

## **LED Flash-Protection Features**

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### **ABSTRACT**

Modern LED camera flash drivers are feature-rich and power dense. Capable of delivering over 2 A of current to dual LEDs in packages as small as 1.69 mm × 1.31 mm, flash LED drivers require built-in safety and protection features to maintain long-term device and system health. Devices such as the LM3643, LM3644, LM3648, LM3646, LM3642, LM36010, and LM36011 all provide many specific protection mechanisms that not only help provide run-time diagnostics but help diagnose manufacturing specific faults associated with the surrounding passive components. This application note will dive into the different protection mechanisms found on LED flash drivers.

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## 1 Introduction

Protection mechanisms on TI flash drivers can be placed into two different categories: faults that protect and disable the device and flags that protect and report a systematic event.

## 2 Faults

Fault-protection events are classified as critical events where the best course of action is for the LED flash driver to enter a shutdown sequence. A list of faults that can force a shutdown event include an output short circuit, an LED short circuit, an LED open circuit or overvoltage protection (OVP), an undervoltage lockout (UVLO), an IC thermal shutdown, and a NTC thermal detection fault. In the event of a fault, a fault flag is usually set in the I2C Faults and Flags registers. When a fault flag is set, the register must be read before any additional flash or torch events are allowed to occur. The Faults and Flags registers are clear-on-read registers.

### 2.1 Output Short Circuit

In the event that the output of the flash LED drivers DC-DC boost converter becomes shorted, the flash device must quickly detect that a short has occurred and shut off the device to prevent long-term damage. On devices like the LM364x and LM3601x family of parts, when an LED short occurs, the boost converter enters a current source mode to limit the allowable current driven (approximately 200 mA) into the short. This helps prevent damage to the series inductor and synchronous PFET of the boost. In addition to scaling back the allowable current, a timer is started to prevent this short condition from continuing for an indefinite time. The timer duration in the case of the LM364x/LM3601x family is approximately 2 ms. Once this time has elapsed, the LM364x and LM3601x devices enter a shutdown sequence disabling the part. At the end of the shutdown, a fault flag is reported in one of the Faults and/or Flags registers available in the I2C register set.

### 2.2 LED Short Circuit

The LED short-circuit protection mechanism is similar to the output short-circuit detection scheme in that it has a voltage and timing condition that must be met before a fault is detected. When the voltage on the LED pin or pins are held to a voltage below 500 mV from more than 256  $\mu$ s, the flash driver enters a reset sequence and sets the LED short flag. The LED driver is protected in this case because even during the 256- $\mu$ s time the fault is present, the peak current is still regulated by the high-side current source. On some devices, this fault can be disabled to help with production test cases where temporary shorts are present.

### 2.3 Overvoltage Protection (OVP) / Open LED

Most DC-DC boost converters have a mechanism to terminate boosting operation in the event the feedback path opens or the output storage capacitor becomes an open circuit. In the flash driver application, when an LED becomes disconnected from current source, the feedback node is pulled up (in the case of a current source) or pulled down (for a current sink), causing the feedback loop to detect that the boost voltage must increase to regain proper regulation. Without a load, the output voltage continues to increase. Once the voltage on the output node reaches the predetermined level, often dictated by the voltage rating of the output capacitor and internal boost FETs, the OVP circuit comparator trips, causing the boost to stop boosting. This halt to boost activity protects the output capacitor and flash LED driver from future damage. Additionally, the OVP circuit works to protect the device in the event that the output capacitor becomes disconnected from the DC-DC converter. In this fault mode, there is no method for the output to be held to a controlled voltage. When the boost begins the power delivery stage, the output voltage increases very quickly unless the OVP detection can react quickly enough to prevent damage. In both the LED open and output capacitor open fault, a flag is set in the Faults and Flags registers.

## 2.4 Undervoltage Lock Out (UVLO)

To prevent operation at low input voltages, a comparator monitoring the value of the input voltage can be used to force the device into a shutdown state. This mode is often called undervoltage lockout, which by definition locks the device from operating in a region that the device was not designed to operate in. In traditional boost converters, the UVLO detection comparator has hysteresis where the falling trip point and the rising trip point are skewed to prevent toggling. In the case of the TI flash LED drivers that employ a digital interface, the UVLO comparator does not need hysteresis because the device shuts down once tripped. To clear a UVLO fault, the Flags and Fault registers must be read before a restart (clear on read). Upon a restart, if the input voltage is still below the UVLO comparator trip point, the device re-enters the fault state.

## 2.5 Thermal Faults

When detecting faults based upon temperature increases, it is important to have both on-chip detection as well as remote detection of the LED. To enable on-chip thermal protection, the LM364x/LM3601x family of flash drivers all have a thermal shutdown detection (TSD) circuit that monitor die temperature. In most cases, when the junction temperature on-chip reaches 150°C, the devices enter a shutdown sequence and set a flag in the Faults and Flags registers. The devices stay in a thermal shutdown state until the TSD fault flag is cleared (clear on read). Once cleared, the flash driver can be re-enabled. If the temperature once again hits the TSD threshold, the device once again enters thermal shutdown.

On the LM36010x devices there is an intermediate temperature-based threshold called thermal scaleback (TSB), which does not force a shutdown but rather reduces the flash current to the value stored in the Torch Brightness register. Upon a restart, LM3601x devices monitor the thermal conditions and determine whether a full-flash or reduced value is allowed.

For remote detection, the use of a negative temperature coefficient (NTC) thermistor can be used to provide some level of remote temperature sensing in the area of the flash LED. The LM364x family of devices provide a bias current for the NTC thermistor and has an internal adjustable voltage comparator to monitor the thermistor voltage. As the temperature of the thermistor increases, the resistance decreases. This forces the sensed voltage to drop as the LED heats up. Once the voltage reaches a pre-programmed value chosen based upon the NTC resistance profile and a desired maximum temperature, the flash drivers have either force a shutdown sequence or force the device to a lower LED current (torch mode value). In the event of a NTC detection event, a NTC flag is set in the Faults and Flags register. Additionally, some of the LM364x family devices can detect an open or shorted NTC thermistor. These faults can often be disabled to help with production level testing where the NTC value might be driven by a supply.

## 3 Flags

In the context of a flash driver, a flag event is one intended to inform the system that a specific event occurred but does not force the driver to enter the shutdown event. Unlike a fault event, a flag event does not need to have its corresponding alert bit cleared before a restart.

### 3.1 Time-Out

The flash time-out period sets the amount of time that the flash current is being sourced from the current source/s (LED1/2). Most newer flash devices have 16 timeout levels ranging from 10 ms up to 1.6 seconds. The time-out value either serves as the flash duration in the case of an I2C initiated flash, or a protection timer in the case of an externally timed strobe initiated event. If the time-out duration elapses, the time-out flag is set, and the device enters the standby state. The time-out flag does not need to be cleared before a restart occurs.

### 3.2 Inductor Current Limit

TI flash drivers often feature two selectable inductor current limits that are programmable through the I<sup>2</sup>C interface. When the inductor current limit is reached, the boost converter terminates the charging phase of the switching cycle. Switching resumes at the start of the next switching period. If the overcurrent condition persists, the device operates continuously in current limit.

Because the current limit is sensed in the NMOS switch, there is no mechanism to limit the current when the device operates in pass mode (current does not flow through the NMOS in pass mode). In boost mode or pass mode if  $V_{OUT}$  falls below 2.3 V, the device stops switching, and the PFET operates as a current source limiting the current to around 200 mA. This prevents damage to the device and excessive current draw from the battery during output short-circuit conditions. The mode bits are not cleared upon a current limit event, but a flag is set.

### 3.3 *Transmit Interrupt*

The TX pins are a power amplifier (PA) 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 flash LED driver 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 returns 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 turns off. When a TX event occurs, a flag is set in the Faults/Flags registers to alert the system that the current changed during transmit interrupt event.

### 3.4 *Input Voltage Flash Monitor*

TI flash drivers have the ability to adjust the flash current based upon the voltage level present at the input utilizing the input voltage flash monitor (IVFM). The adjustable threshold IVFM-D typically ranges from 2.9 V to 3.6 V in 100-mV steps, with up to three different usage modes depending upon the device (stop and hold, adjust down only, adjust up and down). The IVFM flag bit is set when the input voltage crosses the IVFM-D value. Additionally, the IVFM-D threshold sets the input voltage boundary that forces the flash driver to either stop ramping the flash current during start-up (stop and hold mode) or to start decreasing the LED current during the flash (down adjust only and up and down adjust). In adjust up and down mode, the IVFM-D value plus the hysteresis voltage threshold set the input voltage boundary that forces the driver to start ramping the flash current back up towards the target.

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