

# LM3658 Dual Source USB/AC Li Chemistry Charger IC for Portable Applications

Check for Samples: [LM3658](#)

## 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**
- **LDO Mode with 1A of Source Current is Automatically Invoked When the Battery is Absent and the AC Wall Adapter is Connected**
- **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 WSON Package**

## APPLICATIONS

- **Smartphones**
- **Digital Still Cameras**
- **PDA's**
- **Hard Drive and Flash-based MP3 Players**
- **USB-powered Devices**

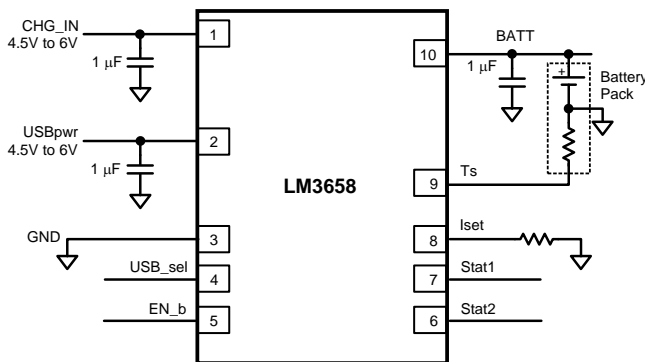
## DESCRIPTION

The LM3658 is a single chip charger IC designed for handheld 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. Additionally, the charger IC operates as a linear regulator in "LDO mode", when the AC wall adapter is connected and no battery is present. 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.

## Typical Application



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## Connection Diagram and Package Mark Information

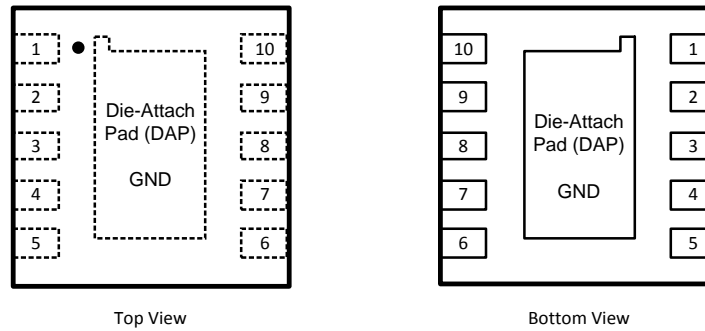


Figure 1. WSON10 Package Drawing

### Pin Descriptions

| 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 <a href="#">Operation Description</a> 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 <a href="#">Operation Description</a> section for more detail.  |
| 8     | I <sub>SET</sub> | 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 <sub>S</sub>   | Battery temperature sense pin. This pin must be connected to battery pack's temperature sense output pin. For the LM3658SD-B version, leaving this pin open indicates that the battery pack is not present. The charger IC will invoke LDO mode if this pin is left floating. See <a href="#">Operation Description</a> section for more detail. |
| 10    | BATT             | Positive battery terminal connection.  |



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### ABSOLUTE MAXIMUM RATINGS <sup>(1)(2)(3)</sup>

|  |                   |                           |
|--|-------------------|---------------------------|
| CHG_IN, USBpwr (V <sub>CC</sub> )          |                   | -0.3V to +6.5V            |
| All other pins except GND                  |                   | -0.3V to CHG_IN or USBpwr |
| Power Dissipation <sup>(4)</sup>           |                   | Internally Limited        |
| Junction Temperature (T <sub>J-MAX</sub> ) |                   | +150°C                    |
| Storage Temperature Range                  |                   | -65°C to +150°C           |
| ESD Rating <sup>(5)</sup>                  | Human Body Model: | 2.0 kV                    |
|  | Machine Model:    | 200V                      |

- (1) All voltages are with respect to the potential at the GND pin.
- (2) Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is specified. Operating Ratings do not imply specified performance limits. For specified performance limits and associated test conditions, see the Electrical Characteristics tables.
- (3) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
- (4) The LM3658 has built-in thermal regulation to regulate the die temperature to 120°C. See [Operation Description](#) section for more detail.
- (5) The Human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin. MIL-STD-883 3015.7

**OPERATING RATINGS** <sup>(1)(2)</sup>

|  |                    |
|--|--------------------|
| 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 <sup>(3)</sup>             | Internally Limited |
| Junction Temperature (T <sub>J</sub> ) Range | -40°C to +125°C    |
| Ambient Temperature (T <sub>A</sub> ) Range  | -40°C to +85°C     |

- (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 specified. Operating Ratings do not imply specified performance limits. For specified performance limits and associated test conditions, see the Electrical Characteristics tables.
- (2) All voltages are with respect to the potential at the GND pin.
- (3) The LM3658 has built-in thermal regulation to regulate the die temperature to 120°C. See [Operation Description](#) section for more detail.

**THERMAL PROPERTIES**

|   |        |
|---|--------|
| θ <sub>JA</sub> , Junction-to-Ambient Thermal Resistance <sup>(1)</sup> | 54°C/W |
|---|--------|

- (1) 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 AN-1187 ([SNOA401](#)) for more detail.

**ELECTRICAL CHARACTERISTICS**

Unless otherwise noted, V<sub>CC</sub> (V<sub>CHG\_IN</sub> and/or V<sub>USBpwr</sub>) = 5V, V<sub>BATT</sub> = 3.5V. C<sub>CHG\_IN</sub> = 1 μF, C<sub>USBpwr</sub> = 1 μF, C<sub>BATT</sub> = 1 μF. Typical values and limits appearing in normal type apply for T<sub>J</sub> = 25°C. Limits appearing in **boldface** type apply over T<sub>J</sub> = 0°C to +85°C. <sup>(1)(2)(3)</sup>

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

- (1) All voltages are with respect to the potential at the GND pin.
- (2) Min and Max limits are specified by design, test, or statistical analysis. Typical numbers are not specified, but do represent the most likely norm.
- (3) LM3658 is not intended as a Li-Ion battery protection device; battery used in this application should have an adequate internal protection.

## ELECTRICAL CHARACTERISTICS (continued)

Unless otherwise noted,  $V_{CC}$  ( $V_{CHG\_IN}$  and/or  $V_{USBpwr}$ ) = 5V,  $V_{BATT} = 3.5V$ .  $C_{CHG\_IN} = 1 \mu F$ ,  $C_{USBpwr} = 1 \mu F$ ,  $C_{BATT} = 1 \mu F$ . Typical values and limits appearing in normal type apply for  $T_J = 25^\circ C$ . Limits appearing in **boldface** type apply over  $T_J = 0^\circ C$  to  $+85^\circ C$ . <sup>(1)(2)(3)</sup>

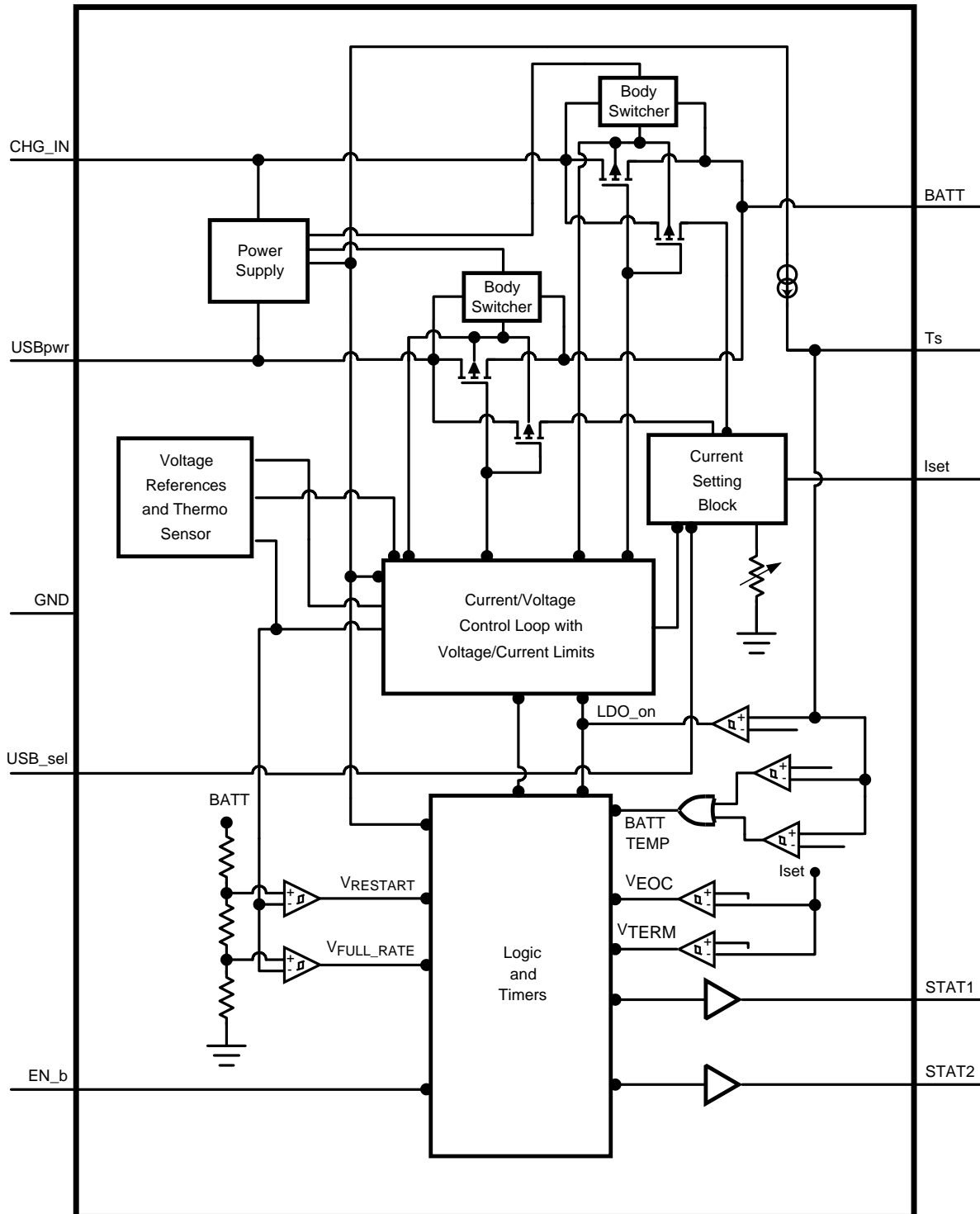
| Symbol                      | Parameter   | Conditions   | Min         | Typ  | Max         | Units      |
|-----------------------------|---|--|-------------|------|-------------|------------|
| $I_{CHG}$                   | CHG_IN Full-Rate Charge Current Range (see <a href="#">full-rate charge mode</a> description)                           | $6V \geq V_{CC} \geq 4.5V$<br>$V_{BATT} < V_{CC} - V_{OK\_CHG}$<br>$V_{FULL\_RATE} < V_{BATT} < V_{TERM}$<br>$I_{CHG} = K_{ISET}/R_{ISET}$ | <b>50</b>   |      | <b>1000</b> | mA         |
| $I_{CHG}$                   | CHG_IN Full Rate Charge Current   | $R_{ISET} = 10k\Omega$   | <b>220</b>  | 245  | <b>270</b>  | mA         |
|                             |   | $R_{ISET} = 5 k\Omega$   | <b>465</b>  | 500  | <b>535</b>  |            |
|                             |   | $R_{ISET} = 3.3k\Omega$  | <b>700</b>  | 760  | <b>820</b>  |            |
| $K_{ISET}$                  | Charge Current Set Coefficient<br>$I_{CHG} = K_{ISET}/R_{ISET}$ (see <a href="#">full-rate charge mode</a> description) | $6V \geq V_{CC} \geq 4.5V$<br>$V_{BATT} < V_{CC} - V_{OK\_CHG}$<br>$V_{FULL\_RATE} < V_{BATT} < V_{TERM}$                                  |             | 2500 |             | AQ         |
| $V_{ISET}$                  | Charge Current Set Voltage  | $6V \geq V_{CC} \geq 4.5V$<br>$V_{BATT} < V_{CC} - V_{OK\_CHG}$<br>$V_{FULL\_RATE} < V_{BATT} < V_{TERM}$                                  |             | 2.5  |             | V          |
| $I_{USB\_L}$                | USB Full-Rate Charge Low Current  |  | <b>80</b>   | 90   | <b>100</b>  | mA         |
| $I_{USB\_H}$                | USB Full-Rate Charge High Current   |  | <b>400</b>  | 450  | <b>500</b>  | mA         |
| $I_{PREQUAL}$               | Pre-Qualification Current   | $V_{BATT} = 2V$ , for both AC adapter and USB  | <b>35</b>   | 45   | <b>55</b>   | mA         |
| $V_{FULL\_RATE}$            | Full-Rate Qualification Threshold   | $V_{BATT}$ rising, transition from pre-qualification to full-rate charging   | <b>2.9</b>  | 3.0  | <b>3.1</b>  | V          |
|                             | Full Rate Hysteresis  | $V_{BATT}$ falling   | <b>50</b>   | 60   | <b>70</b>   | mV         |
| $I_{EOC}$                   | End-of-Charge Current, Percent from Full-Range Current  | $6V \geq V_{CC} \geq 4.5V$<br>$V_{BATT} < V_{CC} - V_{OK\_CHG}$<br>$V_{FULL\_RATE} < V_{BATT} < V_{TERM}$                                  | <b>7</b>    | 9    | <b>11</b>   | %          |
| $I_{TOPOFF}$                | Minimum Top-Off Charge Current  | $6V \geq V_{CC} \geq 4.5V$<br>$V_{BATT} < V_{CC} - V_{OK\_CHG}$<br>$V_{BATT} = V_{TERM}$   | <b>1.25</b> | 2.5  | <b>3.75</b> | %          |
| $V_{RESTART}$               | Restart Threshold Voltage   | $V_{BATT}$ falling, transition from EOC to pre-qualification mode  | <b>3.94</b> | 4.0  | <b>4.07</b> | V          |
| $V_{TL}$                    | Battery Temperature Sense Comparator Low-Voltage Threshold  |  | <b>0.46</b> | 0.49 | <b>0.52</b> | V          |
| $V_{TH}$                    | Battery Temperature Sense Comparator High-Voltage Threshold   |  | <b>2.44</b> | 2.49 | <b>2.54</b> | V          |
| $I_{TSENSE}$                | Battery Temperature Sense Current   |  | <b>94</b>   | 100  | <b>106</b>  | $\mu A$    |
| $T_{REG}$                   | Regulated Junction Temperature  |  |             | 120  |             | $^\circ C$ |
| $T_{SD}$                    | Thermal Shutdown Temperature  |  |             | 165  |             | $^\circ C$ |
| $V_{TLDO}$                  | LDO mode detection threshold  | TS pin voltage for entry into LDO mode. For LM3658SD-B only  | <b>3.95</b> | 4.0  |             | v          |
| $V_{LDO}$                   | LDO Mode Regulation   | $6V \geq V_{CHG\_IN} \geq 4.5V$<br>$T_S = \text{Floating}$<br>$I_{BATT} = 100mA$   | <b>-3.0</b> | 4.2  | <b>+3.0</b> | %          |
| <b>DETECTION AND TIMING</b> |   |  |             |      |             |            |
| $T_{POK}$                   | Power OK Deglitch Time  | $V_{BATT} < V_{CC} - V_{OK\_CHG}$  | <b>40</b>   | 60   | <b>100</b>  | ms         |
| $T_{PREQUAL}$               | Pre-Qualification Timer   |  | <b>27</b>   | 30   | <b>33</b>   | mins       |
| $T_{PQ\_FULL}$              | Deglitch Time for Pre-Qualification to Full-Rate Charge Transition  |  | <b>270</b>  | 300  | <b>330</b>  | ms         |
| $T_{FULL\_PQ}$              | Deglitch Time for Full-Rate to Pre-Qualification Transition   |  | <b>270</b>  | 300  | <b>330</b>  | ms         |

**ELECTRICAL CHARACTERISTICS (continued)**

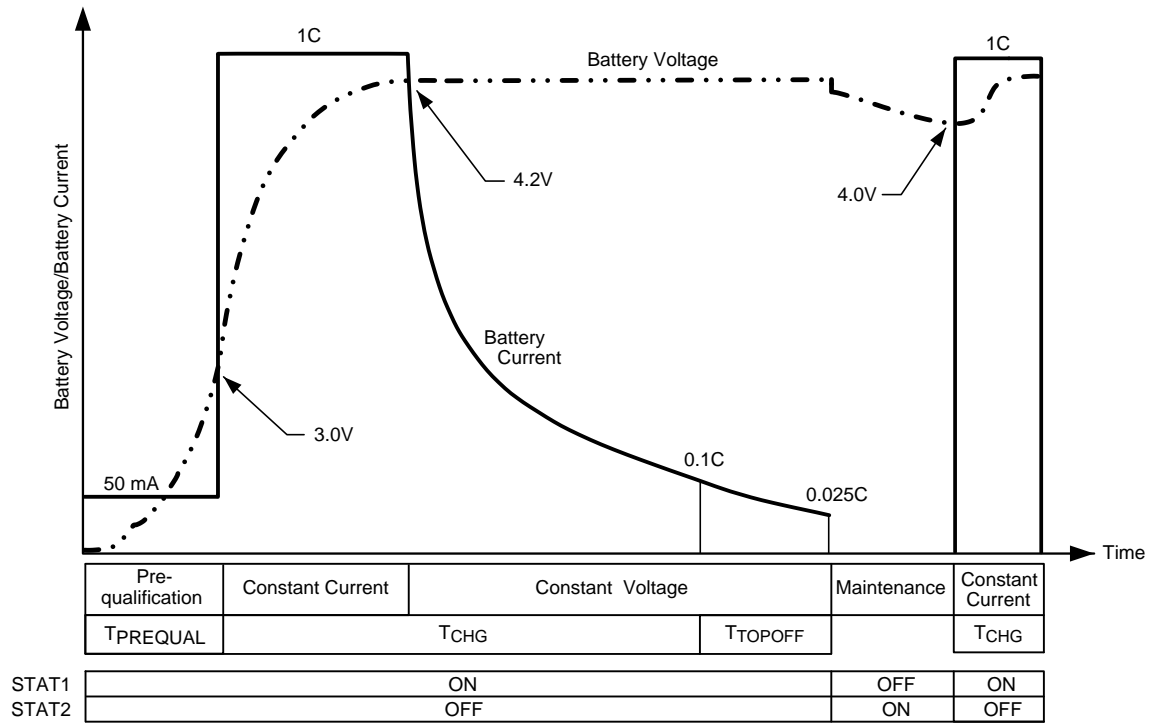
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| Symbol         | Parameter                                    | Conditions  | Min        | Typ  | Max        | Units   |
|----------------|--|---|------------|------|------------|---------|
| $T_{CHG}$      | Charge Timer                                 | LM3658SD, LM3658SD-B and LM3658SD-A with USB_sel=high | <b>270</b> | 300  | <b>330</b> | mins    |
|                |  | LM3658SD-A with USB_sel=low                           | <b>540</b> | 600  | <b>660</b> |         |
| $T_{EOC}$      | Deglintch Time for End-of-Charge Transition  |   | <b>270</b> | 300  | <b>330</b> | ms      |
| $T_{BATTEMP}$  | Deglintch Time for Battery Temperature Fault |   | <b>20</b>  | 40   | <b>80</b>  | ms      |
| $T_{DGL}$      | Deglintch Time for EN_b and USB_sel Pins     |   | <b>20</b>  | 40   | <b>80</b>  | ms      |
| $T_{ITOPPOFF}$ | Deglintch Time for $I_{TOPOFF}$              |   | <b>270</b> | 300  | <b>330</b> | ms      |
| $T_{TOPOFF}$   | Top-Off Charging Timer                       | LM3658SD, LM3658SD-B and LM3658SD-A with USB_sel=high | <b>27</b>  | 30   | <b>33</b>  | mins    |
|                |  | LM3658SD-A with USB_sel=low                           | <b>54</b>  | 60   | <b>66</b>  |         |
| <b>I/O</b>     |  |   |            |      |            |         |
| $V_{IL}$       | Low-Level Input Voltage                      | EN_b  | <b>0</b>   |      | <b>0.7</b> | V       |
|                |  | USB_sel   |            |      | <b>1.5</b> |         |
| $V_{IH}$       | High-Level Input Voltage                     | EN_b  | <b>1.4</b> |      |            | V       |
|                |  | USB_sel   | <b>2.5</b> |      |            |         |
| $I_{OL}$       | Low-Level Output Current                     | STAT1, STAT2, output voltage = 0.25V                  | <b>10</b>  | 25   |            | mA      |
| $I_{OH}$       | High-Level Output Current                    | STAT1, STAT2, output voltage = 6.0V                   |            | 0.01 | <b>1</b>   | $\mu$ A |

BLOCK DIAGRAM



### Li-Ion Charging Profile



## 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  $\mu$ 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 specify 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:

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

Where  $T_A$  is the ambient temperature and  $\theta_{JA}$  is the thermal resistance of the package. Thermal regulation specifies 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 1](#). "ON" means that STATx pin is pulled low as its pull-down transistor is turned on, representing a logic 0.

**Table 1. 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.

The LM3658SD-A version has selectable timers for  $T_{CHG}$  and  $T_{TOPOFF}$ . Based on the logic level applied to the USB\_sel pin, timers can be chosen as follow:

| Input  | USB_SEL | $T_{PREQUAL}$ | $T_{CHG}$ | $T_{TOPOFF}$ |
|--------|---------|---------------|-----------|--------------|
| CHG_IN | Low     | 30 minutes    | 10 hours  | 60 minutes   |
| CHG_IN | High    | 30 minutes    | 5 hours   | 30 minutes   |
| USBpwr | Low     | 30 minutes    | 10 hours  | 60 minutes   |
| USBpwr | High    | 30 minutes    | 5 hours   | 30 minutes   |

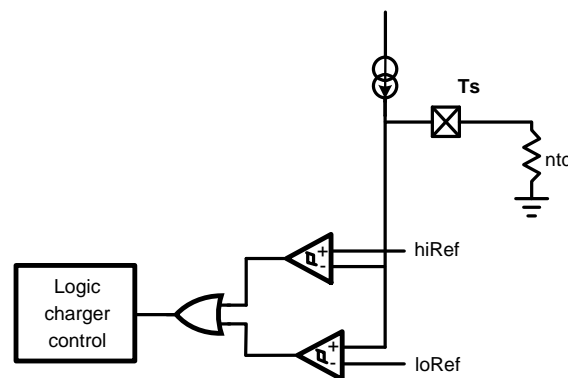
### BATTERY TEMPERATURE MONITORING (SUSPEND MODE)

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.

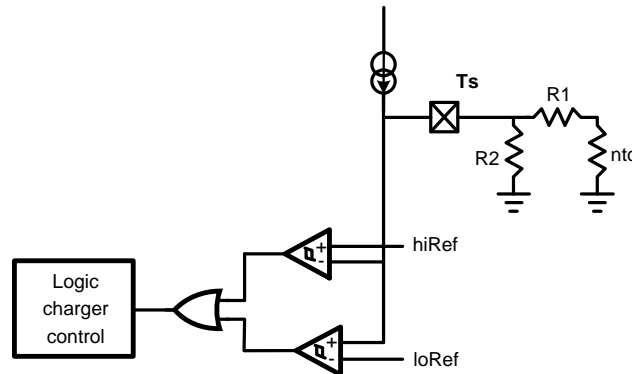
The  $T_S$  pin is only active during charging and draws no current from the battery when no external power source is present.

If the  $T_S$  pin is not used in the application, it should be connected to GND through 10k $\Omega$  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 $\Omega$  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.

## LDO MODE (AVAILABLE ONLY IN LM3658SD-B VERSION)

The LM3658SD-B version enters LDO mode when the  $T_s$  pin is floating and AC wall adapter is still connected to CHG\_IN pin. In LDO mode, STAT1 and STAT2 are both on. The LM3658SD-B becomes a linear regulator capable of delivering 1A of source current. Normally the  $T_s$  pin is connected to the thermistor from the battery pack for temperature monitoring purpose. If this pin is disconnected, the LM3658SD-B assumes that there is no battery present and will automatically invoke the LDO mode. LDO mode allows applications to operate without a battery provided that the AC wall adapter supplies power to the CHG\_IN pin. The LDO mode is not possible in USB mode.

For the other versions of the LM3658, floating the  $T_s$  pin does not invoke LDO mode. Instead, it will go to suspend mode. Please refer to “[Battery Temperature Monitoring](#)” section for more detail.

## 5 HOUR/ 10 HOUR SELECTABLE TIMER (AVAILABLE ONLY IN LM3658SD-A VERSION)

The LM3658SD-A allows the user to select between 5 hour or 10 hour timer based on the polarity of the USB\_sel pin, in both CHG\_IN mode and USBpwr mode. By pulling the USB\_sel pin high, the timer is set to 5 hours. In the USBpwr mode, the polarity of the USB\_sel pin determines the charge current as well as the timer. In CHG\_IN mode, the polarity of the USB\_sel pin determines only the timer. The charge current is set by the resistor at  $I_{set}$  pin.

## INPUT/OUTPUT BYPASS CAPACITORS

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

## THERMAL PERFORMANCE OF THE WSON 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 WSON package and to the PCB layout rules in order to maximize power dissipation of the WSON package.

The WSON 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 WSON reduces one layer in the thermal path.

The thermal advantage of the WSON 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 WSON package, the junction-to-ambient thermal resistance ( $\theta_{JA}$ ) can be improved by a factor of two when the die attach pad of the WSON 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 ([SNOA401](#)) “Leadless Lead Frame Package (LLP).” This application note also discusses package handling, solder stencil and the assembly process.

LM3658 FLOWCHARTS

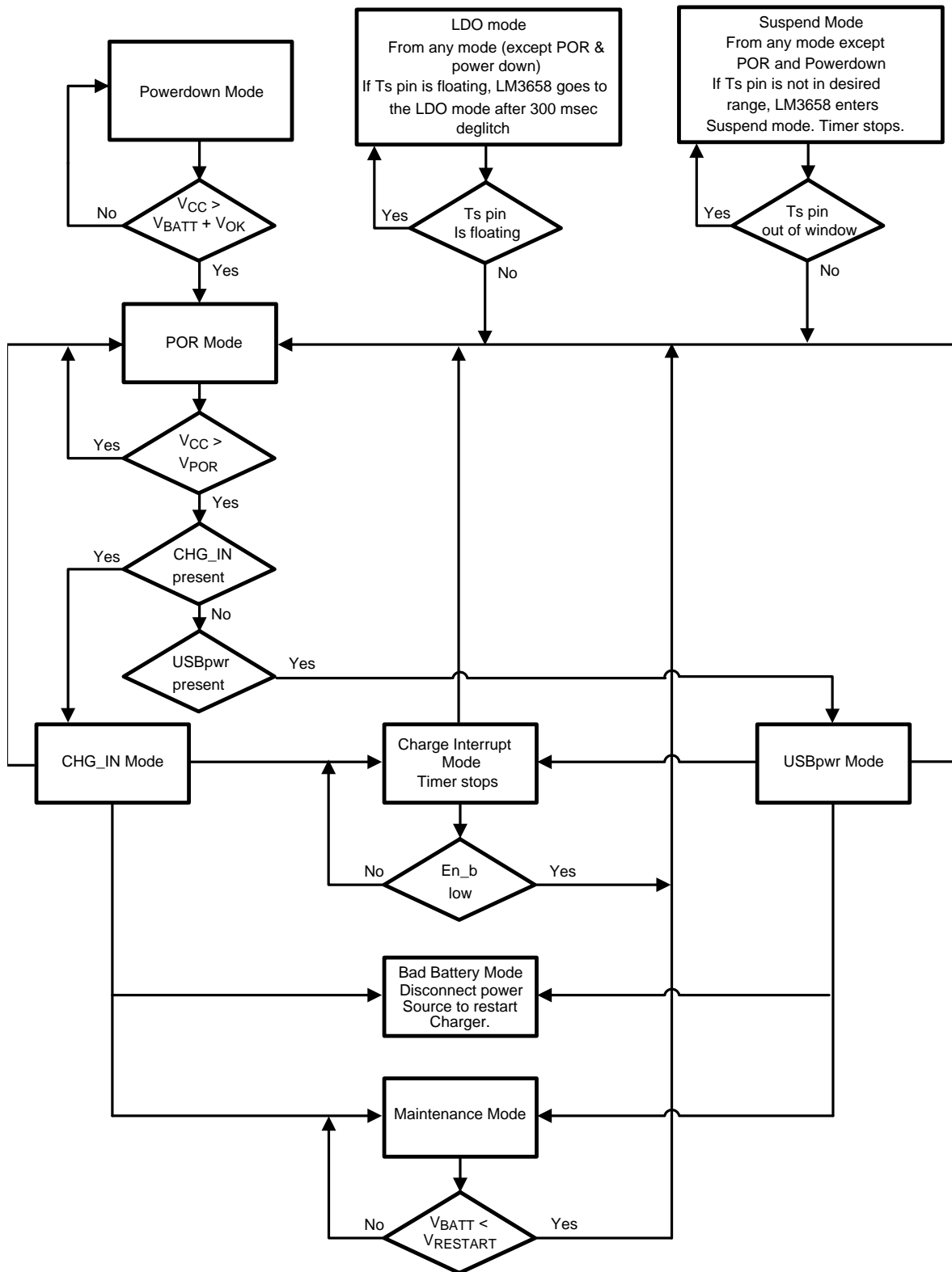


Figure 2. LM3658 Flowchart

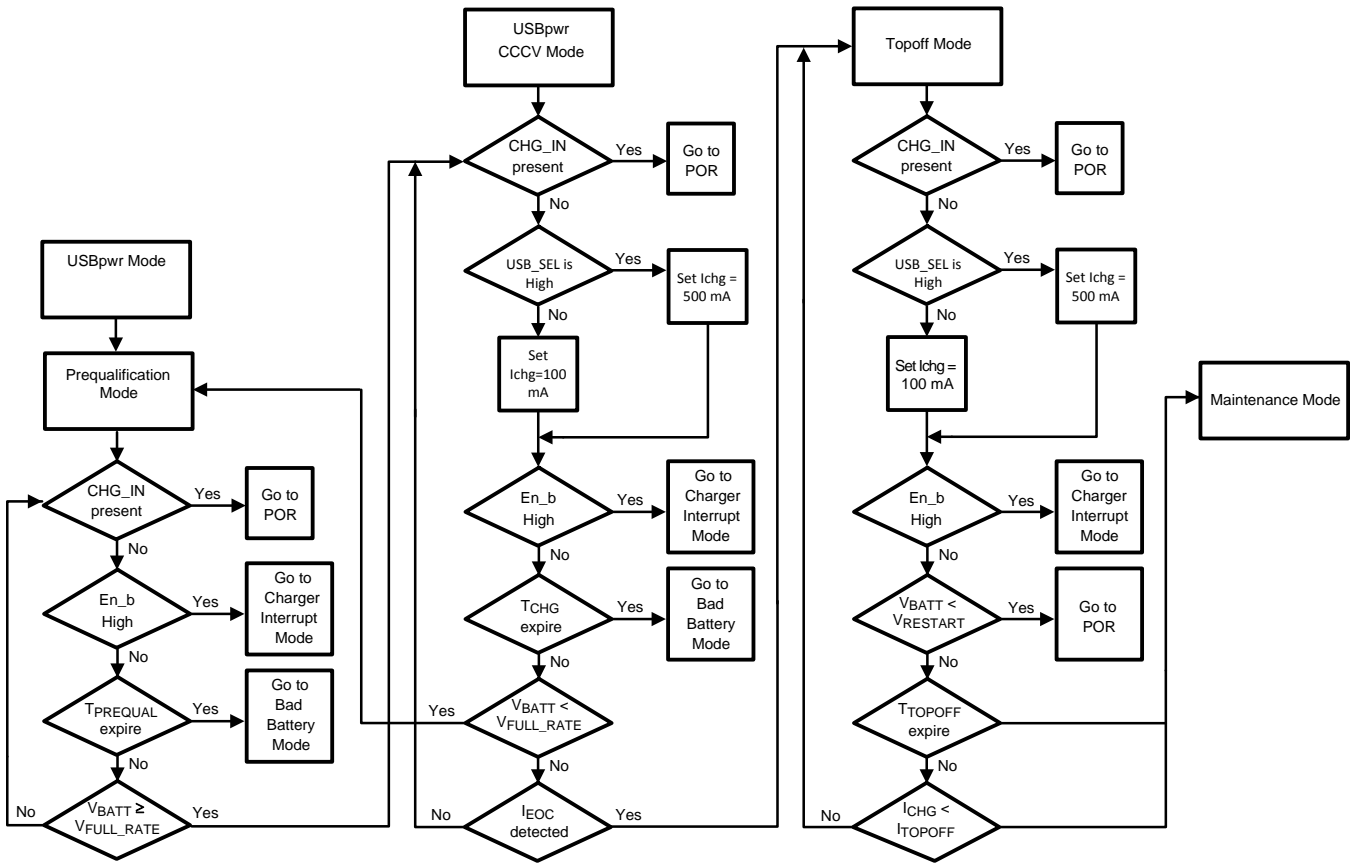


Figure 3. LM3658 USBpwr Mode Flowchart

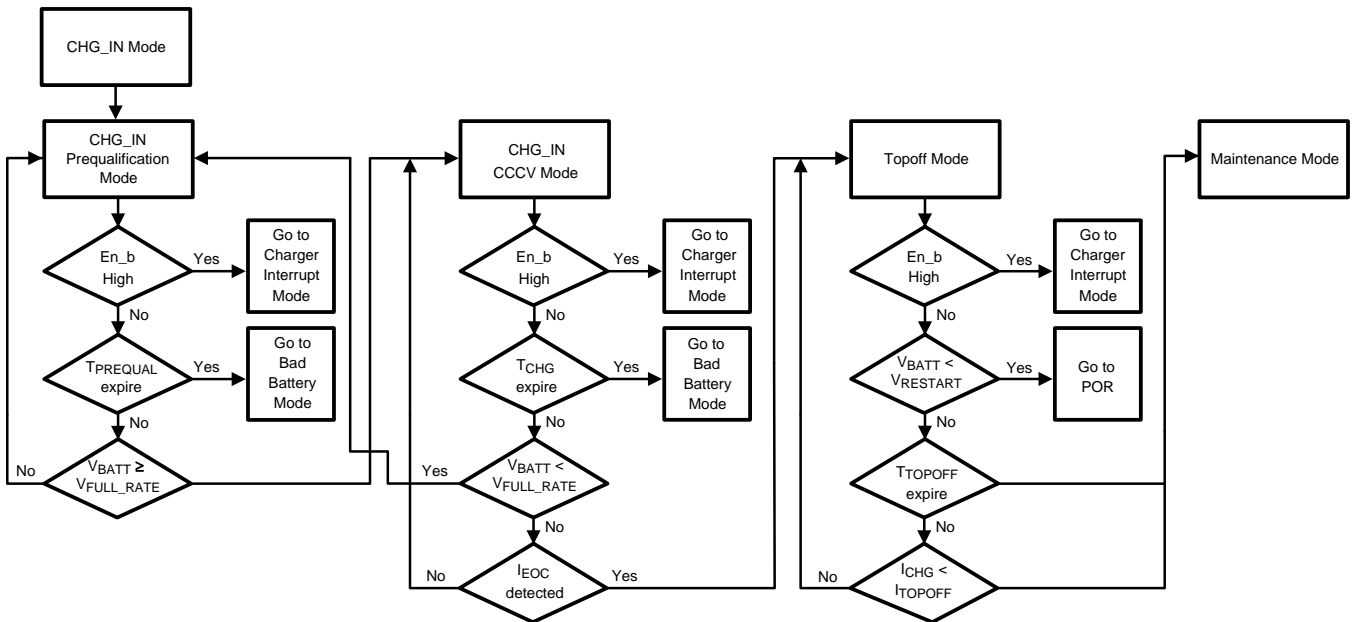


Figure 4. LM3658 CHG\_IN Mode Flowchart

**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan<br>(2)         | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|-----------------|------|-------------|-------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| LM3658SD-A/NOPB  | ACTIVE        | WSO          | DSC             | 10   | 1000        | Green (RoHS & no Sb/Br) | NIPDAU   SN             | Level-1-260C-UNLIM   | -40 to 85    | L155B                   | <a href="#">Samples</a> |
| LM3658SD-B/NOPB  | ACTIVE        | WSO          | DSC             | 10   | 1000        | Green (RoHS & no Sb/Br) | NIPDAU   SN             | Level-1-260C-UNLIM   | -40 to 85    | L156B                   | <a href="#">Samples</a> |
| LM3658SD/NOPB    | ACTIVE        | WSO          | DSC             | 10   | 1000        | Green (RoHS & no Sb/Br) | NIPDAU   SN             | Level-1-260C-UNLIM   | -40 to 85    | L111B                   | <a href="#">Samples</a> |
| LM3658SDX-A/NOPB | ACTIVE        | WSO          | DSC             | 10   | 4500        | Green (RoHS & no Sb/Br) | SN                      | Level-1-260C-UNLIM   | -40 to 85    | L155B                   | <a href="#">Samples</a> |
| LM3658SDX-B/NOPB | ACTIVE        | WSO          | DSC             | 10   | 4500        | Green (RoHS & no Sb/Br) | NIPDAU   SN             | Level-1-260C-UNLIM   | -40 to 85    | L156B                   | <a href="#">Samples</a> |
| LM3658SDX/NOPB   | ACTIVE        | WSO          | DSC             | 10   | 4500        | Green (RoHS & no Sb/Br) | NIPDAU   SN             | Level-1-260C-UNLIM   | -40 to 85    | L111B                   | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSELETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "-" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

<sup>(6)</sup> Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

| Device           | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LM3658SD-A/NOPB  | WSON         | DSC             | 10   | 1000 | 178.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SD-B/NOPB  | WSON         | DSC             | 10   | 1000 | 180.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SD/NOPB    | WSON         | DSC             | 10   | 1000 | 178.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SD/NOPB    | WSON         | DSC             | 10   | 1000 | 180.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SDX-A/NOPB | WSON         | DSC             | 10   | 4500 | 330.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SDX-B/NOPB | WSON         | DSC             | 10   | 4500 | 330.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SDX/NOPB   | WSON         | DSC             | 10   | 4500 | 330.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |
| LM3658SDX/NOPB   | WSON         | DSC             | 10   | 4500 | 330.0              | 12.4               | 3.3     | 3.3     | 1.0     | 8.0     | 12.0   | Q1            |

**TAPE AND REEL BOX DIMENSIONS**

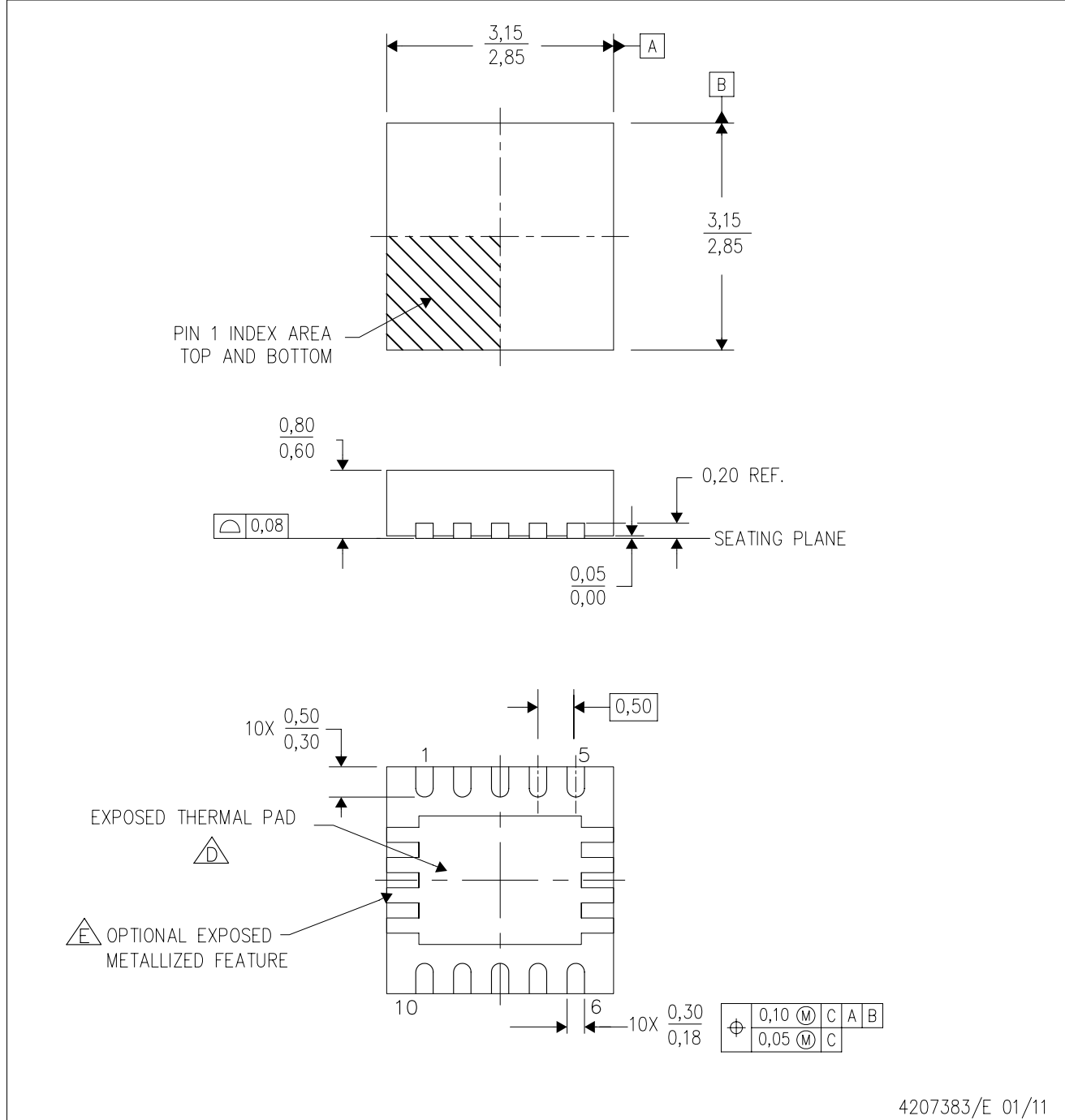

\*All dimensions are nominal

| Device           | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LM3658SD-A/NOPB  | WSON         | DSC             | 10   | 1000 | 210.0       | 185.0      | 35.0        |
| LM3658SD-B/NOPB  | WSON         | DSC             | 10   | 1000 | 203.0       | 203.0      | 35.0        |
| LM3658SD/NOPB    | WSON         | DSC             | 10   | 1000 | 210.0       | 185.0      | 35.0        |
| LM3658SD/NOPB    | WSON         | DSC             | 10   | 1000 | 203.0       | 203.0      | 35.0        |
| LM3658SDX-A/NOPB | WSON         | DSC             | 10   | 4500 | 367.0       | 367.0      | 35.0        |
| LM3658SDX-B/NOPB | WSON         | DSC             | 10   | 4500 | 346.0       | 346.0      | 35.0        |
| LM3658SDX/NOPB   | WSON         | DSC             | 10   | 4500 | 367.0       | 367.0      | 35.0        |
| LM3658SDX/NOPB   | WSON         | DSC             | 10   | 4500 | 346.0       | 346.0      | 35.0        |



DSC (S-PWSON-N10)

PLASTIC SMALL OUTLINE NO-LEAD



4207383/E 01/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - B. This drawing is subject to change without notice.
  - C. Small Outline No-Lead (SON) package configuration.
  - D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
  - E. See the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.

# THERMAL PAD MECHANICAL DATA

DSC (S-PWSON-N10)

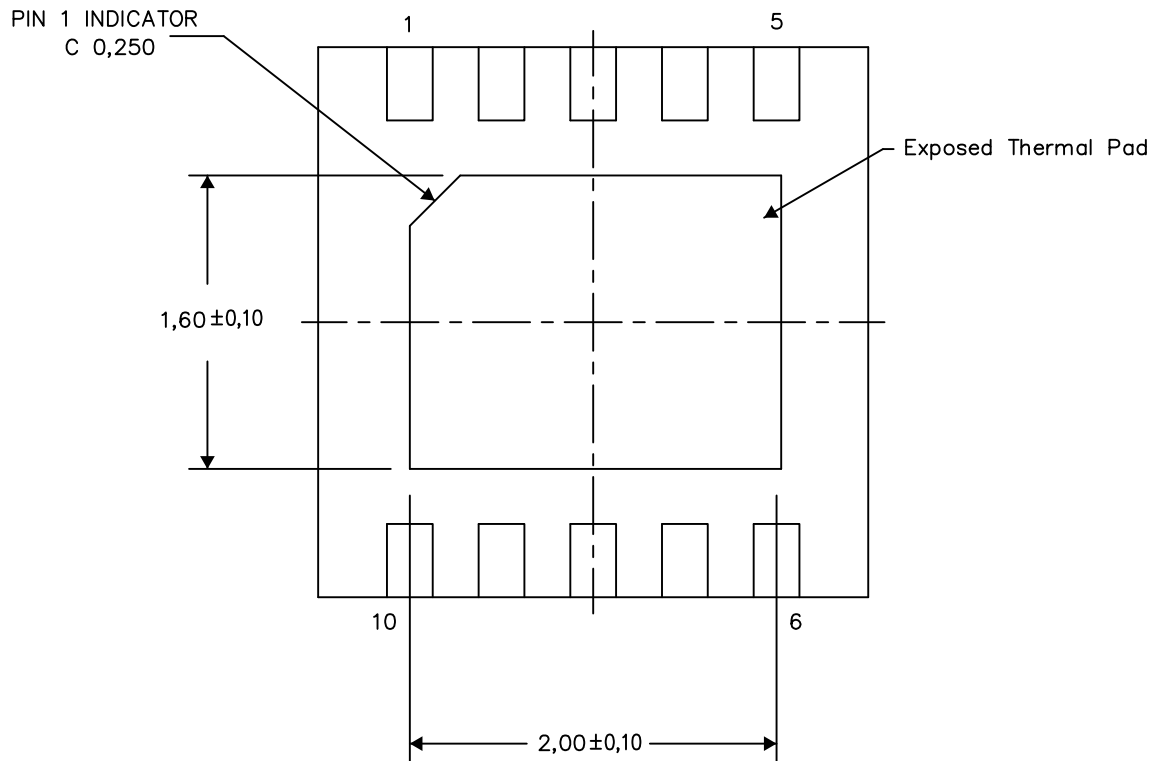
PLASTIC SMALL OUTLINE NO-LEAD

## THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at [www.ti.com](http://www.ti.com).

The exposed thermal pad dimensions for this package are shown in the following illustration.



Bottom View

Exposed Thermal Pad Dimensions

4210391-8/Q 08/15

NOTE: A. All linear dimensions are in millimeters

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