Application Note

Average Current Limiter Operation of the LM51770-Q1 for Automotive LED Lighting Applications

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ABSTRACT

The LM51770-Q1 is a four-switch buck-boost controller that supports average current limiting, making it preferred for constant-current LED driver applications. Its wide output voltage range (up to 78V) easily accommodates multi-string LED loads. The regulated constant output current is set through external components, preferred for automotive lighting systems without communication interfaces or MCUs.

This application note demonstrates an automotive headlight LED driver design based on a modified LM51770EVM-HV. The design is based on the 12V automotive system with input voltage range of 9V to 16V and delivers a regulated output of up to 55V at 1A constant current. Key EVM modifications and component selections are provided to guide designers in replicating this configuration. This design can also be applicable to 48V system due to the 80V input voltage capability.

To address the demands of multi-load headlight systems, where low-beam, high-beam, and corner light can be driven simultaneously or switched dynamically, this application note also presents optimizations for output current ripple and load transient performance during LED switching.

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Trademarks

1 Introduction

LED applications demand precise current regulation to prevent LED damage and verify performance. Unlike voltage-driven loads, LEDs cannot self-limit current. Exceeding the rated current can lead to immediate failure or accelerated degradation. The LM51770-Q1 four-switch buck-boost controller addresses this challenge through its integrated average current limit (ILIM) function, which actively regulates output current to a user-defined threshold. This application note provides comprehensive design guidance for implementing the LM51770-Q1 in LED applications, covering:

- Power Stage Design: Component selection and circuit configuration optimized for LED loads
- ILIM Function Configuration: Step-by-step setup procedures to enable the average current limit function
- Control Loop Optimization: Tuning the ILIM loop to achieve precise current regulation and fast transient response during both LED steady-state operation and switching transitions

2 Automotive LED Application Requirements and System Overview

2.1 Application Requirements

Table 2-1 lists the design LED lighting application specifications.

Table 2-1. Application Requirements

V_{IN}	9V-16V
V_{OUT}	• Corner Lights (CL) → 2 LEDs → (Vout = 5.6V-6V) • Low Beam (LB) → 10 LEDs → (Vout = 29V-30V) • High Beam (HB) → 6 LEDs → (Vout = 14V-15V) • CL + LB + HB → 18 LEDs → 53V-54V
V_{OUT_max}	55V
I_{LED}	1A
Steady State LED current Ripple (I_{Steady_Ripple})	5% (200mA)
Switching State LED current Ripple ($I_{Switcing\_Ripple}$)	40% (400mA)
LED max switching time (t_r and t_f)	1ms

2.2 Typical Automotive Headlight System Overview

A typical automotive headlight system consists of an LED driver (LM51770-Q1), LED light module, and BCM (Body Control Module) for the LED switching control signals. Figure 2-1 presents the system block diagram based on the design of this application note.

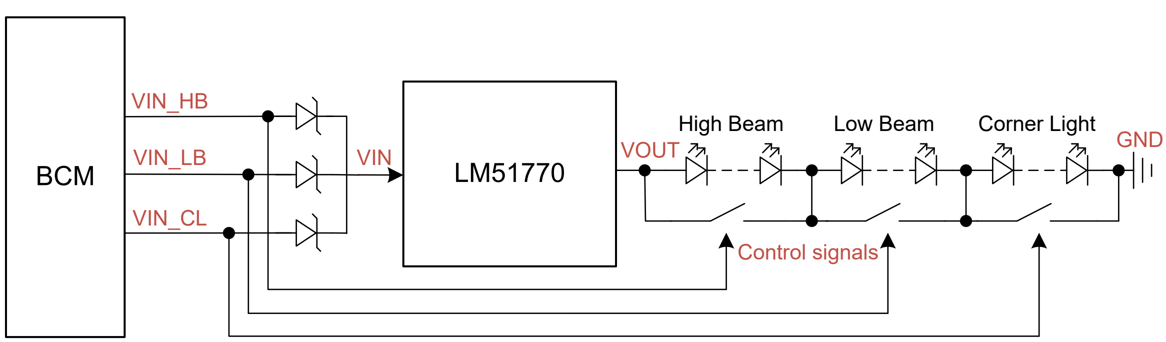

Figure 2-1. Headlight System Block Diagram

The presented design employs an MCU-free architecture in which the LED modules are operated solely as binary (on/off) loads; no dimming, PWM, or animation functions are required. Consequently, the Body-Control

Module (BCM) does not have to generate any communication or control signals for the headlamp assembly. Its only responsibility is to provide the appropriate supply rails for each lighting function.

- Power inputs – The vehicle's 12V system feeds three dedicated lines, labeled in the schematic as VIN_HB, VIN_LB, and VIN_CL. These correspond respectively to the high-beam (HB), low-beam (LB), and corner-light (CL) circuits.
- LED driver topology – A single LM51770-Q1 LED-driver IC is sufficient to power all three illumination channels. The high-beam, low-beam, and corner-light LED modules are connected in series to the constant-current output (V_{OUT}) of the LM51770-Q1.
- Channel isolation – Each LED module is paralleled with a MOSFET that acts as a shunt switch. When the MOSFET is turned on, it bypasses the current flowing through its associated LED string, thereby turning that particular lamp off. Conversely, turning the MOSFET off allows the LM51770-Q1 to source the programmed constant current through the LED module, illuminating the lamp.

2.3 LED Load Configuration and Switching Architecture

As previously mentioned, the LED loads are connected in series. The high beam string typically contains four to six LEDs, the low beam string four to eight LEDs, and the corner light string two to three LEDs. With the typical forward voltage per LED, the total stack voltage reaches up to 55V when all strings are active, which is a big challenge for the LED driver's output voltage range, and LM51770-Q1 is designed for.

For the high beam or low beam, the LED voltage drop is also large, even exceeding 20V. This not only introduces significant current inrush during switching, the optimization of which is elaborated in LED Switching and Buck-boost region, but also imposes a considerable challenge on the driving of the shunt FETs if only NMOS are used for the LED switching.

Generally, for low-side shunt FET driving, we use NMOS transistors; for high-side shunt FET driving, PMOS transistors are adopted to reduce the driving voltage requirement. For the low-beam shunt FET which sits in between, the turn-off logic can be implemented with either NMOS or PMOS. However, the turn-on logic depends heavily on the conduction state of the low-side corner light. Therefore, an NMOS and a PMOS are connected in parallel here to achieve complementary conduction, which is explained in detail in subsequent sections. The LED load structure is shown in Figure 2-2

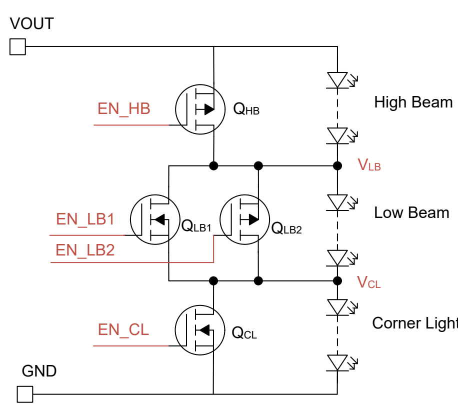

Figure 2-2. LED Load Structure

Figure 2-3 shows the high-beam driving circuit. When the high beam needs to be turned on, the power signal VIN_HB from the BCM goes high at 12V, the driving voltage EN_HB equals VOUT, and the shunt FET Q_{HB} is turned off. When the high beam needs to be turned off, VIN_HB goes low, EN_HB also goes low, Q_{HB} conducts, and the current is bypassed through the shunt FET.

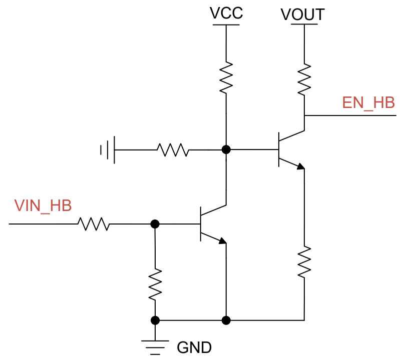

Figure 2-3. High Beam Driving Circuit

Figure 2-4 shows the corner-light driving circuit. When the corner light needs to be turned on, the power signal VIN_CL from the BCM goes high at 12V, the driving voltage EN_CL is low, and the shunt FET Q_{CL} is turned off. When the corner light needs to be turned off, VIN_LB goes low, EN_CL equals VCC, Q_{CL} conducts, and the current is bypassed through the shunt FET.

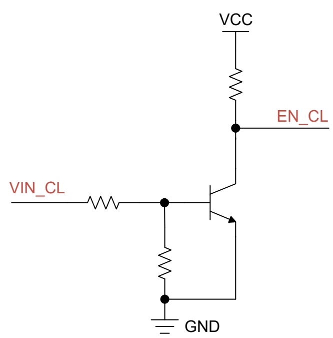

Figure 2-4. Corner Light Driving Circuit

Figure 2-5 shows the low-beam driving circuit. The NMOS shunt FET driving circuit for the low beam is identical to that of the corner light, generating the driving voltage EN_LB1. The PMOS shunt FET driving circuit is identical to that of the high beam, generating the driving voltage EN_LB2. When the low beam needs to be turned on, the power signal VIN_LB from the BCM goes high at 12 V. At this point, the NMOS driving voltage EN_LB1 is low and the PMOS driving voltage EN_LB2 is high at VOUT, so both shunt FETs are turned off.

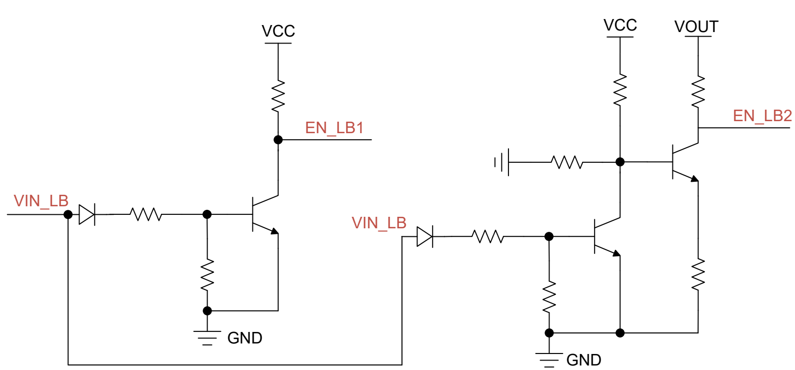

Figure 2-5. Low Beam Driving Circuit

When the low beam needs to be turned off, VIN_LB goes low, EN_LB1 goes to VCC, and EN_LB2 goes low. If the corner light is off at this time and V_{CL} is low, the NMOS conducts while the PMOS remains off, and the current bypass path is shown by the green line in Figure 2-6. If the corner light is on and V_{CL} is high, the PMOS conducts while the NMOS remains off, and the current bypass path is shown by the red line in Figure 2-6. Thus, the parallel NMOS-PMOS arrangement ensures complementary conduction throughout the entire period when the low beam is required to be off, so that the current can always be bypassed through the shunt FET.

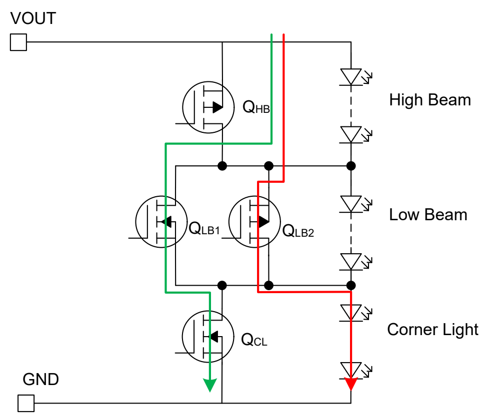

Figure 2-6. Low Beam Bypass Path

3 LM51770-Q1 Pin Configuration for ILIM Function

3.1 LM51770-Q1 Pin Description

For this automotive headlight application, specific pin configurations for LM51770-Q1 are required to achieve constant current regulation below the maximum output voltage, maintain low output current ripple, and minimize current overshoot during dynamic switching among low-beam, high-beam, and corner lamp loads. Table 3-1 lists the pins that must be considered in this design. The following subsections provide detailed descriptions of the most critical pins.

Table 3-1. LM51770-Q1 Pin Description

Pin Name	Pin Function	Description
FB	Voltage feedback input	Set maximum output voltage to 55V via resistor divider.
EN/UVLO	Device enable and input undervoltage lockout	Set UVLO value to monitor VIN for undervoltage protection
COMP	Error amplifier output	Connect RC compensation network to optimize current loop stability and transient response.
ISNSP/ISNSN	Differential average current sense inputs	Place current sense resistor (RSNS) on VOUT side to set the output constant current.
IMONOUT	Current monitor and average current loop compensation	Add RC compensation network at the pin to provide the compensation for the average current loop.
SYNC	Synchronization clock and current limit direction	For unidirectional LED loads, SYNC pin needs to be connected to VCC for forward current limit.
CFG	Device function configuration	Enable positive average current limit for LED operation.
SLOPE	Slope compensation programming	Set slope compensation to prevent subharmonic oscillation in boost mode.

3.2 Pin Configuration for ILIM Operation

The constant output current regulation of the LED driver is implemented via the integrated average current limiter of the LM51770-Q1. The pins of CFG, SYNC, ISNSP/ISNSN, and IMONOUT are associated with this function. Proper configuration of these pins ensures accurate constant current output, stable loop operation, and suppressed current overshoot during LED load switching. Figure 3-1 shows these pins in the application.

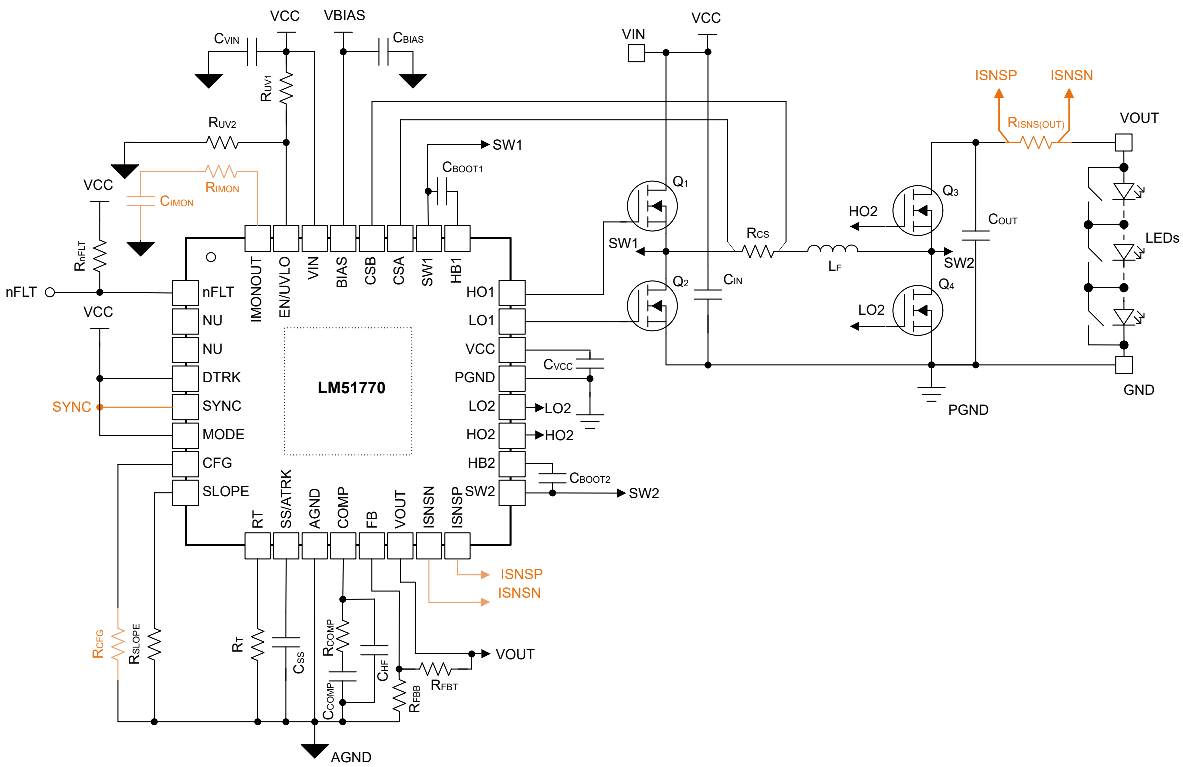

Figure 3-1. Pin Configuration for CC Operation

1. CFG

The LM51770-Q1's CFG pin is programmed with a single precision resistor that is sampled and latched during the device's power-up sequence; the resistor value selects the operating mode (DRSS behavior, SCP-Hiccup activation, PSM entry threshold, and current-limit setting) as defined in Section 8.3.16 of the LM51770-Q1 datasheet. For the headlamp application we use Setting #5 (R_{CFG}=22.7kΩ), which activates the average-current regulation loop and thereby provides a stable constant-current drive for the high-beam, low-beam, and corner-light LED modules.

2. SYNC

The SYNC pin determines the direction of the LM51770-Q1's current-limit function; its state is sampled and latched at power-up. For this unidirectional LED-driver application the SYNC pin must be pulled high during startup, which configures the current-limit circuitry to operate in the forward-direction required for the high-beam, low-beam, and corner-light LED strings.

3. ISNSP/ISNSN

The ISNSP and ISNSN pins form the differential input of the LM51770-Q1's internal average current sense amplifier; they set the target output current by sensing the voltage across an external sense resistor (R_{ISNS}) placed in series with the LED load on the output side. The differential voltage generated by R_{ISNS} is applied to ISNSP/ISNSN, and the resistor value directly determines the regulated constant-current magnitude—selecting R_{ISNS} according to the desired LED current establishes the driver's set-point. The value of R_{ISNS} is calculated by:

$$R_{ISNS} = \frac{\Delta V(ISNS)}{I_{OUT(CC)}} \tag{1}$$

Where, $\Delta V_{(ISNS)}$ is current sense offset and threshold voltage, 50mV in datasheet, $I_{OUT(CC)}$ is the target constant output current, set to 1A in this design

4. IMONOUT

The IMONOUT pin is the compensation node for the LM51770-Q1's average-current loop and can also output an analog current monitor signal. In constant-current mode connect a series RC network (R_{COMP} and C_{COMP}) from IMONOUT to AGND; the resistor sets the loop bandwidth and the capacitor provides the necessary phase-lead to achieve adequate phase margin, ensuring stability and minimizing overshoot/undershoot across the full input-voltage and load range. Detailed component values are given in the loop-compensation section.

Other Important Pin Configurations:

5. FB

The FB pin programs the maximum output voltage through an external resistor divider, set to 55V for this headlight application. During constant-current LED operation, the voltage loop provides secondary overvoltage protection by clamping the output voltage at 55V if the LED load opens, preventing converter and downstream circuit damage. The voltage loop also facilitates seamless transitions between current and voltage regulation modes during load variations.

The maximum output voltage $V_{OUT(max)}$ is established by a resistive divider network consisting of R_{FBT} (connected between V_{OUT} and FB) and R_{FBB} (connected between FB and AGND). The converter regulates the FB pin to an internal reference voltage V_{FB} of 1.0V (typical). The resistor values are calculated using:

$$V_{OUT(max)} = V_{FB} \times \frac{R_{FBT} + R_{FBB}}{R_{FBB}} \tag{2}$$

R_{FBT} is set to 100kΩ and R_{FBB} is set to 1.87kΩ in this application.

6. EN/UVLO

The EN/UVLO pin provides dual functionality: device enable and undervoltage lockout (UVLO) protection. The internal logic and reference circuits activate once the pin voltage exceeds the enable threshold $V_{T+(EN)}$. The integrated UVLO circuit continuously monitors the input voltage; when it falls below the programmed threshold (8V for this application), the converter automatically shuts down to prevent damage to the power stage and LED load from low-voltage operation. The 8V UVLO threshold is established using a resistive divider network: R_{UV1} = 15.8kΩ (connected between V_{IN} and EN/UVLO) and R_{UV2} = 2.94kΩ (connected between EN/UVLO and AGND). The resistor values can be determined using the LM51770-Q1 Calculation Tool or by referencing Section 8.3.5 (Enable and Undervoltage Lockout) in the device LM51770-Q1 datasheet.

4 Automotive LED Lighting Design Application

4.1 Power Stage Design

For this application, LM51770EVM-HV the evaluation board is used for the design. Based on the design specifications, the power stage components were recalculated and modified on the board as shown in Figure 4-1. The LM51770-Q1 Buck-Boost Quickstart Calculator Tool can be used to select the required external components for this application setup, and the detailed formulation for each power stage component is covered thoroughly in the LM51770-Q1 datasheet. The updated power stage components are listed in Table 4-1.

1. Inductor Value: Selection must be balanced for both buck and boost regions of the converter. It should target stability (higher right half plane zero frequency in boost region) and lower inductor current ripple (around 33% duty cycle in boost and buck region).
2. Peak Current Sense Resistor Value: Targeting a peak current limit between 10-15% higher than the peak inductor current value shows better results during buck-boost region operation and improves switch node jitter while enhancing loop stability.
3. Output Capacitance Value: The recommended output capacitance value from the calculator is a good starting point, but optimization must be performed in the lab.
4. Output Capacitor Type: Ceramic capacitors are recommended because they have low ESR and faster response time. In contrast, electrolytic capacitors have higher ESR and slower response time, which do not help during LED steady-state and switching operation, resulting in higher output current ripple.
5. Placement of Output Capacitors: All output capacitors must be placed before the ILIM sense resistor; otherwise, the discharge current of the capacitors will not be controlled by the ILIM loop.
6. Slope Compensation: The optimal value is very important for the stability of the control loop, especially for higher boost ratios (for example, Vin = 9V and Vout = 55V) and duty cycles (D>50%).

Regarding the compensation selection for the voltage and ILIM loop are discussed in the subsequent section.

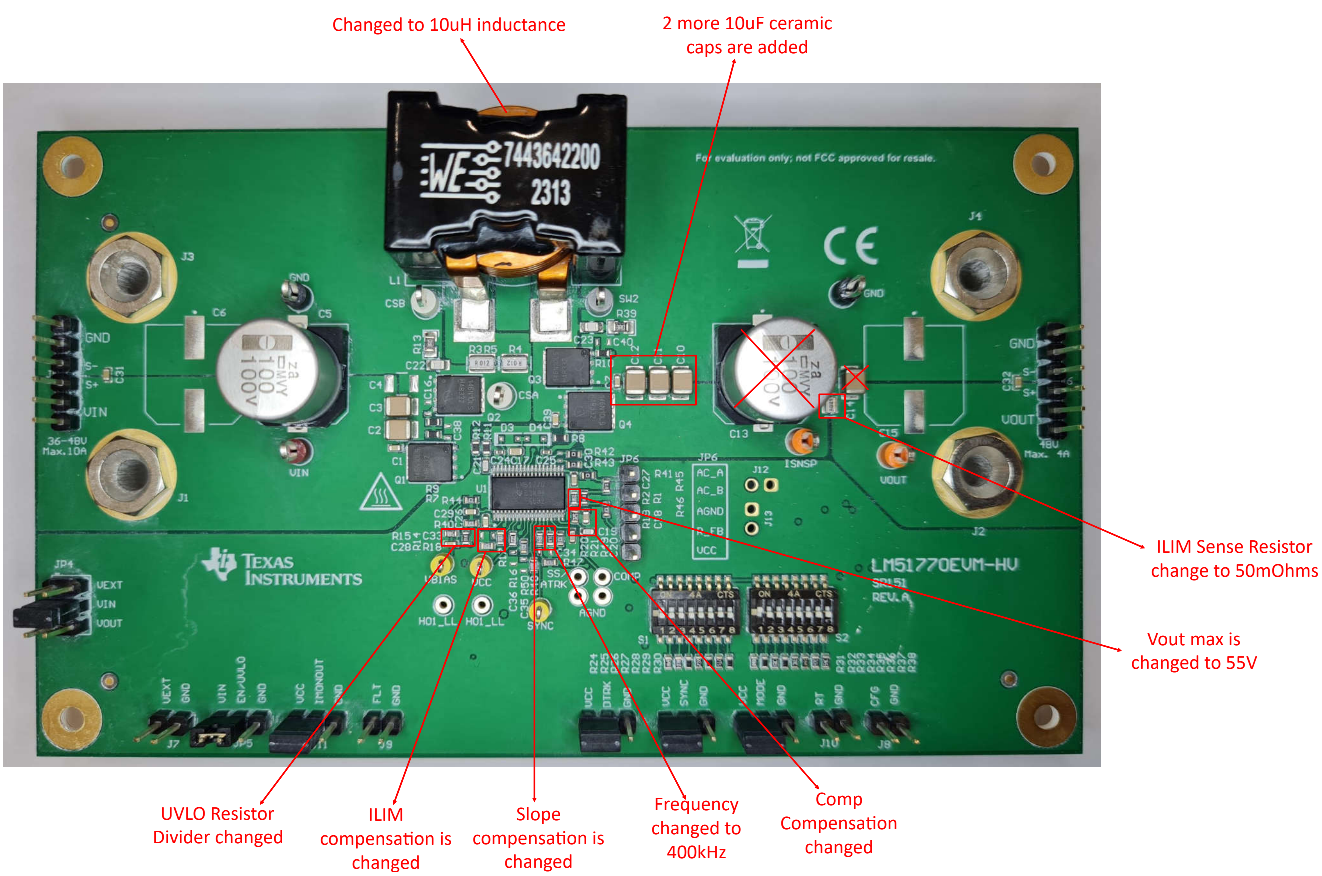

Figure 4-1. Modifications to LM51770 EVM

Table 4-1. List of Component Change

Function	Specification	Component Values
UVLO	8V	R14 =15.8k, R15 = 2.94k
Inductor		L1 = 10uH
Switching Freq	400kHz	R21 = 75k
ILIM Sensing	1A	R6 = 50m
$Vout_{max}$	55V	R2 = 1.87k
Slope Compensation	Duty $cycle_{max}$ = 84%	R20 = 124k
Output Capacitance	50uF (only ceramic caps)	C10 to C14 = 10uF

4.2 Control Loop Architecture

The LM51770 integrates three inherent control loops —one voltage loop and two current control loops (peak current limit and average current limit) — to regulate the output voltage and current to the desired set points. The interaction between these loops is illustrated in Figure 4-2.

1. Voltage Control Loop: The voltage control loop continuously monitors the output voltage and compares it against an internal reference. The resulting error signal drives the error amplifier, which adjusts the COMP pin voltage to modulate the PWM duty cycle until the output voltage converges to the desired set point.
2. Peak Current Limit Loop: The peak current limit loop measures the instantaneous inductor current and compares it against the COMP voltage generated by the voltage loop error amplifier. When the load current increases and the peak inductor current reaches the programmed maximum threshold — set by the current sense resistor R_{CS} — the loop regulates the peak inductor current to that maximum value. Under these conditions, the voltage loop responds by raising the COMP voltage, which in turn reduces the PWM duty cycle and reduce the output voltage. While the peak current limit loop can be utilized for LED current control in certain applications, its inherent limitations in accuracy make it less suitable for precision LED drive applications where tight current regulation is required.The transfer function and control equations for the peak current mode control is well covered in the LM51770-Q1 datasheet and this Switch-mode power converter compensation made easy. Whereas, the important equations for the poles and zero for the type II compensation for the voltage control loop is given by the equation 3-4.

   $$F_{V\_pole,\ origin} = 0 \tag{3}$$

   Frequency for the Pole on origin:Frequency for the Zero:

   $$F_{V\_zero} = \frac{1}{2 \times \pi \times R_{comp} \times C_{comp}} \tag{4}$$

   Frequncy for the high frequency pole:

   $$F_{V\_pole,\ HF} = \frac{1}{2 \times \pi \times R_{comp} \times C_{hf,\,comp}} \tag{5}$$

3. Average Current Control Loop: For applications demanding precise output current regulation such as LED applications, the LM51770's average current control loop offers a more appropriate solution. This loop senses the DC output current directly via the current sense resistor R_{ISNS}, placed after the output filter. The sensed average current value is used to directly control the COMP voltage to regulate the inductor current, which modulates the PWM duty cycle to tightly regulate the output current, as illustrated in Figure 4-2 . This closed-loop approach makes the average current control loop particularly well-suited for high-accuracy LED drive and constant-current applications. Whereas, the small-signal stability of the ILIM loop is governed by the current limit loop gain, denoted as $T_{ilim}(s)$ as given by the equation 6.

   $$T_{ilim}(s) = G_{vc,\ isns}(s) \times R_{sns,\ ilim} \times G_{ilim}(s) \tag{6}$$

   Where:

   A. $\boldsymbol{R_{sns,\ ilim}}$ **:**

   Where:

is the ILIM current sense resistor (labeled by R_6 in the EVM)

B. Control-to-Sense Plant Transfer Function: $G_{\mathrm{vc,\ isns}}(s)$

The plant component represents the relationship between the control signal (Duty Cycle) and the resulting voltage across the current sense resistor. It incorporates the modulator dynamics and the power stage inductor current response.

$$G_{vc,\ isns}\left(s\right) = \frac{F_m\left(s\right) \times G_{d,\ i_S}\left(s\right)}{1 + F_m\left(s\right) \times K_{CS} \times H_e\left(s\right) \times G_{d,\ i_L}\left(s\right)} \tag{7}$$

Where:

- $$T_{\mathrm{PK}}\left(s\right) = F_m\left(s\right) \times F_{CS} \times H_e\left(s\right) \times G_{d,\ i_L}\left(s\right) \tag{8}$$

  is internal peak-current sensing gain in (V/A).
- $G_{\mathrm{d,i_L}}(s) = \frac{\hat{i}_L(s)}{\hat{d}(s)}$ is the duty cycle to inductor current transfer function (9)
- $$G_{\mathrm{d,i_S}}(s) = \frac{\hat{i}_{SNS}(s)}{\hat{d}(s)} \tag{10}$$

  is the duty cycle to average current sense transfer function
- Internal peak-current sensing gain (K_{CS}): convertes the small signal inductor current into the internal peak-current sense voltage.

  $$K_{CS} = \frac{\hat{v}_{CSA}}{\hat{i}_L} \tag{11}$$
- ***H*** **e*(s)*** is sampling correction**:** Represents the sampled-data effect of constant frequency peak current mode control. The peak-current comparator samples and terminates the switching cycle once per switching period, so the inner current loop is not purely continuous-time.

  $$H_e\left(s\right) = 1 - \frac{s}{2f_S} + \frac{s^2}{(\pi f_S)^2} \tag{12}$$
- ***F**m**(s)*** is modulator gain**:** The gain of the PWM modulator, which relates the control voltage to the duty cycle *D*. For a Buck-Boost converter, this is approximately:

  $$F_m = \frac{1}{T_S \times (S_n + S_e)} = \frac{f_S}{S_n + S_e} \tag{13}$$

  $$-S_n \tag{14}$$

  is the natural sensed-current ramp slope in V/s

  $-S_e$ is the slope-compensation ramp in V/s (15)

  $-F_S$ is the switching frequency. (16)

C. Current Limit Compensator: $G_{\mathrm{ilim}}(s)$

The compensation network $G_{ilim}(s)$ is a high-order compensator designed to provide sufficient phase margin at the current loop crossover frequency and to reject high-frequency noise from the current sensing path. Based on the implemented control architecture, the transfer function is defined as:

$$G_{ilim}\left(s\right) = G_{m,\ ilim} * \frac{1 + s\left(R_{c,\ ilim}\ C_{c,ilim}\right)}{sC_{c,\ ilim} \times \left(1 + sR_{c,\ ilim}\ C_{hf,\ ilim}\right)} \tag{17}$$

Where:

- $$G_{m,\ ilim} \tag{18}$$
  is the DC gain of the ILIM current error amplifier.
- $R_{c,\ ilim}$ is the resistor in the compensation network, determines the location of the zero and HF pole (labeled by R_{17} in the EVM) (19)
- $$C_{c,\ ilim} \tag{20}$$
  is the capacitor in the compensation network, determines the integration strength and zero location (labeled by C_{18} in the EVM).
- $$C_{hf,\ ilim} \tag{21}$$
  is the capacitor in the compensation network, creates the high-frequency roll-off pole (labeled by C_{33} in the EVM).

The equations for the poles and zero for the type II compensation for the average current control loop is given by the equation 12-14.

$$F_{ILIM\_pole,\ origin} = 0 \tag{22}$$

Frequency for the Pole on origin:

Frequency for the Zero:Frequency for the high frequency pole:

$$F_{ILIM\_zero} = \frac{1}{2 \times \pi \times R_{c,\ ilim} \times C_{c,\ ilim}} \tag{23}$$

$$F_{ILIM\_pole,\ HF} = \frac{1}{2 \times \pi \times R_{c,\ ilim} \times C_{hf,\ ilim}} \tag{24}$$

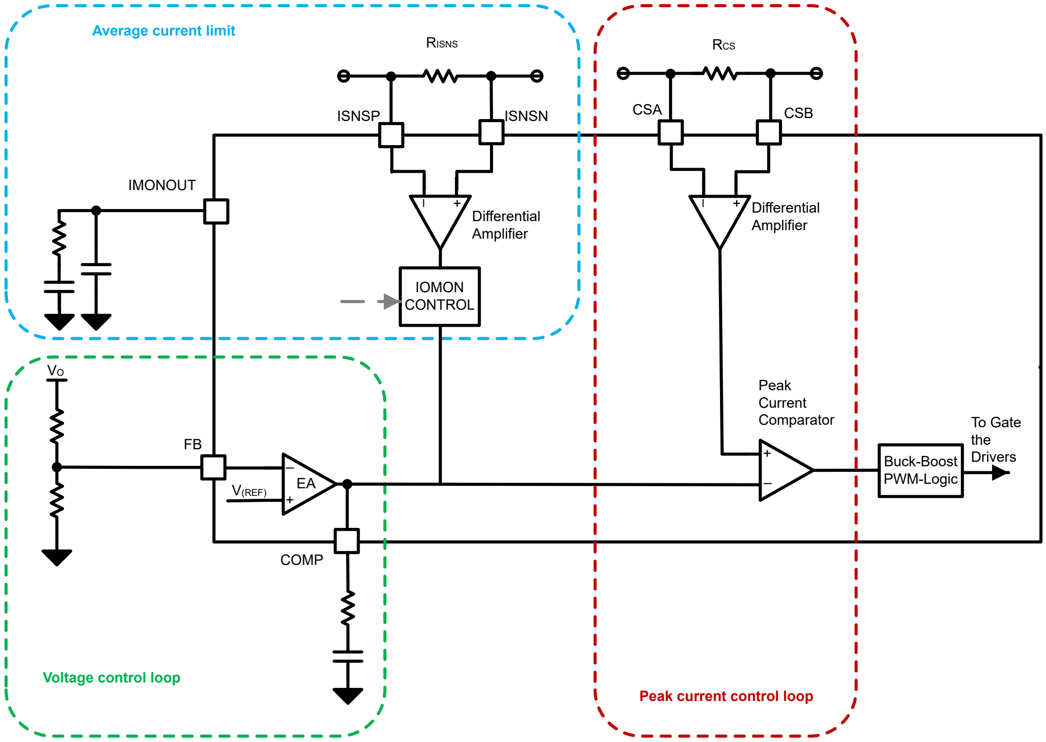

Figure 4-2. Control Loops for LM51770 Device

5 ILIM Loop Optimization and Measurement Results

ILIM Loop Optimization

As explained in the previous section, the ILIM loop operates as a supervisory loop that sits above the voltage loop. It controls the inductor current by directly overriding the COMP voltage. Consequently, a strong voltage loop compensation can adversely interfere with the ILIM loop operation, degrading its ability to regulate current effectively. To mitigate this interaction, it is recommended that the ILIM loop bandwidth be designed to be 3 to 5 times higher than the voltage loop bandwidth. Alternatively, a sufficiently weak voltage loop compensation can also yield acceptable performance.

To validate this recommendation, a comparative test was conducted using two compensation configurations — strong and weak voltage loop compensation — while keeping the ILIM loop compensation identical in both cases.

5.1 Strong Voltage Loop Compensation

The strong voltage loop compensation bode plots are illustrated in Figure 5-1, and the corresponding component values for the configuration are listed in Table 5-1. The measured results demonstrate a significant higher output current ripple in steady-state, as shown in Figure 5-2. The strong COMP pin compensation results in a steady-state output current ripple of 394mA, indicating substantial interference with the ILIM loop regulation.

Table 5-1. Compensation Network Values

Function	Components	Value	Bandwidth
COMP Compensation	R_{comp} (R_{19})	25k	• Vout = 7V, BW = 7.3kHz • Vout = 21V, BW = 4.2kHz • Vout = 35V, BW = 2.6kHz • Vout = 56V, BW = 1.7kHz
	C_{comp} (C_{18})	12nF	
	$C_{hf,comp}$ (C_{19})	100pF	
ILIM Compensation	$R_{c,ilim}$ (R_{17})	143k	• Vout = 7V, BW = 5kHz • Vout = 21V, BW = 1kHz • Vout = 35V, BW = 0.5kHz • Vout = 56V, BW = 0.25kHz
	$C_{c,ilim}$ (R_{18} now C_{18})	26n	
	$C_{hf,ilim}$ (C_{33})	50pF	

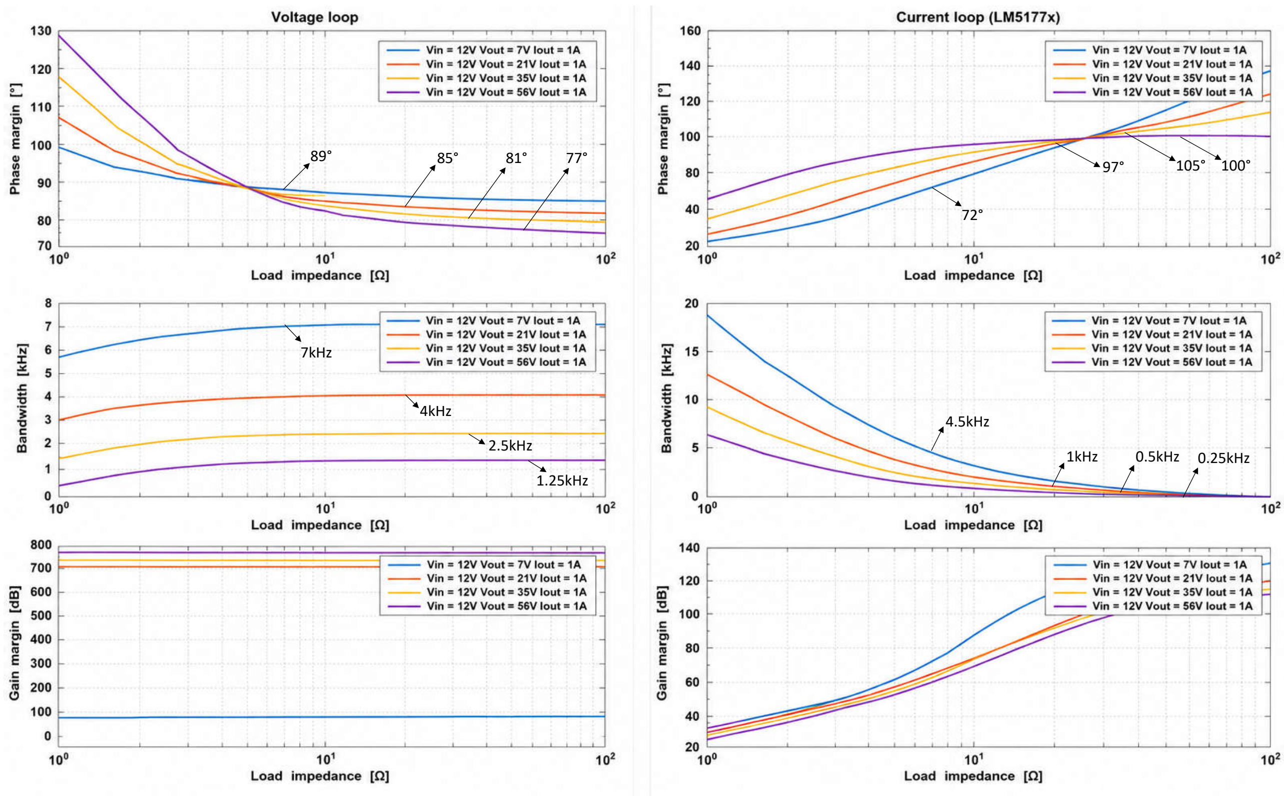

Figure 5-1. Bode Results for Strong Voltage Loop Compensation

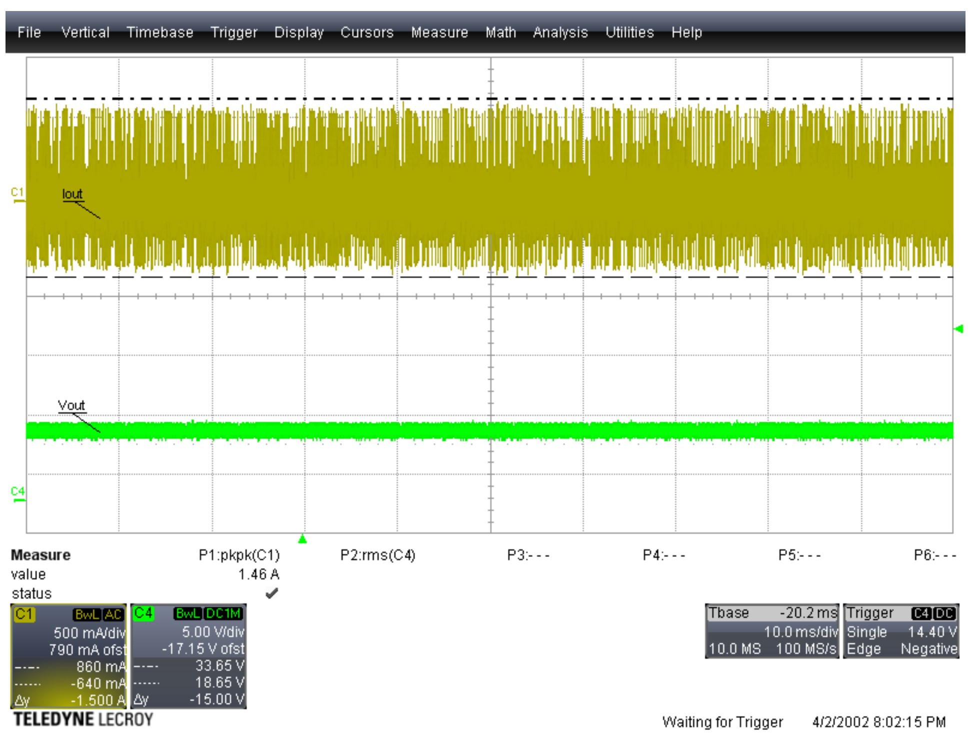

Figure 5-2. Results with Strong COMP Pin compensation (Vin = 12V and 2 LEDs)

5.2 Weak Voltage Loop Compensation

The weak voltage loop compensation bode plot is illustrated in Figure 5-3, and the corresponding component values for the configuration is summarized in Table 5-2. In contrast to results shown in Figure 5-2, Figure 5-4 shows that reducing the COMP pin compensation to a weak configuration reduces the steady-state output current ripple to only 31.8 mA, a reduction of more than 90%. These results clearly confirm that minimizing the voltage loop compensation strength is critical to achieving ILIM loop performance.

Table 5-2. Compensation Network Values

Function	Components	Value	Bandwidth
COMP Compensation	R_{comp} (R_{19})	143	• Vout = 7V, BW = 1.46kHz • Vout = 21V, BW = 1.15kHz • Vout = 35V, BW = 0.9kHz • Vout = 56V, BW = 0.7kHz
	C_{comp} (C_{18})	12nF	
	$C_{hf,comp}$ (C_{19})	100pF	
ILIM Compensation	$R_{c,ilim}$ (R_{17})	143k	• Vout = 7V, BW = 5kHz • Vout = 21V, BW = 1kHz • Vout = 35V, BW = 0.5kHz • Vout = 56V, BW = 0.25kHz
	$C_{c,ilim}$ (R_{18} now C_{18})	26n	
	$C_{hf,ilim}$ (C_{33})	50pF	

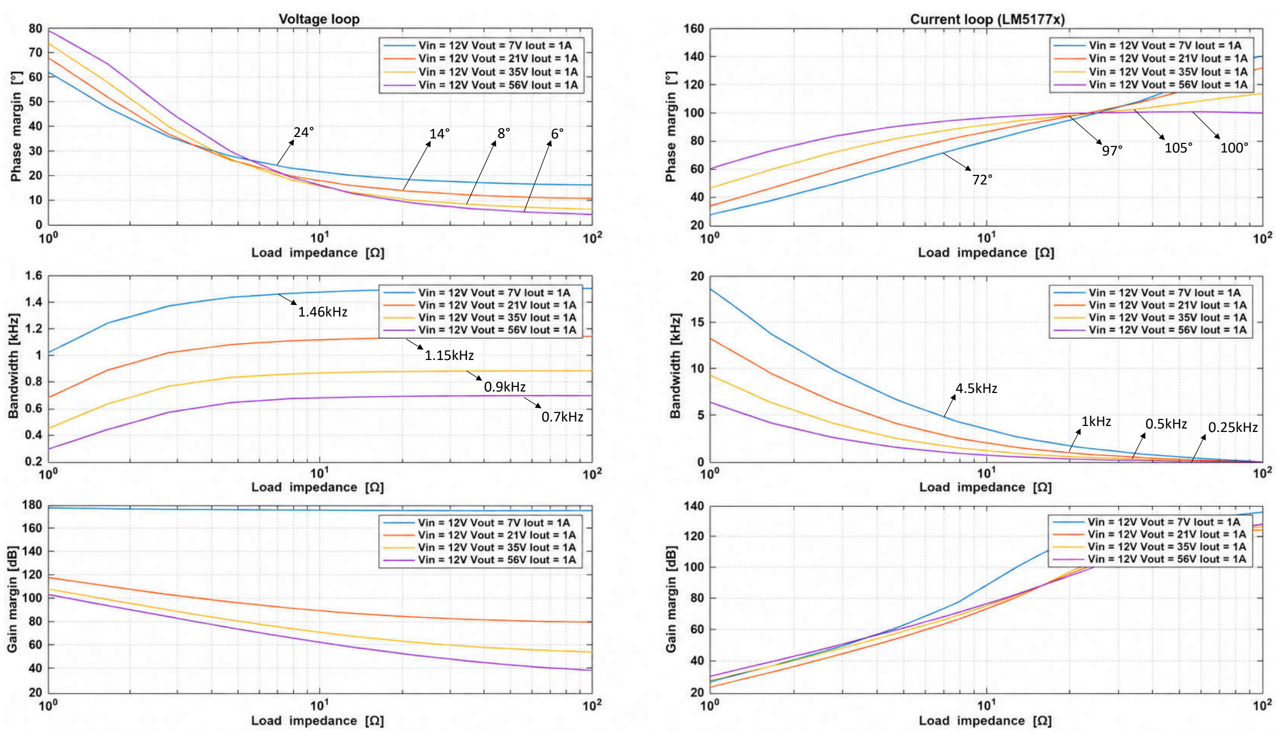

Figure 5-3. Bode Plot Results for Weak Voltage Loop Compensation

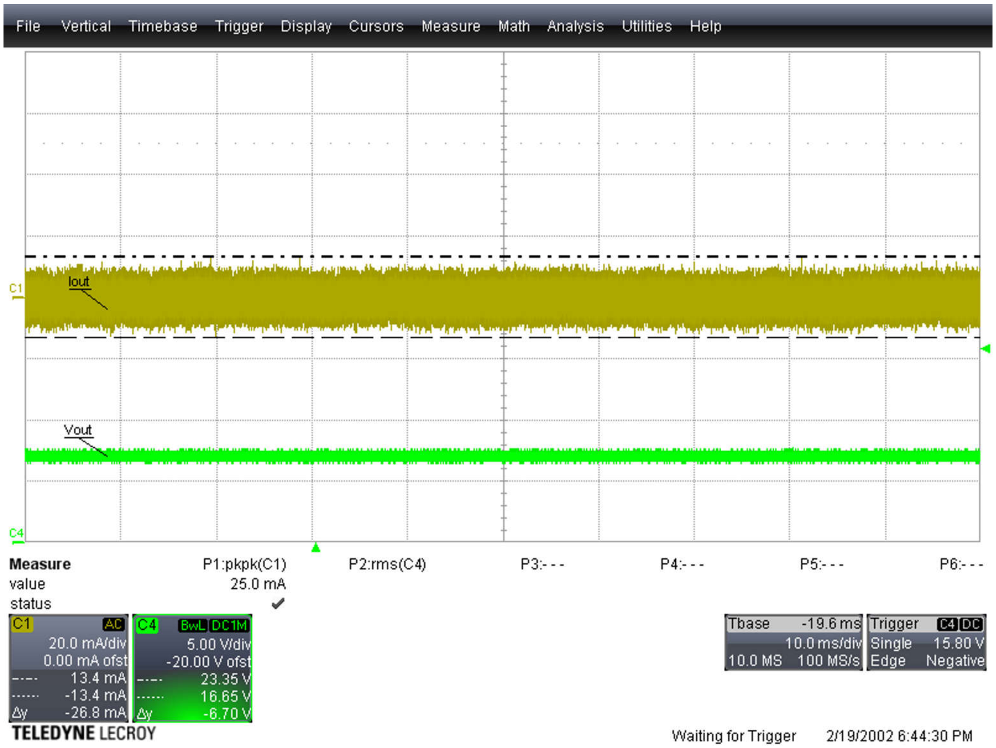

Figure 5-4. Results with Weak COMP Pin Compensation (Vin = 12V and 2 LEDs)

5.3 LED Switching and Buck-Boost Region

As known from the LED application, the output voltage of the converter is determined by the number of LEDs connected at the output. When LEDs are switched from a higher to a lower number at the converter output, an output current ripple is generated, which must be kept within 40% of the maximum output current. This ripple current is primarily dependent on the output capacitance — the higher the output capacitance and the higher the voltage to which it is charged, the greater the output current ripple will be during capacitor discharge.

In addition to this, when the LED operates in its steady state during the buck-boost region of the LM51770-Q1 device, a high current ripple can also be observed. This is because the device can become slightly unstable in the buck-boost region, losing control over the loop, which results in higher switch node jitter and consequently leads to a higher output current ripple.

To optimize the output current ripple during both LED switching and buck-boost region operation, following techniques can be applied.

1. The amplitude of the current ripple can be minimized by tuning the ILIM loop compensation; however, compensating the loop across such a wide output voltage range (6V to 54V) proves to be very challenging.
2. Increasing the peak current sense resistor can help reduce jitter and improve loop regulation, though its value should be selected such that the peak current limit remains 10% to 15% higher than the peak inductor current.
3. Adding a small series damping resistor between the converter output and the LEDs is an effective way to reduce the amplitude of the current ripple during both switching and steady-state operation. The high-level schematic of the circuit incorporating the damping resistor is illustrated in Figure 5-5.

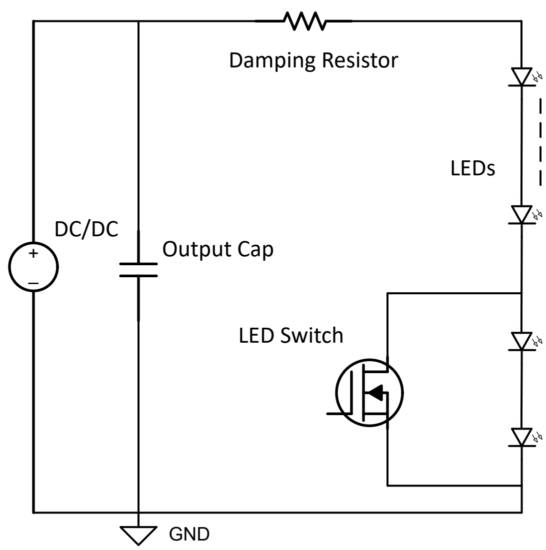

Figure 5-5. Schematic Overview of LED Application with Damping Resistor

Figure 5-6 presents the results for LED operation in the buck-boost region without the series damping resistor, where both the input and output voltage are equal to 12V and the output current is 1A. The results indicate that the current ripple is 129mA, which exceeds the 5% requirement. A subsequent test was conducted with a series damping resistor of 1.5 ohms, and the results shown in Figure 5-7 demonstrate that the addition of the damping resistor significantly reduces the current ripple to 49.4mA.

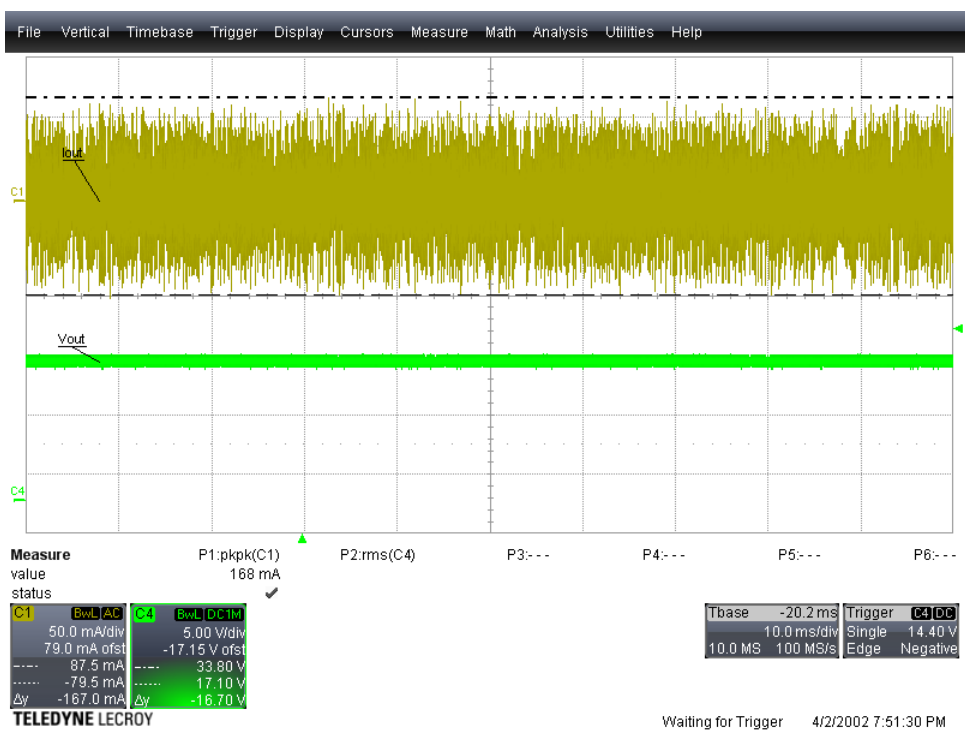

Figure 5-6. Results Without Damping Resistor (Vin = 12V, Vout = 12V, and 4 LEDs)

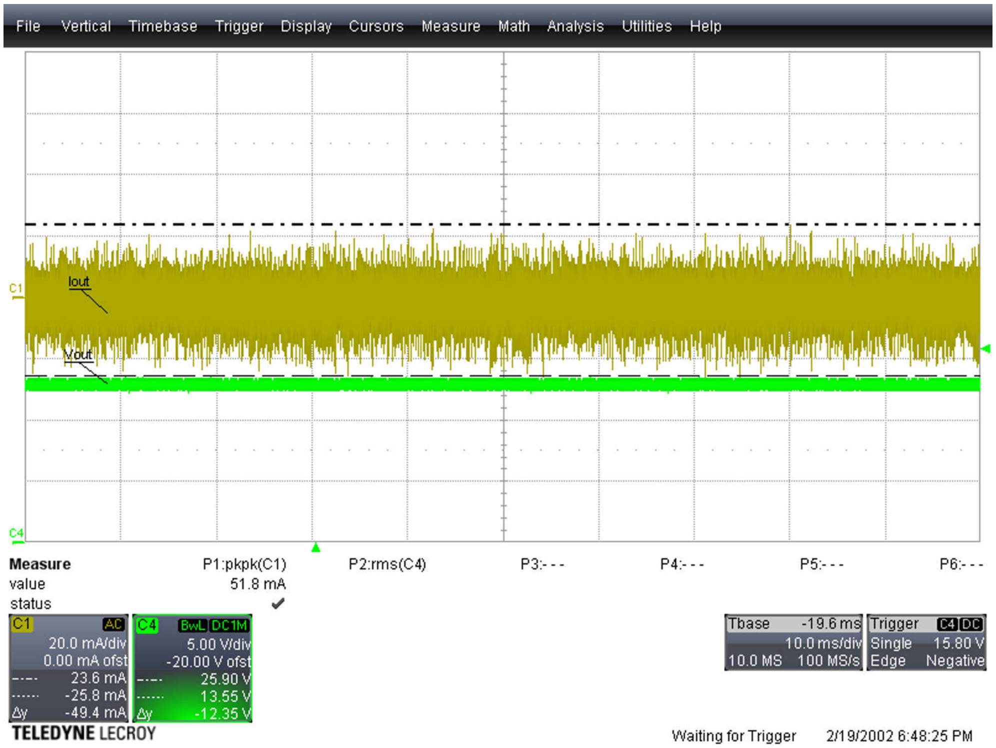

Figure 5-7. Results With Damping Resistor (Vin = 12V, Vout = 12V, and 4 LEDs)

Similarly, the results for LED switching (from 2 LEDs to 10 LEDs) without a damping resistor are presented in Figure 5-8, which show that the output current ripple reaches 420mA, exceeding the required specification. In contrast, Figure 5-9 illustrates the results obtained with the addition of a damping resistor, demonstrating a significant reduction in the output current ripple to 230mA, which falls within the required specifications.

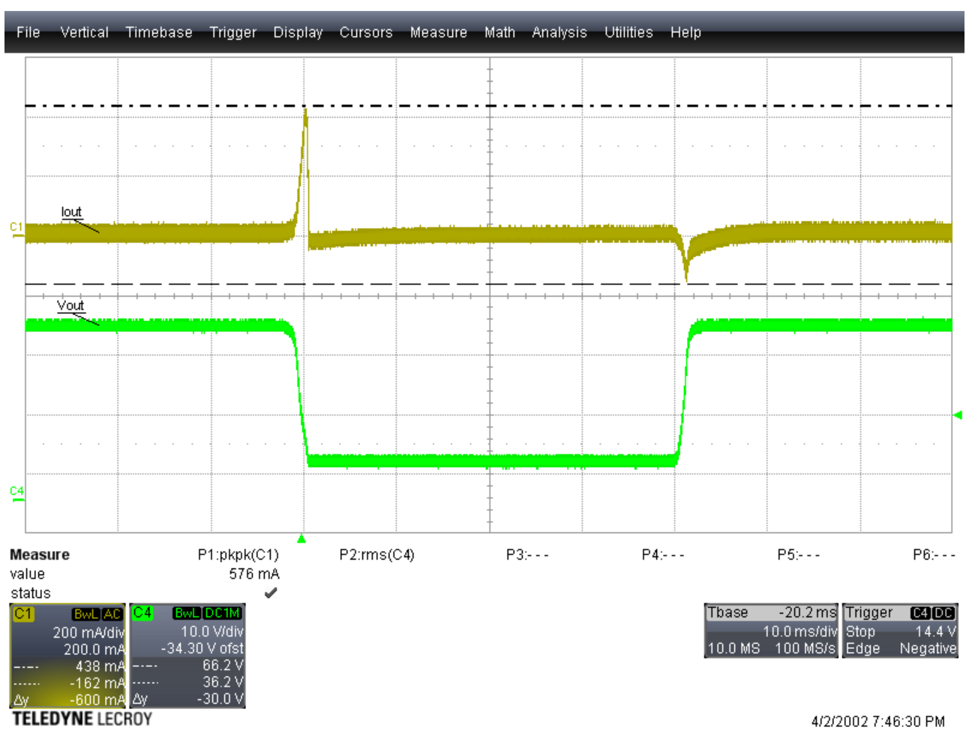

Figure 5-8. Results Without Damping Resistor and Switching Between 2 LEDs to 10 LEDs (Vin = 12V)

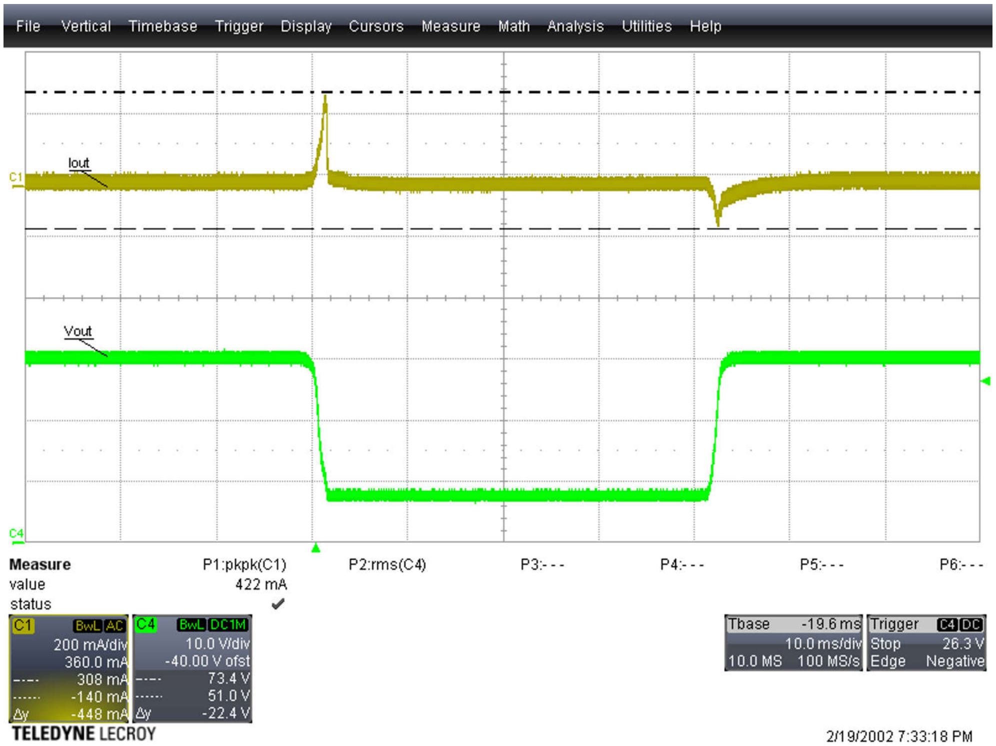

Figure 5-9. Results with Damping Resistor and Switching Between 2 LEDs to 10 LEDs (Vin = 12V)

6 Detailed Results

6.1 LED Steady State Operation Results

To evaluate the device performance at steady state LED operation, the test were conducted for different input voltages for instance 9V, 12V, and 16V at different number of LED load (2, 4, 6, 10, 18). The test were conducted with the optimal compensation calculated for the COMP and ILIM loop in the previous section and with damping resistor of 1.5ohms. The results shows that under all these operations, the output current ripple remains under 5% of total load.

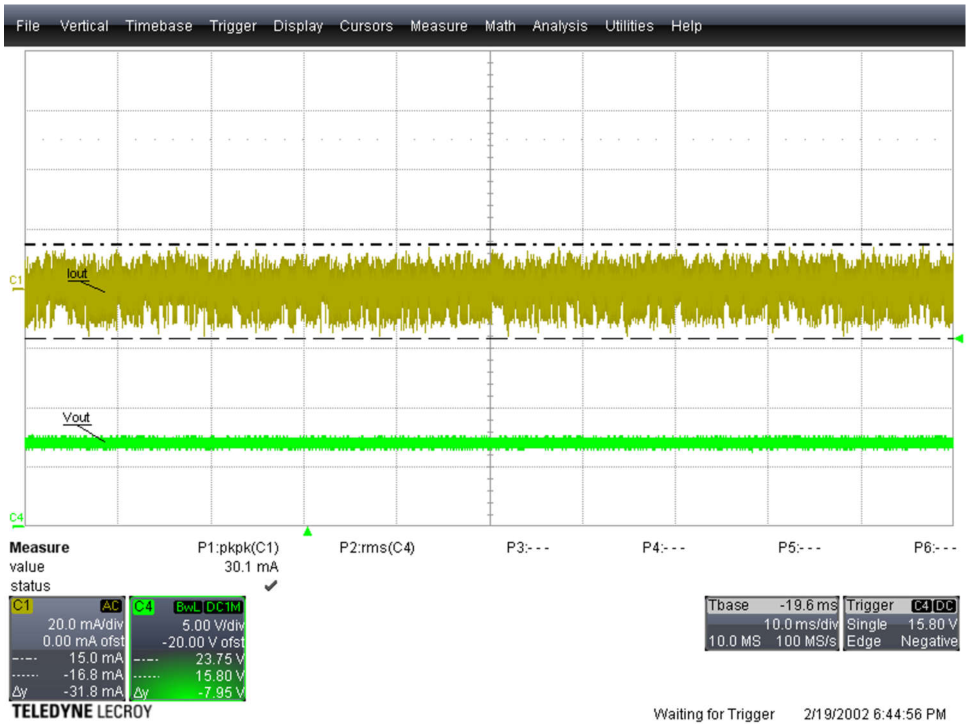

Figure 6-1. Vin=9V and 2 LEDs

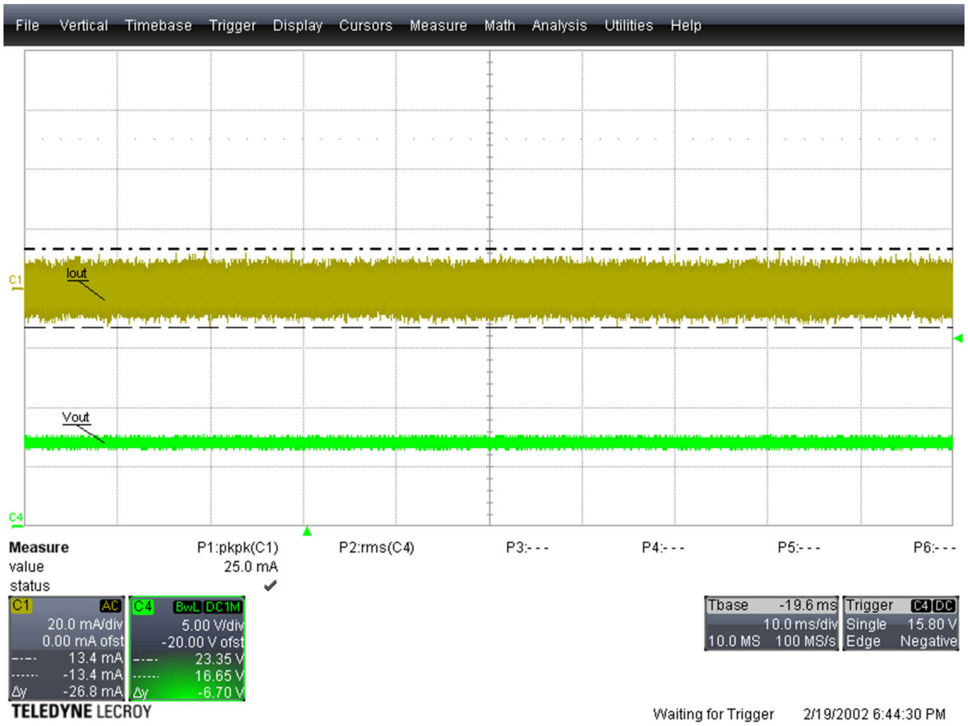

Figure 6-2. Vin=12V and 2 LEDs

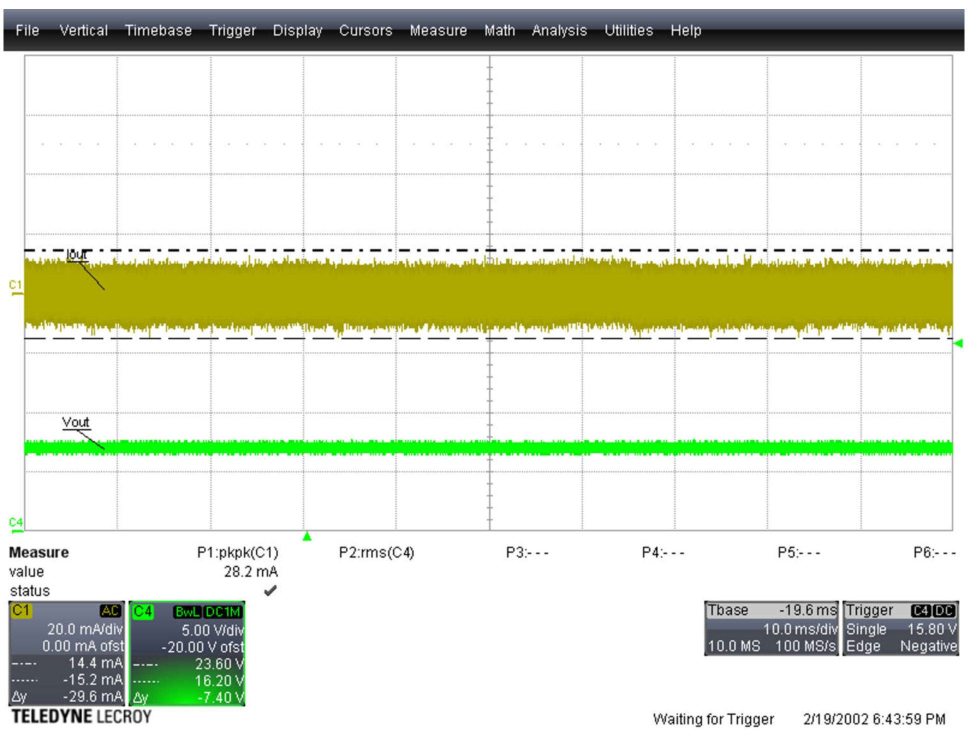

Figure 6-3. Vin=16V and 2 LEDs

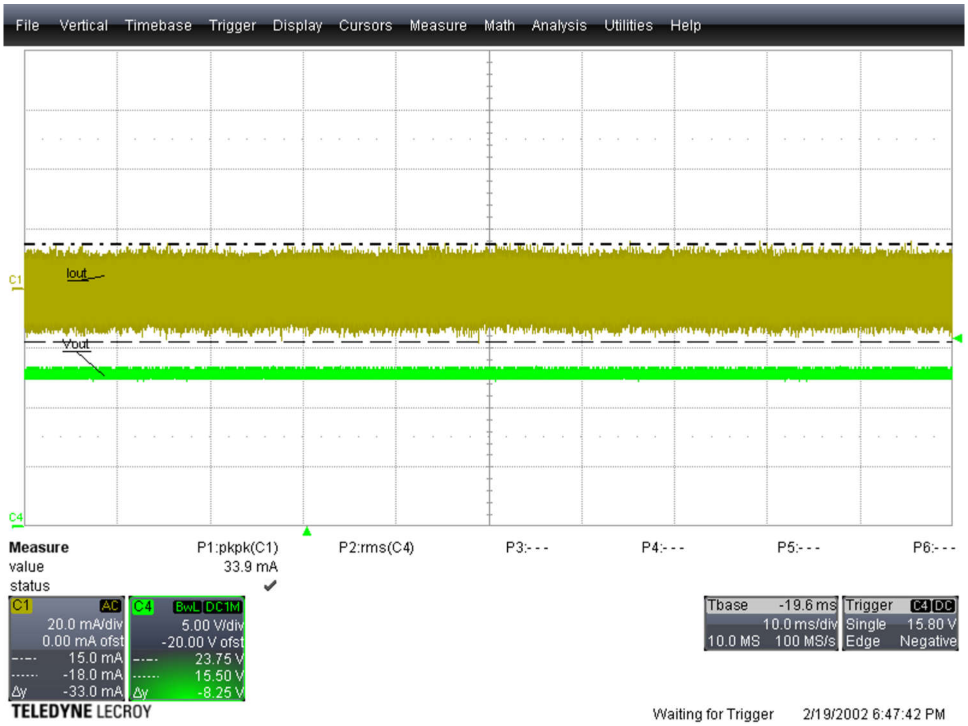

Figure 6-4. Vin=9V and 4 LEDs

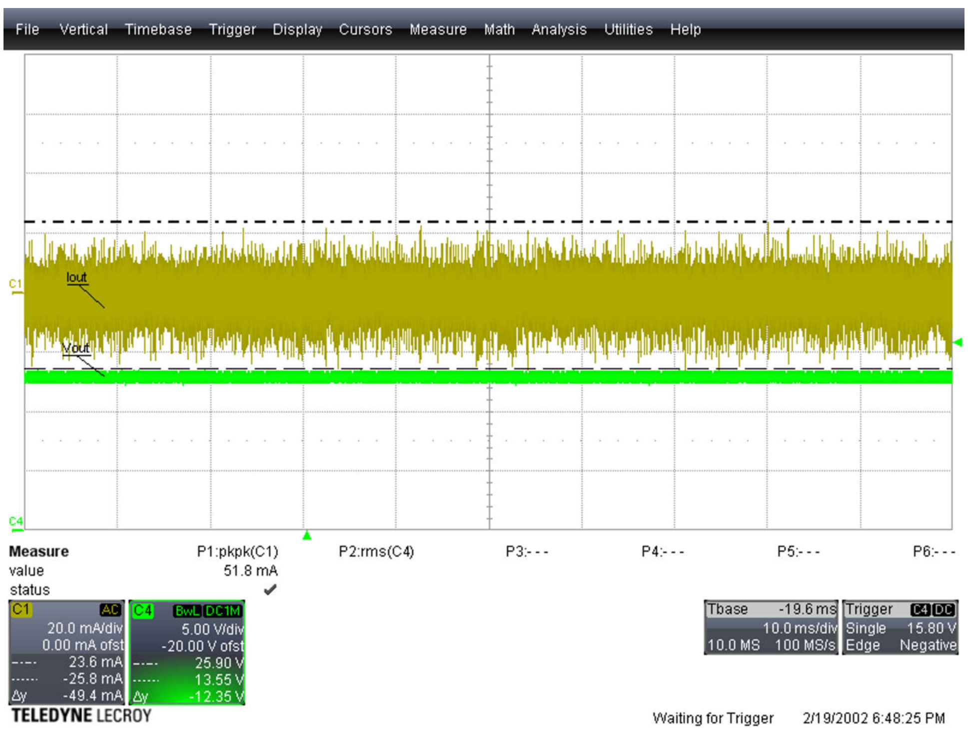

Figure 6-5. Vin=12V and 4 LEDs

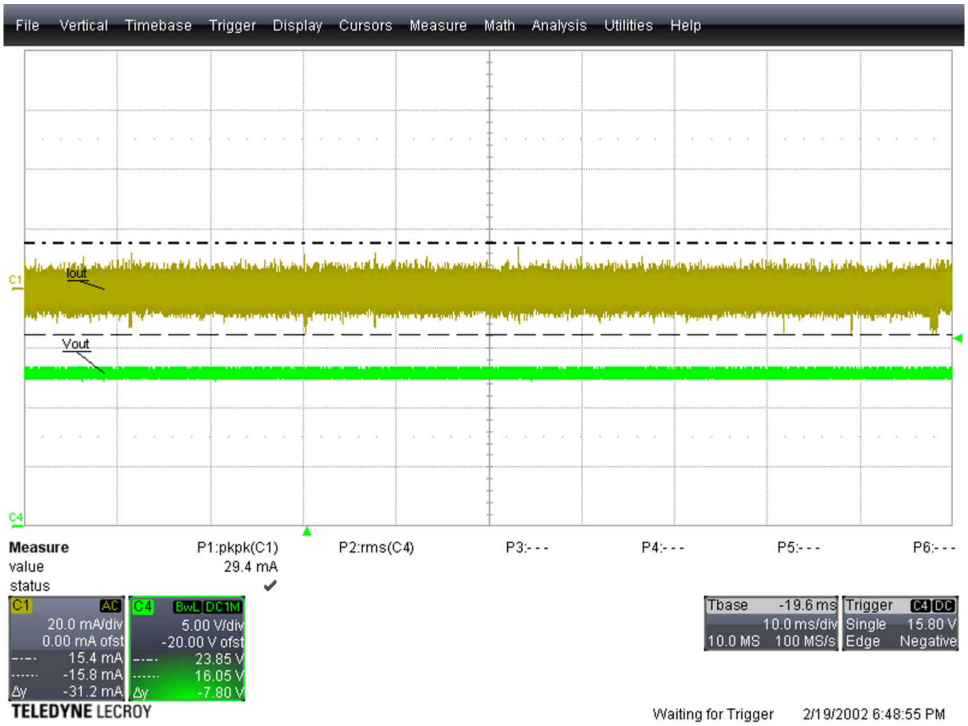

Figure 6-6. Vin=16V and 4 LEDs

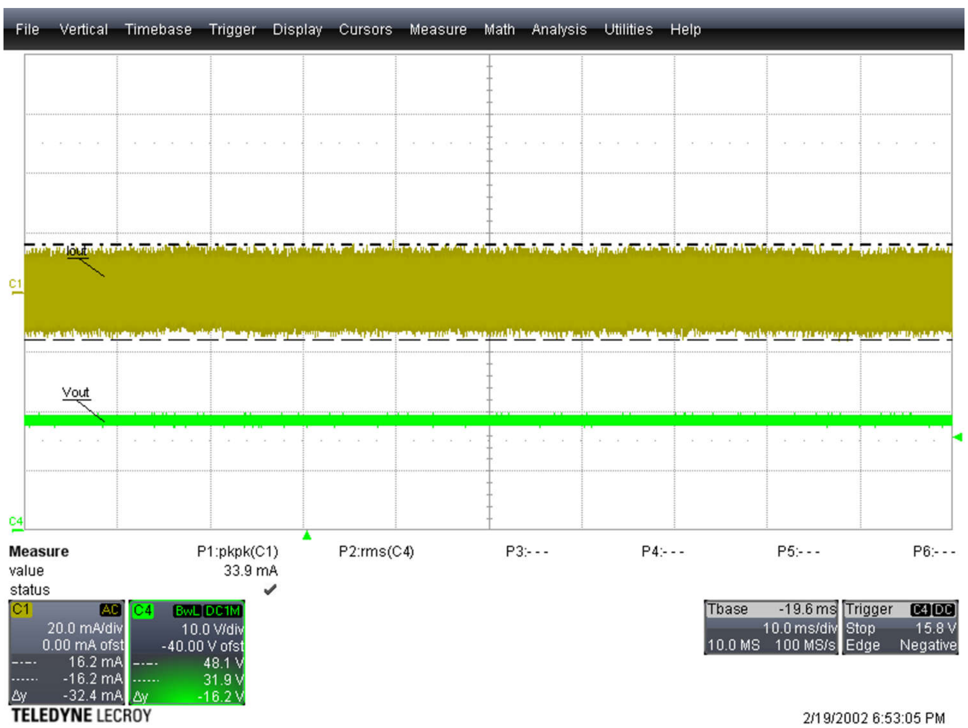

Figure 6-7. Vin=9V and 6 LEDs

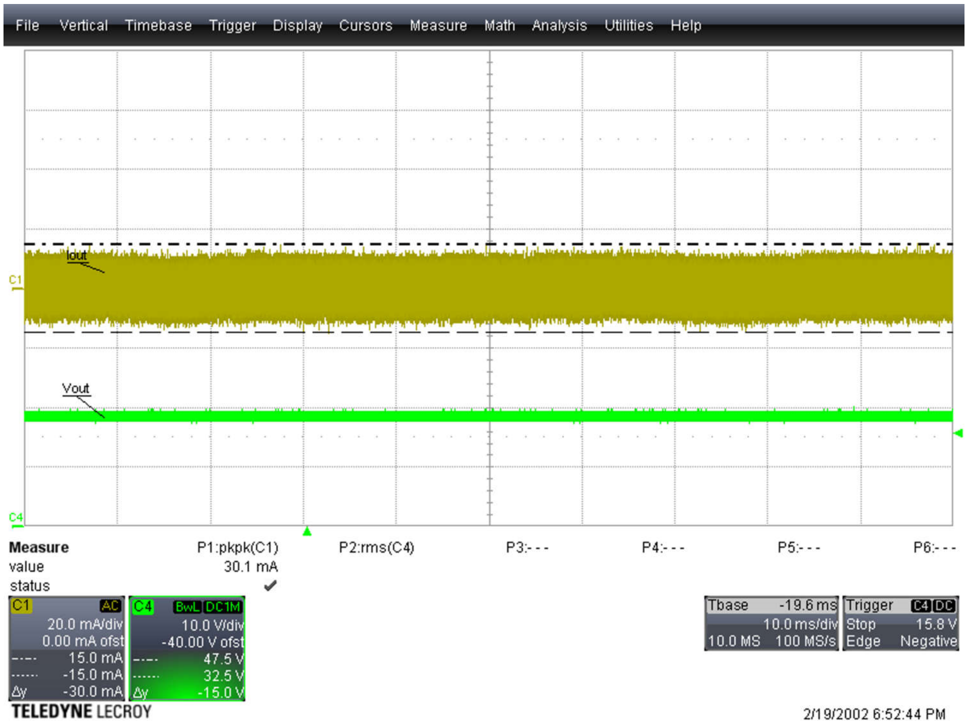

Figure 6-8. Vin=12V and 6 LEDs

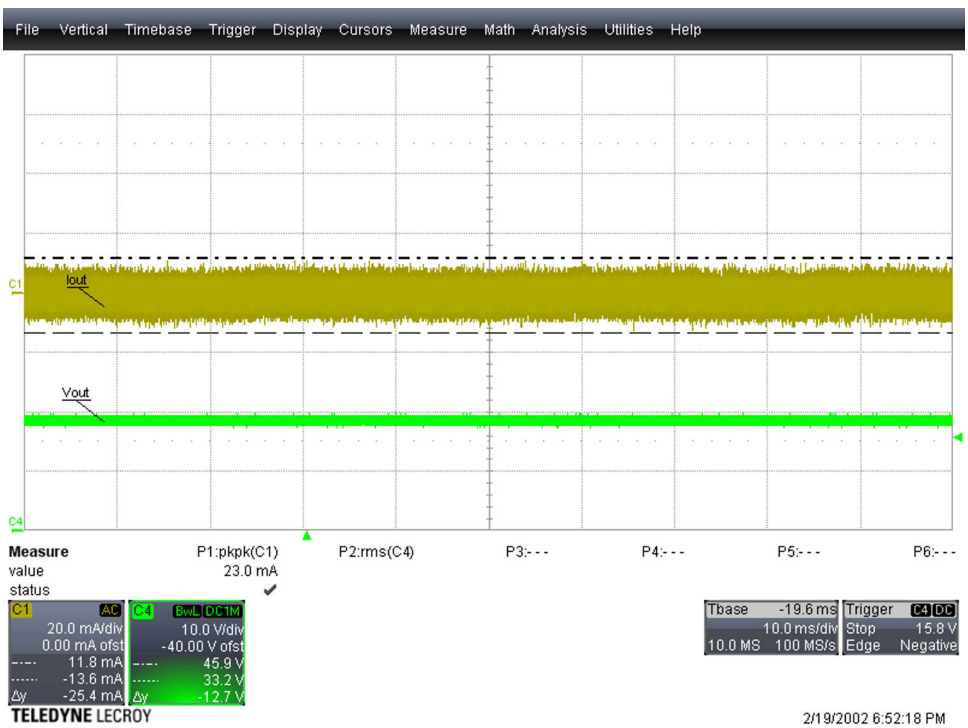

Figure 6-9. Vin=16V and 6 LEDs

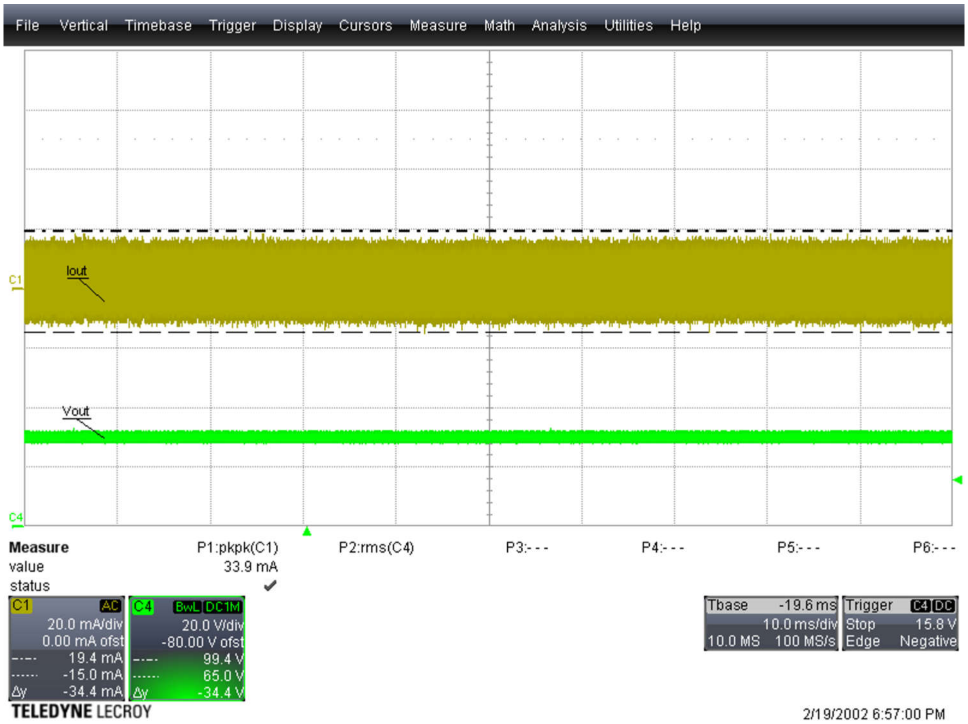

Figure 6-10. Vin=9V and 10 LEDs

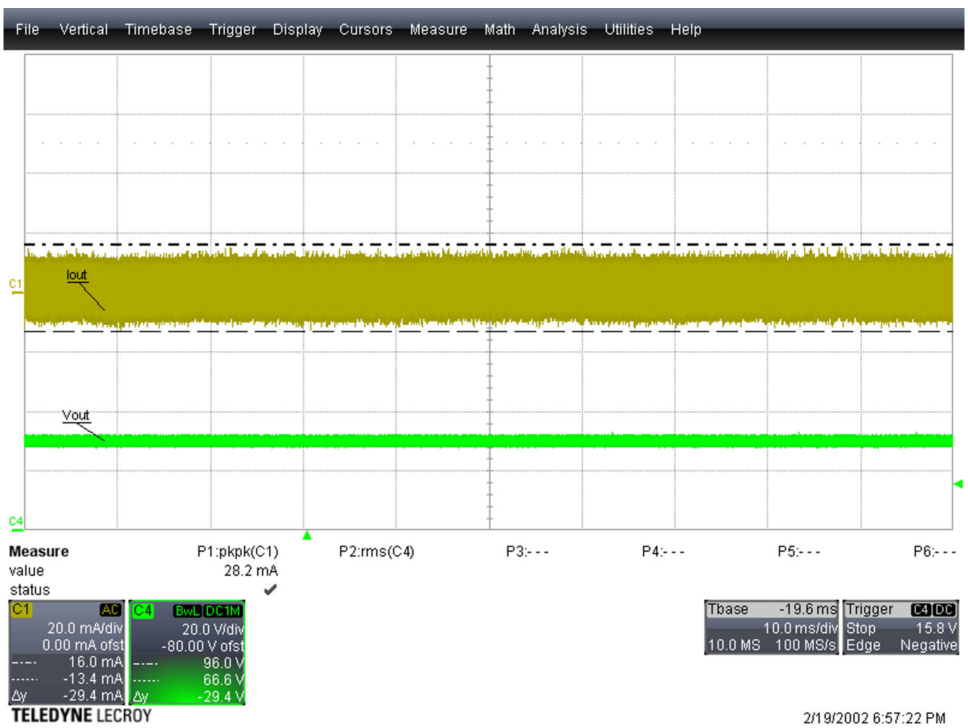

Figure 6-11. Vin=12V and 10 LEDs

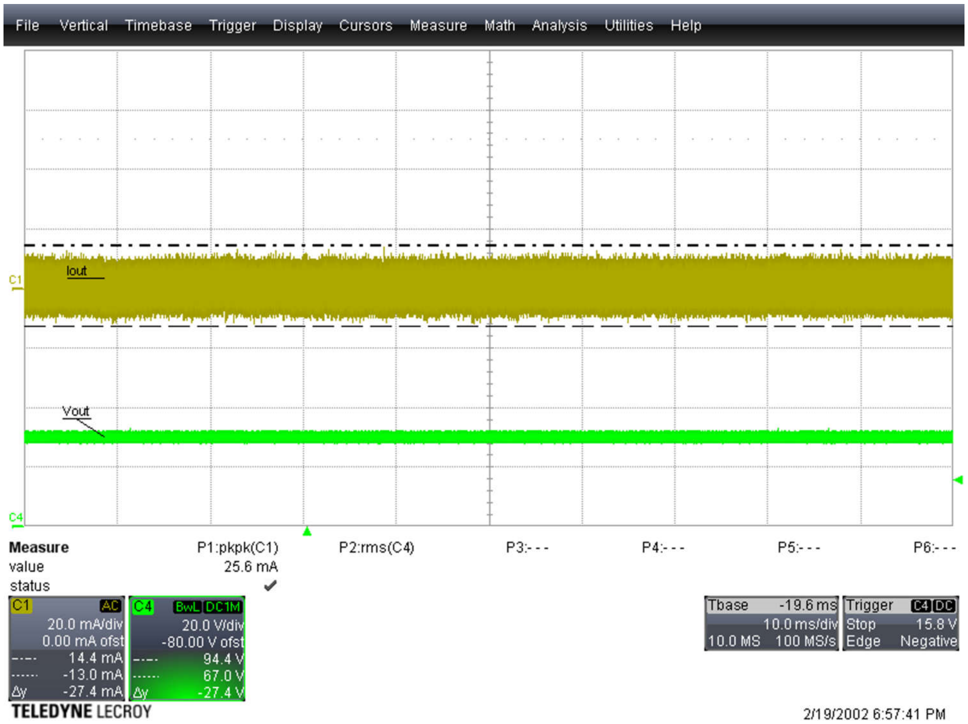

Figure 6-12. Vin=16V and 10 LEDs

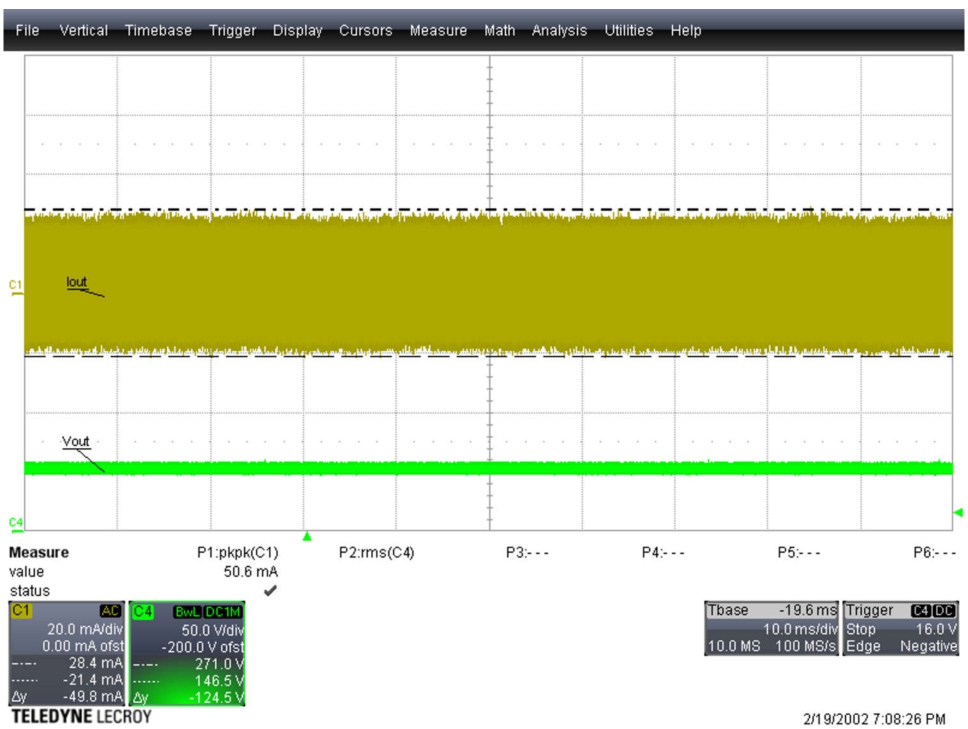

Figure 6-13. Vin=9V and 18 LEDs

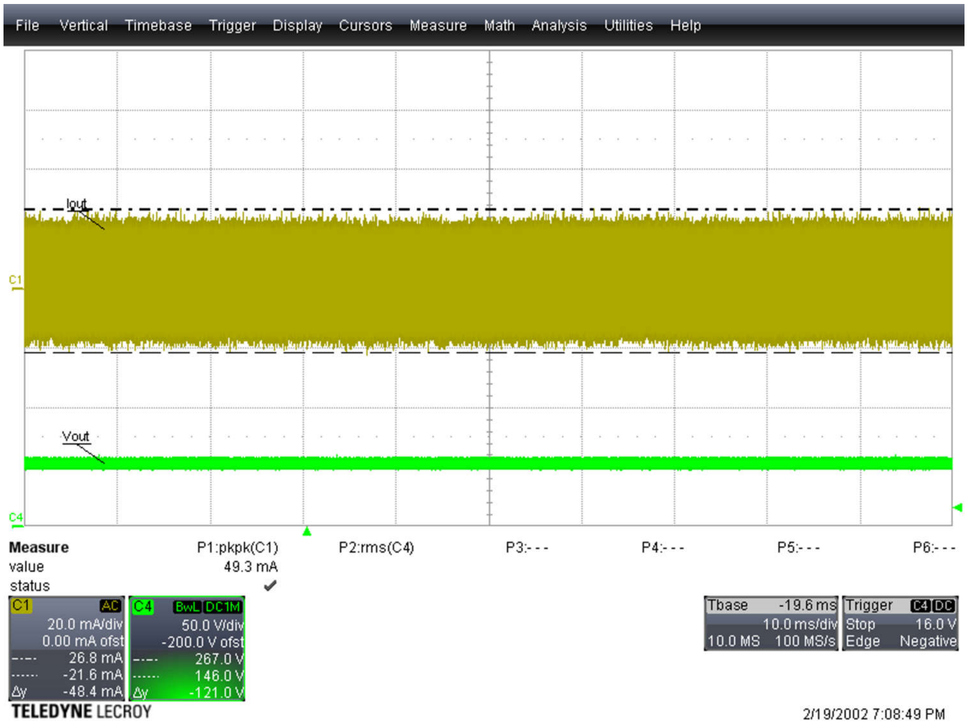

Figure 6-14. Vin=12V and 18 LEDs

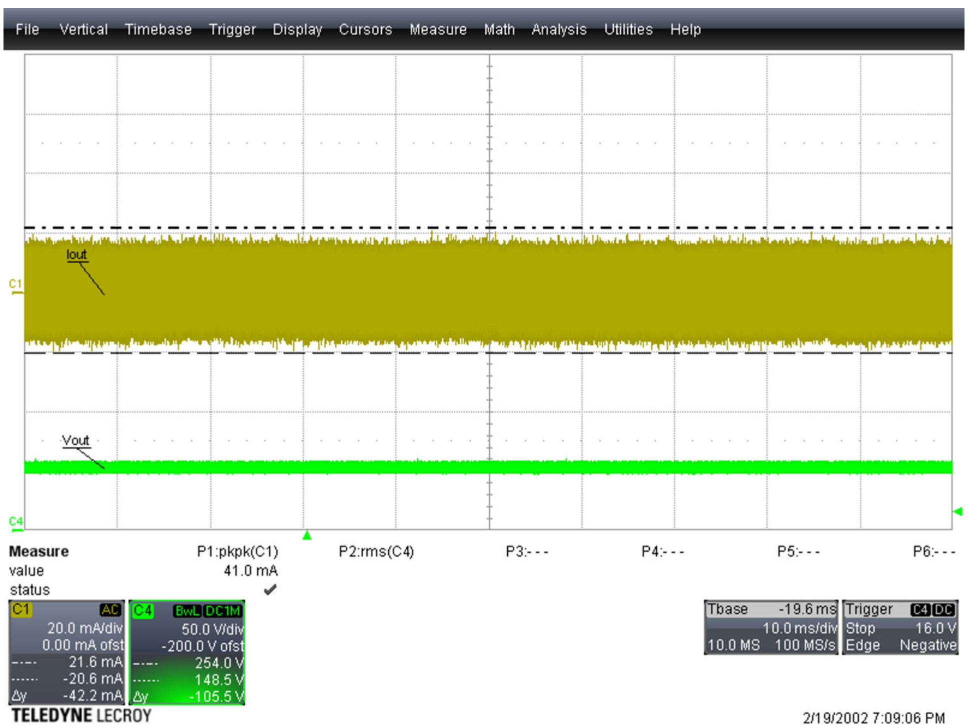

Figure 6-15. Vin=16V and 18 LEDs

6.2 LED Switching State Operation Results

Similarly, the test were conducted for the LED switching. The purpose of the test was to check whether the output current ripple remain within the 40% criteria during the LED switching transition. The results for different number of LEDs switching is shown in the following images.

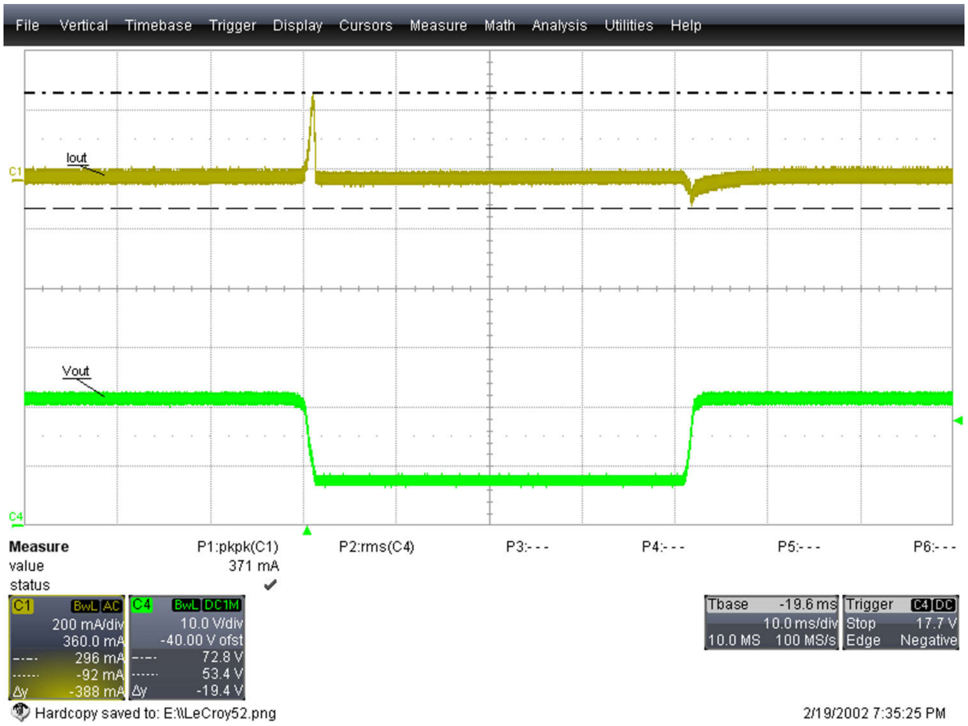

Figure 6-16. Switching Between 2 LEDs to 7 LEDs (Vin = 12V)

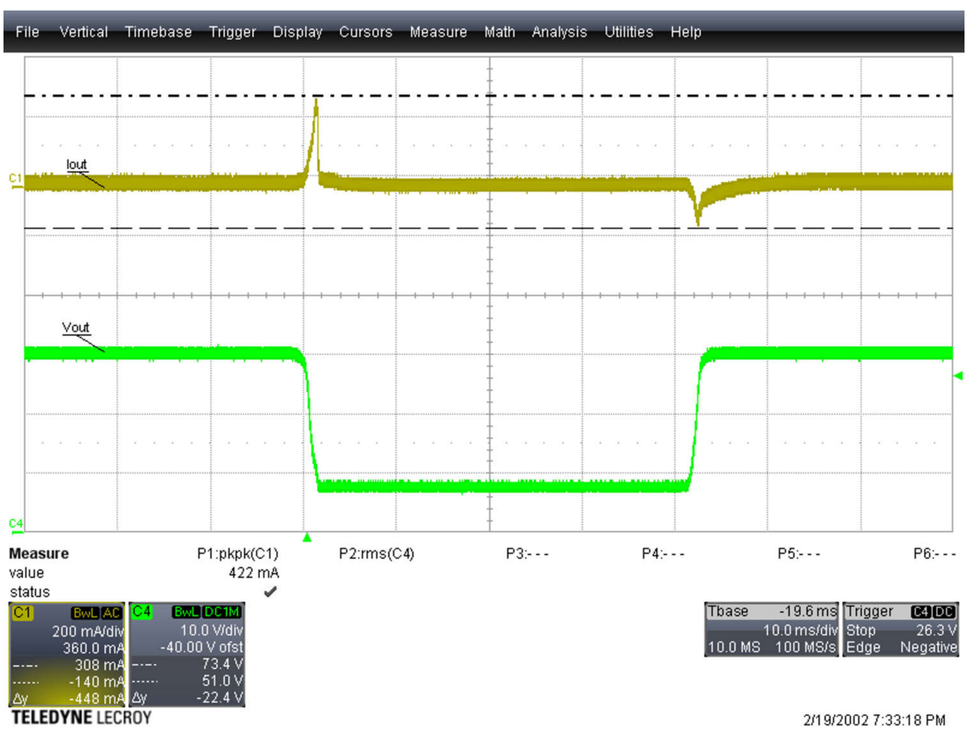

Figure 6-17. Switching Between 2 LEDs to 10 LEDs (Vin = 12V)

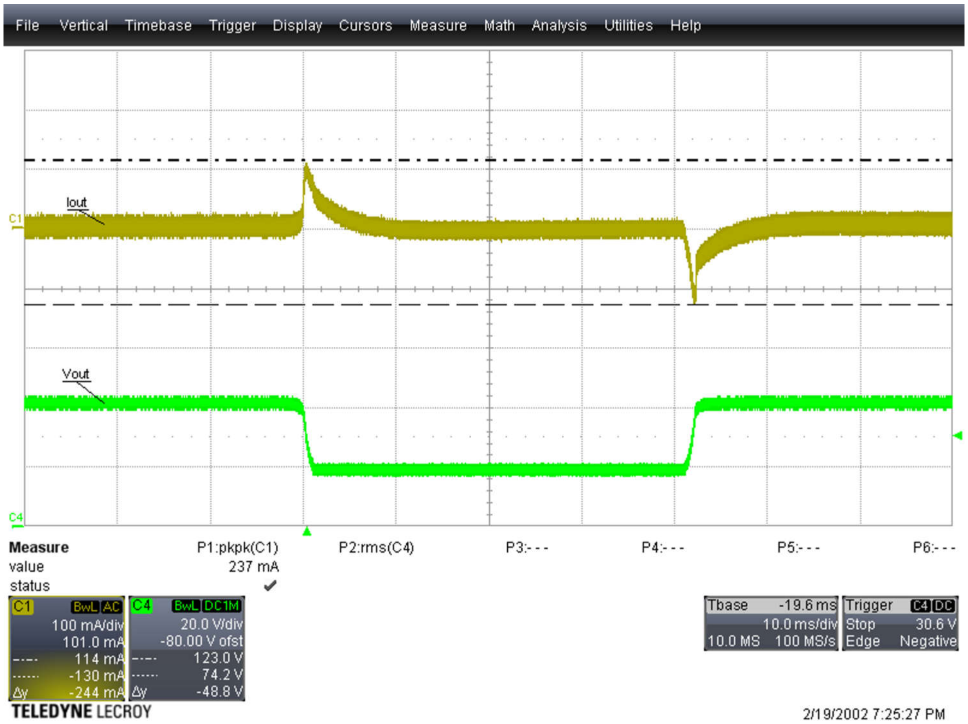

Figure 6-18. Switching Between 6 LEDs to 14 LEDs (Vin = 12V)

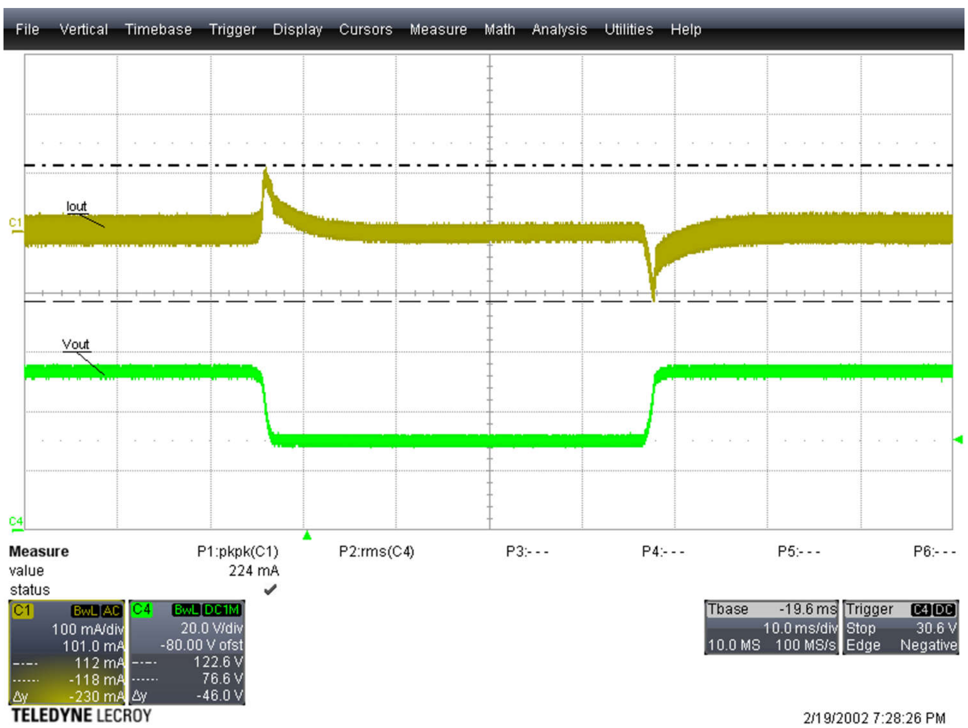

Figure 6-19. Switching Between 10 LEDs to 18 LEDs (Vin = 12V)

7 Summary

This application note demonstrates how the LM51770-Q1 four-switch buck-boost controller can be implemented in automotive headlight LED driver designs. Leveraging the LM51770EVM-HV as a design platform, the application note presents a practical reference design tailored for 12V automotive systems (9–16V input) delivering up to 55V at 1A constant current, with scalability to 48V platforms thanks to its 80V input rating. Key board modifications and component selections are explained in detail. Furthermore, the design is optimized for output current ripple and load-switching overshoot to accommodate multi-beam headlight architectures. Overall this report provides a solid, validated example of deploying the LM51770-Q1 in constant-current LED lighting applications.

8 References

For related documentation, see the following:

- Texas Instruments, *LM51770-Q1 80V Wide VIN Bidirectional 4-Switch Buck-Boost Controller* datasheet.
- Texas Instruments, *Switch-Mode Power Converter Compensation Made Easy* white paper.
- Texas Instruments, *LM51770 BuckBoost Quickstart Calculator Tool*, calculation tool.
- Texas Instruments, *LM51770 Buck-Boost Controller Evaluation Module*, webpage.
- Texas Instruments, *Establishing a Precise Current Limiter Over Wide Operation Voltages in Buck-Boost Converters*, application brief.
- Texas Instruments, *Constant Current Operation Using the Internal Current Limiter* , application brief.