



LM3646 具有双高侧电流源 和 I²C 兼容接口的 1.5A 同步升压转换器

1 特性

- 高侧电流源支持 LED 阴极接地以改进热管理
- 在手电筒模式和闪光灯模式下效率高达 85% 以上
- 小型解决方案尺寸: < 20mm²
- 精确的可编程闪光灯 LED 电流范围: 24mA 至 1.5A (以 11.7mA 为单位增量)
- 精确的可编程手电筒 LED 电流范围: 2.5mA 至 187mA (以 1.5mA 为单位增量)
- 针对双 LED 驱动的 1.5A 双高侧电流源
- 硬件闪光灯和手电筒使能
- 硬件使能引脚
- 用于保护电池的软启动操作
- LED 热感应以及电流按比例缩减功能
- 针对射频 (RF) 功率放大器脉冲事件的同步输入
- VIN 闪存监控器优化
- 1MHz I²C 兼容接口
- I²C 可编程的负温度系数 (NTC) 跳变点
- 0.4mm 间距, 20 凸点芯片尺寸球状引脚栅格阵列 (DSBGA)

2 应用

可拍照手机 LED 闪光灯和手电筒

3 说明

LM3646 采用 4MHz 固定频率同步升压转换器为双 1.5A LED 恒流源供电。高侧电流源支持 LED 阴极接地操作, 可提供的最高总闪光灯电流达 1.5A。自适应余量调节方案可确保 LED 电流保持可调节状态, 并且能够以最大限度提高效率。LM3646 具有双 LED 驱动能力、高 LED 电流、小型解决方案尺寸以及更强的适应能力, 因此成为了可拍照手机 LED 闪光灯和手电筒应用的理想选择。

LM3646 通过 I²C 兼容接口进行控制。LM3646 的主要特性包括: 用于直接触发闪光灯脉冲的硬件闪光灯使能 (STROBE) 输入、用于摄像模式或手电筒功能的硬件手电筒使能 (TORCH) 输入、用于强制闪光灯脉冲进入低电流手电筒模式以与射频 (RF) 功率放大器事件或其他高电流状况同步的 TX 输入、设计用于监视 NTC 热敏电阻以及中断 LED 电流的集成比较器、用于监视电池电压并可在低电池电压情况下降低闪光灯电流的可编程输入电压监视器。硬件使能 (ENABLE) 输入可在系统软件出现故障时提供硬件关断功能。

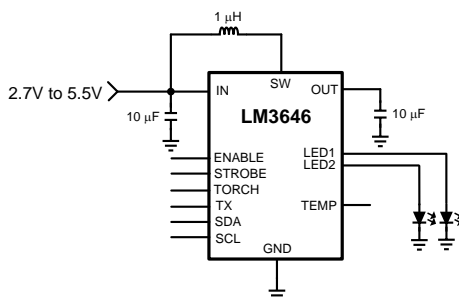
该器件具有 4MHz 开关频率、以及过压保护和可调节限流功能, 因此可以使用小型贴片电感和 (10μF) 陶瓷电容。该器件采用 20 凸点小型芯片尺寸球状引脚栅格阵列 (DSBGA) 封装, 工作温度范围为 -40°C 至 85°C。

器件信息(1)

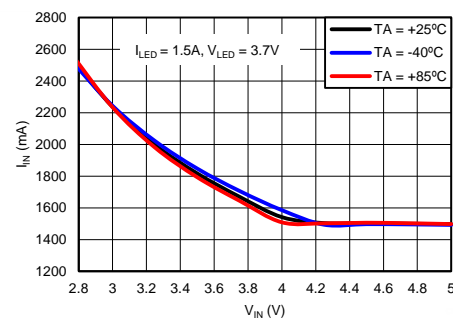
| 器件型号 | 封装 | 封装尺寸 (标称值) |
|--------|------------|-------------------|
| LM3646 | DSBGA (20) | 2.015mm x 1.615mm |

(1) 如需了解所有可用封装, 请见数据表末尾的可订购产品附录。

典型应用电路



系统性能



目录

| | | | | | |
|------------|---|-----------|-------------|---|-----------|
| 1 | 特性 | 1 | 7.4 | Device Functional Modes | 14 |
| 2 | 应用 | 1 | 7.5 | Programming | 17 |
| 3 | 说明 | 1 | 7.6 | Register Map | 19 |
| 4 | 修订历史记录 | 2 | 8 | Application and Implementation | 24 |
| 5 | Pin Configuration and Functions | 3 | 8.1 | Application Information | 24 |
| 6 | Specifications | 4 | 8.2 | Typical Application | 24 |
| 6.1 | Absolute Maximum Ratings | 4 | 9 | Power Supply Recommendations | 32 |
| 6.2 | Handling Ratings | 4 | 10 | Layout | 32 |
| 6.3 | Recommended Operating Conditions | 4 | 10.1 | Layout Guidelines | 32 |
| 6.4 | Thermal Information | 4 | 10.2 | Layout Example | 33 |
| 6.5 | Electrical Characteristics | 5 | 11 | 器件和文档支持 | 34 |
| 6.6 | Timing Requirements | 6 | 11.1 | 器件支持 | 34 |
| 6.7 | Typical Characteristics | 7 | 11.2 | 文档支持 | 34 |
| 7 | Detailed Description | 12 | 11.3 | 商标 | 34 |
| 7.1 | Overview | 12 | 11.4 | 静电放电警告 | 34 |
| 7.2 | Functional Block Diagram | 13 | 11.5 | 术语表 | 34 |
| 7.3 | Feature Description | 13 | 12 | 机械封装和可订购信息 | 34 |

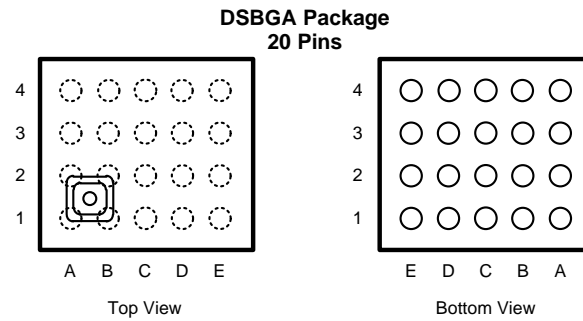
4 修订历史记录

Changes from Original (December 2013) to Revision A

Page

| | |
|--|-----------|
| • 已添加 器件信息和处理额定值表，特性描述，器件功能模式，应用和实施，电源相关建议，布局，器件和文档支持以及机械、封装和可订购信息部分；已将一些曲线移至应用曲线部分 | 1 |
| • Deleted "TX interrupt" | 12 |
| • Changed reference to "Max LED Control Register (0x05)" to "Enable Register (0x01)" | 14 |
| • Added Control Truth table | 17 |

5 Pin Configuration and Functions



Pin Functions

| PIN | | | TYPE | DESCRIPTION |
|------------|-------|--------|------|--|
| NUMBER | COUNT | NAME | | |
| A1, B1 | 2 | GND | - | Ground. |
| A2, B2 | 2 | SW | O | Drain Connection for Internal NMOS and Synchronous PMOS Switches. |
| A3, B3, C3 | 3 | OUT | O | Step-Up DC/DC Converter Output. Connect a 10- μ F ceramic capacitor between this pin and GND. |
| A4,B4 | 2 | LED1 | O | High-Side Current Source Output for Flash LED. Both bumps must be connected for proper operation. |
| C1 | 1 | AGND | - | Analog Ground. |
| C2 | 1 | TORCH | I | Active High Hardware Torch Enable. Drive TORCH high to turn on Torch/Movie Mode. Used for External PWM mode. Has an internal pull-down resistor of 200 k Ω between TORCH and GND. |
| C4, D4 | 2 | LED2 | O | High-Side Current Source Output for Flash LED. Both bumps must be connected for proper operation. |
| D1 | 1 | IN | I | Input Voltage Connection. Connect IN to the input supply, and bypass to GND with a 10- μ F or larger ceramic capacitor. |
| D2 | 1 | SCL | I | Serial Clock Input. |
| D3 | 1 | ENABLE | I | Active High Enable Pin. High = Standby, Low = Shutdown/Reset. Has an internal pull-down resistor of 200 k Ω between ENABLE and GND. |
| E1 | 1 | TEMP | O | Threshold Detector for LED Temperature Sensing and Current Scale Back. |
| E2 | 1 | SDA | I/O | Serial Data Input/Output. |
| E3 | 1 | STROBE | I | Active High Hardware Flash Enable. Drive STROBE high to turn on Flash LEDs. STROBE overrides TORCH. Has an internal pull-down resistor of 200 k Ω between STROBE and GND. |
| E4 | 1 | TX | I | Configurable Dual Polarity Power Amplifier Synchronization Input. Has an internal pull-down resistor of 200 k Ω between TX and GND. |

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾⁽²⁾

| | MIN | MAX | UNIT |
|---|--------------------|-------------------------------------|------|
| SCL, SDA, ENABLE, STROBE, TX, TORCH, LED1, LED2, TEMP | −0.3 | the lesser of (VIN+0.3) w/ 6 max | V |
| IN, SW, OUT | −0.3 | 6 | V |
| Continuous power dissipation ⁽³⁾ | Internally Limited | | |
| Junction temperature (T _{J-MAX}) | | 150 | °C |
| Maximum lead temperature (soldering) | See ⁽⁴⁾ | | |

- (1) Stresses 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 under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltages are with respect to the potential at the GND pin.
- (3) Internal thermal shutdown circuitry protects the device from permanent damage. Thermal shutdown engages at T_J = 135°C (typ.). Thermal shutdown is verified by design.
- (4) For detailed soldering specifications and information, please refer to Texas Instruments Application Note 1112: *DSBGA Wafer Level Chip Scale Package* (SNVA009).

6.2 Handling Ratings

| | | | MIN | MAX | UNIT |
|--------------------|---------------------------|--|-------|------|------|
| T _{stg} | Storage temperature range | | −65 | 150 | °C |
| V _(ESD) | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins ⁽¹⁾ | −2500 | 2500 | V |
| | | Charged device model (CDM), per JEDEC specification JESD22-C101, all pins ⁽²⁾ | −1500 | 1500 | |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)⁽¹⁾⁽²⁾

| | MIN | MAX | UNIT |
|--|-----|-----|------|
| VIN | 2.7 | 5.5 | V |
| Junction temperature (T _J) | −40 | 125 | °C |
| Ambient temperature (T _A) ⁽³⁾ | −40 | 85 | °C |

- (1) Stresses 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 under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltages are with respect to the potential at the GND pin.
- (3) In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature (T_{A-MAX}) is dependent on the maximum operating junction temperature (T_{J-MAX-OP} = 125°C), the maximum power dissipation of the device in the application (P_{D-MAX}), and the junction-to-ambient thermal resistance of the part/package in the application (R_{θJA}), as given by the following equation: T_{A-MAX} = T_{J-MAX-OP} − (R_{θJA} × P_{D-MAX}).

6.4 Thermal Information

| THERMAL METRIC ⁽¹⁾ | LM3646 | UNIT |
|---|---------|------|
| | YFQ | |
| | 20 PINS | |
| R _{θJA} Junction-to-ambient thermal resistance | 53.4 | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

6.5 Electrical Characteristics

Typical (TYP) limits apply for $T_A = 25^\circ\text{C}$. Minimum (MIN) and maximum (MAX) limits apply over the full operating ambient temperature range ($-40^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$). Unless otherwise specified, $V_{IN} = 3.6\text{ V}$.⁽¹⁾⁽²⁾

| PARAMETER | | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|--|--|-------|-----------------|------|-----------------|------|
| CURRENT SOURCE SPECIFICATIONS | | | | | | | |
| I _{LED1/2} | Current source accuracy | 1.5A Flash, V _{OUT} = 4 V, LED1 or LED2 Active | | 1.395 (-7%) | 1.5 | 1.605 (7%) | A |
| | | 93.4 mA Torch, V _{OUT} = 3.6 V, LED1 or LED2 Active | | 84.06 (-10%) | 93.4 | 102.74 (10%) | mA |
| V _{OUT} - V _{LED1/2} | Current source regulation | I _{LED} = 1.5A | Flash | | 250 | 280 (12%) | mV |
| | | I _{LED} = 93.4 mA | Torch | | 150 | 172.5 (15%) | |
| STEP-UP DC/DC CONVERTER SPECIFICATIONS | | | | | | | |
| I _{CL} | Switch current limit | | | -15% | 1 | 15% | A |
| | | | | -10% | 3.1 | 10% | |
| V _{OVP} | Output overvoltage protection trip point | ON threshold | | 4.85 | 5.0 | 5.15 | V |
| | | OFF threshold | | 4.65 | 4.8 | 4.95 | |
| R _{PMOS} | RPMOS switch on-resistance | I _{PMOS} = 1A | | | 85 | | mΩ |
| R _{NMOS} | NMOS switch on-resistance | I _{NMOS} = 1A | | | 65 | | |
| UVLO | Undervoltage lockout threshold | Falling V _{IN} | | 2.74 | 2.8 | 2.85 | V |
| V _{NTC-Trip} | NTC comparator trip threshold | | | -6% | 600 | 6% | mV |
| I _{NTC} | NTC Current | | | -6% | 50 | 6% | μA |
| V _{NTC-Open} | NTC open trip threshold | | | 2.2 | 2.3 | 2.4 | V |
| V _{NTC-Short} | NTC short trip threshold | | | 75 | 100 | 125 | mV |
| V _{IVFM} | Input voltage flash monitor trip threshold | | | -5% | 2.9 | 5% | V |
| f _{SW} | Switching frequency | 2.8 V ≤ V _{IN} ≤ 4.8 V | | 3.72 | 4 | 4.28 | MHz |
| I _{SD} | Shutdown supply current | Device disabled, EN = 0 V 2.8 V ≤ V _{IN} ≤ 4.8 V | | | 0.1 | 1.3 | μA |
| I _{SB} | Standby supply current | Device disabled, EN = 1.8 V 2.8 V ≤ V _{IN} ≤ 4.8 V | | | 2.5 | 10 | μA |
| ENABLE, STROBE, TORCH, TX VOLTAGE SPECIFICATIONS | | | | | | | |
| V _{IL} | Input logic low | 2.8 V ≤ V _{IN} ≤ 4.2 V | | 0 | | 0.4 | V |
| V _{IH} | Input logic high | | | 1.2 | | V _{IN} | |
| I ² C-COMPATIBLE INTERFACE SPECIFICATIONS (SCL, SDA) | | | | | | | |
| V _{IL} | Input logic low | 2.8 V ≤ V _{IN} ≤ 4.2 V | | 0 | | 0.4 | V |
| V _{IH} | Input logic high | | | 1.2 | | V _{IN} | |
| V _{OL} | Output logic low | I _{LOAD} = 1.5 mA | | | | 300 | mV |
| t _{SCL} | SCL clock period | | | 1 | | | μs |

(1) All voltages are with respect to the potential at the GND pin.

(2) Min and Max limits are 100% production tested at an ambient temperature (T_A) of 25°C . Limits over the operating temperature range are specified through correlation using Statistical Quality Control (SQC) methods.

6.6 Timing Requirements

| DELAY | EXPLANATION | TIME |
|-------|---|-------------|
| t_a | Time for the LED current to start ramping up after an I ² C Write command. | 560 μ s |
| t_b | Time for the LED current to start ramping down after an I ² C Stop command. | 120 μ s |
| t_c | Time for the LED current to start ramping up after the STROBE pin is raised high. | 560 μ s |
| t_d | Time for the LED current to start ramping down after the STROBE pin is pulled low. | 8 μ s |
| t_e | Time for the LED current to start ramping up after the TORCH pin is raised high. | 560 μ s |
| t_f | Time for the LED current to start ramping down after the TORCH pin is pulled low. | 8 μ s |
| t_g | Time for the LED current to start ramping down after the TX pin is pulled high. | 3 μ s |
| t_h | Time for the LED current to start ramping up after the TX pin is pulled low, provided the part has not timed out in flash mode. | 2 μ s |

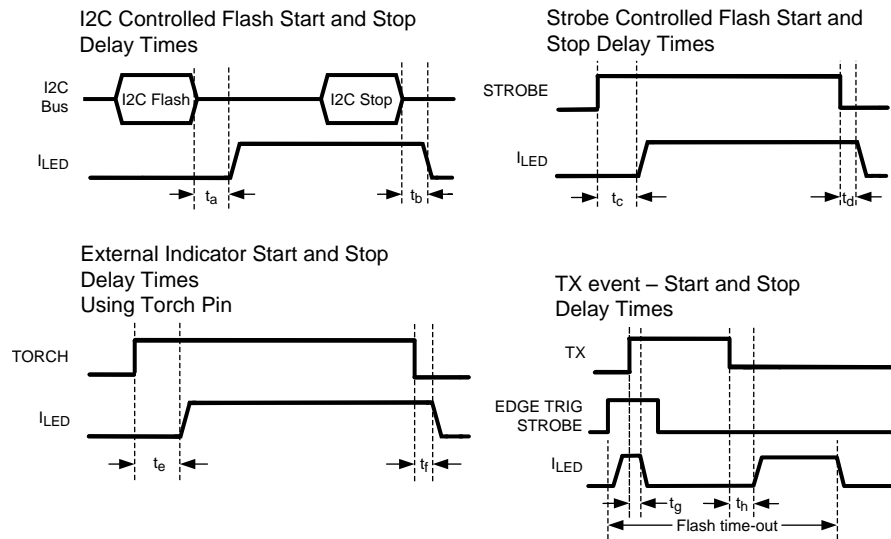


Figure 1. Control Logic Delays

6.7 Typical Characteristics

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

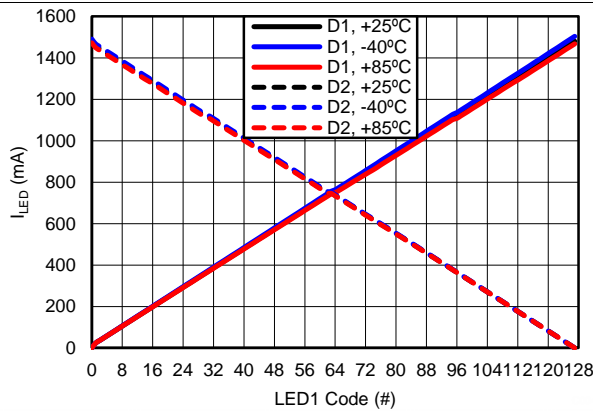


Figure 2. Flash LED Current vs. Brightness Code

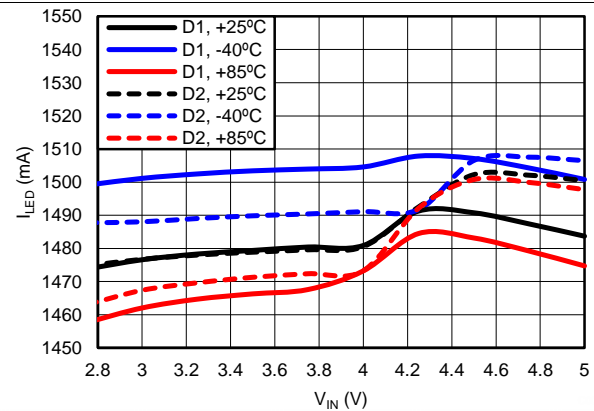


Figure 3. Flash LED Current Line Regulation, $I_{LED} = 1.5\text{ A}$

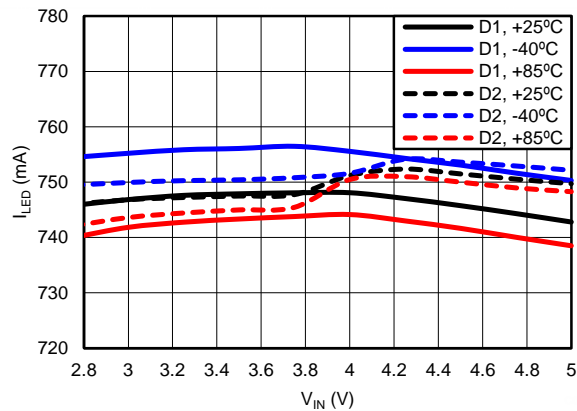


Figure 4. Flash LED Current Line Regulation,
 $I_{LED1} = I_{LED2} = 0.75\text{ A}$

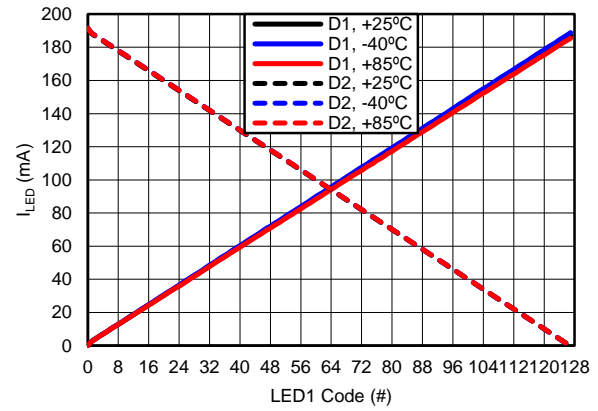


Figure 5. Torch LED Current vs. Brightness Code

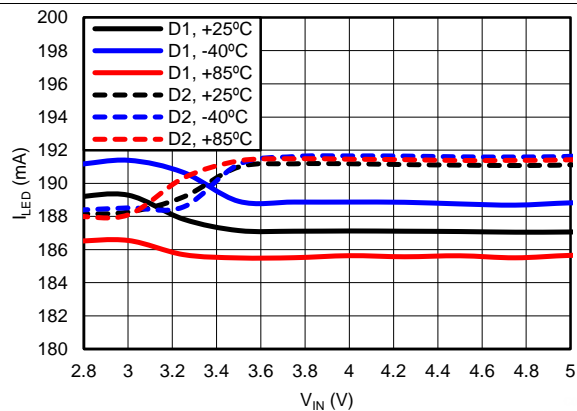


Figure 6. Torch LED Current Line Regulation,
 $I_{LED} = 187.1\text{ mA}$

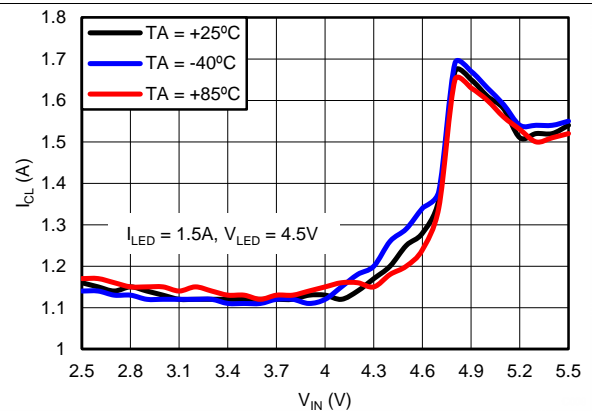


Figure 7. Inductor Current vs. Input Voltage, $C_L = 1\text{ A}$

Typical Characteristics (continued)

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

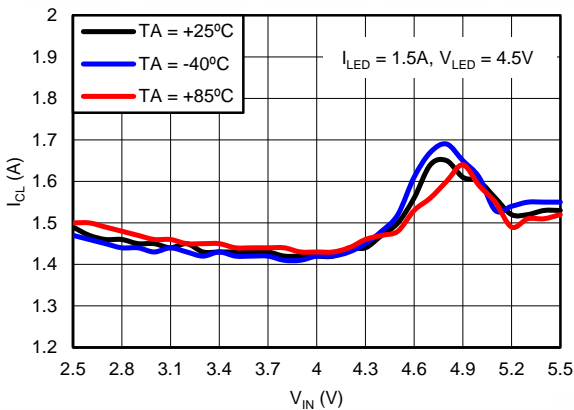


Figure 8. Inductor Current vs. Input Voltage, CL = 1.3 A

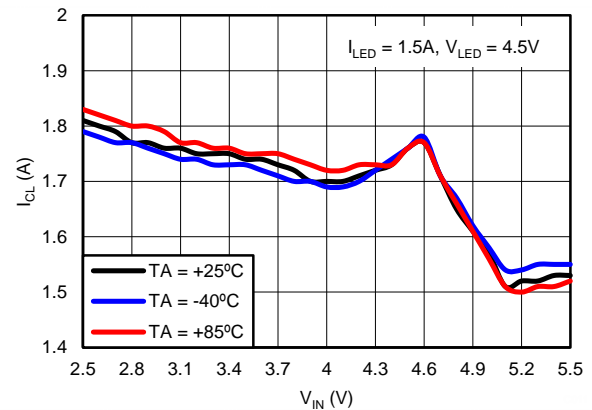


Figure 9. Inductor Current vs. Input Voltage, CL = 1.6 A

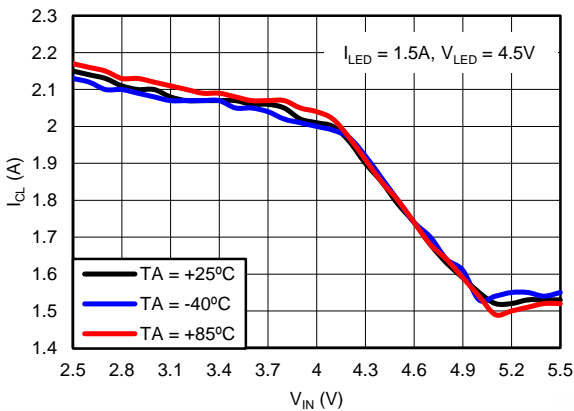


Figure 10. Inductor Current vs. Input Voltage, CL = 1.9 A

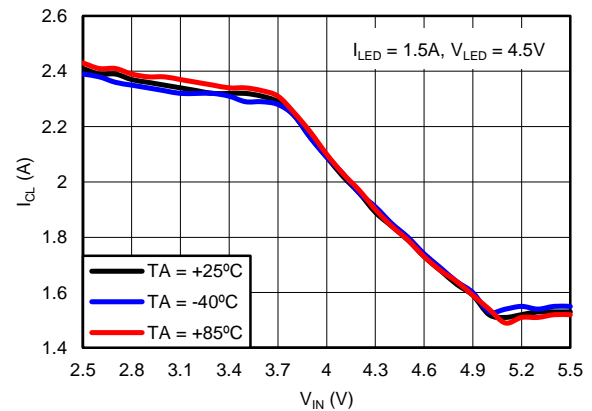


Figure 11. Inductor Current vs. Input Voltage, CL = 2.2 A

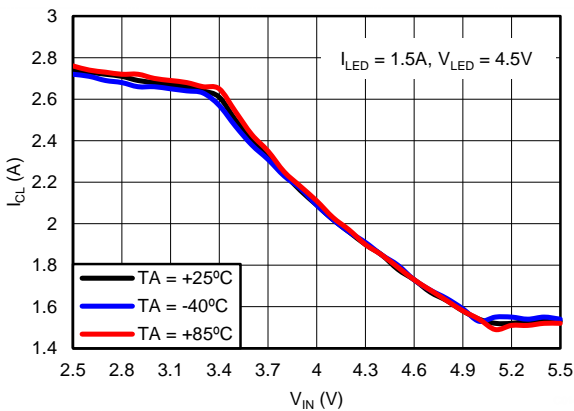


Figure 12. Inductor Current vs. Input Voltage, CL = 2.5 A

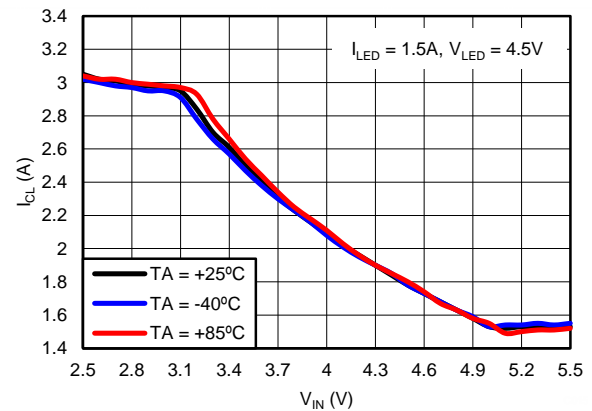


Figure 13. Inductor Current vs. Input Voltage, CL = 2.8 A

Typical Characteristics (continued)

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

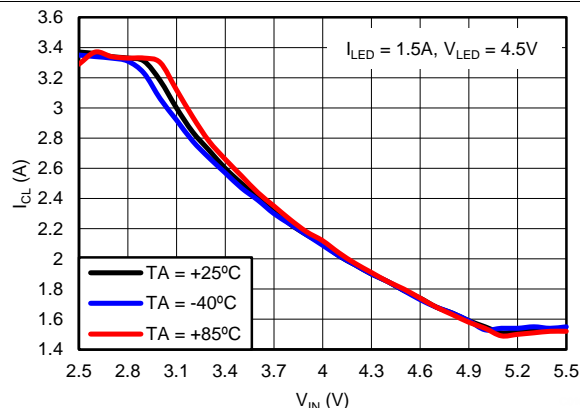


Figure 14. Inductor Current vs. Input Voltage, CL = 3.1 A

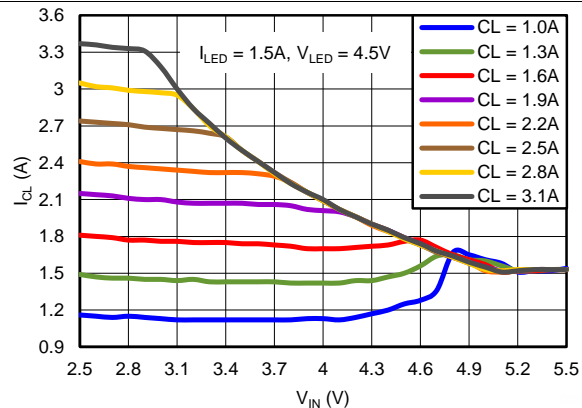


Figure 15. Inductor Current Limit vs. Input Voltage

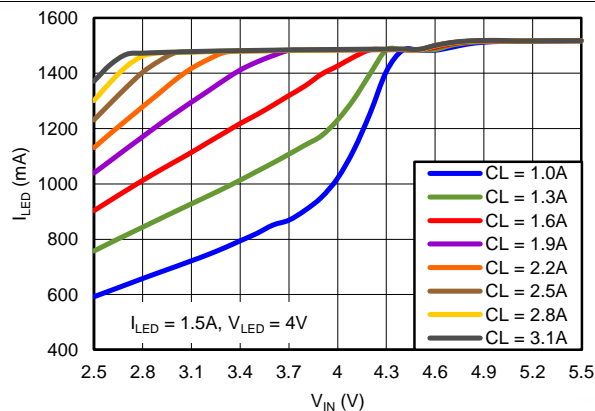


Figure 16. Flash LED Current vs. Input Voltage in Current Limit

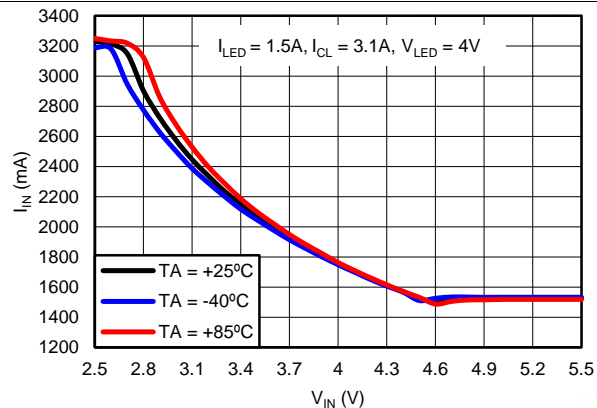


Figure 17. Input Current vs. Input Voltage

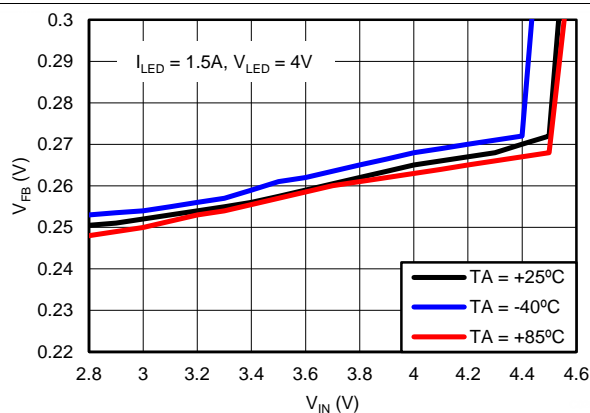


Figure 18. Current Source Headroom vs. Input Voltage

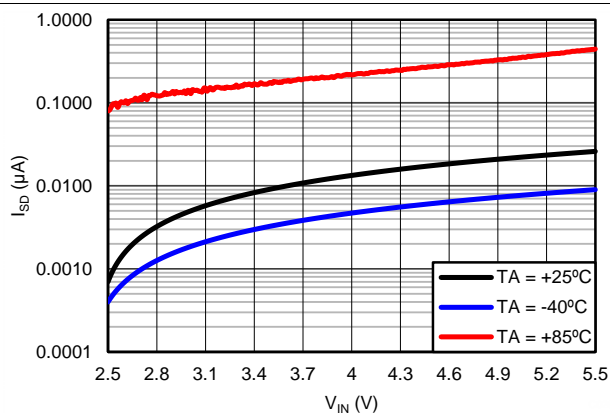


Figure 19. Shutdown Current vs. Input Voltage

Typical Characteristics (continued)

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

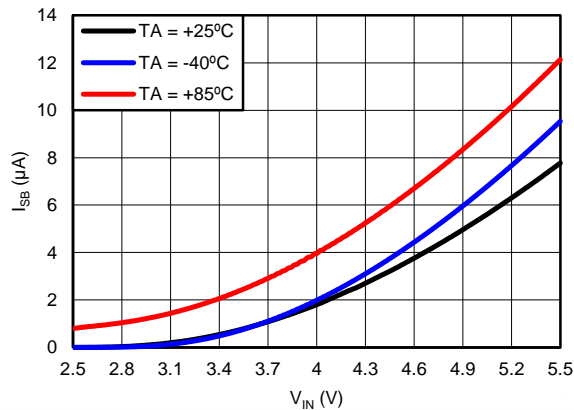


Figure 20. Standby Current vs. Input Voltage, $V_{EN} = 1.8\text{ V}$

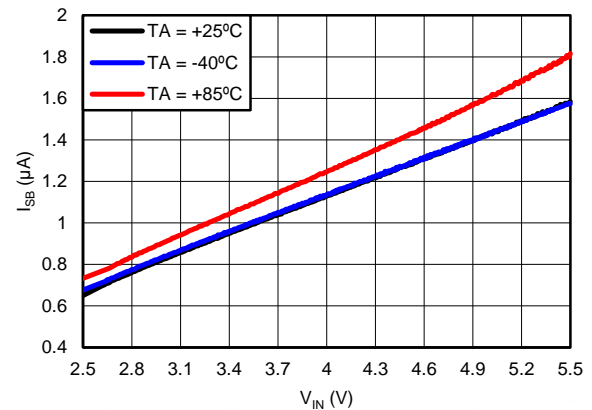


Figure 21. Standby Current vs. Input Voltage, $V_{EN} = V_{IN}$

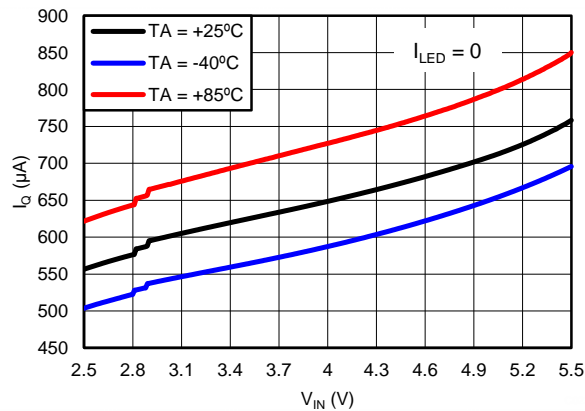


Figure 22. Input Current vs. Input Voltage in Pass Mode

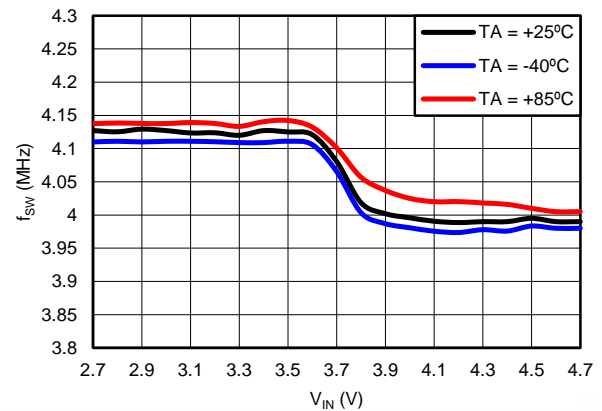


Figure 23. Frequency vs. Input Voltage

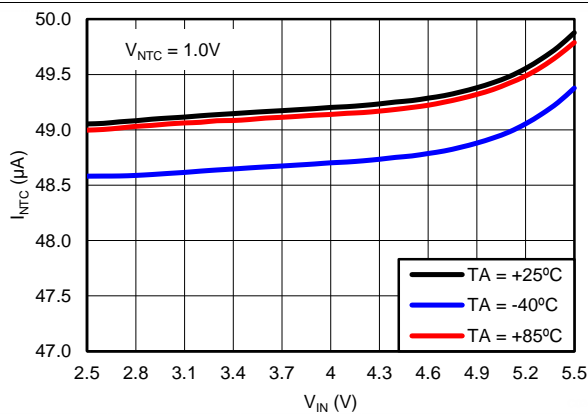


Figure 24. NTC Bias Current vs. Input Voltage

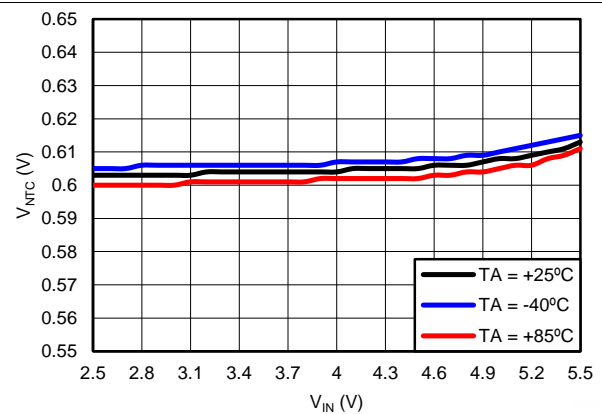


Figure 25. NTC Threshold vs. Input Voltage, $V_{NTC} = 0.6\text{ V}$

Typical Characteristics (continued)

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

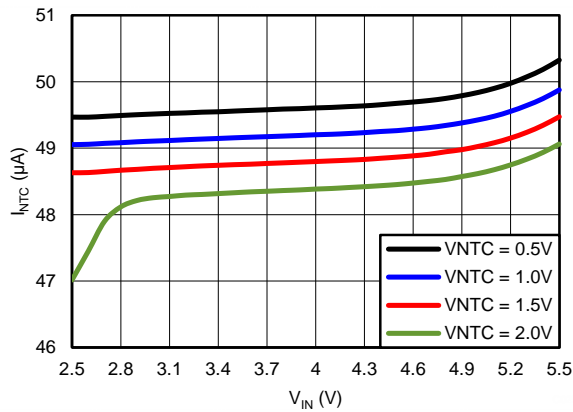


Figure 26. NTC Bias Current vs. Input Voltage at Different V_{NTC}

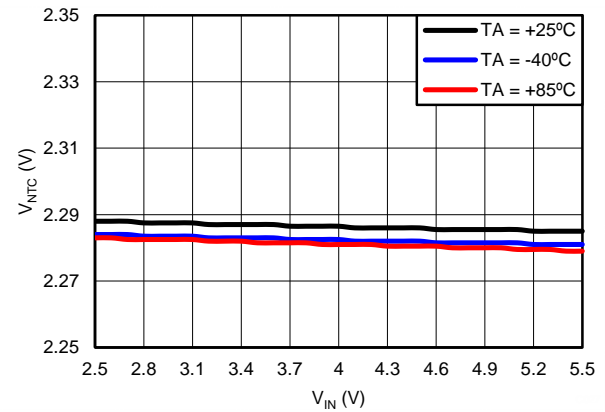


Figure 27. NTC Open Threshold vs. Input Voltage

7 Detailed Description

7.1 Overview

The LM3646 is a high-power white LED flash driver capable of delivering up to 1.5 A (total LED current) into two parallel LEDs. The device incorporates a 4-MHz constant frequency, synchronous Current-Mode PWM boost converter, and two high-side current sources to regulate the LED current over the 2.7 V to 5.5 V input voltage range.

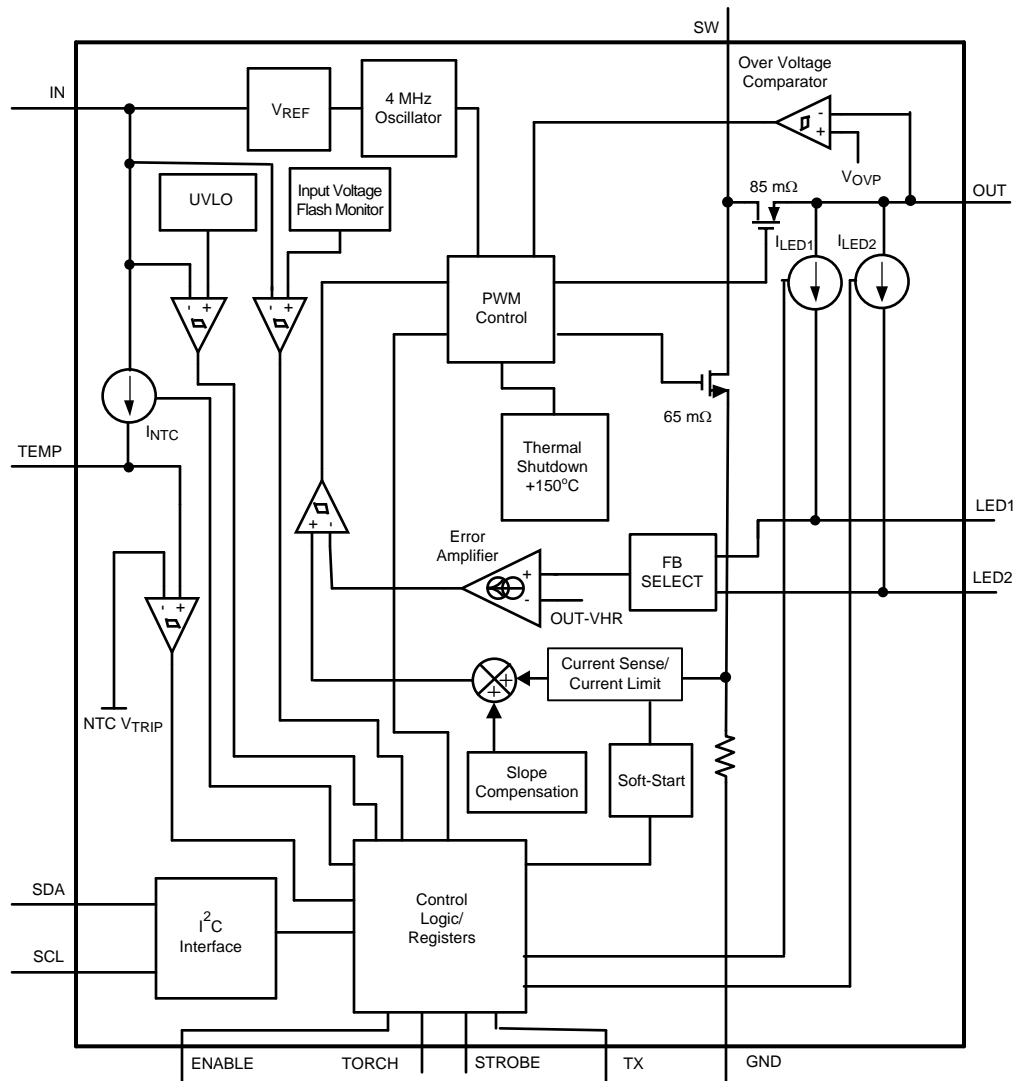
The LM3646 PWM converter switches and maintains at least V_{HR} across the current sources (LED1 and LED2). This minimum headroom voltage ensures that the current source remains in regulation. If the input voltage is above the LED voltage + current source headroom voltage, the device does not switch and turns the PFET on continuously (Pass Mode). In Pass Mode the difference between $(V_{IN} - I_{LED} \times R_{PMOS})$ and the voltage across the LED is dropped across the current sources.

The LM3646 has three logic inputs including a hardware Flash Enable (STROBE), a hardware Torch Enable (TORCH) used for external Torch Mode control, and a Flash Interrupt input (TX) designed to interrupt the flash pulse during high battery current conditions. All three logic inputs have internal 200 k Ω (typ.) pull-down resistors to GND.

Additional features of the LM3646 include an internal comparator for LED thermal sensing via an external NTC thermistor and an input voltage monitor that can reduce the Flash current (during low V_{IN} conditions).

Control of the LM3646 is done via an I²C-compatible interface. This includes adjustment of the Flash and Torch current levels, current source selection, changing the Flash Timeout Duration, changing the switch current limit, and enabling the NTC block. Additionally, there are flag and status bits that indicate flash current time-out, LED over-temperature condition, LED failure (open/short), device thermal shutdown and V_{IN} undervoltage conditions.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Flash Mode

In Flash Mode, the LED current sources (LED1/2) provide 128 target current levels from 0 mA to 1500 mA. The Flash currents are adjusted via bits[3:0] of the [Max LED Current Control Register \(0x05\)](#) and bits[6:0] of the [LED1 Flash Current Control Register \(0x06\)](#). Flash Mode is activated by the [Enable Register \(0x01\)](#), or by pulling the STROBE pin HIGH. Once the Flash sequence is activated the current source (LED) will ramp up to the programmed Flash current by stepping through all current steps until the programmed current is reached.

While both LED1 and LED2 are capable of delivering 1.5A to the LED, the sum total of the LED current will not exceed the value stored in the Max LED Current Control Register. LED1 will receive the current value stored in the LED1 Flash Current Control Register, and LED2 will receive the difference of the value stored in the MAX LED Current Control Register and LED1 Flash Current Control Register.

If LED1 and LED2 Active:

LED1 = LED1 Flash Current Control Value

LED2 = MAX Flash Current Control Value - LED1 Flash Current Control Value

If MAX Flash Current Control Value < LED1 Flash Current Control Value

LED1 = MAX Flash Current Control Value

Feature Description (continued)

LED2 = Off

If the LED1 Current Control Value is set to a level that is higher than the MAX Flash LED Current Control Value, LED1 receives the MAX Flash LED Current Control value, and LED2 is disabled.

When the part is enabled in Flash Mode through the Enable Register or the STROBE pin, all mode bits in the Enable Register are cleared after completion of the flash event. Before the device can be enabled again, the mode bits need to be set.

7.3.2 Torch Mode

In Torch Mode, the LED current sources (LED1/2) provide 128 target current levels from 0 mA to 187.5 mA. The Torch currents are adjusted via bits[6:4] of the [Max LED Current Control Register \(0x05\)](#) and bits[6:0] of the [LED1 Torch Current Control Register \(0x07\)](#). Torch Mode is activated by the [Enable Register \(0x01\)](#), or by pulling the TORCH pin HIGH. Once the TORCH sequence is activated the current source (LED) will ramp up to the programmed Torch current by stepping through all current steps until the programmed current is reached.

LED1 receives the current value stored in the LED1 Torch Current Control Register, and LED2 receives the difference of the value stored in the MAX LED Current Control Register and LED1 Torch Current Control Register.

If LED1 and LED2 Active:

LED1 = LED1 Torch Current Control Value

LED2 = MAX Torch Current Control Value - LED1 Torch Current Control Value

If MAX Torch Current Control Value < LED1 Torch Current Control Value

LED1 = MAX Torch Current Control Value

LED2 = Off

If the LED1 Torch Current Control Value is set to a level that is higher than the MAX Torch LED Current Control Value, LED1 receives the MAX Torch LED Current Control value, and LED2 is disabled. Torch Mode is not affected by Flash Timeout.

7.4 Device Functional Modes

7.4.1 Start-Up (Enabling the Device)

Turn on of the LM3646 Torch and Flash Modes can be done through the [Enable Register \(0x01\)](#). On start-up, when V_{OUT} is less than V_{IN} , the internal synchronous PFET turns on as a current source and delivers 200 mA (typ.) to the output capacitor. During this time the current source (LED) is off. When the voltage across the output capacitor reaches 2.2 V (typ.) the current source turns on. At turnon the current source steps through each FLASH or TORCH level until the target LED current is reached. This gives the device a controlled turn-on and limits inrush current from the VIN supply.

7.4.2 Pass Mode

The LM3646 starts up in Pass Mode and stays there until Boost Mode is needed to maintain regulation. In Pass Mode the boost converter does not switch and the synchronous PFET turns fully on bringing V_{OUT} up to $V_{IN} - (I_{LED} \times R_{PMOS})$. In Pass Mode the inductor current is not limited by the peak current limit. In this situation the output current must be limited to 2A. If the voltage difference between V_{OUT} and V_{LED} falls below V_{HR} , the device switches to Boost Mode.

7.4.3 Power Amplifier Synchronization (TX)

The TX pin is a Power Amplifier Synchronization input. This is designed to reduce the flash LED current and thus limit the battery current during high battery current conditions such as PA transmit events. When the LM3646 is engaged in a Flash event and the TX pin is pulled high, the LED current is forced into Torch Mode at the programmed Torch current setting. If the TX pin is then pulled low before the Flash pulse terminates, the LED current will return to the previous Flash current level. At the end of the Flash time-out, whether the TX pin is high or low, the LED current will turn off. The TX input can be disabled by setting bit TX Pin Enable to a '0' in the [Enable Register \(0x01\)](#).

Device Functional Modes (continued)

7.4.4 Input Voltage Flash Monitor (IVFM)

The LM3646 has the ability to adjust the flash current based upon the voltage level present at the IN pin utilizing an Input Voltage Flash Monitor. The IVFM block has an adjustable threshold (IVM-D) ranging from 2.9 V to 3.2 V in 100-mV steps as well as adjustable hysteresis. The IVFM threshold and hysteresis are controlled by bits[4:3] and bits[2:1] respectively, in the *IVFM Mode Register (0x02)*. *Flags Register1 (0x08)* has the IVFM flag (bit[3]) set when the input voltage crosses the IVFM value. The IVFM threshold sets the input voltage boundary that forces the LM3646 to stop ramping the flash current during startup in Stop and Hold Mode, or to actively adjust the LED current lower in Down Adjust Mode, or to continuously adjust the LED current up and down in Up & Down mode.

Stop and Hold Mode (Figure 28): Stops Current Ramp and Holds the level for the remaining flash if V_{IN} crosses IVM-D Line. Sets IVFM Flag (bit[3] in Flags Register1) upon crossing IVM-D Line.

Down Mode (Figure 29): Adjusts current down if V_{IN} crosses IVM-D Line and stops decreasing once V_{IN} rises above the IVM-D line + the IVFM hysteresis setting. The LM3646 will decrease the current throughout the flash pulse anytime the input voltage falls below the IVM-D line, not just once. The flash current will not increase again until the next flash. Sets IVFM Flag (bit[3] in Flags Register1) upon crossing IVM-D Line.

Up and Down Mode (Figure 30): Adjusts current down if V_{IN} crosses IVM-D Line and adjusts current up if V_{IN} rises above the IVM-D line + the IVFM hysteresis setting. In this mode, the current will continually adjust with the rising and falling of the input voltage throughout the entire flash pulse. Sets IVFM Flag (bit[3] in Flags Register1) upon crossing IVM-D Line.

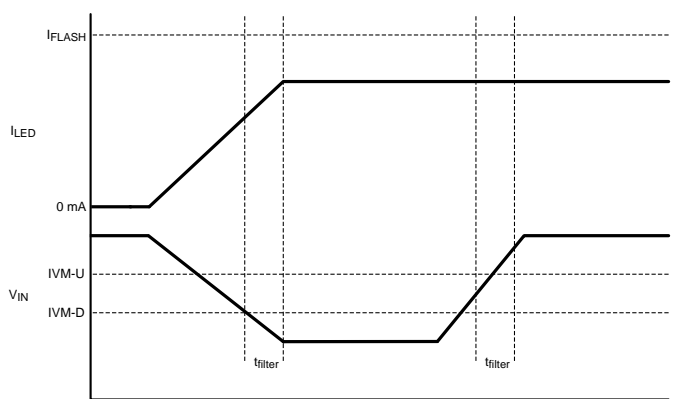


Figure 28. IVFM Stop and Hold Mode

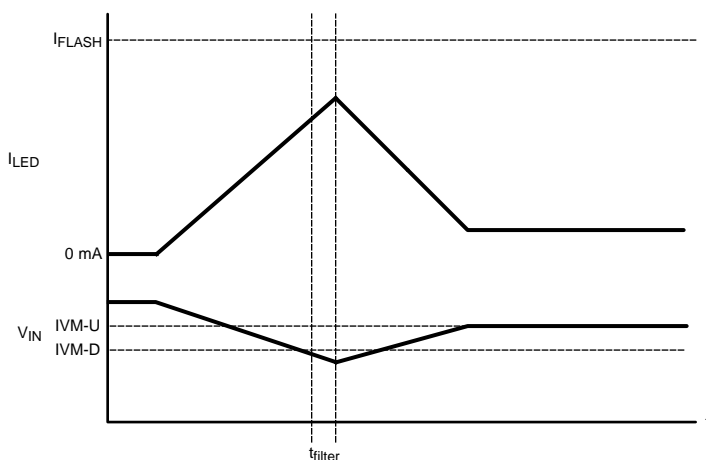


Figure 29. IVFM Down Mode

Device Functional Modes (continued)

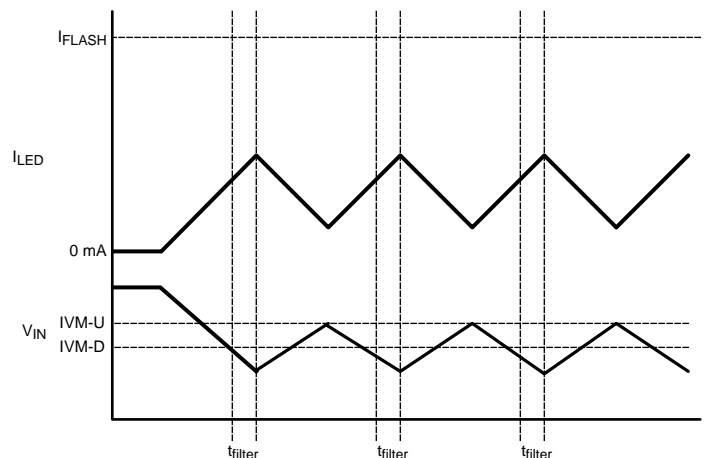


Figure 30. IVFM Up and Down Mode

7.4.5 Fault/Protections

7.4.5.1 Fault Operation

Upon entering a fault condition, the LM3646 sets the appropriate flag in the [Flags Register1 \(0x08\)](#) or [Flags Register2 \(0x09\)](#), and place the part into standby by clearing and locking the Torch Enable bit (bit[7] in [LED1 Torch Current Control Register \(0x07\)](#)) and Mode Bits (M1, M0) in the [Enable Register \(0x01\)](#), until the Flags Register1 or Flags Register2 is read back via I²C.

7.4.5.2 Flash Time-Out

The Flash Time-Out period sets the amount of time that the Flash Current is being sourced from the current source (LED). The LM3646 has 8 timeout levels ranging 50 ms to 400 ms in 50 ms steps. The Flash Time-Out period is controlled by bits[2:0] in the [Flash Timing Register \(0x04\)](#). Flash Time-Out only applies to the Flash Mode operation. The mode bits are cleared and bit[0] is set in the [Flags Register1 \(0x08\)](#) upon a Flash Timeout.

7.4.5.3 Overvoltage Protection (OVP)

The output voltage is limited to typically 5 V (see **V_{OVP}** Spec). In situations such as an open LED, the LM3646 raises the output voltage in order to try to keep the LED current at its target value. When V_{OUT} reaches 5 V (typ.) the overvoltage comparator trips and turns off the internal NFET. When V_{OUT} falls below the “**V_{OVP} Off Threshold**”, the LM3646 begins switching again. The mode bits are cleared, and the OVP flag is set (bit[7] in [Flags Register1 \(0x08\)](#)) when an OVP condition is present for 512 microseconds, preventing momentary OVP events from forcing the part to shut down.

7.4.5.4 Current Limit

The LM3646 features 8 selectable inductor current limits ranging from 1 A to 3.1 A in 300-mA steps. The current limit is programmable through bits[7:5] of the [Enable Register \(0x01\)](#) of the I²C-compatible interface. When the inductor current limit is reached, the LM3646 terminates the charging phase of the switching cycle.

Since the current limit is sensed in the NMOS switch, there is no mechanism to limit the current when the device operates in Pass Mode. In Boost Mode or Pass Mode if V_{OUT} falls below 2.3 V, the part stops switching, and the PFET operates as a current source limiting the current to 200 mA. This prevents damage to the LM3646 and excessive current draw from the battery during output short-circuit conditions. The mode bits are not cleared upon a Current Limit event, but the OCP flag (bit[4]) in [Flags Register1 \(0x08\)](#) is set.

Device Functional Modes (continued)

7.4.5.5 NTC Thermistor Input (TEMP)

The TEMP pin serves as a threshold detector for negative temperature coefficient (NTC) thermistors. It interrupts the LED current and sets the NTC TRIP flag bit[6] in [Flags Register1 \(0x08\)](#) when the voltage at TEMP goes below the programmed threshold. The NTC threshold voltage is adjustable from 200 mV to 900 mV in 100 mV steps via the [NTC and Torch Ramp Register \(0x03\)](#). The NTC current is set to 50 μ A. When an over-temperature event is detected, the LM3646 is forced into shutdown. The NTC detection circuitry can be enabled or disabled via bit[4] of the [Enable Register \(0x01\)](#). If Enabled, the NTC block will turn on and off during the start and stop of a Flash/Torch event. The mode bits are cleared upon an NTC event.

Additionally, the NTC input looks for an open NTC connection and a short NTC connection. If the NTC input falls below 100 mV, the NTC short flag is set (bit[1] in [Flags Register2 \(0x09\)](#)), and the part is disabled. If the NTC input rises above 2.3 V, the NTC Open flag is set (bit[0] in [Flags Register2](#)), and the part is disabled. These fault detections can be individually disabled/enabled via the NTC Open Detect Enable bit in [IVFM Mode Register \(0x02\)](#) and the NTC Short Fault Enable bit in [Flags Register2](#).

7.4.5.6 Undervoltage Lockout (UVLO)

The LM3646 has an internal comparator that monitors the voltage at IN and forces the LM3646 into shutdown if the input voltage drops to 2.8 V. If the UVLO monitor threshold is tripped, the UVLO flag bit is set in [Flags Register1 \(0x08\)](#). If the input voltage rises above 2.8 V, the LM3646 is not available for operation until there is an I²C read command initiated for the [Flags Register1](#). Upon a read, [Flags Register1](#) is cleared, and normal operation can resume if the input voltage is greater than 2.8 V. This feature can be disabled by writing a '0' to the UVLO Enable bit in the [IVFM Mode Register \(0x02\)](#). The mode bits are cleared upon a UVLO event.

7.4.5.7 Thermal Shutdown (TSD)

When the LM3646's die temperature reaches 135°C the boost converter shuts down, and the NFET and PFET turn off, as does the current source (LED). When the thermal shutdown threshold is tripped, a '1' gets written to bit[5] of [Flags Register1 \(0x08\)](#) (Thermal Shutdown bit), and the LM3646 will go into standby. The LM3646 is allowed to restart only after [Flags Register1](#) is read, clearing the fault flag. Upon restart, if the die temperature is still above 135°C, the LM3646 resets the Fault flag and re-enters standby. The mode bits are cleared upon a TSD.

7.4.5.8 LED and/or VOUT Short Fault

The LED Fault flags (bit[2] or bit[3]) in [Flags Register2 \(0x09\)](#) read back a '1' if the part is active in Flash or Torch Mode and either LED output experiences a short condition. The Output Short Fault flag (bit[1] in [Flags Register1 \(0x08\)](#)) reads back a '1' if the part is active in Flash or Torch Mode and the boost output experiences a short condition. An LED short condition is determined if the voltage at LED goes below 500 mV (typ.); VOUT short condition occurs if the voltage at OUT goes below 2.1 V (typ.) while the device is in Torch or Flash Mode. There is a delay of 256 μ s deglitch time before the LED flag is valid and 2.048 ms before the VOUT flag is valid. This delay is the time between when the Flash or Torch current is triggered, and when the LED voltage and the output voltage are sampled. The LED and VOUT short flags can only be reset to '0' by removing power to the LM3646, or by reading back the [Flags Register1](#) or [Flags Register2](#). The mode bits are cleared upon an LED and/or VOUT short fault.

7.5 Programming

7.5.1 Control Truth Table

Table 1. Control Truth Table

| MODE1 | MODE0 | STROBE EN | TORCH EN | STROBE PIN | TORCH PIN | ACTION |
|-------|-------|-----------|----------|------------|-----------|-----------|
| 0 | X | X | 0 | X | X | Standby |
| 0 | X | X | 1 | X | pos edge | Ext Torch |
| 1 | 1 | 1 | X | pos edge | X | Ext Flash |
| 1 | 0 | X | 0 | X | X | Int Torch |
| 1 | 1 | 0 | X | X | X | Int Flash |

7.5.2 I²C-Compatible Interface

7.5.2.1 Data Validity

The data on SDA line must be stable during the HIGH period of the clock signal (SCL). In other words, state of the data line can only be changed when SCL is LOW.

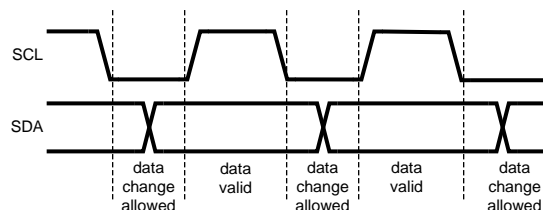


Figure 31. Data Validity Diagram

A pull-up resistor between the controller's VIO line and SDA must be greater than $[(V_{IO}-V_{OL}) / 3mA]$ to meet the V_{OL} requirement on SDA. Using a larger pullup resistor results in lower switching current with slower edges, while using a smaller pullup results in higher switching currents with faster edges.

7.5.2.2 START and STOP Conditions

START and STOP conditions classify the beginning and the end of the I²C session. A START condition is defined as the SDA signal transitioning from HIGH to LOW while SCL line is HIGH. A STOP condition is defined as the SDA transitioning from LOW to HIGH while SCL is HIGH. The I²C-compatible master always generates START and STOP conditions. The I²C-compatible bus is considered to be busy after a START condition and free after a STOP condition. During data transmission, the I²C-compatible master can generate repeated START conditions. First START and repeated START conditions are equivalent, function-wise.

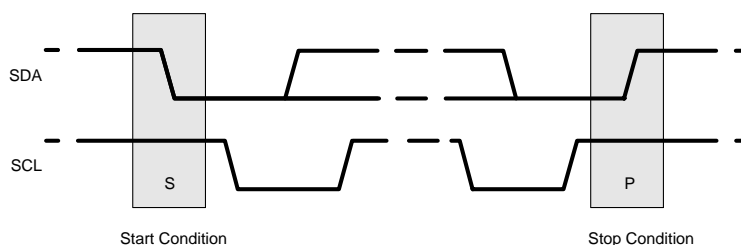


Figure 32. Start and Stop Conditions

7.5.2.3 Transferring Data

Every byte put on the SDA line must be eight bits long, with the most significant bit (MSB) transferred first. Each byte of data has to be followed by an acknowledge bit. The acknowledge related clock pulse is generated by the master. The master releases the SDA line (HIGH) during the acknowledge clock pulse. The LM3646 pulls down the SDA line during the 9th clock pulse, signifying an acknowledge. The LM3646 generates an acknowledge after each byte is received. There is no acknowledge created after data is read from the LM3646.

After the START condition, the I²C master sends a chip address. This address is seven bits long followed by an eighth bit which is a data direction bit (R/W). The LM3646 7-bit address is 0x67 (Figure 33). For the eighth bit, a '0' indicates a WRITE, and a '1' indicates a READ. The second byte selects the register to which the data will be written. The third byte contains data to write to the selected register.

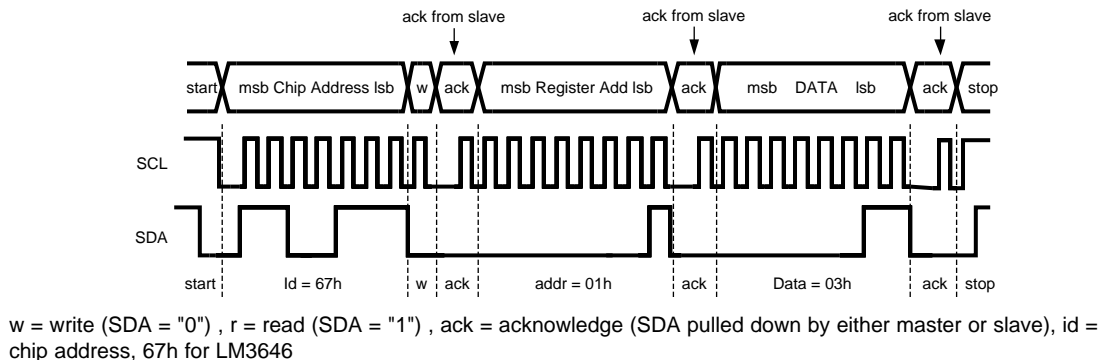


Figure 33. Write Cycle for the LM3646

7.5.2.4 I²C-Compatible Chip Address

The device address for the LM3646 is 1100111 (67). After the START condition, the I²C-compatible master sends the 7-bit address followed by an eighth read or write bit (R/W). R/W = 0 indicates a WRITE and R/W = 1 indicates a READ. The second byte following the device address selects the register address to which the data will be written. The third byte contains the data for the selected register.

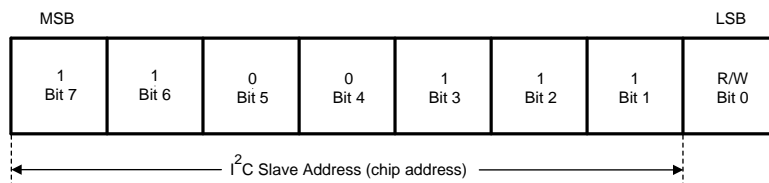


Figure 34. I²C-Compatible Device Address for LM3646

7.6 Register Map

Table 2. LM3646 Internal Registers

| Register Name | Internal Hex Address | Power On/RESET Value ⁽¹⁾ |
|-------------------------------------|----------------------|-------------------------------------|
| SILICON REVISION REGISTER | 0x00 | 0x11 |
| ENABLE REGISTER | 0x01 | 0xE0 |
| IVFM MODE REGISTER | 0x02 | 0xA4 |
| NTC AND TORCH RAMP REGISTER | 0x03 | 0x20 |
| FLASH TIMING REGISTER | 0x04 | 0x42 |
| MAX LED CURRENT CONTROL REGISTER | 0x05 | 0x7F |
| LED1 FLASH CURRENT CONTROL REGISTER | 0x06 | 0x7F |
| LED1 TORCH CURRENT CONTROL REGISTER | 0x07 | 0x7F |
| FLAGS REGISTER1 | 0x08 | 0x00 |
| FLAGS REGISTER2 | 0x09 | 0x30 |

(1) All unused bits are internally pulled HIGH.

LM3646

ZHCSD42A–DECEMBER 2013–REVISED NOVEMBER 2014

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7.6.1 Silicon Revision Register (0x00)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|-------|-------|-------------------------------|-------|-------|--|-------|-------|
| RFU | | Chip ID Current Value = '010' | | | Silicon Revision Current Value = '001' | | |

7.6.2 Enable Register (0x01)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|-------------------------------|-------|-------|------------------------|------------------------|-------------------------------|------------------------------|-------|
| Inductor Current Limit | | | NTC Enable | TX Pin Enable | Soft-Start Enable | LED Mode Bits: M1, M0 | |
| 000 = 1.0A | | | 0 = Disabled (default) | 0 = Disabled (default) | Enable 0 = Disabled (default) | 00 = Standby (default) | |
| 001 = 1.3A | | | 1 = Enabled | 1 = Enabled | 1 = Enabled | 01 = Standby | |
| 010 = 1.6A | | | | | | 10 = Torch | |
| 011 = 1.9A | | | | | | 11 = Flash | |
| 100 = 2.2A | | | | | | | |
| 101 = 2.5A | | | | | | | |
| 110 = 2.8A | | | | | | | |
| 111 = 3.1A (default) | | | | | | | |

NTC Enable Enables or Disables the NTC detection block when the LM3646 is enabled

TX Pin EN Enables the TX pin and TX current reduction function

Soft-Start EN Enables the Pass-Mode startup sequence

LED Mode Bits (M1, M0)

00–Standby Off

01–Standby Off

10–Torch Sets Torch Mode. If Torch EN = 0, Torch will start after I²C-compatible command.

11–Flash Sets Flash Mode. If Strobe EN = 0, Flash will start after I²C-compatible command.

7.6.3 IVFM Mode Register (0x02)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---------------------------|-------------------------|-----------------------|------------------------------------|-------|-----------------------------|-------|------------------------------|
| UVLO Enable(2.8 V) | IVFM Filter | IVFM Enable | IVFM Level Adjust Threshold | | IVFM Mode/Hysteresis | | NTC Open Fault Enable |
| 0 = Disabled | 0 = 4 μ s (default) | 0 = Disabled | 00 = 2.9V (default) | | 00 = Ramp and Hold | | 0 = Disabled (default) |
| 1 = Enabled (default) | 1 = 256 μ s | 1 = Enabled (default) | 01 = 3.0V | | 01 = 0mV Hyst | | 1 = Enabled |
| | | | 10 = 3.1V | | 10 = 50 mV Hyst (default) | | |
| | | | 11 = 3.2V | | 11 = 100 mV Hyst | | |

7.6.4 NTC and Torch Ramp Register (0x03)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|--------------------------|-------|----------------------------|-------|-------|---------------------------------|-------|-------|
| Boost Mode | | NTC Trip Thresholds | | | Torch Current Ramp Times | | |
| 00 = Automatic (default) | | 000 = 200 mV | | | 000 = Ramp Disabled (default) | | |
| 01 = Force Pass-Mode | | 001 = 300 mV | | | 001 = 16 ms | | |
| 10 = Force Boost-Mode | | 010 = 400 mV | | | 010 = 32 ms | | |
| 11 = Automatic | | 011 = 500 mV | | | 011 = 64 ms | | |
| | | 100 = 600 mV (default) | | | 100 = 128 ms | | |
| | | 101 = 700 mV | | | 101 = 256 ms | | |
| | | 110 = 800 mV | | | 110 = 512 ms | | |
| | | 111 = 900 mV | | | 111 = 1024 ms | | |

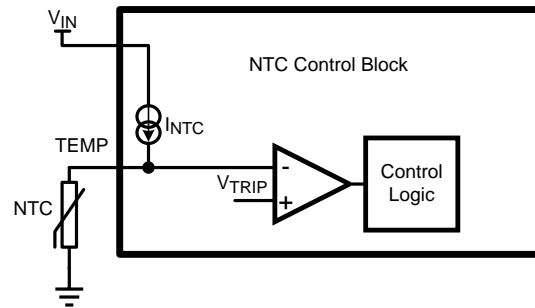


Figure 35. NTC Control Block

The TEMP node is connected to an NTC resistor as shown in Figure 35. A constant current source from the input is connected to this node. Any change in the voltage because of a change in the resistance of the NTC resistor is compared to a set V_{TRIP} . The trip thresholds are selected by Bits[5:3] of the NTC and Torch Ramp Register.

7.6.5 Flash Timing Register (0x04)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---|--|--|-------|-------|---|-------|-------|
| IVFM Modulation 0 = Down Adjust (default) 1 = Up/Down Adjust | Strobe Usage 0 = Level (default) 1 = Edge (default) | Flash Ramp Time 000 = 256 μ s (default) 001 = 512 μ s 010 = 1.024 ms 011 = 2.048 ms 100 = 4.096 ms 101 = 8.192 ms 110 = 16.384 ms 111 = 32.768 ms | | | Flash Time-Out Time 000 = 50 ms 001 = 100 ms 010 = 150 ms (default) 011 = 200 ms 100 = 250 ms 101 = 300 ms 110 = 350 ms 111 = 400 ms | | |

7.6.6 Max LED Current Control Register (0x05)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|--|--|-------|-------|---|-------|-------|-------|
| LED Short Fault Enable 0 = Down Adjust (default) 1 = Up/Down Adjust | Max Torch Current 000 = 23.04 mA 001 = 46.48 mA 010 = 69.91 mA 011 = 93.35 mA 100 = 116.79 mA 101 = 140.23 mA 110 = 163.66 mA 111 = 187.10 mA (default) | | | Max Flash Current 0000 = 93.35 mA 0001 = 187.10 mA 0010 = 280.85 mA 0011 = 374.60 mA 0100 = 468.35 mA 0101 = 562.10 mA 0110 = 655.85 mA 0111 = 749.60 mA 1000 = 843.35 mA 1001 = 937.10 mA 1010 = 1030.85 mA 1011 = 1124.60 mA 1100 = 1218.35 mA 1101 = 1312.10 mA 1110 = 1405.85 mA 1111 = 1499.60 mA (default) | | | |

If LED1 and LED2 Active:

LED2 = MAX Current Control Value - LED1 Current Control Value

If MAX Current Control Value < LED1 Current Control Value

LED1 = MAX Current Control Value

LED2 = Off

LM3646

ZHCSD42A–DECEMBER 2013–REVISED NOVEMBER 2014

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7.6.7 LED1 Flash Current Control Register (0x06)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|--|---|-------|-------|-------|-------|-------|-------|
| Strobe Pin Enable Bit 0 = Disabled (default) 1 = Enabled | LED1 Flash Current Level | | | | | | |
| | 0x00= 0 mA, LED1 Disabled, LED2 = Max Flash Current | | | | | | |
| | 0x01 = 23.04 mA | | | | | | |
| | 0x02 = 34.76 mA | | | | | | |
| | 0x03 = 46.48 mA | | | | | | |
| | 0x04 = 58.19 mA | | | | | | |
| | ... | | | | | | |
| | 0x7D = 1476.16 mA | | | | | | |
| 0x7E = 1487.88 mA | | | | | | | |
| 0x7F = 1499.60 mA, LED2 Disabled (default) | | | | | | | |

7.6.8 LED1 Torch Current Control Register (0x07)
LED1 TORCH CURRENT CONTROL REGISTER (0x07)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---|---|-------|-------|-------|-------|-------|-------|
| Torch Pin Enable Bit 0 = Disabled (default) 1 = Enabled | LED1 Torch Current Level | | | | | | |
| | 0x00= 0 mA, LED1 Disabled, LED2 = Max Torch Current | | | | | | |
| | 0x01 = 2.53 mA | | | | | | |
| | 0x02 = 3.99 mA | | | | | | |
| | 0x03 = 5.46 mA | | | | | | |
| | 0x04 = 6.92 mA | | | | | | |
| | ... | | | | | | |
| | 0x7D = 184.17 mA | | | | | | |
| | 0x7E = 185.64 mA | | | | | | |
| | 0x7F = 187.10 mA, LED2 Disabled (default) | | | | | | |

7.6.9 Flags Register1 (0x08)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|--------------------|-------------------------|---------------------------------|--------------------|---------------------|---------------------|---------------------------------|------------------------------|
| OVP 0 = Default | NTC TRIP 0 = Default | THERMAL SHUTDOWN 0 = Default | OCF 0 = Default | IVFM 0 = Default | UVLO 0 = Default | VOUT SHORT FAULT 0 = Default | FLASH TIMEOUT 0 = Default |

| | |
|---|---|
| OVP Fault | Over-Voltage Protection tripped. Open Output capacitor or open LED. |
| NTC Trip Fault | NTC Threshold crossed. |
| Thermal Shutdown Fault | LM3646 Die temperature reached thermal shutdown value. |
| Over-Current Protection Event Flag | Inductor Current limit value was reached. |
| IVFM Flag | IVFM block adjusted LED current. |
| UVLO Fault | UVLO Threshold crossed. |
| VOUT Short Fault | VOUT Short detected. |
| Time-Out Flag | Flash Time-Out detected. |

Note: Faults require an I²C read-back of the “Flags Register” to resume operation. Flags report an event occurred, but do not inhibit future functionality. A read-back of the Flags Register will only get updated again if the fault or flag is still present upon a restart.

7.6.10 Flags Register2 (0x09)

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|-------|--|---|--|--|--|--|---|
| RFU | SOFTWARE RESET Bit 0 = Normal Operation (Default) 1 = RESET | Fault Shutdown Enable 0 = Disabled 1 = Enabled (default) | NTC Short Fault Enable 0 = Disabled 1 = Enabled (default) | LED2 Short Fault 0 = Default | LED1 Short Fault 0 = Default | NTC Short Flag 0 = Default | NTC Open Flag 0 = Default |

| | |
|-------------------------------|--|
| Software Reset Bit | Writing to this bit resets the LM3646 to the default power up conditions. This bit self-clears upon assertion. |
| Fault Shutdown Enable | When Enabled, faults will force the LM3646 to shutdown. When disabled, faults will not force the LM3646 to shutdown. The LM3646 protection mechanisms will remain active until the part is manually disabled via the I ² C bus. |
| NTC Short Fault Enable | When enabled, NTC Short faults will be detected and reported. When disabled, NTC Short faults will not be detected or reported. |
| LED2 Short Fault | Set to a '1' if LED2 is shorted. |
| LED1 Short Fault | Set to a '1' if LED1 is shorted. |
| NTC Short Fault | The NTC Short Flag is set if the NTC pin voltage crosses below 100 mV during operation. |
| NTC Open Fault | The NTC Open Flag is set if the NTC pin voltage crosses above 2.3V during operation. |

Note: An I²C readback of the Flags Register2 will clear both the NTC Open and NTC Short Flags.

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The LM3646 can drive two flash LED at currents up to 1.5 A total. The 4-MHz DC/DC boost regulator allows for the use of small value discrete external components.

8.2 Typical Application

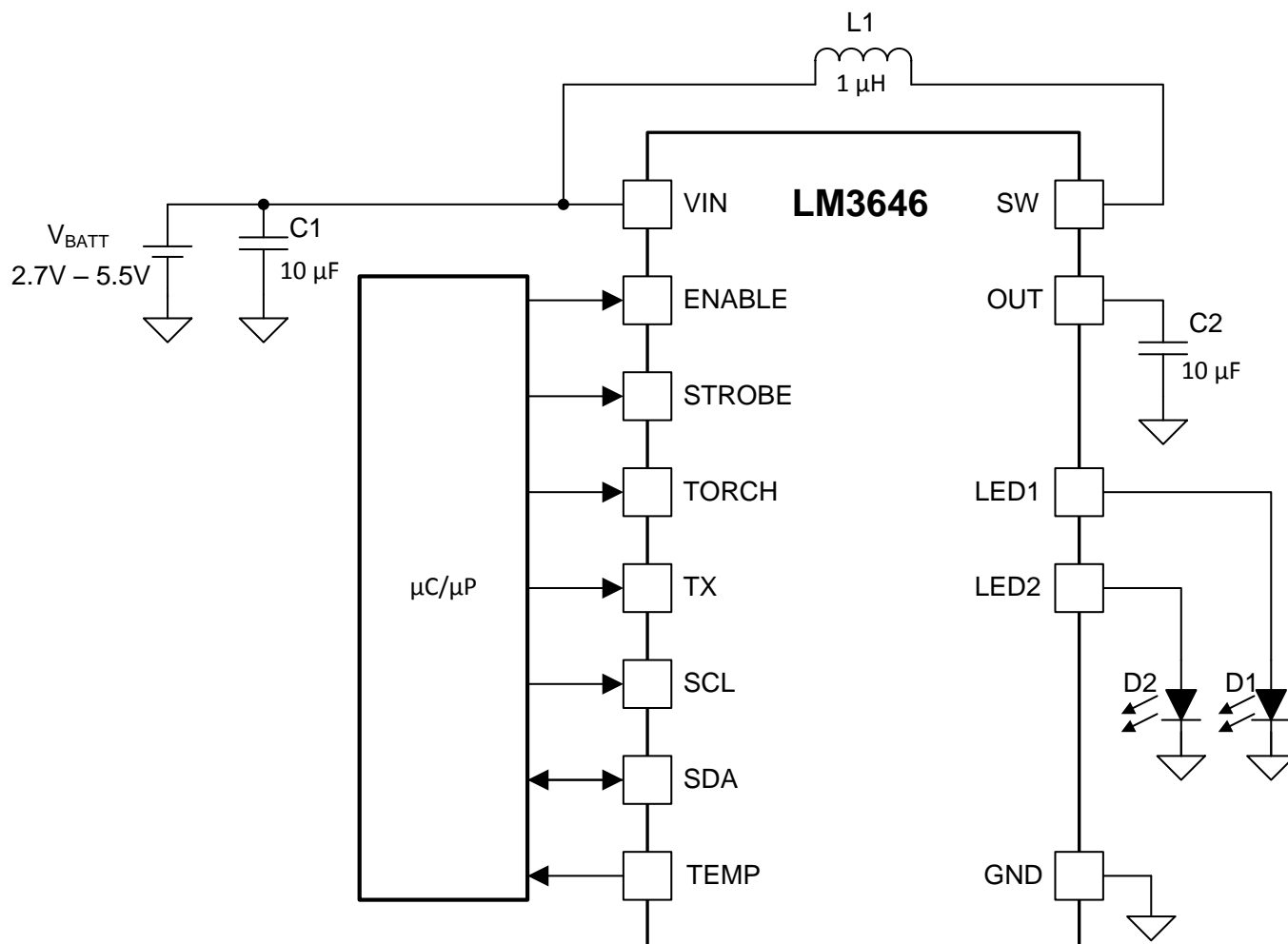


Figure 36. Typical Application Circuit

Typical Application (continued)

8.2.1 Design Requirements

Example requirements based on default register values:

| DESIGN PARAMETER | EXAMPLE VALUE |
|--------------------------|--------------------------------|
| Input voltage range | 2.5 V to 5.5 V |
| Brightness control | I ² C Register |
| Inductor | 1-μH, 3.1-A saturation Current |
| LED configuration | 2 Flash LEDs |
| Maximum flash brightness | 1.5 A |
| Flash brightness | 1.5 A on LED1, LED2 Disabled |

8.2.2 Detailed Design Procedure

8.2.2.1 Output Capacitor Selection

The LM3646 is designed to operate with at least a 10-μF ceramic output capacitor. When the boost converter is running, the output capacitor supplies the load current during the boost converter's on-time. When the NMOS switch turns off, the inductor energy is discharged through the internal PMOS switch, supplying power to the load and restoring charge to the output capacitor. This causes a sag in the output voltage during the on-time and a rise in the output voltage during the off-time. The output capacitor is therefore chosen to limit the output ripple to an acceptable level depending on load current and input/output voltage differentials and also to ensure the converter remains stable.

For proper operation the output capacitor must be at least a 10-μF ceramic. Larger capacitors such as a 22-μF or capacitors in parallel can be used if lower output voltage ripple is desired. To estimate the output voltage ripple considering the ripple due to capacitor discharge (ΔV_Q) and the ripple due to the capacitor's ESR (ΔV_{ESR}), use the following equations:

For continuous conduction mode, the output voltage ripple due to the capacitor discharge is:

$$\Delta V_Q = \frac{I_{LED} \times (V_{OUT} - V_{IN})}{f_{SW} \times V_{OUT} \times C_{OUT}} \quad (1)$$

The output voltage ripple due to the output capacitor's ESR is found by:

$$\Delta V_{ESR} = R_{ESR} \times \left(\frac{I_{LED} \times V_{OUT}}{V_{IN}} + \Delta I_L \right)$$

where

$$\Delta I_L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{2 \times f_{SW} \times L \times V_{OUT}} \quad (2)$$

In ceramic capacitors the ESR is very low so a close approximation is to assume that 80% of the output voltage ripple is due to capacitor discharge and 20% from ESR. [Table 3](#) lists different manufacturers for various output capacitors and their case sizes suitable for use with the LM3646.

8.2.2.2 Input Capacitor Selection

Choosing the correct size and type of input capacitor helps minimize the voltage ripple caused by the switching of the LM3646 device's boost converter, and reduces noise on the boost converter's input pin that can feed through and disrupt internal analog signals. In the [Figure 36](#) a 10-μF ceramic input capacitor works well. It is important to place the input capacitor as close as possible to the LM3646's input (IN) pin. This reduces the series resistance and inductance that can inject noise into the device due to the input switching currents. [Table 3](#) lists various input capacitors that are recommended for use with the LM3646.

Table 3. Recommended Input/Output Capacitors (X5R Dielectric)

| MANUFACTURER | PART NUMBER | VALUE | CASE SIZE | VOLTAGE RATING |
|-----------------|---------------|-------|-----------------------------------|----------------|
| TDK Corporation | C1608JB0J106M | 10 μF | 0603 (1.6 mm × 0.8 mm × 0.8 mm) | 6.3V |
| TDK Corporation | C2012JB1A106M | 10 μF | 0805 (2.0 mm × 1.25 mm × 1.25 mm) | 10V |

Table 3. Recommended Input/Output Capacitors (X5R Dielectric) (continued)

| MANUFACTURER | PART NUMBER | VALUE | CASE SIZE | VOLTAGE RATING |
|-----------------|--------------------|------------|-----------------------------------|----------------|
| TDK Corporation | C2012JB0J226M | 22 μ F | 0805 (2.0 mm x 1.25 mm x 1.25 mm) | 6.3V |
| Murata | GRM21BR61A106KE19 | 10 μ F | 0805 (2.0 mm x 1.25 mm x 1.25 mm) | 10V |
| Murata | GRM21BR60J226ME39L | 22 μ F | 0805 (2.0 mm x 1.25 mm x 1.25 mm) | 6.3V |

8.2.2.3 Inductor Selection

The LM3646 is designed to use a 1 μ H or 2.2 μ H inductor. [Table 4](#) lists various inductors and their manufacturers that can work well with the LM3646. When the device is boosting ($V_{OUT} > V_{IN}$) the inductor will typically be the largest area of efficiency loss in the circuit. Therefore, choosing an inductor with the lowest possible series resistance is important. Additionally, the saturation rating of the inductor should be greater than the maximum operating peak current of the LM3646. This prevents excess efficiency loss that can occur with inductors that operate in saturation and prevents over-heating of the inductor and further efficiency loss. For proper inductor operation and circuit performance ensure that the inductor saturation and the peak current limit setting of the LM3646 is greater than I_{PEAK} in the following calculation:

$$I_{PEAK} = \frac{I_{LOAD}}{\eta} \times \frac{V_{OUT}}{V_{IN}} + \Delta I_L \quad \text{where} \quad \Delta I_L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{2 \times f_{SW} \times L \times V_{OUT}} \quad (3)$$

where $f_{SW} = 4$ MHz, and efficiency can be found in the [Typical Characteristics](#) plots.

Table 4. Recommended Inductors

| MANUFACTURER | VALUE | PART NUMBER | DIMENSIONS (LxWxH) | I_{SAT} | R_{DC} |
|--------------|-----------|---------------------|--------------------------|-----------|---------------|
| TOKO | 1 μ H | 1286AS-H-1R0N | 2.0 mm x 1.6 mm x 1.2 mm | 3.1A | 68 m Ω |
| TOKO | 1 μ H | 1285AS-H-1R0M | 2.0 mm x 1.6 mm x 1.0 mm | 2.7A | 80 m Ω |
| TDK | 1 μ H | TFM201610G-1R0M-T05 | 2.0 mm x 1.6 mm x 1.0 mm | 2.9A | 60 m Ω |

8.2.2.4 NTC Thermistor Selection

The TEMP pin is a comparator input for flash LED thermal sensing. NTC Mode is intended to monitor an external thermistor which monitors LED temperature and prevents LED overheating. An internal comparator checks the voltage on the TEMP pin against the trip point programmed in the [NTC and Torch Ramp Register \(0x03\)](#). The thermistor is driven by an internally regulated current source, and the voltage on the TEMP pin is related to the source current and the NTC resistance. NTC thermistors have a temperature to resistance relationship of:

$$R(T) = R_{25^{\circ}C} \times e^{\left[\beta \left(\frac{1}{T^{\circ}C + 273} - \frac{1}{298} \right) \right]} \quad (4)$$

where β is given in the thermistor datasheet and $R_{25^{\circ}C}$ is the thermistor's value at 125°C.

Table 5. Application Circuit Component List

| COMPONENT | MANUFACTURER | VALUE | PART NUMBER | SIZE | CURRENT/VOLTAGE RATING (RESISTANCE) |
|-----------|--------------|------------|----------------|---------------------------------|-------------------------------------|
| L | TOKO | 1 μ H | 1286AS-H-1R0N | 2.0 mm x 1.6 mm x 1.2 mm | $I_{SAT} = 3.1$ A (68 m Ω) |
| COUT1,2 | Murata | 10 μ F | GRM188R60J106M | 1.6 mm x 0.8 mm x 0.8 mm (0603) | 6.3 V |
| CIN1,2 | Murata | 10 μ F | GRM188R60J106M | 1.6 mm x 0.8 mm x 0.8 mm (0603) | 6.3 V |

8.2.3 Application Curves

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

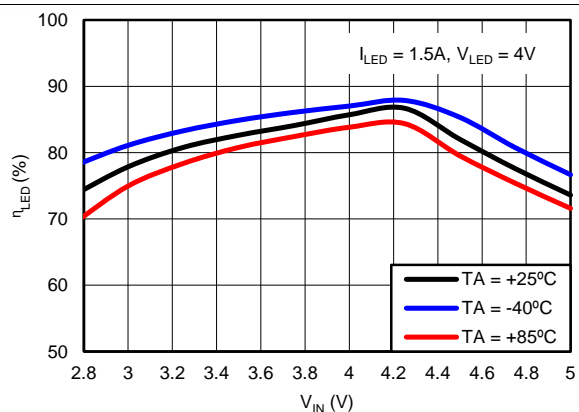


Figure 37. Flash LED Efficiency vs. Input Voltage

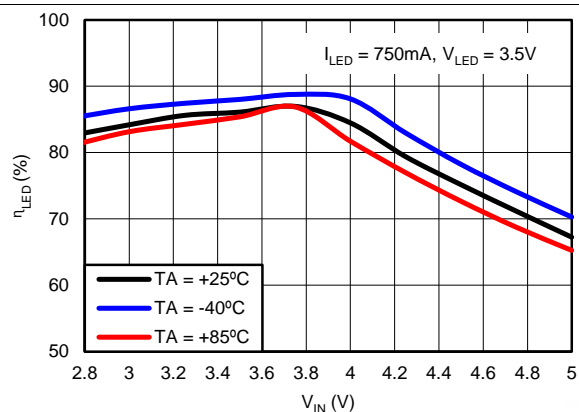


Figure 38. Flash LED Efficiency vs. Input Voltage

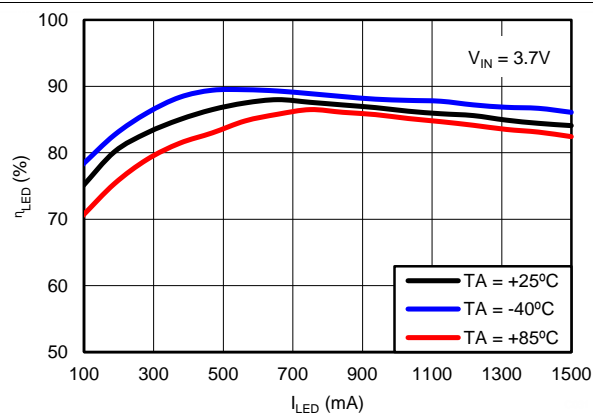


Figure 39. Flash LED Efficiency vs. LED Current

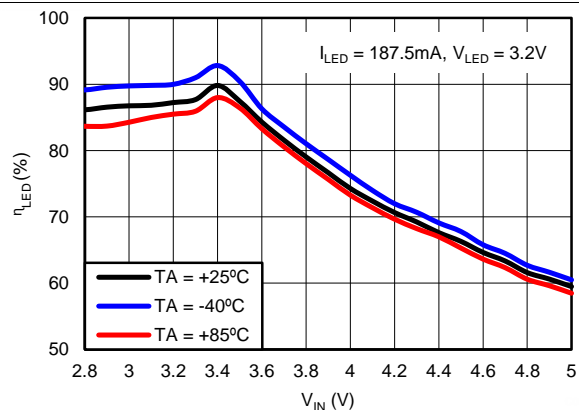


Figure 40. Torch LED Efficiency vs. Input Voltage

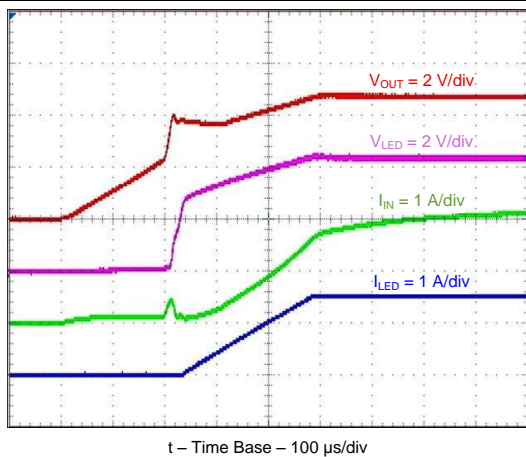


Figure 41. Flash Ramp-Up

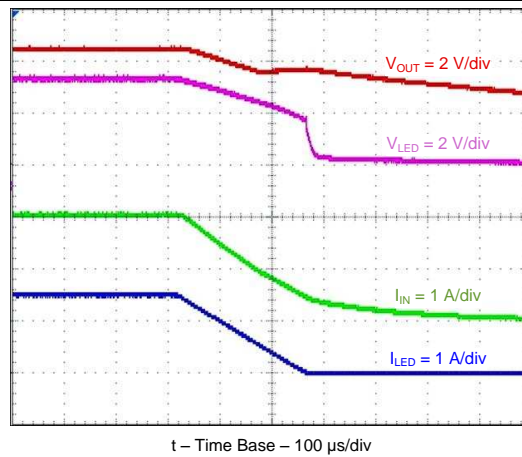


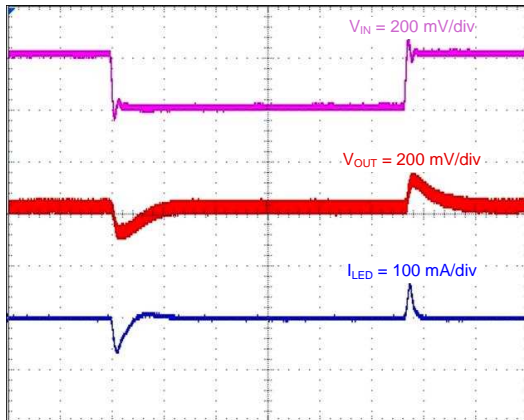
Figure 42. Flash Ramp-Down

LM3646

ZHCSD42A–DECEMBER 2013–REVISED NOVEMBER 2014

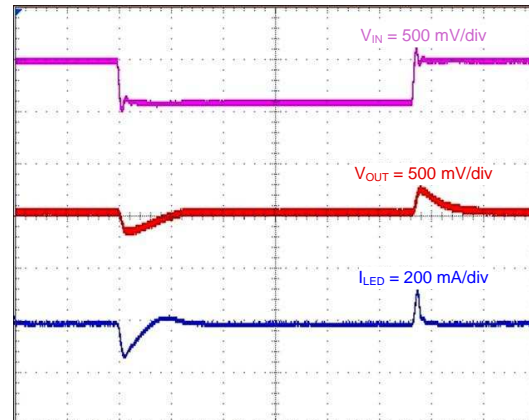
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Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.



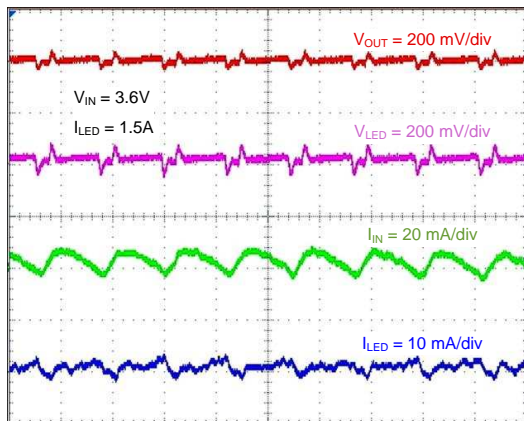
t – Time Base – 40 $\mu\text{s}/\text{div}$

Figure 43. Line-step (200 mV) During Flash



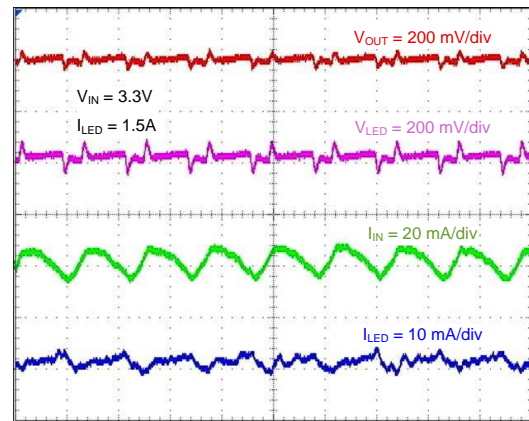
t – Time Base – 40 $\mu\text{s}/\text{div}$

Figure 44. Line-step (400 mV) During Flash



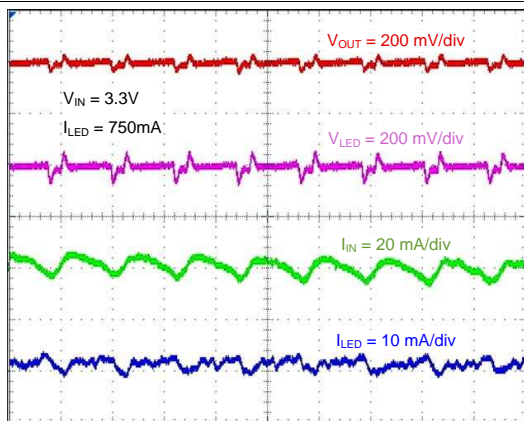
t – Time Base – 200 ns/div

Figure 45. LED Current Ripple



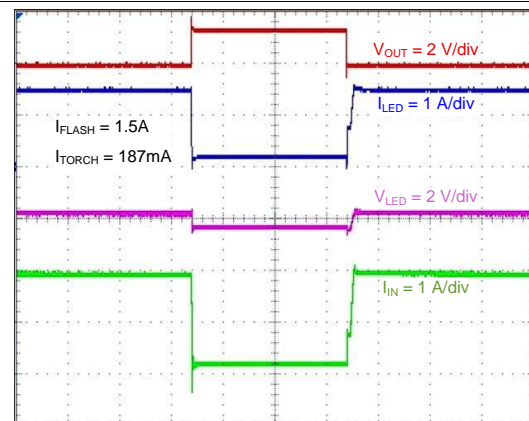
t – Time Base – 200 ns/div

Figure 46. LED Current Ripple



t – Time Base – 200 ns/div

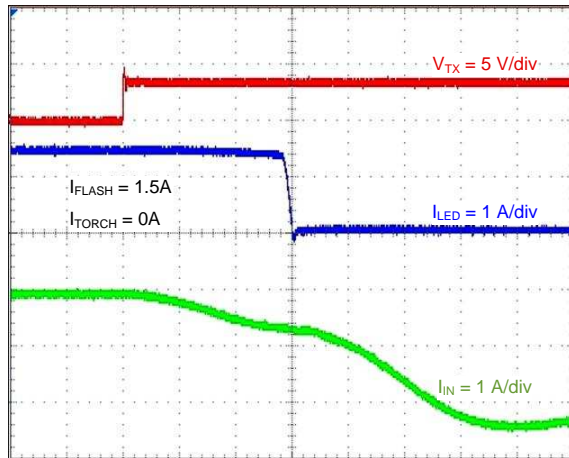
Figure 47. LED Current Ripple



t – Time Base – 1 ms/div

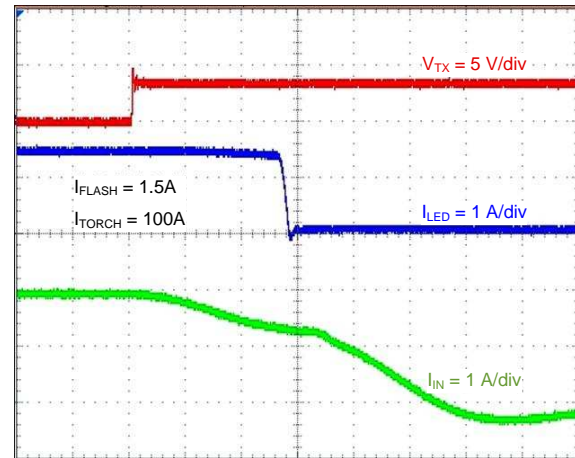
Figure 48. TX-Mask Event, Default Settings

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.



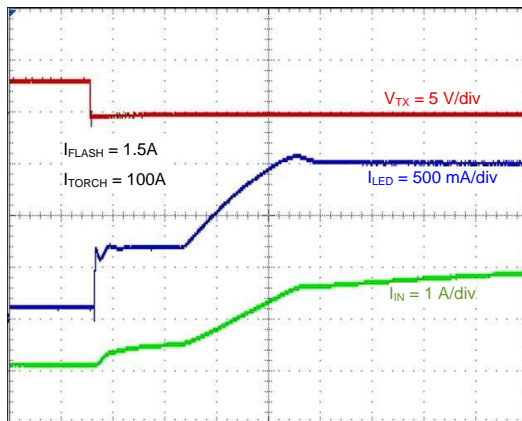
t – Time Base – 1 $\mu\text{s/div}$

Figure 49. TX Signal Low-to-High Transition



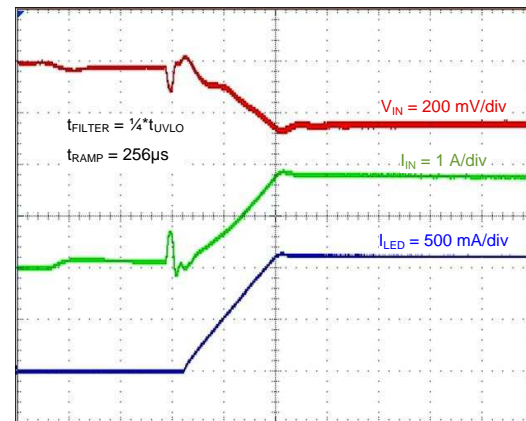
t – Time Base – 1 $\mu\text{s/div}$

Figure 50. TX Signal Low-to-High Transition



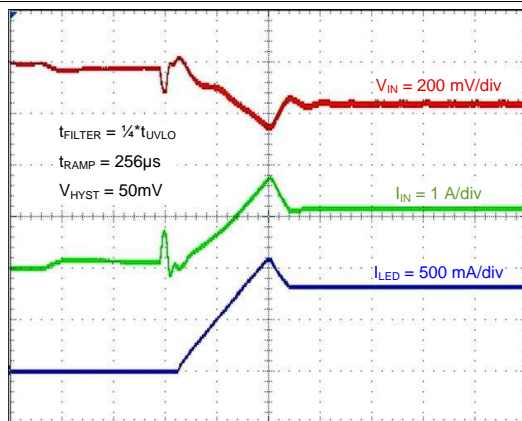
t – Time Base – 40 $\mu\text{s/div}$

Figure 51. TX Signal High-to-Low Transition



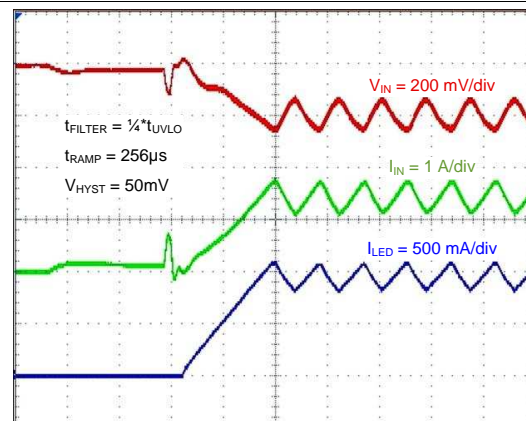
t – Time Base – 100 $\mu\text{s/div}$

Figure 52. Input Voltage Flash Monitor, Stop & Hold Mode, Default settings



t – Time Base – 100 $\mu\text{s/div}$

Figure 53. Input Voltage Flash Monitor, Down Mode, Default Settings



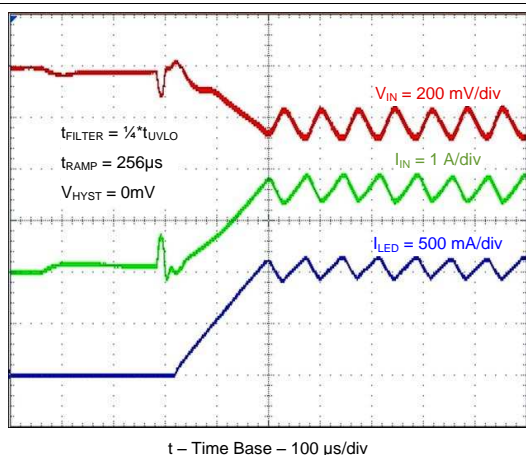
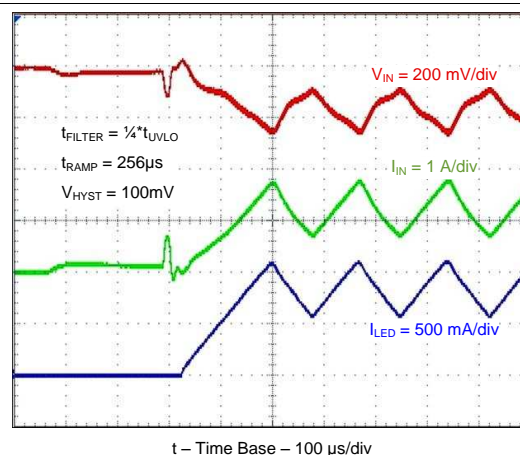
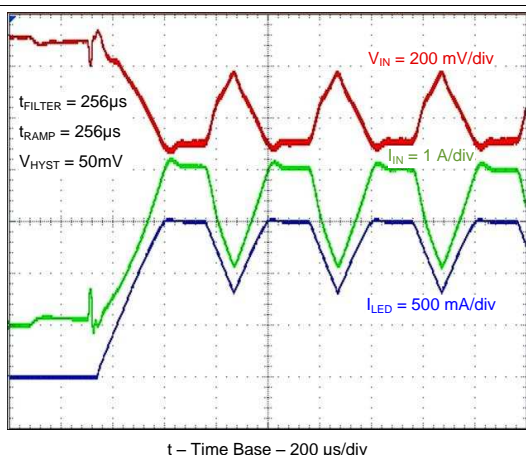
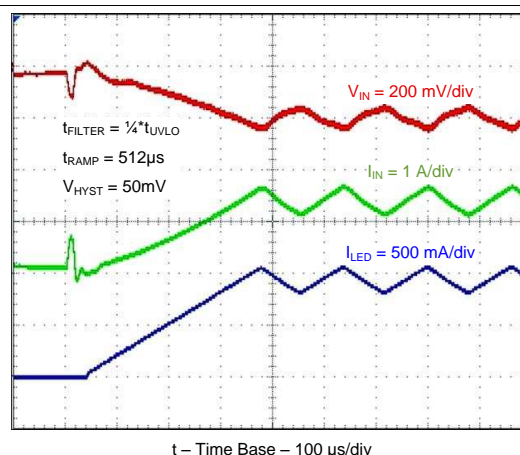
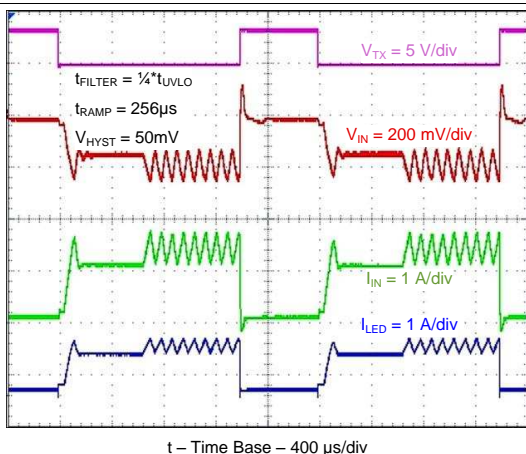
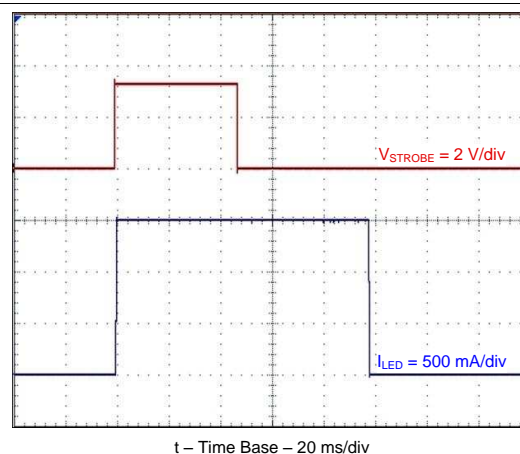
t – Time Base – 100 $\mu\text{s/div}$

Figure 54. Input Voltage Flash Monitor, Up & Down Mode, Default Settings

LM3646

ZHCSD42A–DECEMBER 2013–REVISED NOVEMBER 2014

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 Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

Figure 55. Input Voltage Flash Monitor, Up & Down Mode,

Figure 56. Input Voltage Flash Monitor, Up & Down Mode,

Figure 57. Input Voltage Flash Monitor, Up & Down Mode

Figure 58. Input Voltage Flash Monitor, Up & Down Mode

Figure 59. Input Voltage Flash Monitor, Up & Down Mode with TX Event

Figure 60. Edge-Sensitive Strobe

Unless otherwise specified: $T_A = 25^\circ\text{C}$; $V_{IN} = 3.6\text{ V}$; $V_{EN} = V_{IN}$; $C_{IN} = 10\text{ }\mu\text{F}$; $C_{OUT} = 10\text{ }\mu\text{F}$; $L = 1\text{ }\mu\text{H}$.

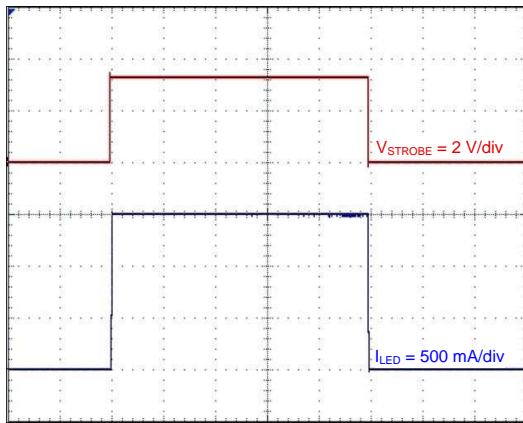


Figure 61. Level-Sensitive Strobe without Timeout

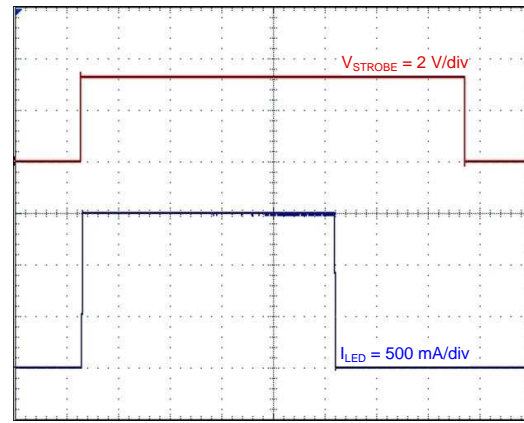


Figure 62. Level-Sensitive Strobe with Timeout

9 Power Supply Recommendations

The LM3646 is designed to operate from an input voltage supply range between 2.5 V and 5.5 V. This input supply must be well regulated and capable to supply the required input current. If the input supply is located far from the LM3646 additional bulk capacitance may be required in addition to the ceramic bypass capacitors.

10 Layout

10.1 Layout Guidelines

The high switching frequency and large switching currents of the LM3646 make the choice of layout important. The following steps should be used as a reference to ensure the device is stable and maintains proper LED current regulation across its intended operating voltage and current range.

1. Place C_{IN} on the top layer (same layer as the LM3646) and as close to the device as possible. The input capacitor conducts the driver currents during the low-side MOSFET turn-on and turn-off and can see current spikes over 1 A in amplitude. Connecting the input capacitor through short, wide traces to both the IN and GND pins will reduce the inductive voltage spikes that occur during switching and which can corrupt the V_{IN} line.
2. Place C_{OUT} on the top layer (same layer as the LM3646) and as close as possible to the OUT and GND pins. The returns for both C_{IN} and C_{OUT} should come together at one point, as close to the GND pin as possible. Connecting C_{OUT} through short, wide traces will reduce the series inductance on the OUT and GND pins that can corrupt the OUT and GND lines and cause excessive noise in the device and surrounding circuitry.
3. Connect the inductor on the top layer close to the SW pin. There should be a low-impedance connection from the inductor to SW due to the large DC inductor current, and at the same time, the area occupied by the SW node should be small to reduce the capacitive coupling of the high dV/dt present at SW that can couple into nearby traces.
4. Avoid routing logic traces near the SW node to avoid any capacitively coupled voltages from SW onto any high impedance logic lines such as TORCH, STROBE, ENABLE, TEMP, TX, SDA and SCL. A good approach is to insert an inner layer GND plane underneath the SW node and between any nearby routed traces. This creates a shield from the electric field generated at SW.
5. Terminate the Flash LED cathodes directly to the GND pin of the LM3646. If possible, route the LED returns with a dedicated path to keep the high amplitude LED currents out of the GND plane. For Flash LEDs that are routed relatively far away from the LM3646, a good approach is to sandwich the forward and return current paths over the top of each other on two layers. This will help in reducing the inductance of the LED current paths.

10.2 Layout Example

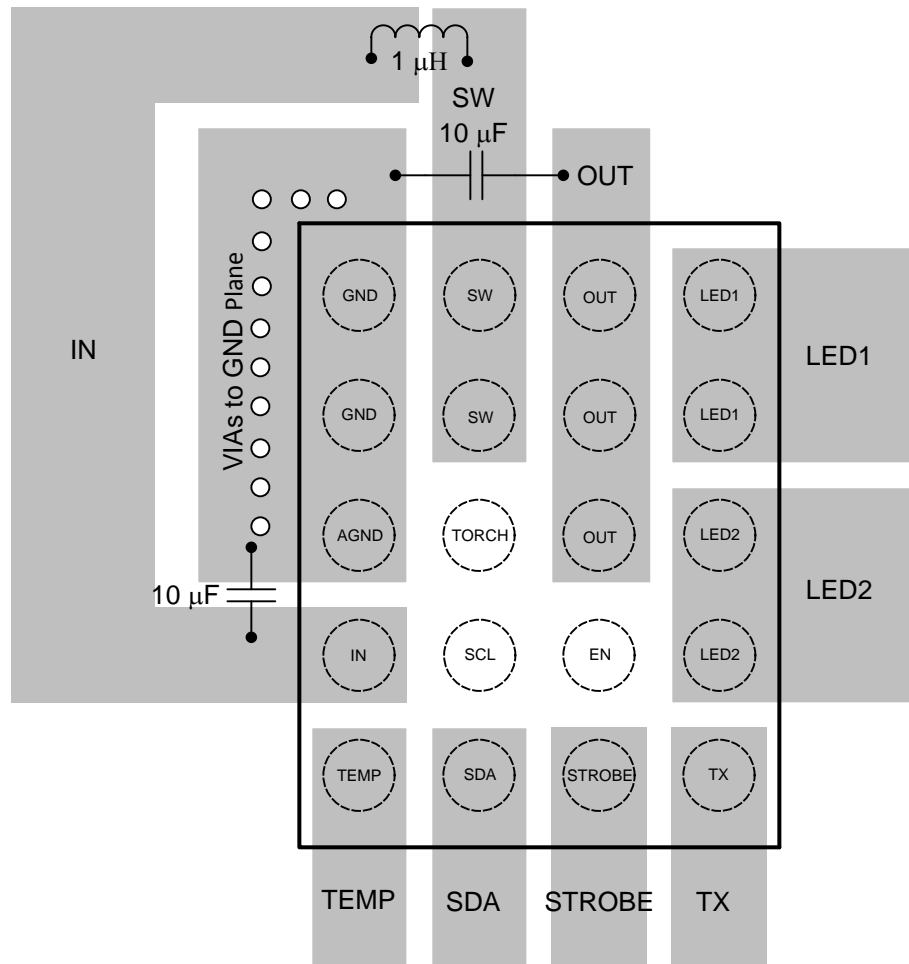


Figure 63. LM3646 Layout

11 器件和文档支持

11.1 器件支持

11.1.1 第三方产品免责声明

TI 发布的与第三方产品或服务有关的信息，不能构成与此类产品或服务或保修的适用性有关的认可，不能构成此类产品或服务单独或与任何 TI 产品或服务一起的表示或认可。

11.2 文档支持

11.2.1 相关文档

相关文档如下：

德州仪器 (TI) 应用手册 1112: 《DSBGA 晶圆级芯片规模封装》（文献编号: [SNVA009](#)）。

11.3 商标

All trademarks are the property of their respective owners.

11.4 静电放电警告



ESD 可能会损坏该集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理措施和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

11.5 术语表

[SLYZ022](#) — TI 术语表。

这份术语表列出并解释术语、首字母缩略词和定义。

12 机械封装和可订购信息

以下页中包括机械封装和可订购信息。 这些信息是针对指定器件可提供的最新数据。 这些数据会在无通知且不对本文档进行修订的情况下发生改变。 欲获得该数据表的浏览器版本，请查阅左侧的导航栏。

PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|--------------|--------------------|------|----------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|---------|
| LM3646YFQR | NRND | DSBGA | YFQ | 20 | 3000 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | 3646 | |

(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.

OBSOLETE: 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.

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

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TAPE AND REEL INFORMATION


*All dimensions are nominal

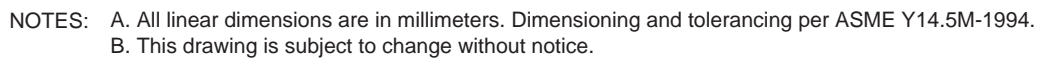
| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LM3646YFQR | DSBGA | YFQ | 20 | 3000 | 178.0 | 8.4 | 1.78 | 2.2 | 0.78 | 4.0 | 8.0 | Q1 |

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LM3646YFQR | DSBGA | YFQ | 20 | 3000 | 220.0 | 220.0 | 35.0 |



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