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TPS61060/61/62: Single-Wire Digital Brightness Control

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ABSTRACT

The TPS6106x features a simple digital interface to allow brightness control using a single wire to control the converter. This application report shows the circuit configuration and the programming of the interface.

Contents

List of Figures

List of Tables

1   Description

The TPS61060/61/62 is a high-frequency, synchronous boost converter with constant current output to drive up to five white LEDs. For maximum safety, the device features overvoltage and an advanced short-circuit protection when the output is shorted to ground. The device operates with 1-MHz fixed switching frequency to allow the use of small external components and to simplify possible EMI problems. The device comes with three different overvoltage protection thresholds (14 V/18 V/23 V) to allow the use of inexpensive and small-output capacitors with lower voltage ratings. The LED current is initially set with the external sense the feedback voltage is regulated to 500 mV or 250 mV, depending on the ILED pin configuration. Digital brightness control is implemented by applying a simple digital signal to the ILED pin. Alternatively, a pulse width modulated (PWM) signal up to 1 kHz can be applied to the enable pin to control the LED brightness. During shutdown, the output is disconnected from the input to avoid leakage current through the LEDs.

2   Single-Wire Digital Interface for LED Brightness Control

In order to implement a single-wire digital interface, the enable pin (EN) is directly connected to the ILED pin. This allows simple implementation of the digital programming and enabling/disabling of the device. Figure 1 shows a typical schematic with a single-wire digital dimming interface.

Because the converter is designed to support fast PWM dimming, the device only enters shutdown when the enable pin is held low, i.e., ≥ 50 ms. When the EN pin is low for less than 50 ms, the converter stops switching and the LEDs are disconnected from the converter output. This allows the converter's internal circuits to remain active while the LEDs are turned off. With this implementation, the LEDs are turned off during digital programming because the ILED/EN pin is held low for most of the time during the digital programming sequence. See Table 1 for the timing of the digital interface.
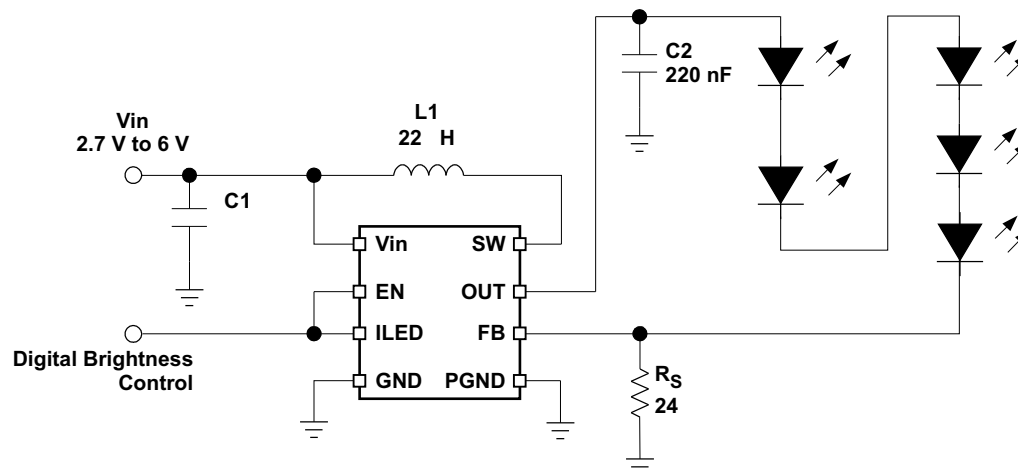

Figure 1. TPS6106x With Digital Dimming Interface

After enabling, the TPS6106x starts with the default dimming value set by the ratio of the default feedback voltage (250 mV) divided by the value of the sense resistor (R_S).The step counter (internal 5-bit DAC) is set to its center position. This allows programming 16 steps in both directions in order to increase or decrease the LED current. The internal DAC setting is lost when the device is disabled by pulling the ILED/EN pin low for more than 550 µs. Therefore, the former brightness setting value has to be reprogrammed whenever the device is turned on again.

The ILED pin basically sets the feedback regulation voltage (VFB) via the internal 5-bit DAC; thus, it sets the LED current. The digital brightness control is implemented by adjusting the feedback voltage in digital steps with a typical maximum voltage of V_{FB} = 500 mV. For this purpose, a 5-bit DAC is used, giving 32 steps equal to a 15.6-mV change in feedback voltage per step. To increase or decrease the internal reference voltage, the ILED pin needs to be pulled low over time as outlined in Table 1. When the internal DAC is programmed, it stays at this value until it gets reprogrammed.

Table 1. Increase/Decrease Internal Reference Voltage

FEEDBACK VOLTAGE		TIME ILED[1]	LOGIC LEVEL
Start sequence	(t_{START})	100 µs to 150 µs	High
Increase	(t_{UP})	1 µs to 75 µs	Low
Decrease	(t_{DOWN})	180 µs to 300 µs	Low
Delay between steps	(T_D)	≥1.5 µs	High
Brightness control disabled	(t_{OFF})	≥550 µs	Low
Device shutdown	(t_{DS})	≥50 ms	Low

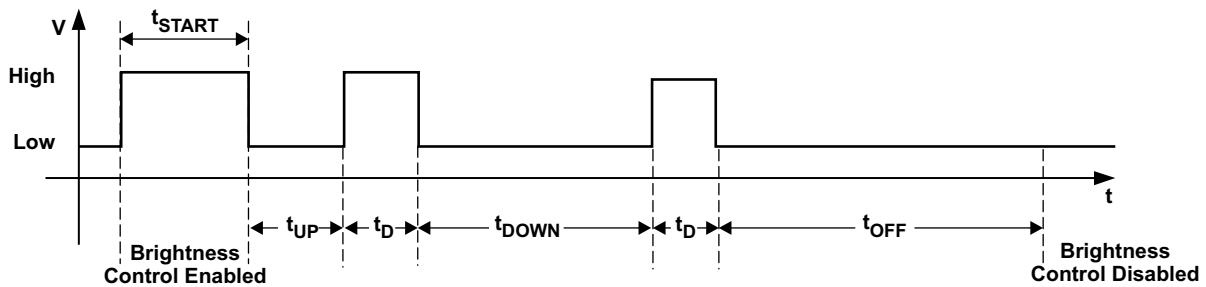[1] Between each cycle, the ILED pin needs to be pulled high for 1.5 µs.

Figure 2. ILED Timing Diagram

Two cases of digital brightness control can be implemented. Assuming a typical LED current with maximum brightness at 20 mA, the two applications can be realized as follows:

1. High efficiency, lower brightness control resolution (16 steps)

   The efficiency of the converter is affected by the voltage drop over the sense resistor. The lower the voltage drop, the higher the efficiency of the LED driver. To keep this voltage drop as small as possible, the feedback voltage has to be 250 mV for maximum brightness (20-mA LED current). The sense resistor then is calculated to be 12.5 Ω for a 20- mA LED current at a 250- mV feedback voltage. After turning on the converter, the feedback voltage starts with its default DAC center-point value of 250 mV, which in this case causes the maximum brightness of the LEDs. Because 20 mA is the maximum LED current, the LED current should only be programmed downward. As a result, only 16 steps remain from the available 32 steps of the entire DAC range.

2. High brightness control resolution (32 steps)

   For a higher resolution in brightness control, the maximum LED current of 20 mA should be reached at 500 -mV feedback voltage in order to have the full 32 DAC steps available. Calculating the value of the sense resistor for this case computes 25 Ω for a 20-mA LED current. When starting the converter, the internal DAC starts with its default dimming value, which in this case is half of the maximum current because the default feedback voltage is still 250 mV (250 mV/25 Ω = 10 mA). To reach the maximum current, a programming sequence with 16 up pulses (see Table 1) needs to be sent to the ILED/EN pin if the maximum brightness needs to be programmed. Also, 16 steps down are possible, starting from the default midpoint value, if the lowest brightness value needs to be programmed. This results in a 32-step resolution for the entire brightness control.

3 Software Implementation of the Digital Brightness Control

Each programming sequence has to start with a 100- to 150-µs starting pulse where the ILED/EN pin is held high, followed by the pulses programming the feedback voltage up or down. It is important that the starting pulse is not much longer than 100 µs to avoid any LED current being forced through the LEDs before the programming sequence is completed. Note: The LED current is only zero when ILED/EN is low. As shown in the following oscilloscope screen shots, (see Figure 3 and Figure 4) during all down pulses, the controller output switch is turned off and the current through the LEDs is zero. The short delays between the down pulses (typical 1.5 µs), where the ILED/EN signal is high, are not long enough to make the converter switching and force a current through the LEDs. Because of this, the LED current turns on only after the programming sequence is completed and comes up straight away with the correct programmed value.
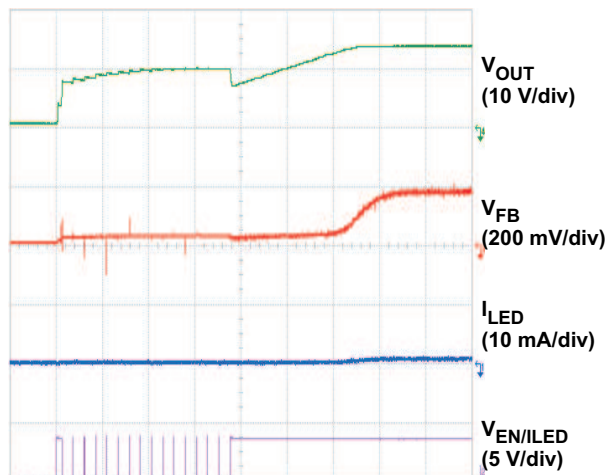
Figure 3. A 16-Steps-Down Programming Sequence From Start-up Midpoint Value to Minimum Current (750 μs/div)
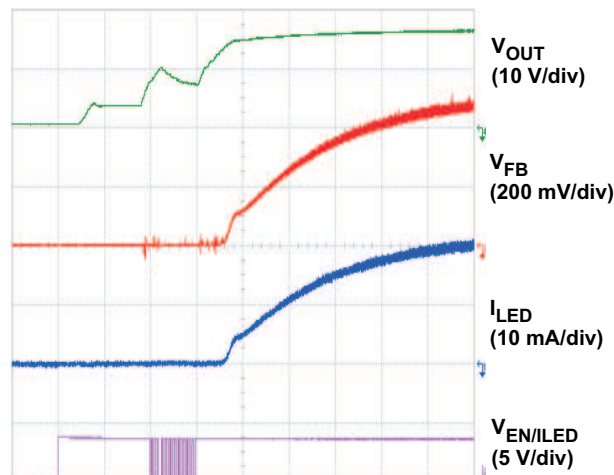

Figure 4. A 16-Steps-Up Programming Sequence From Start-Up Midpoint Value to Maximum Current. (50 μs/div)

Also, when the programming sequence is applied during operation, as shown in Figure 5, the converter output switch is turned off during the entire programming sequence, and therefore the LEDs are also turned off. As shown in Figure 5, this off-time is too short to be recognized by the human eye which usually notices differences in LED brightness only when they are longer than 10 ms.
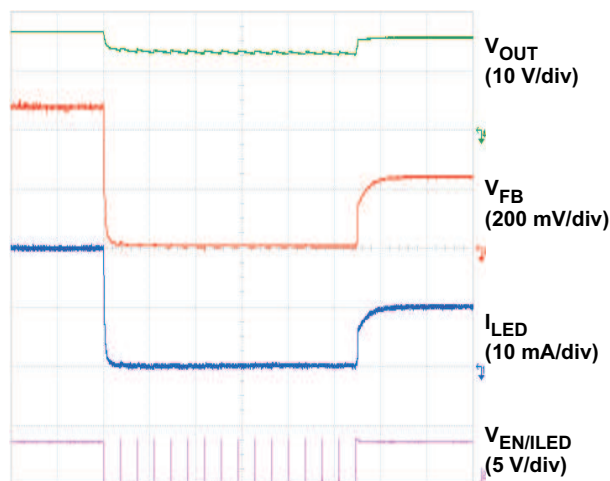

Figure 5. A 16-Steps-Down Programming Sequence From 20 mA Down to 10 mA. (500 μs/div)

It is also possible to achieve a smooth transition in brightness. This is implemented with a delay time between single down pulses of around 3.4 ms (see Figure 6). The light is smoothly getting darker in comparison to the implementation in Figure 5 where only a single brightness step from really bright to reduced brightness is noticeable.
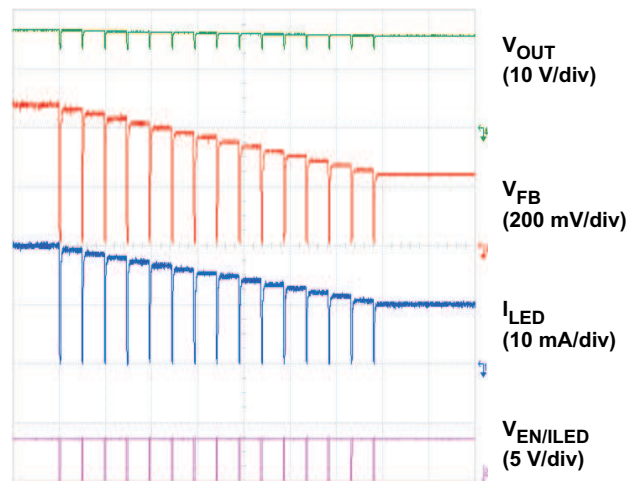
Figure 6. A 16-Steps-Down Programming Sequence With Long Delay (~3.4 ms) Between a Single Down Step. (10 ms/div)

4   Digital Programming Guidelines

The digital interface is simple to implement. Because it is a single-wire interface, the timing is important to achieve reliable brightness control. Usually, this is not a problem but special care must be taken during software implementation. Generally, the main processor, where the programming software is implemented, can cause high-priority interrupts causing possible time shifts during programming. To minimize these effects, the TPS6106x digital interface has a wide time specification as outlined in Table 1. To best deal with interrupts, the following is recommended:

1. The best way to minimize interference with high-priority processor interrupts is to mask the entire programming sequencing. This means that a dimming sequence is always finished before the controller is doing something else.
2. If the first rule is not possible, then it is recommended to always program the minimum time periods of Table 1 to allow maximum time shift in case of a high-priority interrupt. The most critical cases during programming are the pulses when the ILED/EN is high. If the ILED/EN is high for too long a time, the converter LED current comes up with an undesired value before the programming sequence is completed.
3. Remember that when the down pulse is longer than 550 µs, all information programmed is lost. This is important when high-priority interrupts could cause time shifts longer 550 µs.
4. To keep the program code easy, each programming sequence should start with the starting pulse having ILED/EN high for 100 µs, followed by the pulses programming the feedback/LED brightness up or down.

5   EVM and Controlling Software

For easy evaluation and verification of the digital dimming interface, an EVM with a USB module is available to control the interface by a standard personal computer. The USB module enables the generation of all kinds of pulses necessary for programming the device. A small user interface allows the programming of sequences and a single pulse to control the brightness of the TPS6106X. With this evaluation kit, the behavior of the converter can be evaluated at start-up as well as when the device is already enabled.

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