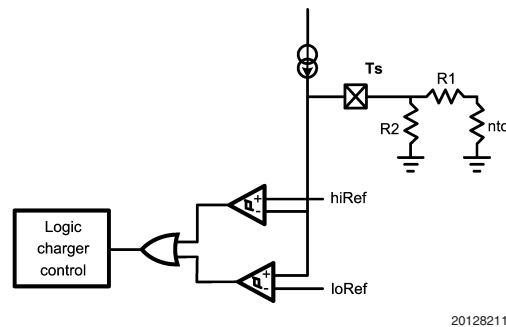
The T_S pin is only active during charging and draws no current from the battery when no external power source is present.

If the T_S pin is not used in the application, it should be connected to GND through 10k Ω pulldown resistor.

When the T_S pin is left floating (battery removal), then the charger will be disabled as the T_S voltage exceeds the upper temperature limit.



The LM3658 battery temperature feature is tailored to use negative temperature coefficient (NTC) 103AT thermistors with 10k Ω impedance. If alternative thermistors need to be used in the system, supplemental external resistors are needed to create a circuit with equivalent impedance.



DISABLING CHARGER (Charge Interrupt Mode)

Charging can be safely interrupted by pulling the EN_b pin high and charging can resume upon pulling the EN_b pin low. The enable pin can be permanently tied to GND with no extra current consumption penalty during power down mode. When the charger is disabled, timer holds its count value, and STAT1 and STAT2 are both off.

INPUT/OUTPUT BYPASS CAPACITORS

Care should be taken to support the stability of the charge system by connecting a 1 μ F capacitor as close as possible to the BATT pin. An input capacitor ranging from 1.0 μ F–10.0 μ F must be connected to the CHG_IN and $USBpwr$ input pins. Low cost ceramic capacitors can be selected.

THERMAL PERFORMANCE OF THE LLP PACKAGE

The LM3658 is a monolithic device with integrated power FETs. For that reason, it is important to pay special attention to the thermal impedance of the LLP package and to the PCB layout rules in order to maximize power dissipation of the LLP package.

The LLP package is designed for enhanced thermal performance and features an exposed die attach pad at the bottom center of the package that creates a direct path to the PCB for maximum power dissipation. Compared to the traditional leaded packages where the die attach pad is embedded inside the molding compound, the LLP reduces one layer in the thermal path.

LM3658 Operation Description

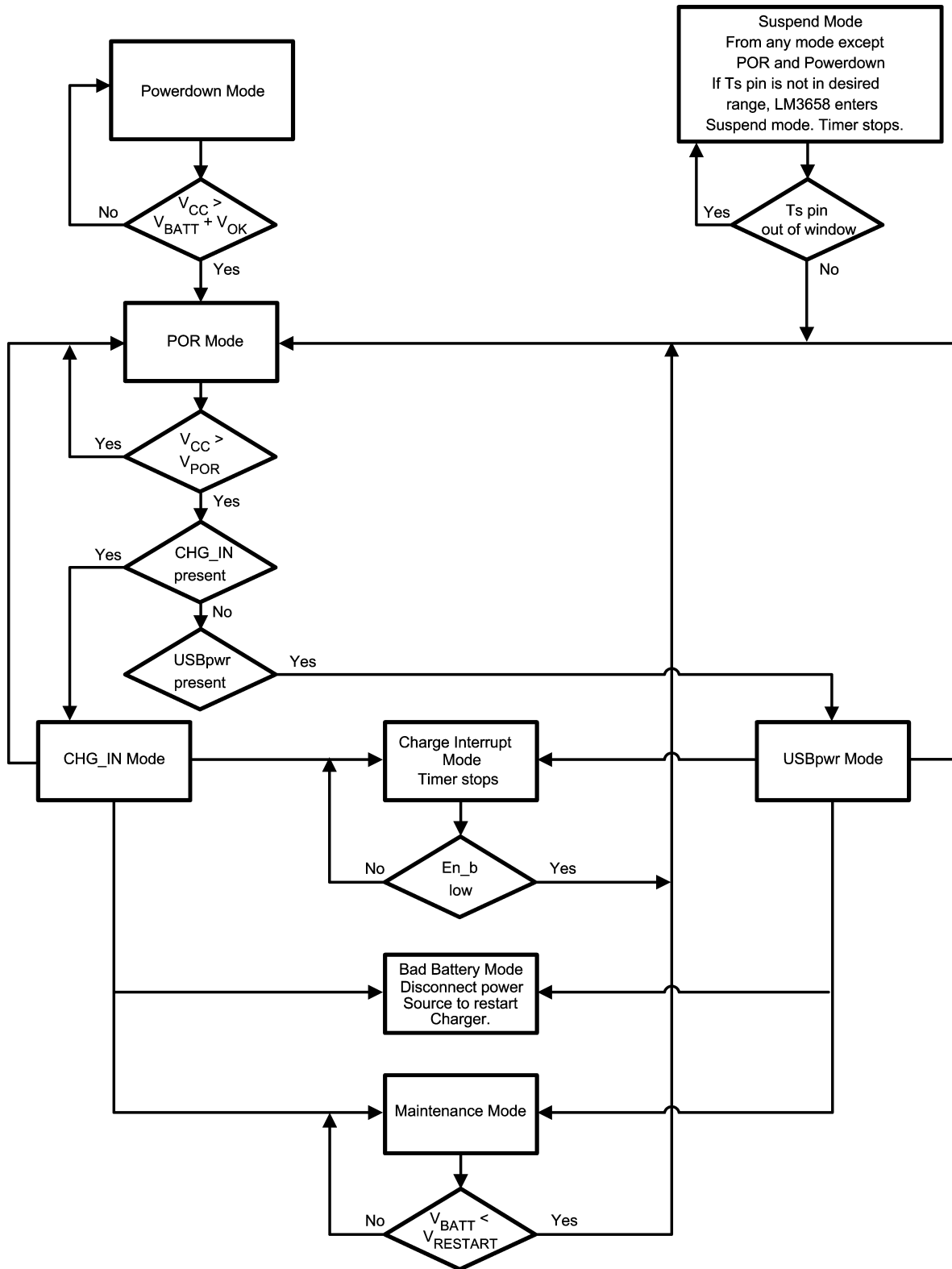
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The thermal advantage of the LLP package is fully realized only when the exposed die attach pad is soldered down to a thermal land on the PCB board with thermal vias planted underneath the thermal land. Based on thermal analysis of the LLP package, the junction-to-ambient thermal resistance (θ_{JA}) can be improved by a factor of two when the die attach pad of the LLP package is soldered directly onto the PCB with thermal land and thermal vias, as opposed to an alternative with no direct soldering to a thermal land. Typical pitch

and outer diameter for thermal vias are 1.27 mm and 0.33 mm respectively. Typical copper via barrel plating is 1 oz, although thicker copper may be used to further improve thermal performance. The LM3658 die attach pad is connected to the substrate of the IC and therefore, the thermal land and vias on the PCB board need to be connected to ground (GND pin).

For more information on board layout techniques, refer to Application Note 1187 "Leadless Lead Frame Package (LLP)." This application note also discusses package handling, solder stencil and the assembly process.

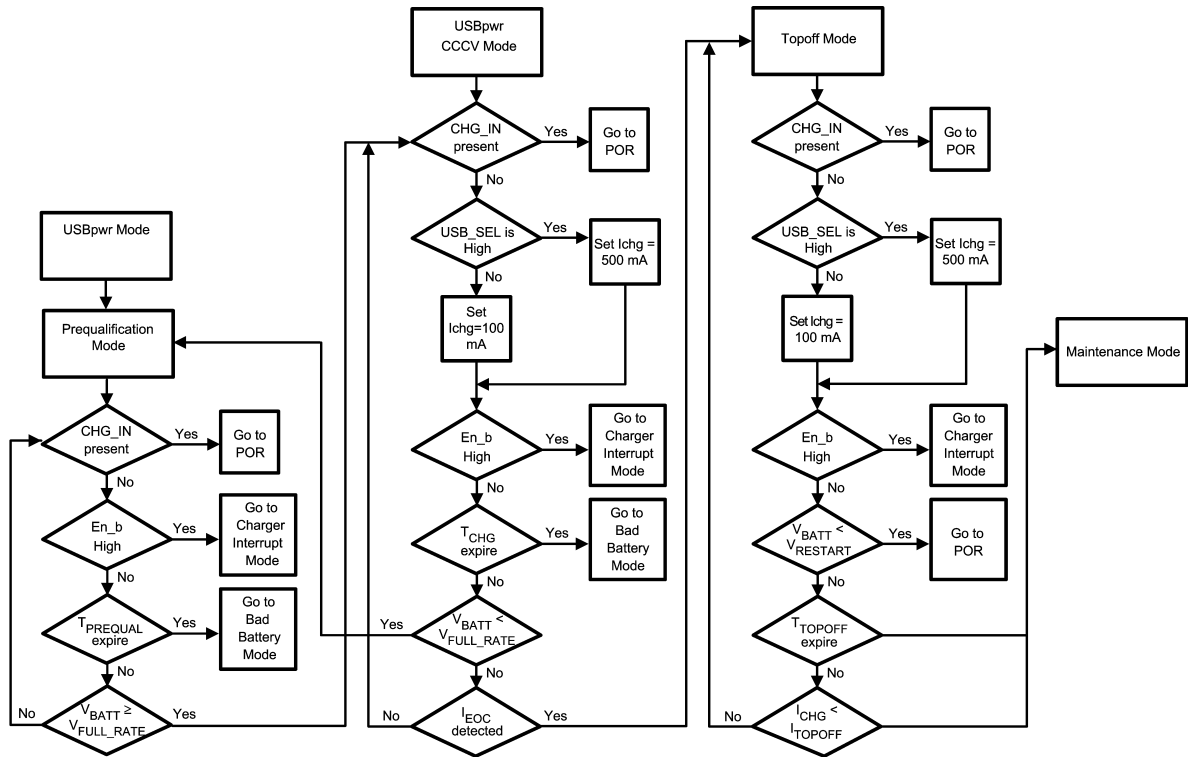
LM3658 Operation Description (Continued)



LM3658 Flowcart

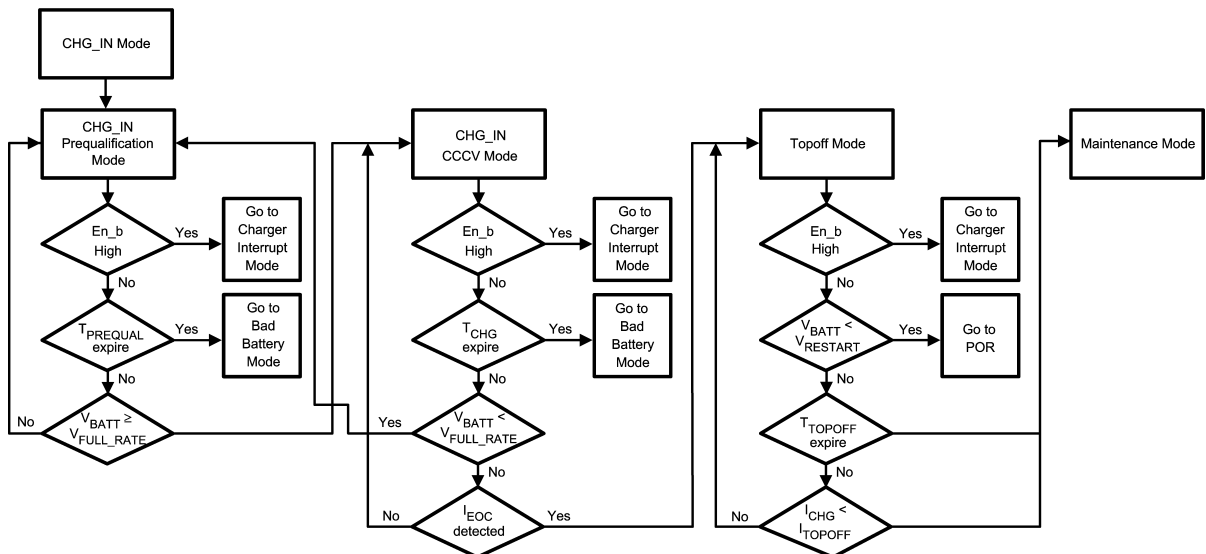
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LM3658 Operation Description (Continued)



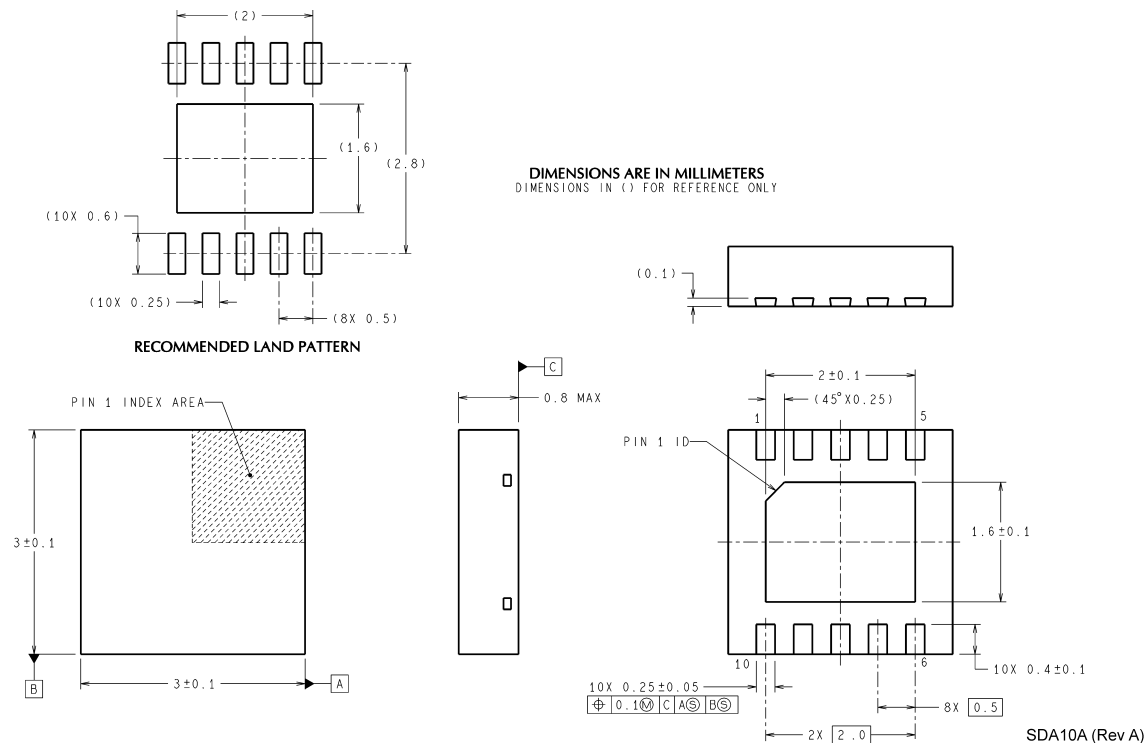
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LM3658 USBpwr Mode Flowcart



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LM3658 CHG_IN Mode Flowcart

Physical Dimensions inches (millimeters) unless otherwise noted

LLP10 Package Drawing
NS Package Number SDA10A

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 Fax: +49 (0) 180-530 85 86
 Email: europe.support@nsc.com
 Deutsch Tel: +49 (0) 69 9508 6208
 English Tel: +44 (0) 870 24 0 2171
 Français Tel: +33 (0) 1 41 91 8790

National Semiconductor
Asia Pacific Customer
Support Center
Email: ap.support@nsc.com

National Semiconductor
Japan Customer Support Center
 Fax: 81-3-5639-7507
 Email: jpn.feedback@nsc.com
 Tel: 81-3-5639-7560