Application Note

Powering LED Strobe Application with the TPS92205x Buck LED Driver

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ABSTRACT

LED-based fire-strobe products must generate a repeatable, high-intensity light pulse while minimizing input energy. The UL 1638 / ULC 526 update requires the rated light output to be based on a maximum 20-ms light pulse, which makes LED-current rise time a direct contributor to effective strobe efficiency. This application note explains how to use the TPS92205x buck LED driver family in short-pulse strobe designs, with emphasis on avoiding repeated device shutdown and soft-start during low-duty-cycle operation. A pre-conditioning EN/PWM pulse is introduced to prepare the internal reference and control loop before the main optical pulse. External compensation, output capacitance, and inductor selection are also discussed to help reduce current rise time while maintaining stable operation, acceptable overshoot.

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1 Introduction

Visible fire-strobe products are increasingly transitioning from xenon tubes to LEDs. Compared with xenon solutions, LEDs can reduce standby and flash energy, simplify optical and mechanical design, improve system lifetime, and enable digitally controlled light profiles.

However, LED-based strobe systems must deliver most of their useful optical energy within a very short time window. If the LED current rises slowly, part of the available flash duration is consumed before the LED reaches its rated current. This reduces the effective optical output and lowers the effective candela per joule. Therefore, the LED driver must provide a fast, repeatable, and nearly square current pulse during the main strobe event.

The 2023 edition of UL 1638 / ULC 526 defines requirements for visible signaling devices used in fire-alarm and signaling systems. For public-mode visible signal devices, the flash rate must be 1 to 2 flashes per second, the flash duration must not exceed 200ms when measured between the 10% amplitude points, and the rated light output is based on a maximum 20-ms light pulse. If the actual pulse duration is longer than 20 ms, the measured light output is converted to a 20-ms equivalent value. As a result, the LED-current rise time becomes a critical factor in meeting the required effective light output.

The TPS92205x family is well suited for high-efficiency LED strobe designs. The devices integrate a power MOSFET, support high-voltage buck LED-driver operation, regulate LED current through an external sense resistor, and provide PWM and analog dimming options. TPS922050 and TPS922051 are suitable for 1-A and 2-A applications, while TPS922052, TPS922053, TPS922054, and TPS922055 support higher-current LED-driver designs.

For high-power strobe applications using TPS922055, one important design consideration is the EN/PWM low-time behavior. If the EN/PWM pin remains low for an extended period, the device will enter a shutdown state, the next pulse must go through the startup and soft-start sequence before the LED current reaches the programmed level. In a 1-Hz strobe application with a 20-ms optical pulse, this delay can significantly reduce the useful light output. This application note discusses timing-control and peripheral-circuit optimization methods to improve LED-current rise time and strobe efficiency when using TPS92205x devices.

2 EN/PWM Timing Design to Avoid Repeated Soft-Start

2.1 TPS922050/1 Fast PWM Dimming Behavior

For TPS922050/1, the LED current follows the DIM input with fast response during PWM dimming. As Figure 2-1 shows, when the PWM input is high, inductor current ramps to the regulated value. When the PWM input is low, the LED current falls to zero. Because the device is intended to support fast PWM dimming, TPS922050/1 is a good fit for lower-current strobe designs.

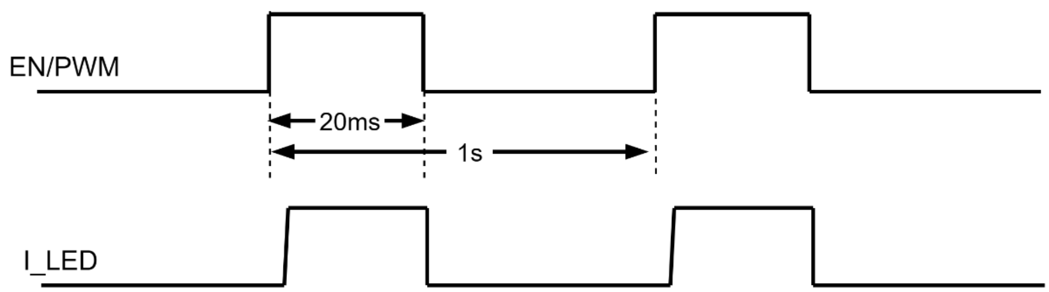

Figure 2-1. TPS922050/1 LED Current Response During Fast PWM Dimming

2.2 TPS922052/3/4/5 Fast PWM Dimming Behavior

For TPS922052/3/4/5, the EN/PWM pin can support fast response if the off-time is kept shorter than the PWM input minimum off time to disable device ($t_{PWM\_IN\_OFF}$). If EN/PWM remains low for longer than the $t_{PWM\_IN\_OFF}$, the device will be disabled. The next EN/PWM pulse must re-enable the device, satisfy startup and dimming-mode entry requirements, and allow the internal reference and compensation path to settle. Figure 2-2 shows the repeated soft-start can make the LED current ramp slowly at the beginning of every flash.

The datasheet describes the startup sequence and dimming-mode entry requirements. An initial enable pulse longer than 5 us is required at EN/PWM to enable the device, and the dimming mode starts after the internal timing sequence. For analog, hybrid, or flexible dimming cases, VREF can require millisecond-level settling; the initial VREF change is approximately 5ms when the target reference is 200 mV.

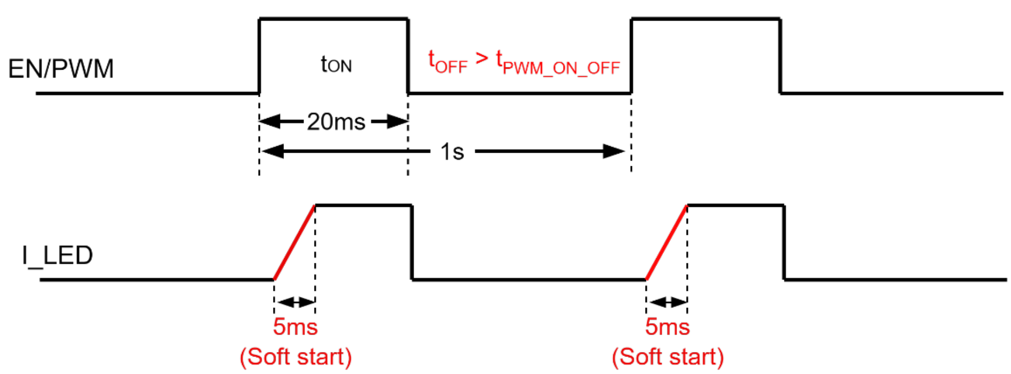

Figure 2-2. TPS922052/3/4/5 LED current delay caused by repeated soft-start during PWM dimming

To avoid LED current delay caused by repeated shutdown and soft-start, a narrow pre-conditioning pulse can be inserted before the normal PWM on pulse. The pre-pulse is not intended to generate useful optical output. Its purpose is to wake up the device, satisfy the startup and dimming-mode selection requirements, and allow the internal reference path to prepare before the main PWM pulse starts.

The recommended sequence is:

- First apply a narrow pulse on EN/PWM;
- Then keep EN/PWM low for a controlled off-time
- Finally apply the normal PWM on pulse after the internal reference has had sufficient time to settle.

Figure 2-3 shows a typical example:

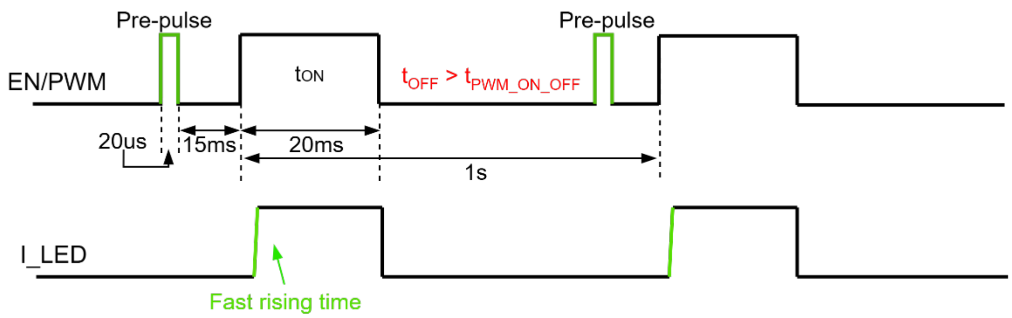

Figure 2-3. EN/PWM pre-pulse timing to eliminate the soft-start delay in strobe operation

2.3 Timing Design Guideline

Table 2-1 summarizes the recommended timing parameters for the pre-pulse method. The following data values are selected according to the following principles:

- For the pre-pulse width, the minimum pulse duration should be longer than the total system delay time to ensure that the driver and LED current path have sufficient time to respond. The maximum pre-pulse width should be limited such that the LED current has not yet fully settled to the regulated output level, preventing the pre-pulse from producing unintended visible light output.
- For the controlled off-time after the pre-pulse, the minimum off-time should be long enough to allow the device to complete soft-start and ensure that the internal reference, bias circuits, and control loops have reached a stable operating condition. The maximum controlled off-time must remain shorter than the minimum PWM input off-time required to disable the device, so that the IC stays enabled and ready for the subsequent main flash pulse.

Table 2-1. Recommended Timing Parameters for the Pre-Pulse Method

Parameter	Recommended Value	Design Purpose	Risk if Violated
Pre-pulse width, t_{pre_pulse}	10us $< t_{pre\_pulse} <$ 150us	Enable the device and satisfy dimming-mode entry logic	Too long: visible flash or unwanted current
Controlled off-time after pre-pulse, t_{OFF}	10ms $< t_{OFF} < t_{PWM\_IN\_OFF}$	Allow internal VREF/soft-start settling while avoiding another shutdown	Too short: current ramps slowly; Too long: device may re-enter shutdown
Main PWM pulse width	20ms	Generate the intended optical output pulse	If applied before VREF settles, LED current is not square-wave-like

2.4 Test Verification and Results

The timing design was validated under the following test conditions: Vin=54V, Vout=30V, I_LED=3A. Two cases were compared: repeated startup without a pre-pulse and operation with a pre-conditioning pulse before the main PWM pulse.

- Without Pre-Pulse

When no pre-pulse is applied, the device repeatedly enters shutdown during long off-times. Each subsequent PWM pulse triggers a full soft-start cycle, resulting in a slow LED current rise time of approximately 5ms. Figure 2-4 shows a gradual current ramp with significant delay before reaching the target amplitude.

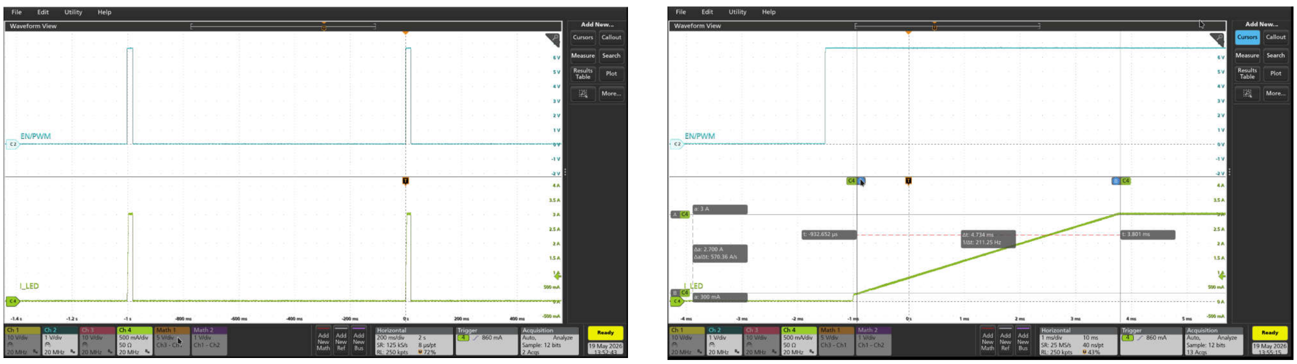

Figure 2-4. LED-Current Startup Response Without Pre-pulse

- With Pre-Pulse

With the narrow pre-pulse inserted, the internal reference and control loops are already settled when the main PWM pulse is applied. Figure 2-5 confirm a drastically reduced rising time of microseconds, achieving near-instantaneous current response.

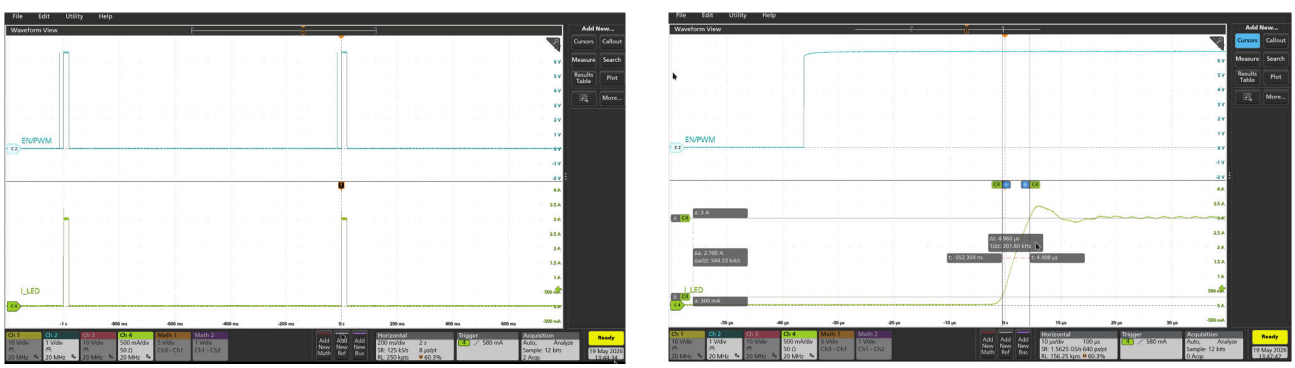

Figure 2-5. LED-Current Startup Response With Pre-pulse

3 Peripheral Circuit Parameter Optimization

This section describes how the external loop-compensation network, output capacitor, and inductor affect the LED-current turn-on transient. The objective is to reduce the rising time while maintaining acceptable overshoot, loop stability, LED current stress, and output-voltage ripple. The simplified buck LED-driver power stage is shown in Figure 3-1 is used as the reference circuit.

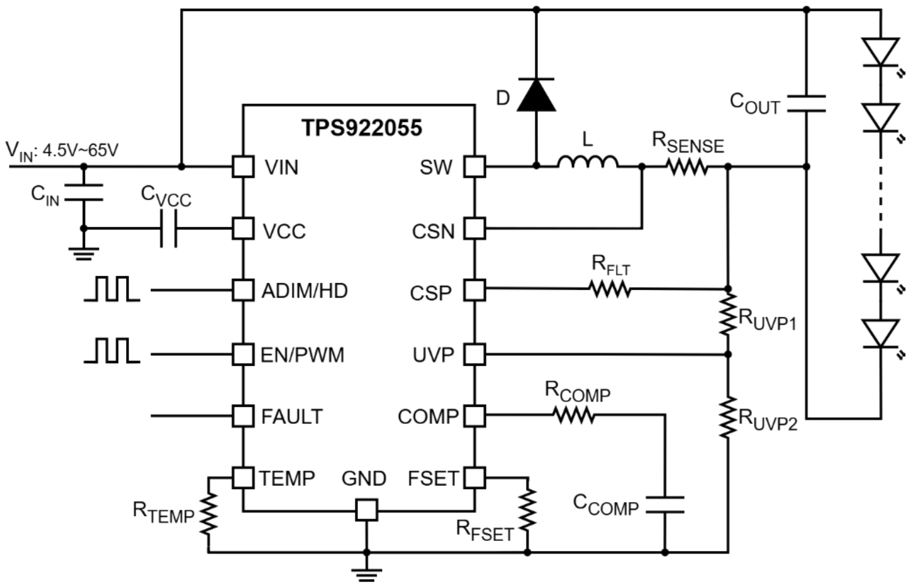

Figure 3-1. Simplified Schematic

3.1 Compensation Network

For a buck LED driver, the compensation network defines the dynamic response of the current regulation loop. A smaller C_{COMP} increases the theoretical loop bandwidth because the dominant compensation pole moves to a higher frequency. When R_{COMP} is used in series with C_{COMP} , the compensation zero is approximately:

$$f_z = \frac{1}{2\pi \times R_{COMP} \times C_{COMP}} \tag{1}$$

Reducing C_{COMP} shifts the dominant compensation pole to a higher frequency and increases the loop gain in the low-to-mid-frequency range. As a result, the current regulation loop can achieve a higher crossover frequency and a faster transient response, provided that sufficient phase margin is maintained. Figure 3-2 and Table 3-1 show the simulation results. During PWM dimming turn-on, this faster response helps the LED current reach its target value more quickly, thereby reducing the LED-current rising time. However, a smaller C_{COMP} may increase the overshoot of LED current. Therefore, C_{COMP} should be selected by balancing dimming response speed, loop stability, peak LED current.

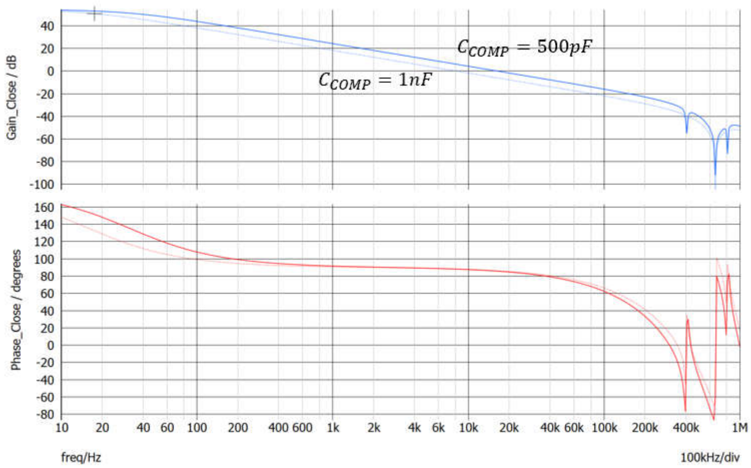

Figure 3-2. Loop Simulation with Different CCOMP

Table 3-1. Effect of COUT on Rising Time and Peak Current

C_{COMP} (pF)	Peak Current (A)	Rising Time (us)
470	3.81	4.21
690	3.61	4.36
910	3.42	4.92
1000	3.29	6.11

3.2 C_{OUT}

Reducing C_{OUT} can also reduce the rising time because less output-node charge must be established during turn-on. However, C_{OUT} is also the main damping and ripple-filtering element at the LED output. As a result, an aggressively small C_{OUT} can increase LED-current ripple, output-voltage ringing, and peak current during the transition. A practical target is to select the smallest C_{OUT} that still meets LED-current ripple, overshoot, acoustic-noise, and EMI requirements across line, load, temperature, and dimming-frequency conditions.

Table 3-2. Effect of C_{OUT} on Rising Time and Peak Current

C_{OUT} (uF)	Peak Current (A)	Rising Time (us)
1	3.73	4.32
2.2	3.42	4.92
3.2	3.38	6.71
4.4	3.29	7.08

4 Summary

For LED fire-strobe applications, the driver must deliver useful optical energy within a short-rated pulse. A narrow EN/PWM pre-conditioning pulse allows the device to wake up and prepare the internal reference and control loop before the main 20-ms optical pulse. Bench data showed rise-time improvement from approximately 5ms without the pre-pulse to approximately 5μs with the pre-pulse. With the timing scheme properly set, C_{COMP} , C_{OUT} , and the inductor value can be optimized to further improve rising time while controlling overshoot, ripple, EMI, and LED stress. The recommended design approach is to optimize timing first, then tune the power-stage components using measured current waveforms and finally find the optimal solution.

5 References

1. Texas Instruments, *TPS922050/1 65V 1A/2A Buck LED Driver with PWM/Analog Dimming*, datasheet.
2. Texas Instruments, *TPS92205x 65V 2A / 4A Buck LED Driver with Inductive Fast Dimming* , datasheet.
3. UL 1638 UL 1638, webpage.

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