HV9963 Boost LED Driver Demonstration Board User's Guide

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Object of Declaration: HV9963 Boost LED Driver Demonstration Board

EU Declaration of Conformity

Manufacturer: Microchip Technology Inc.
2355 W. Chandler Blvd.
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USA

This declaration of conformity is issued by the manufacturer.

The development/evaluation tool is designed to be used for research and development in a laboratory environment. This development/evaluation tool is not a Finished Appliance, nor is it intended for incorporation into Finished Appliances that are made commercially available as single functional units to end users under EU EMC Directive 2004/108/EC and as supported by the European Commission's Guide for the EMC Directive 2004/108/EC (8th February 2010).

This development/evaluation tool complies with EU RoHS2 Directive 2011/65/EU.

This development/evaluation tool, when incorporating wireless and radio-telecom functionality, is in compliance with the essential requirement and other relevant provisions of the R&TTE Directive 1999/5/EC and the FCC rules as stated in the declaration of conformity provided in the module datasheet and the module product page available at www.microchip.com.

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Signed for and on behalf of Microchip Technology Inc. at Chandler, Arizona, USA

Derek Carlson

Derek Carlson
VP Development Tools

12-Sep-14
Date

NOTES:

Table of Contents

NOTES:

HV9963 BOOST LED DRIVER DEMONSTRATION BOARD USER'S GUIDE

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our website (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXXXXA", where "XXXXXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the HV9963 Boost LED Driver Demonstration Board. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Website
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the HV9963 Boost LED Driver Demonstration Board as a development tool to emulate and debug firmware on a target board. The manual layout is as follows:

- **Chapter 1. "Product Overview"** – Important information about the HV9963 Boost LED Driver Demonstration Board.
- **Chapter 2. "Installation and Operation"** – This chapter includes a detailed description of each function of the demonstration board and instructions for how to use the board.
- **Appendix A. "Schematic and Layouts"** – Shows the schematic and layout diagrams for the HV9963 Boost LED Driver Demonstration Board.
- **Appendix B. "Bill of Materials (BOM)"** – Lists the parts used to build the HV9963 Boost LED Driver Demonstration Board.
- **Appendix C. "Plots and Waveforms"** – Describes the various plots and waveforms for the HV9963 Boost LED Driver Demonstration Board.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	*MPLAB® IDE User’s Guide*
	Emphasized text	...is the *only* compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	select Enable Programmer
Quotes	A field name in a window or dialog	“Save project before build”
Underlined, italic text with right angle bracket	A menu path	<u>*File>Save*</u>
Bold characters	A dialog button	Click **OK**
	A tab	Click the **Power** tab
N‘Rnnnn	A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.	4‘b0010, 2‘hF1
Text in angle brackets < >	A key on the keyboard	Press <Enter>, <F1>
Courier New font:		
Plain Courier New	Sample source code	`#define START`
	Filenames	`autoexec.bat`
	File paths	`c:\mcc18\h`
	Keywords	`_asm, _endasm, static`
	Command-line options	`-Opa+, -Opa-`
	Bit values	`0, 1`
	Constants	`0xFF, ‘A’`
Italic Courier New	A variable argument	*`file`*`.o`, where *`file`* can be any valid filename
Square brackets [ ]	Optional arguments	`mcc18 [options]` *`file`* `[options]`
Curly brackets and pipe character: { | }	Choice of mutually exclusive arguments; an OR selection	`errorlevel {0|1}`
Ellipses...	Replaces repeated text	`var_name [, var_name...]`

	Represents code supplied by user	`void main (void)`
		`{ ...`
		`}`

RECOMMENDED READING

This user's guide describes how to use the HV9963 Boost LED Driver Demonstration Board. Another useful document is listed below. The following Microchip document is available and recommended as a supplemental reference resource:

- **HV9963 Data Sheet – *"Closed Loop LED Driver with Enhanced PWM Dimming" (DSFP-HV9963).***

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
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- Field Application Engineer (FAE)
- Technical Support

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Technical support is available through the website at:
http://www.microchip.com/support

DOCUMENT REVISION HISTORY

Revision A (January 2016)

- Initial Release of this Document.

NOTES:

Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the HV9963 Boost LED Driver Demonstration Board and covers the following topics:

- HV9963 Device Short Overview
- What is the HV9963 Boost LED Driver Demonstration Board?
- HV9963 Device Features
- HV9963 Boost LED Driver Demonstration Board Technical Specifications
- Functional Description
- What the HV9963 Boost LED Driver Demonstration Board User's Guide Kit Contains

1.2 HV9963 DEVICE SHORT OVERVIEW

The HV9963 is a current mode control LED driver IC designed to control single switch PWM converters (buck, boost, buck-boost or Single-Ended Primary Inductor Converter - SEPIC) in a constant frequency mode. The controller uses a peak current-mode control scheme (with programmable slope compensation) and includes an internal transconductance amplifier to accurately control the output current over all line and load conditions. Multiple HV9963s can be synchronized to each other or to an external clock using the SYNC pin.

The IC also provides a disconnect switch gate drive output, which can be used to disconnect the LEDs in case of a fault condition using an external disconnect FET. The 10V external FET drivers allow the use of standard level FETs. The low voltage 5.0V AV_{DD} is used to power the internal logic and also acts as a reference voltage to set the current level. The HV9963 includes an enhanced PWM dimming logic (patented) that enables very high PWM dimming ratios. The HV9963 also provides a TTL-compatible, low-frequency PWM dimming input that can accept an external control signal with a duty ratio of 0-100% and a frequency of up to a few tens of kilohertz.

1.3 WHAT IS THE HV9963 BOOST LED DRIVER DEMONSTRATION BOARD?

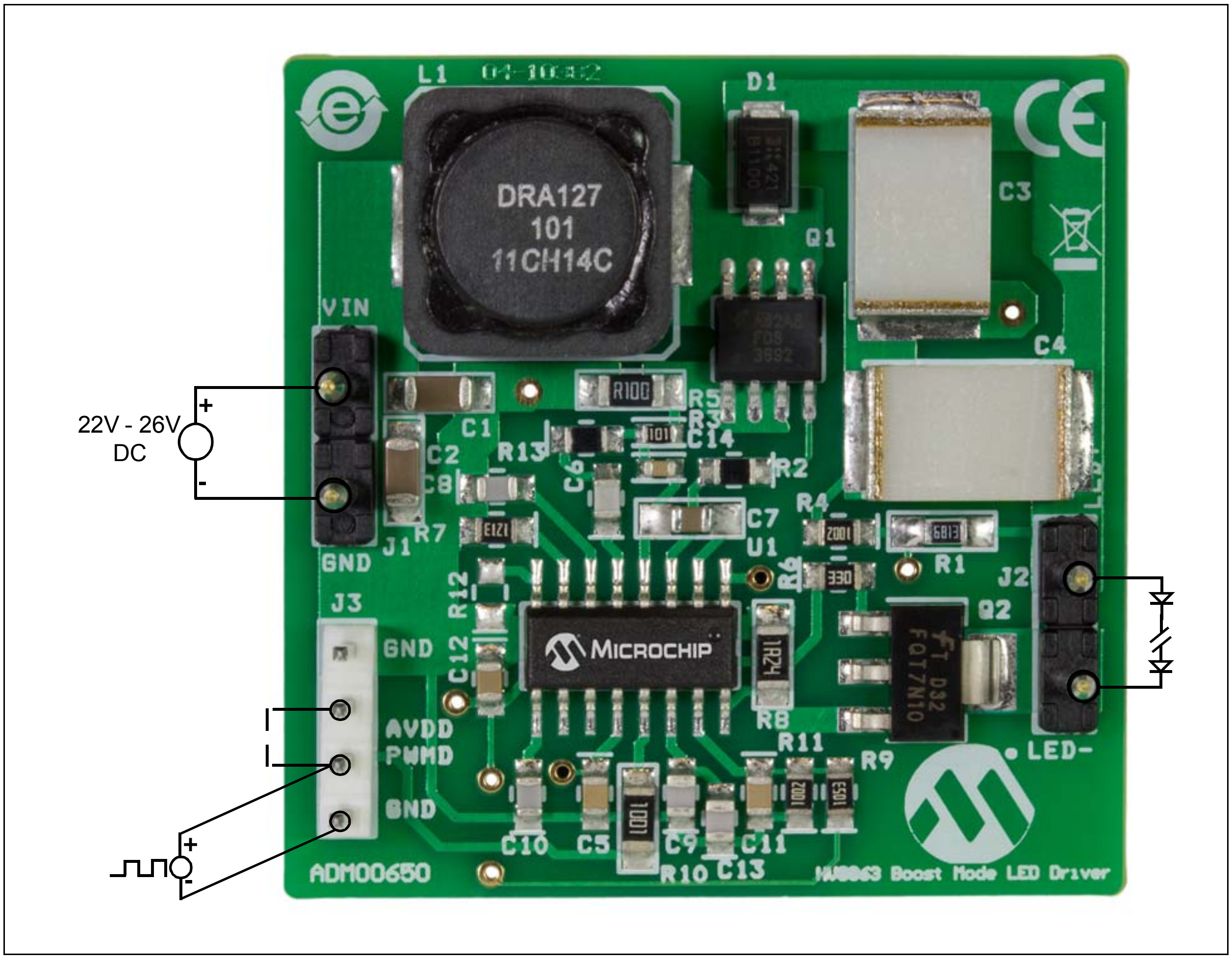
The HV9963 Boost LED Driver Demonstration Board is a Boost Mode LED Driver capable of driving up to 20 one-watt LEDs in series from an input of 22V - 26V DC. It uses the Microchip Technology Inc. HV9963 device in a boost topology. The converter has very good initial regulation (+/-5%) and excellent line and load regulation over the entire input and output voltage range (< +/-1%). The full load efficiency of the converter is typically greater than 90%.

The HV9963 Boost LED Driver Demonstration Board is protected against open-LED and output short circuit conditions. It is also protected from input undervoltage conditions by limiting the input current. It has excellent pulse-width modulation (PWM) dimming response, with typical rise and fall times less than 1.0 µs, which allows very high PWM dimming ratios. The switching frequency of the HV9963 can be synchronized to other HV9963 boards or to an external 200 kHz clock by connecting the clock to the SYNC pin of the HV9963 demo board.

The HV9963 Boost LED Driver Demonstration Board features Hiccup-mode short circuit and open-LED protection. Upon detection of either fault condition, the IC shuts down the driver and periodically attempts to restart until the fault condition ends. The board also features a built-in 500 ns blanking to prevent false tripping of the overcurrent comparator due to parasitic capacitance spikes during PWM dimming.

Note: This application uses a Peak Current Mode Control. Use only the HV9963 device option for this board.

CONNECTION DIAGRAM



1.4 HV9963 DEVICE FEATURES

- Switch Mode controller for single-switch converters (Buck, Boost, Buck-Boost and SEPIC)
- High output current accuracy
- High PWM dimming ratio (more than 5000:1)
- Internal 40V linear regulator
- Internal ±2% voltage reference
- Constant frequency operation with synchronization capability
- Programmable soft start
- 10V GATE drivers
- Hiccup-mode protection for both short-circuit and open-circuit conditions

1.5 HV9963 BOOST LED DRIVER DEMONSTRATION BOARD TECHNICAL SPECIFICATIONS

- Mode of Operation: Continuous Conduction Mode
- Input Voltage (steady state): 22V - 26V DC
- Output LED String Voltage: 40V - 75V maximum
- Output Current: 350 mA +/-5%
- Output Current Ripple: 6.5% Typical
- Switching Frequency: 200 kHz
- Full-Load Efficiency: 93% (at 24V Input)
- Open-LED Protection: Shuts Down at 86.4V
- Output Short Circuit Protection: Included
- Input Undervoltage Protection: Included
- PWM Dimming: 1:5000 Dimming Ratio at 200 Hz

Figure 1-1 shows a simplified block diagram of the application.

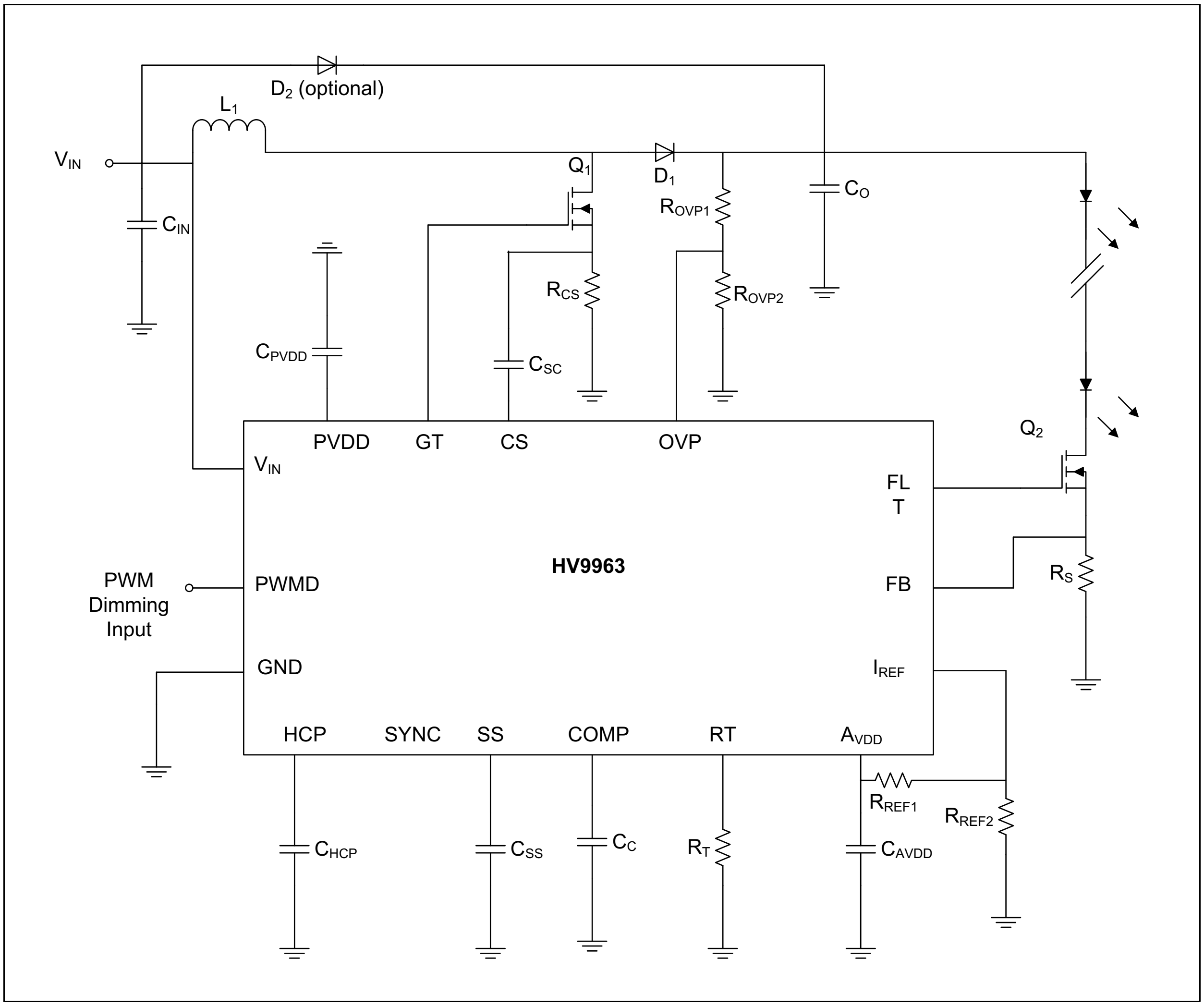


FIGURE 1-1: *HV9963 Boost LED Driver Demonstration Board Simplified Block Diagram.*

1.6 FUNCTIONAL DESCRIPTION

The HV9963 device provides all the analog functions necessary to implement a Peak Current Mode PWM DC-DC Converter. The power train is based on the Boost topology. The converter provides adjustable constant current at the output, necessary to drive high-power LED applications. The output (load) current is sensed with a 1.24Ω shunt resistor (Rs). The voltage across this shunt resistor is compared with the reference voltage at the I_{REF} pin by the HV9963 device's transconductance amplifier. The reference voltage for the HV9963 output current is set by the resistor divider formed by R_{REF1} and R_{REF2}. The output current is calculated with Equation 1-1

EQUATION 1-1:

$$I_{OUT} = \frac{V_{REF}}{1.24}$$

EQUATION 1-2:

$$V_{REF} = \frac{R_{REF2}}{R_{REF1} + R_{REF2}} \times 5V$$

For continuous conduction mode converters operating in the constant frequency mode, slope compensation becomes necessary to ensure stability of the peak current mode controller, if the operating duty cycle is greater than 0.5.

Choosing a slope compensation that is one half of the down slope of the inductor current ensures that the converter will be stable for all duty cycles.

Slope compensation in the HV9963 can be programmed by one external capacitor (C_{SC}) in series with the CS pin. A current proportional to the switching frequency is sourced out of the CS pin.

EQUATION 1-3:

$$I_{SC} = 2\mu A \times f_S \times \frac{1}{100kHz}$$

This current flows into the capacitor and produces a ramp voltage across the capacitor.

The voltage at the CS pin is then the sum of the voltage across the capacitor and the voltage across the current sense resistor, with the voltage across the capacitor providing the required slope compensation. When the GATE turns off, an internal pull-down MOSFET discharges the capacitor.

Assuming a down slope of DS (A/µs) for the inductor current and a maximum desired peak inductor current of I_{SAT}, the sense resistor can be computed as:

EQUATION 1-4:

$$R_{CS} = \frac{1}{12} \times (AV_{DD} - 0.7V) \times \frac{1}{\left(DS \times 10^6 \times \frac{0.93}{2 \times f_s}\right) + I_{SAT}}$$

The slope compensation capacitor is chosen to provide the required amount of slope compensation needed to maintain stability.

EQUATION 1-5:

$$C_{SC} = \frac{I_{SC}}{(0.5 \times DS \times R_{CS})}$$

1.6.1 ENHANCED PWM DIMMING:

The HV9963 has enhanced PWM dimming capability, which allows PWM dimming widths less than one switching cycle with no drop in the LED current.

The enhanced PWM dimming performance of the HV9963 can be best explained by considering a typical boost converter circuit without this functionality. When the PWM dimming pulse becomes very small (less than one switching cycle for a DCM design or less than five switching cycles for a CCM design), the boost converter is turned off before the input current can reach its steady state value. This causes the input power to droop, which is manifested in the output as a droop in the LED current.

The inductor current does not rise enough to trip the CS comparator. This causes the closed loop amplifier to lose control of the LED current and COMP rails to V_{DD}.

In the HV9963, however, this problem is overcome by keeping the boost converter ON, even though the PWM signal has gone to zero to ensure that enough power is delivered to the output. Thus, the amplifier still has control over the LED current and the LED current will be in regulation. See the HV9963 data sheet for more information on Enhanced PWM Dimming.

1.7 WHAT THE HV9963 BOOST LED DRIVER DEMONSTRATION BOARD USER’S GUIDE KIT CONTAINS

The HV9963 Boost LED Driver Demonstration Board User’s Guide includes:

- HV9963 Boost LED Driver Demonstration Board (ADM00650)
- Important Information Sheet

NOTES:

Chapter 2. Installation and Operation

2.1 GETTING STARTED

The HV9963 Boost LED Driver Demonstration Board is fully assembled and tested. The board requires the use of an external input voltage source (22V to 26V) and an external LED load.

2.1.1 Additional Tools Required for Operation

- A DC power supply, a bench supply that can produce 30V and 3A is recommended to operate the board at the full rated power.
- An oscilloscope and/or a multimeter to observe the waveforms and measure the electrical parameters (optional).
- A Signal Generator capable of generating a TTL compatible, low-frequency Pulse waveform with variable pulse widths that can achieve PWM Dimming.

2.2 SETUP PROCEDURE

To operate the HV9963 Boost LED Driver Demonstration Board, the following steps must be completed:

1. Attach an LED load (or dummy load) to the J2 Output Connector (observe the polarity).
2. Connect a jumper between the PWMD input and AVDD of the J3 Input Connector as shown by the dashed lines in Figure 2-1. To synchronize the switching frequencies of two or more HV9963 demo boards, connect an external push-pull waveform source between the terminals PWMD and GND of J3 connector as shown by the solid lines.
3. Connect a power supply to the J1 Input Connector (observe the polarity).
4. To synchronize two or more boards, connect the SYNC pins of all the boards together. To synchronize the HV9963 Boost LED Driver Demonstration Board to an external 200 kHz clock, connect the clock between the SYNC and GND pins of connector J3.

Note:	During PWM dimming, Pin 2 of the J3 connector should be left open. Also, the PWM signal must have the proper polarity with the positive connected to Pin 3 of J3 connector. Note that Pin 4 of J3 is internally connected to the return path of the input voltage

WARNING
Please observe the polarity for all steps to avoid board damage.

2.2.1 Demonstration Board Output Current Configuration

The board is configured to deliver a nominal value of 350 mA to the LEDs' load. The maximum output voltage is set to be approximately 75V with overvoltage protection set at approximately 83V.

2.2.2 Connecting the Load

A string of LEDs (1W each) can be powered by this board. The LED's string must be mounted on an appropriate heat sink to keep the maximum junction temperature at safe level (consult the HV9963 data sheet for details). The nominal current delivered by the board to the LED's string is set to 350 mA and the maximum output voltage is 75V.

The LED's string can be replaced by a resistor of 220Ω and 20W dissipated power (dummy load). In this case, the power delivered to the load will be about 27W.

Connect the LEDs' string to the J3 connector. It is very important to use the correct polarity (see Figure 2-1).

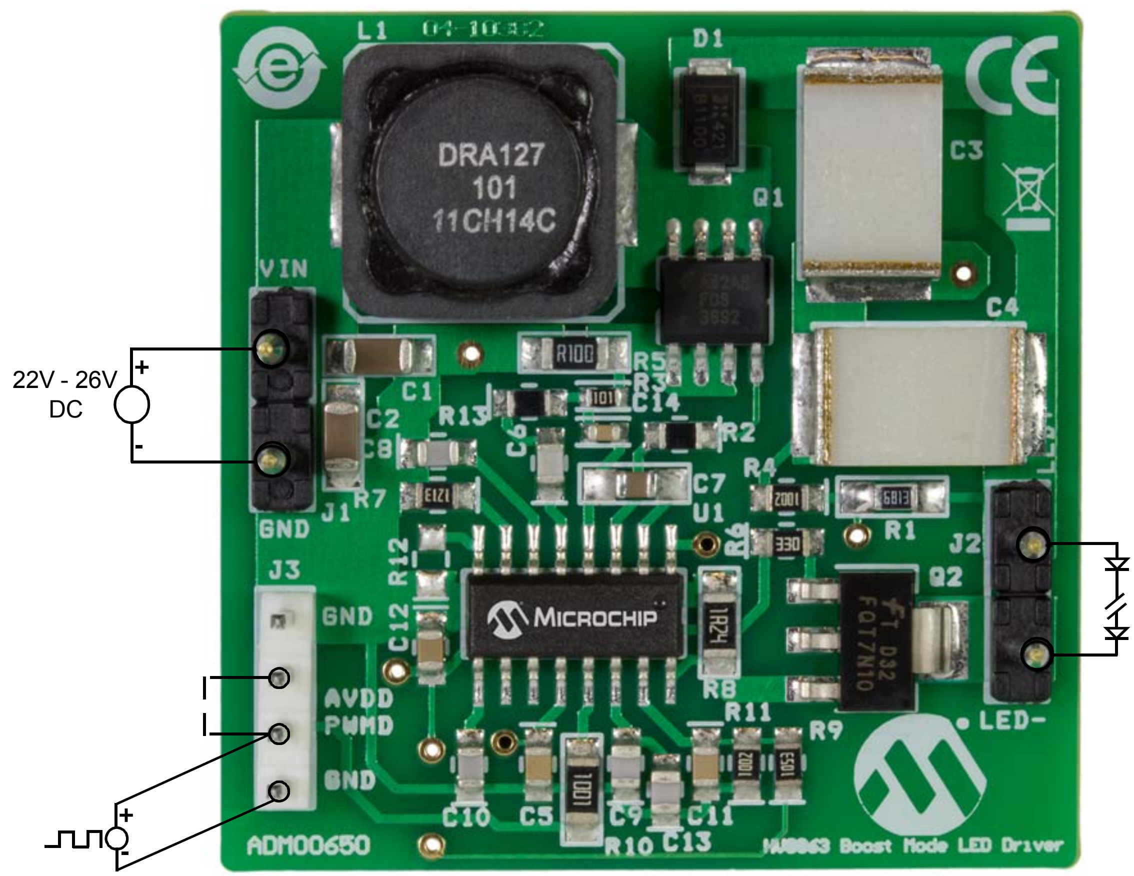


FIGURE 2-1: Power Supply and Load Connection Diagram.

> **Note:** This board has no Thermal Shut-Down function implemented. Ensure that the load is properly cooled.

2.2.3 Using the Reference Board

The board has Undervoltage Lock-Out and Overvoltage protections. The thresholds are 4.7 V_{DC} for AV_{DD} and 83 V_{DC}, respectively.

The board is protected against both No-Load and short circuit conditions.

2.2.4 Connectors

Table 2-1 shows the available connectors on the board.

TABLE 2-1: CONNECTORS DESCRIPTION

Connector	Description	Pins	Connection to PIN
J1	Input Connector	VIN	Connect the positive end of the input voltage
		GND	Connect the negative end of the input voltage
J2	Output Connector	LED+	Connect the Anode of LED string
		LED-	Connect the Cathode of LED string
J3	Signal Connector	GND	Connected to negative of input voltage
		AVDD	Connected to the AVDD pin of the HV9963 (5V)
		PWMD	Connect to AVDD to enable the evaluation board; connect to a TTL compatible signal to enable PWM Dimming

2.3 EVALUATING THE HV9963 BOOST LED DRIVER DEMONSTRATION BOARD

The best way to evaluate the HV9963 Boost LED Driver Demonstration Board is to examine the circuit and measure the voltages and currents with a Digital Voltage Meter (DVM) and probe the board with an oscilloscope.

Additional tools (current probe, IR camera) are necessary to evaluate some technical parameters of the board (temperature of power components, ability to withstand surge voltage pulse on input, EMI).

2.4 DEMONSTRATION BOARD TESTING

1. **Normal Operation:** Connect the input source and the output LEDs as shown in the Connection Diagram (Figure 2-1) and enable the board. The LEDs will glow with a steady intensity.

   Connecting an ammeter in series with the LEDs will allow measurement of the LED Current. The current will be 350 mA ±5%.

2. **Current Regulation:** With the input power to the converter disconnected, change the LED string voltage within the specifications mentioned.

   The output current of the HV9963 will remain very steady over the entire load range. Vary the input voltage while the circuit is operational. The current will be regulated over the entire line range (see Figures C-3 and C-4).

3. **Open LED Test**: Connect a voltmeter across the output terminals of the HV9963. Start the demo board normally and once the LED current reaches steady state, unplug one end of the LED string from the demo board.

   The output voltage will rise to about 83V and the HV9963 will shut down. Once the LED string is reconnected, the driver will start regulating current again (see Figures C-5 and C-6).

4. **Short Circuit Test**: When the HV9963 is operating in steady state, connect a jumper across the terminals of the LED string.

   Notice that the output current will immediately go to zero and the converter will shut down. Removing the jumper will cause the HV9963 to restart and continue to regulate the LED current (see Figures C-7 and C-8).

5. **PWM Dimming**: With the input voltage to the board disconnected, apply a TTL-compatible, push-pull square wave signal between PWMD and GND terminals of J3 connector as shown in the Connection Diagram (Figure 2-1). Turn the input voltage back on and adjust the duty cycle and/or frequency of the PWM dimming signal. The output current will track the PWM dimming signal. Note that, although the converter operates perfectly at 1 kHz PWM dimming frequency, the widest PWM dimming ratio can be obtained at lower frequencies like 100 Hz or 200 Hz (see Figures C-9 — C-17).

Some typical voltage and waveforms are provided in **Appendix C. "Plots and Waveforms"**.

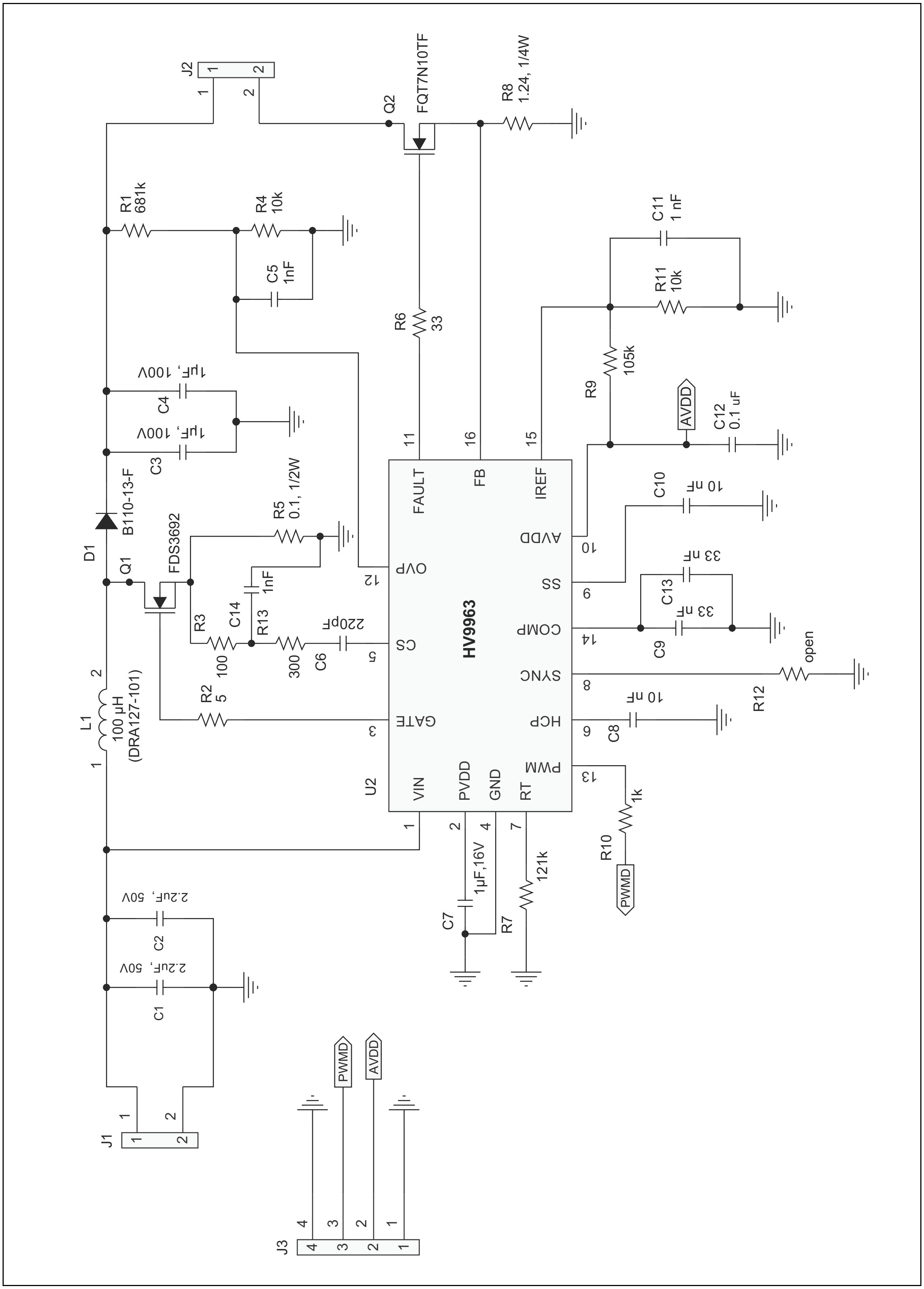
Appendix A. Schematic and Layouts

A.1 INTRODUCTION

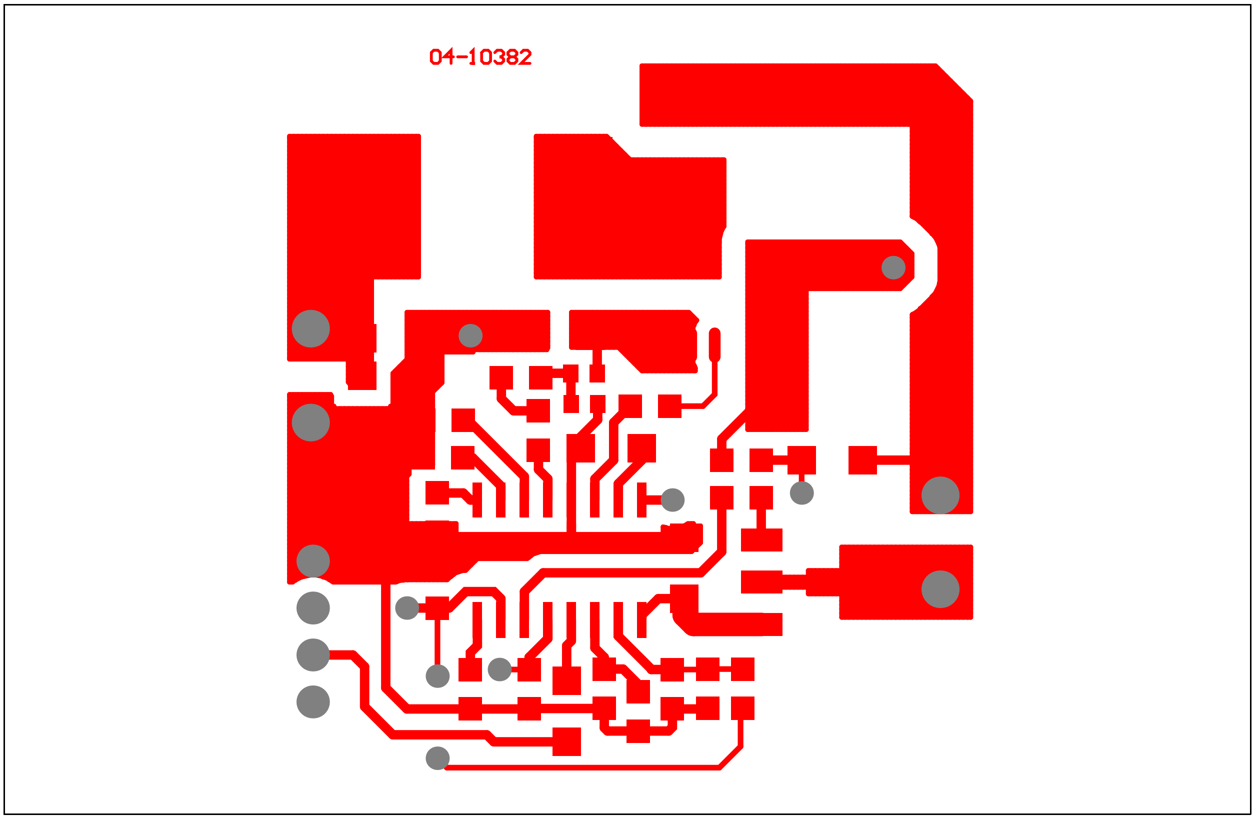
This appendix contains the following schematics and layouts for the HV9963 Boost LED Driver Demonstration Board:

- Board – Schematic
- Board – Top Layer
- Board – Top Silk Layer
- Board – Bottom Layer

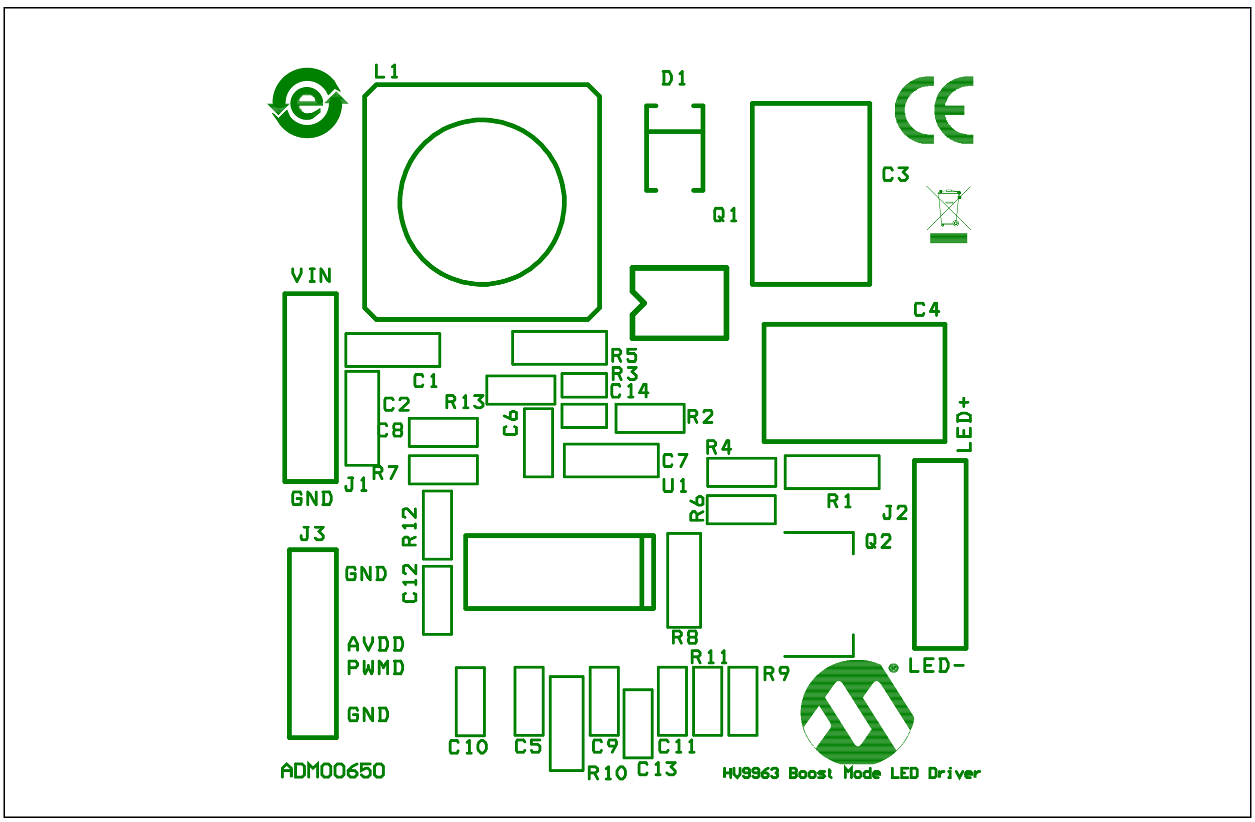
A.2 BOARD – SCHEMATIC



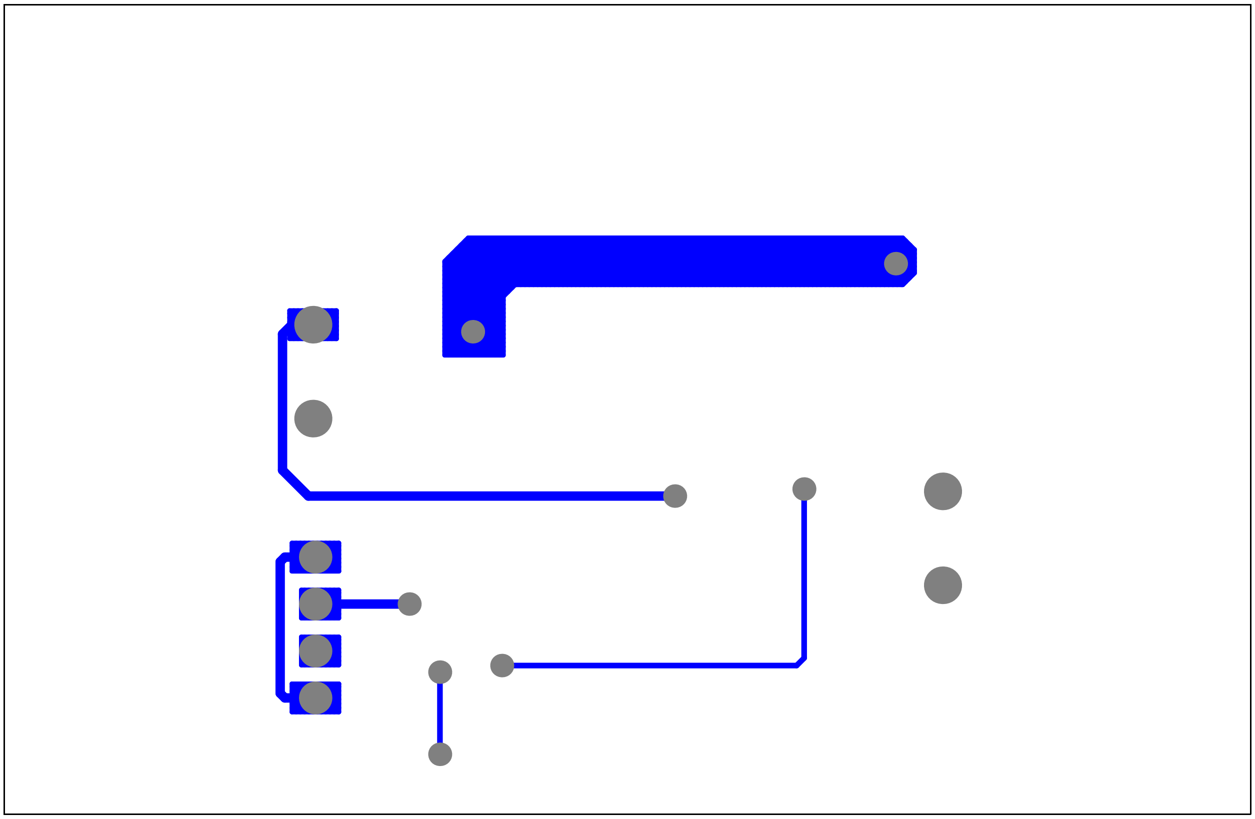
A.3 BOARD – TOP LAYER



A.4 BOARD – TOP SILK LAYER



A.5 BOARD – BOTTOM LAYER



Appendix B. Bill of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
2	C1, C2	2.2 µF, 10% 50V X7R ceramic capacitor	Murata Electronics®	GRM31CR71H225KA88L
2	C3, C4	1 µF, 10%, 100V PEN film capacitor	Panasonic® ECG	ECW-U1105KCV
2	C5, C11	1 nF, 10%, 50V X7R ceramic capacitor	TDK Corporation	C2012X7R1H102K
1	C6	220 pF, 5%, 50V C0G ceramic capacitor	AVX Corporation	08055A221JAT2A
1	C7	1 µF, 10%, 16V X7R ceramic capacitor	Murata Electronics®	GRM21BR71C105KA01L
2	C8, C10	10 nF, 5%, 50V C0G ceramic capacitor	Murata Electronics®	GRM2195C1H103JA01D
2	C9, C13	33 nF, 5%, 25V C0G ceramic capacitor	TDK Corporation	C2012C0G1H333J125AA
1	C12	0.1 µF, 10%, 16V X7R ceramic capacitor	Murata Electronics®	GRM219R71C104KA01D
1	C14	1 nF, 10%, 50V X7R ceramic capacitor	TDK Corporation	C1608X7R1H102K
1	D1	100V, 1A Schottky diode	Diodes® Incorporated	B1100-13-F
2	J1, J2	2 Position 5 mm pitch header	TE Connectivity Ltd.	1546931-2
1	J3	4 Position 2.54 mm pitch header	Molex®	22-03-2041
1	L1	100 µH, 2.77A sat, 1.89A rms inductor	Eaton	DRA127-101-R
1	PCB	Printed Circuit Board - HV9963 Boost LED Driver Demo Board	Microchip Technology Inc.	04-10382
1	Q1	100V, 60 mΩ, 15 nC N-channel MOSFET	Fairchild Semiconductor®	FDS3692
1	Q2	100V, 350 mΩ, 7.5 nC N-channel MOSFET	Fairchild Semiconductor®	FQT7N10TF
1	R1	681K, 1/4W, 1% chip resistor	Yageo Corporation	RC1206FR-07681KL
1	R2	5, 1/8W, 5% chip resistor	Vishay Precision Group (VPG)	Y4015R00000F9W
1	R3	100, 1/10W, 5% chip resistor	Yageo Corporation	RC0603FR-07100RL
2	R4, R11	10K, 1/8W, 1% chip resistor	Yageo Corporation	RC0805FR-0710KL
1	R5	0.1, 1/2W, 1% chip resistor	Yageo Corporation	RL1206FR-7W0R1L
1	R6	33, 1/8W, 5% chip resistor	Yageo Corporation	RC0805JR-0733RL
1	R7	121K, 1/8W, 1% chip resistor	Yageo Corporation	RC0805FR-07121KL
1	R8	1.24, 1/4W, 1% chip resistor	Yageo Corporation	RC1206FR-071R24L
1	R9	105K, 1/8W, 1% chip resistor	Yageo Corporation	RC0805FR-07105KL
1	R10	1K, 1/4W, 5% chip resistor	Yageo Corporation	RC1206JR-071KL
1	R12	Not Installed/Used		
1	R13	300, 1/8W, 5% chip resistor	Yageo Corporation	RC0805JR-07300RL
1	U2	HV9963NG	Microchip Technology Inc.	HV9963NG-G

1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

NOTES:

Appendix C. Plots and Waveforms

C.1 PLOTS AND WAVEFORMS EXAMPLES

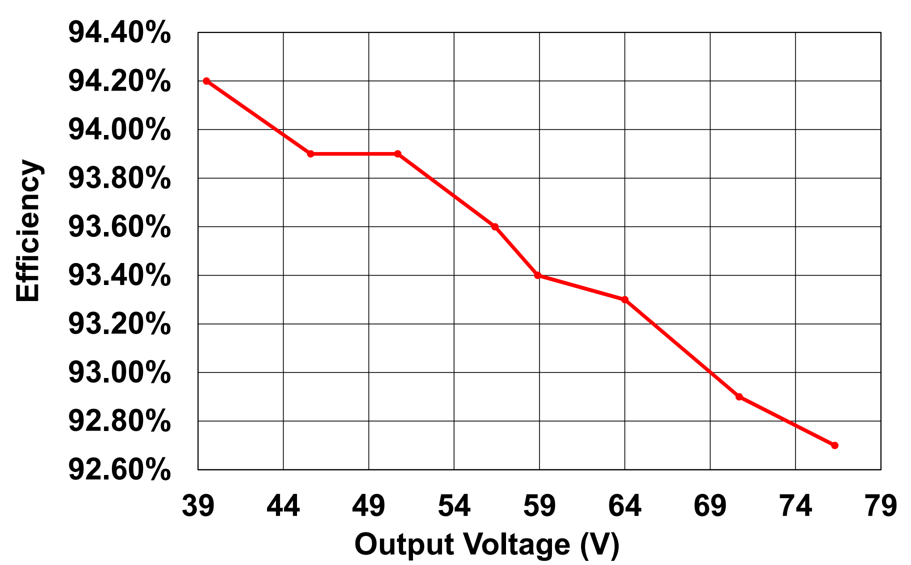


FIGURE C-1: *Efficiency vs. Output Voltage, V_{IN} = 24V.*

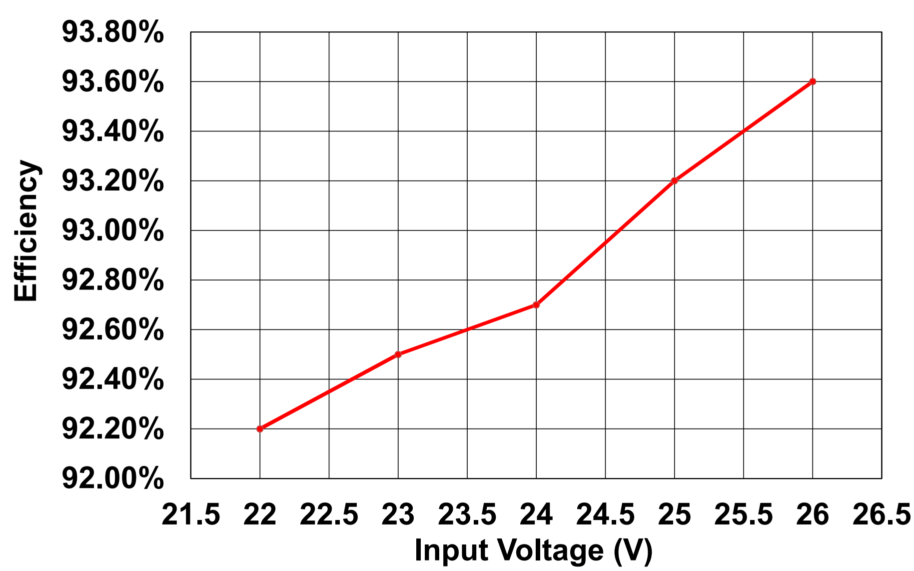


FIGURE C-2: *Efficiency vs. Input Voltage, V_{OUT} = 72V.*

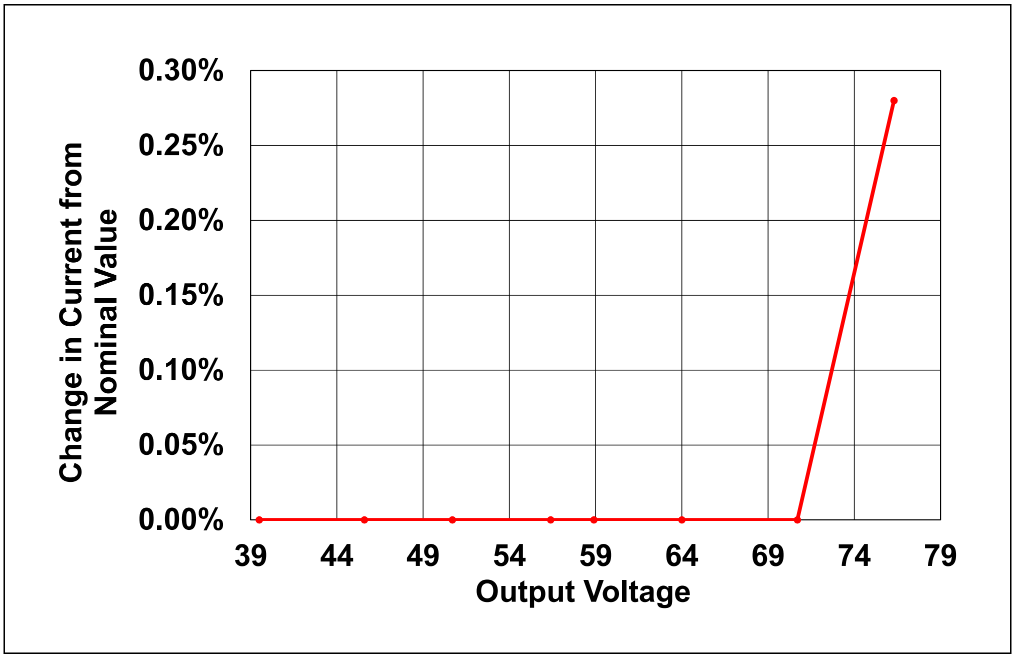


FIGURE C-3: *Change in Output Current from Nominal Value vs. Output Voltage, V_{IN} = 24V (Nominal Value is the Output Current at V_{OUT} = 70V).*

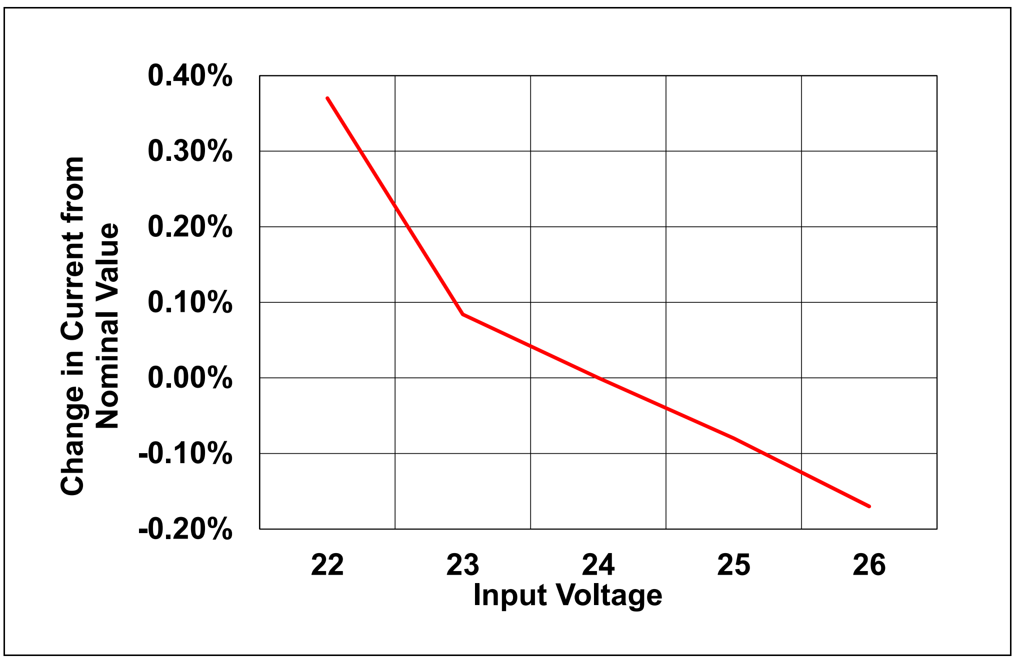


FIGURE C-4: *Output Current vs. Input Voltage, V_{OUT} = 72V.*

C.1.1 Various Signals During Open LED Protection

Figures C-5 and C-6 show the Hiccup-mode overvoltage protection. When the open circuit condition occurs, the LED current immediately goes to zero. At that point, the inductor charges the output capacitor and the COMP voltage is pulled to GND. Once the output voltage reaches the overvoltage threshold, the converter shuts down and the output voltage slowly decays because the output capacitor is discharged by the overvoltage sensing resistor network. Once the output voltage falls to 90% of its trip point, the converter tries to restart. Since the fault condition still persists, the converter shuts down almost immediately. Thus, the HV9963 maintains the output voltage in a band until the LED string reconnects.

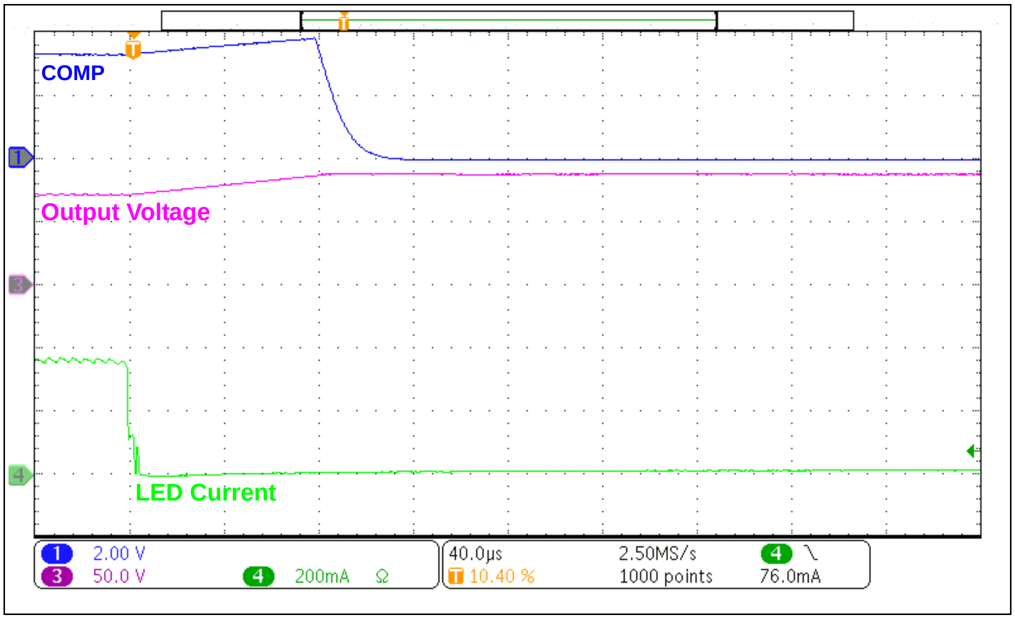


FIGURE C-5: Hiccup Mode Overvoltage Protection.

The figure below shows the recovery of the HV9963 from an overvoltage condition. In this case, the LED string has reconnected at some point when the converter is turned off. When the converter attempts to restart, the overvoltage condition is no longer met, therefore it starts up normally. There is no significant overshoot in the LED current.

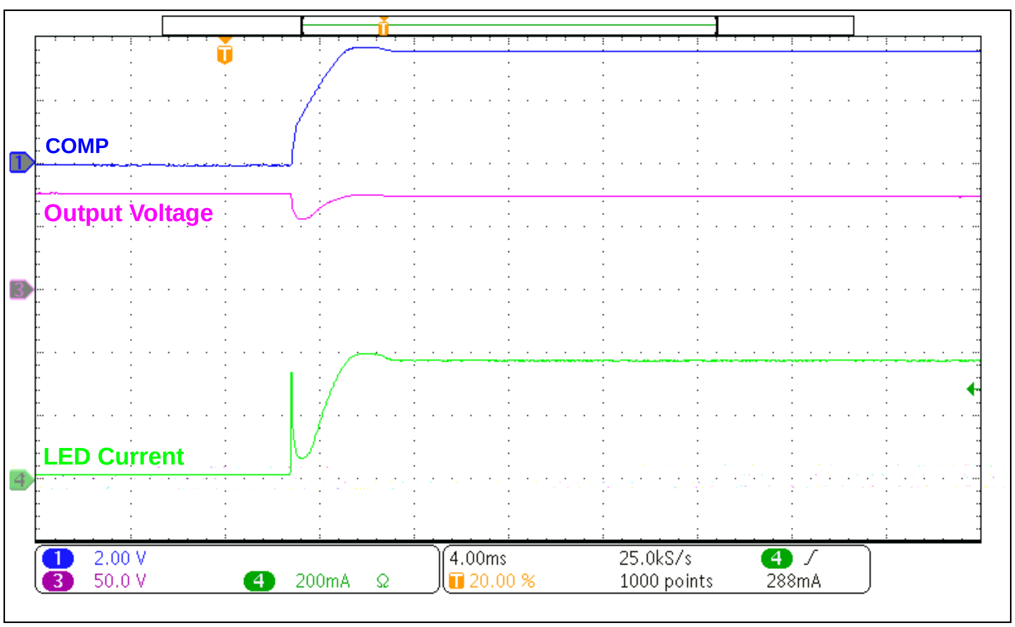


FIGURE C-6: Recovery From Open-LED Condition.

C.1.2 Short Circuit Protection

Figure C-7 shows various signals during short circuit protection. The onset of the output short circuit is indicated by the first spike in the LED current. At this point, the HV9963 shuts down and the hiccup mode protection takes over. After the hiccup time ends, the converter attempts to restart and finding the fault condition still present, shuts down again.

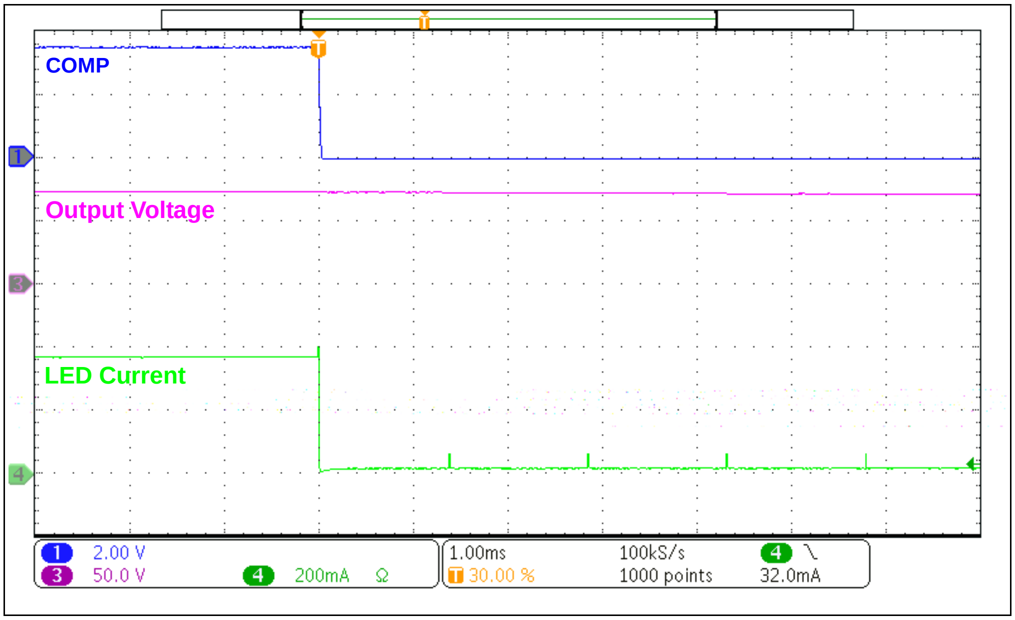


FIGURE C-7: Short Circuit Protection.

In Figure C-8, the short across the LED string is removed at some point when the converter is turned off. When the converter attempts to restart, it finds the condition has disappeared and it starts up normally. There is no overshoot in the LED current.

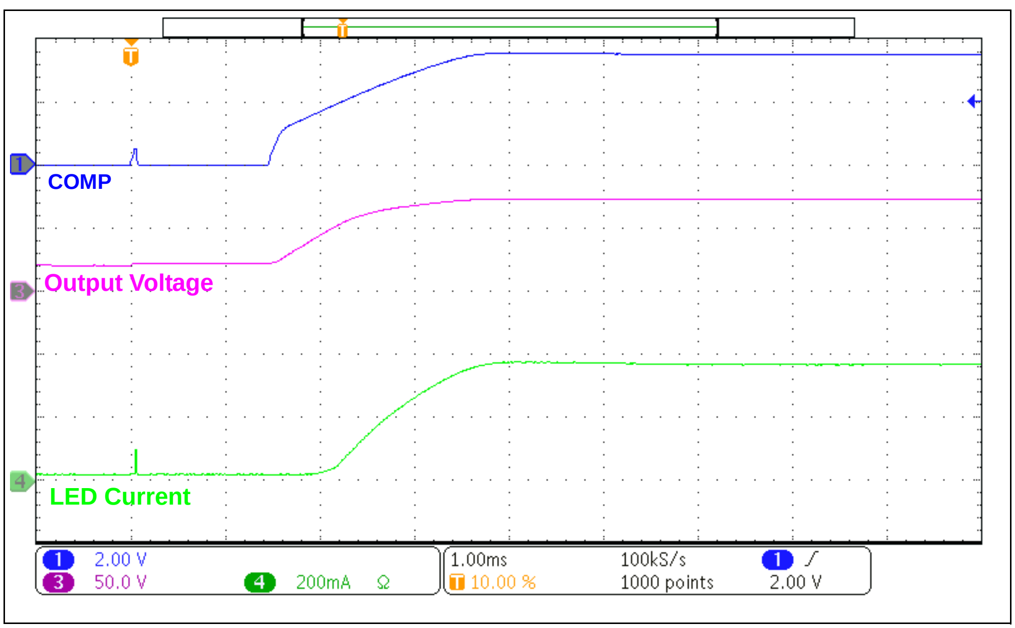


FIGURE C-8: Recovery From Short Circuit Condition.

C.1.3 PWM Dimming Edge Waveforms

Figure C-9 shows various signals during PWM dimming, when PWMD goes low. The LED current falls to zero with a fall time of about 1 µs.

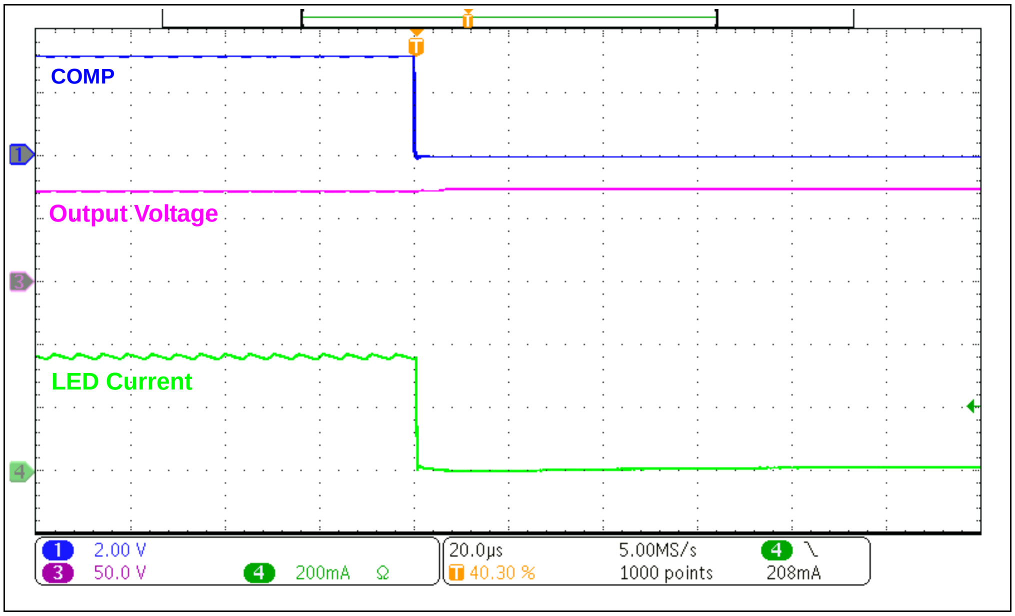


FIGURE C-9: PWM Dimming at V_{OUT} = 54V.

Figure C-10 shows various signals during PWM dimming, when PWMD goes high.The LED current reaches its final steady state value without any significant overshoot.

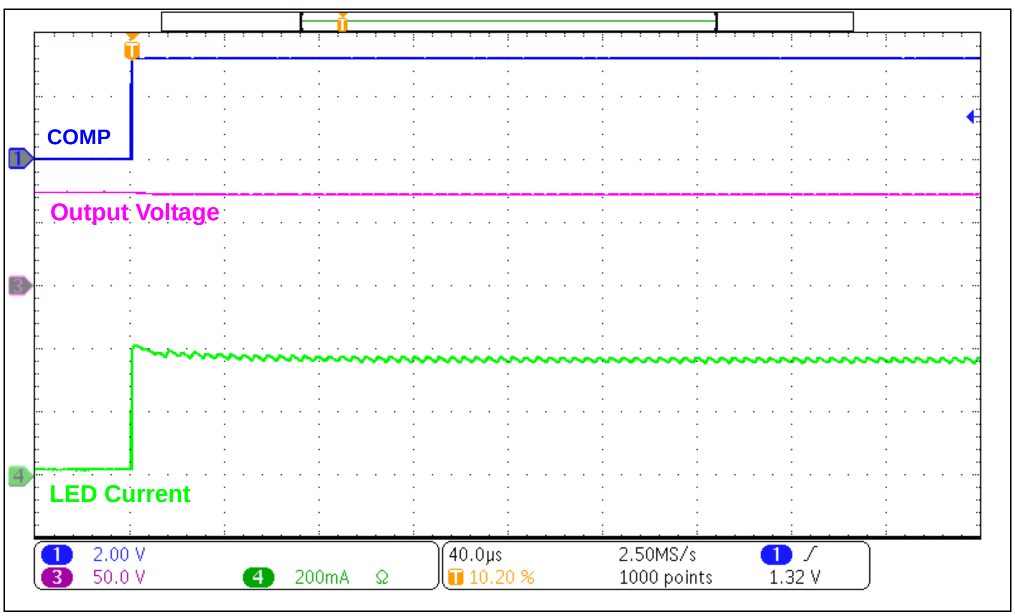


FIGURE C-10: PWM Dimming at V_{OUT} = 54V.

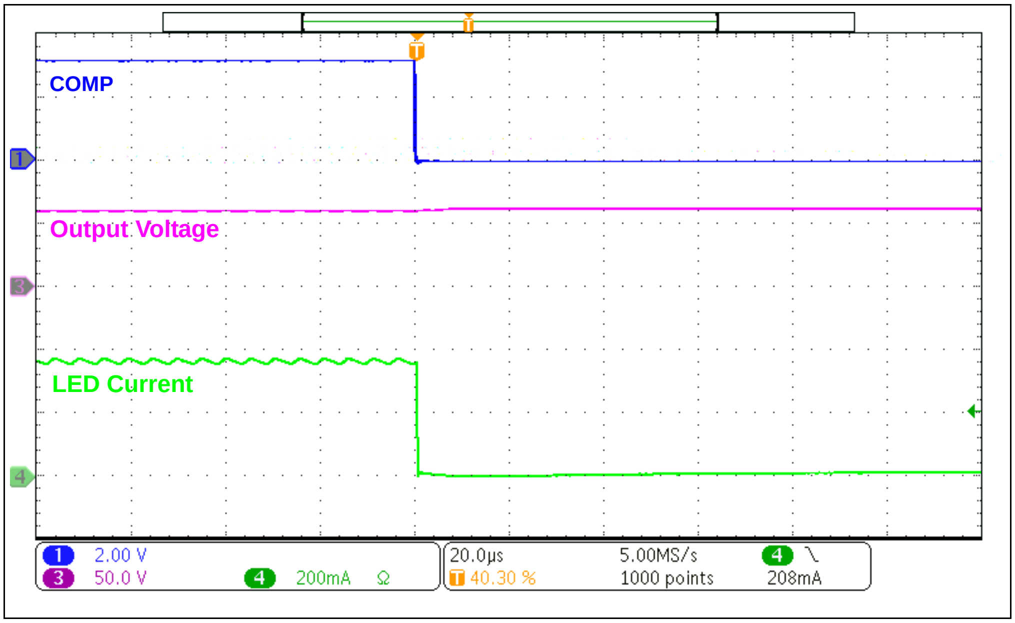


FIGURE C-11: *PWM Dimming at V_{OUT} = 40V.*

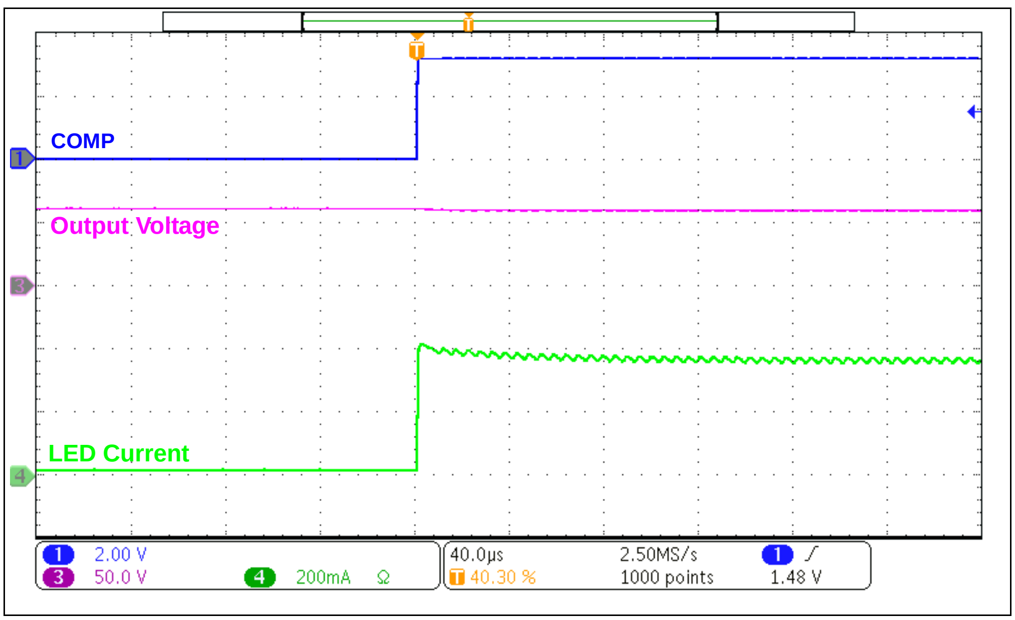


FIGURE C-12: *PWM Dimming at V_{OUT} = 40V.*

C.1.4 PWM Dimming with Narrow Pulse Widths

Figure C-13 below shows the PWMD dimming input, the GATE drive output and the LED current for a pulse width of 800 ns (which is less than 1 period of the switching frequency waveform). As shown in Figure C-13, the GATE drive does not turn off immediately when the PWMD input goes low. The frequency of the Dimming input is 1 kHz.

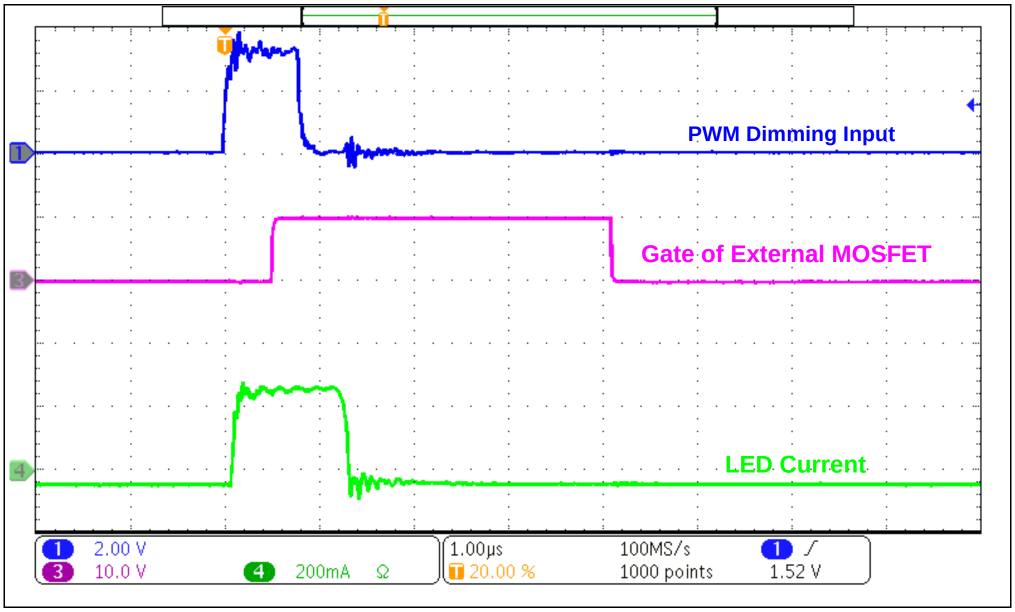


FIGURE C-13: *PWM Dimming with PWMD Pulse Width = 800 ns.*

Figure C-14 shows the PWMD dimming input, the GATE drive output and the LED current for a pulse width of 2.5 µs (less than one period of f_{sw}). Also, for this case, the LED current reaches it's required value of 350 mA. Dimming input frequency = 1 kHz.

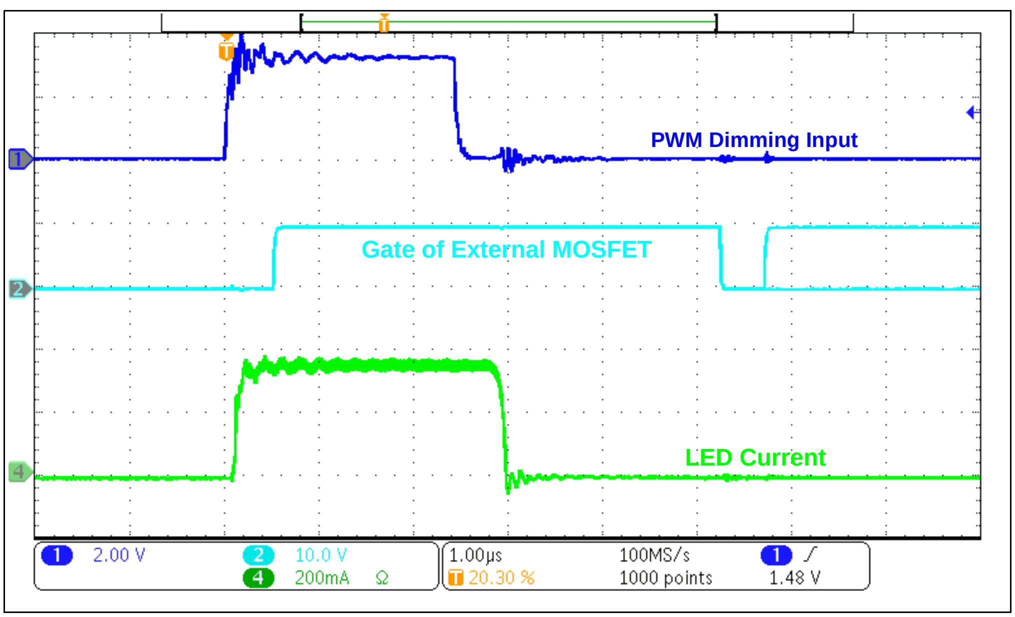


FIGURE C-14: *PWM Dimming with PWMD Pulse Width = 2.5 µs.*

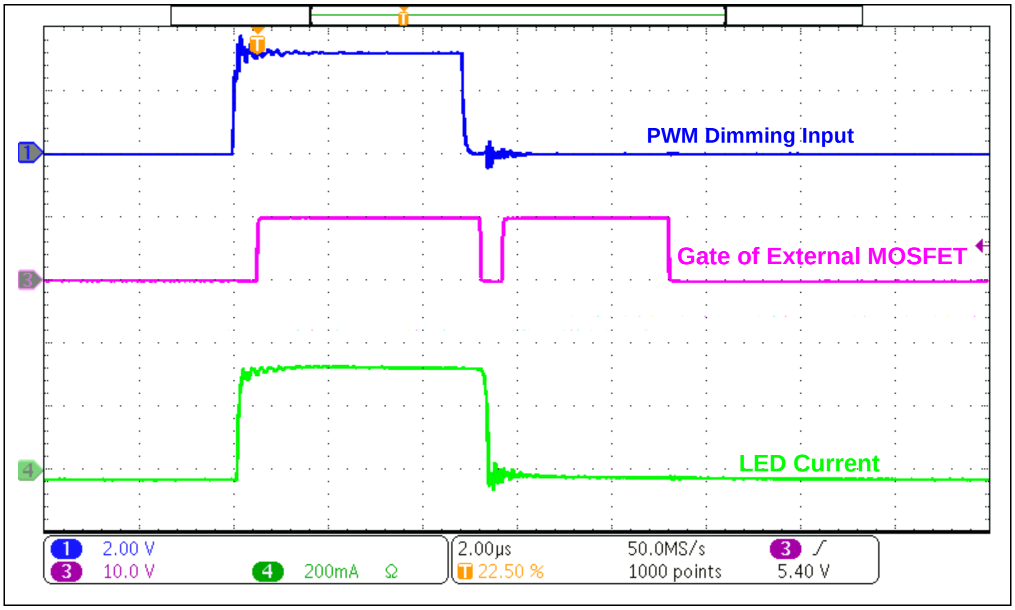


FIGURE C-15: *PWM Dimming with PWMD Pulse Width = 5 µs; Dimming Frequency = 1 kHz.*

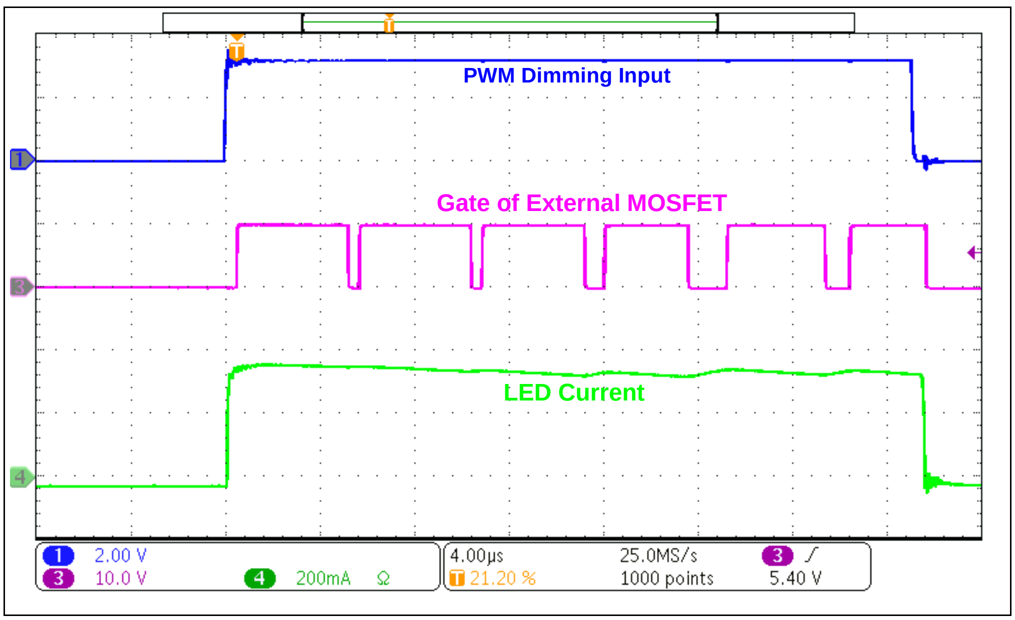


FIGURE C-16: *PWM Dimming with PWMD Pulse Width = 30 µs; Dimming Frequency = 1 kHz.*

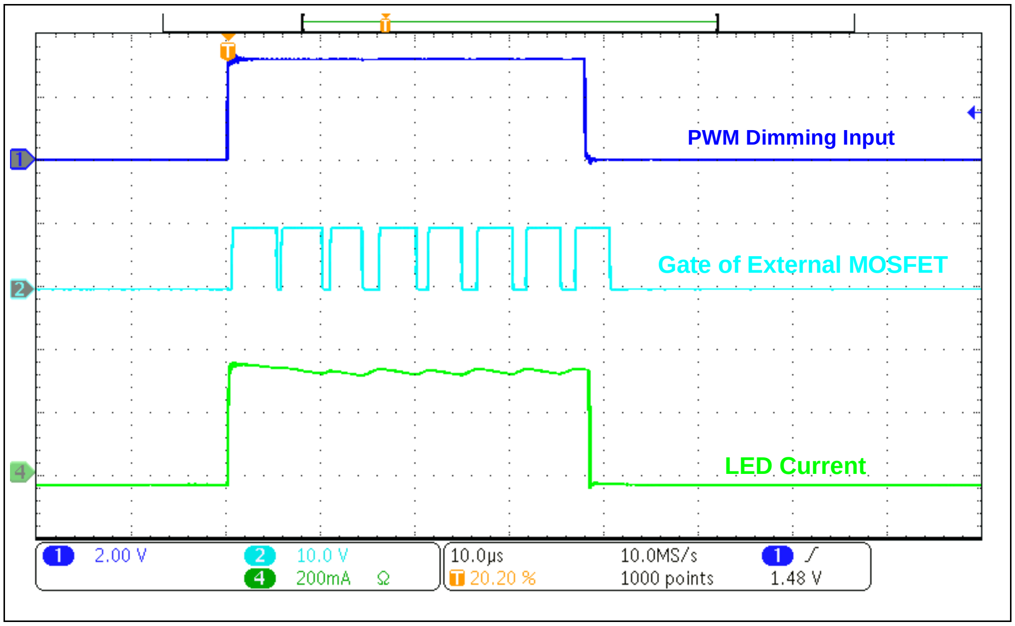


FIGURE C-17: *PWM Dimming with PWMD Pulse Width = 35 µs; Dimming Frequency = 200 Hz.*

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