TI Designs：TIDA-01635
适用于 90Hz 刷新速率虚拟/增强现实显示的背光和 LCD 偏置参考设计

说明

此参考设计介绍了可穿戴设备，尤其是增强现实 (AR) 和虚拟现实 (VR) 耳机中 LCD 显示屏的电源解决方案。LP8556 实现了高电流精度背光驱动器，可在小占空比期间提供与刷新率同步的高电流。该 LCD 偏置电源驱动器由采用小型封装的易用型 TPS65132 提供。此外还讨论了详细的设计原理、组件选择和测试结果。

资源

TIDA-01635	设计文件夹
LP8556	产品文件夹
TPS65132	产品文件夹
TPS61089	产品文件夹
TPS563201	产品文件夹

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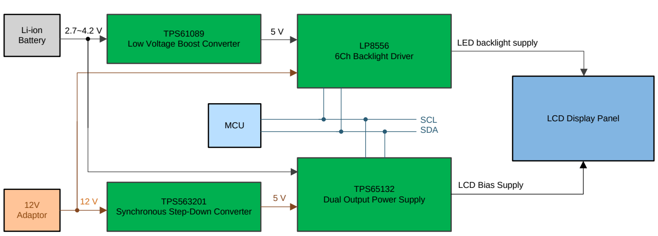
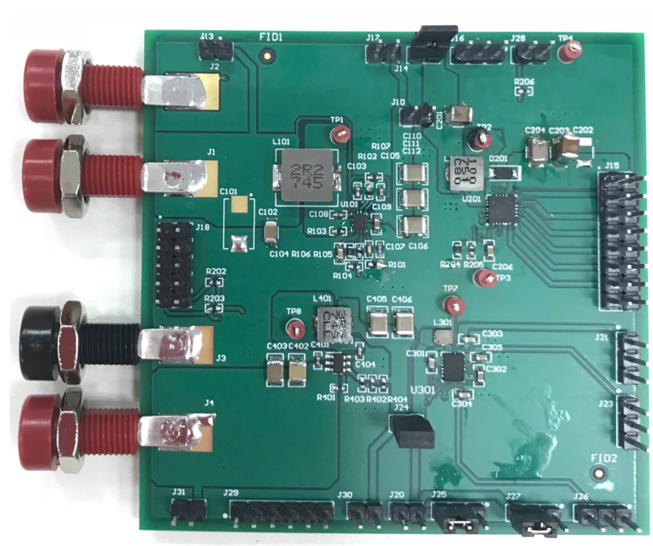
特性

- 具有 90Hz 刷新率的闪光灯背光
- 支持 50mA 电流，具有 6 个通道
- 具有 10% 占空比突发模式的背光
- 支持一节锂离子电池输入或 12V 适配器输入

应用

- 虚拟或增强现实耳机和眼镜
- 手机：智能手机
- STB 和 DVR





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1 System Description

Virtual reality (VR) and augmented reality (AR) are hot new things in technology at the moment. VR/AR headsets or glasses are essential equipment that require a high refresh rate to provide good experience. This reference design describes the high current accuracy backlight and LCD bias solution for 90-Hz refresh-rate AR/VR displays.

1.1 Key System Specifications

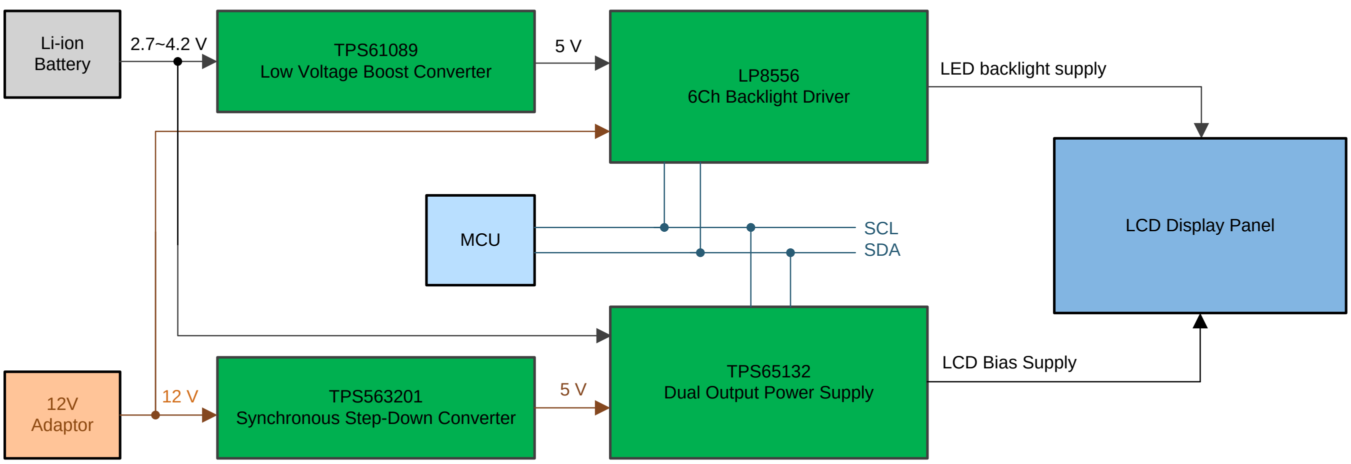
表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
V_{IN} range	One Li-ion battery input or 12-V adaptor
LED configuration	8 LEDs in series × 2 strings
High LED current	Maximum 95 mA per string × 2 strings
High current accuracy	1% accuracy and 0.5% mismatching
Dimming control	PWM dimming frequency 90 Hz, 10% duty cycle

2 System Overview

2.1 Block Diagram

图 1. TIDA-01635 Block Diagram



2.2 Design Considerations

In this reference design, a 6-channel, maximum 50 mA per channel LED backlight driver (LP8556) is used to drive 2 strings of 8-pcs LEDs with constant a 90-Hz, 10% duty strobe light. It supports an I^2C interface to online configure the device to achieve various output settings. The TPS65132 device is used as the LCD bias power supply. TPS61089 and TPS563201 are boost and buck converters, respectively, which provide proper input voltage for the backlight and bias drivers.

2.3 Highlighted Products

Key features of the devices used in this reference design are described in the following descriptions. For complete details, see the device product folders (LP8556, TPS65132, TPS61089, and TPS563201).

2.3.1 LP8556

The LP8556 is a 6-channel WLED backlight driver with wide VDD input voltage of 2.7 V to 20 V. 7-V to 43-V boost switch output-voltage range supports as few as 3 WLEDs in series per channel and as many as 12. The configurable channel count (1 to 6) supports 50 mA per channel. The boost converter uses adaptive output voltage control for setting the optimal LED driver voltages, minimizing power consumption by adjusting the output voltage to lowest sufficient level under all conditions. Output resolution can be set up to 15 bits for smoother and pleasant brightness changes. Programmable slew rate control and spread spectrum scheme minimize switching noise and improve EMI performance. In addition, phase shifted LED PWM dimming allows reduced audible noise and smaller boost output capacitors. The LP8556 has a comprehensive set of safety features that ensure robust operation of the device and external components.

2.3.2 TPS65132

The TPS65132 family is designed to supply positive/negative driven applications. The device uses a single inductor scheme for both outputs to provide the user smallest solution size, a small bill-of-material as well as high efficiency. The devices offer best line and load regulation at low noise. With its input voltage range of 2.5 V to 5.5 V, it is optimized for products powered by single-cell batteries (Li-Ion, Ni-Li, Li-Polymer) and fixed 3.3-V and 5-V rails. The TPS656132 family provides 80 mA and 150 mA output current options with programmability to 40 mA. There are both CSP and QFN package options available.

2.3.3 TPS61089

The TPS61089 is a fully-integrated synchronous boost converter with a 19-mΩ main power switch and a 27-mΩ rectifier switch. The device provides a high efficiency and small size power solution for portable equipment. The TPS61089 features wide input voltage range from 2.7 V to 12 V to support applications powered with single cell or two cell lithium-ion/polymer batteries. The TPS61089 has 7-A continuous switch current capability and provides output voltage up to 12.6 V.

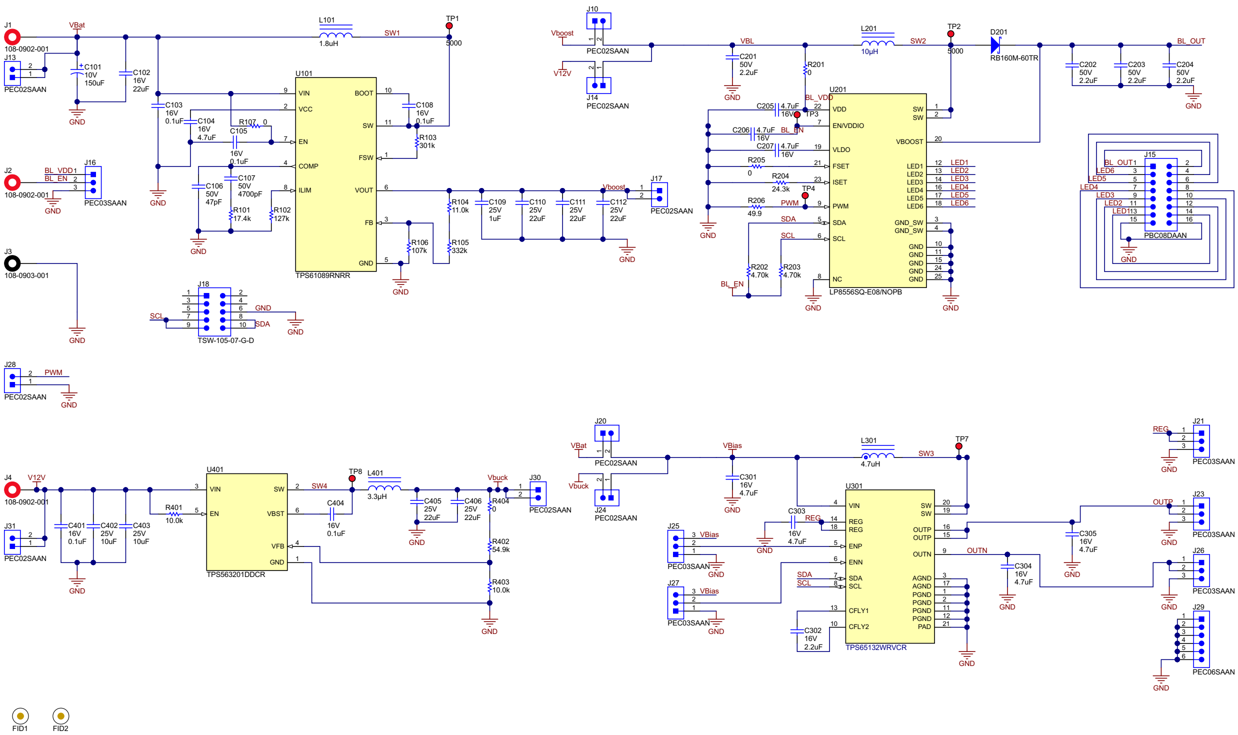
2.3.4 TPS563201

The TPS563201 is a simple, easy-to-use, 3-A synchronous step-down converter in SOT-23 package. The device is optimized to operate with minimum external component counts and also optimized to achieve low standby current. TPS563201 operates in pulse-skip mode, which maintains high efficiency during light load operation.

2.4 System Design Theory

This reference design uses one LP8556 as backlight converter to control 2 strings of LEDs. The design offers a strobe light with 10% duty at 90 Hz. In VR headset glasses, each string gives backlight to display of each eye. A TPS65132 is used to drive LCD bias. The other TPS61089 and TPS563201 converter input voltage to regulated 5 V. Either the lithium-ion battery input or 12-V adaptor input could be applied, they could not be provided both together.

图 2. TIDA-01635 Schematic



2.4.1 Backlight Driver Design

Requirements for the backlight driver:

表 2. Design Parameters

SPECIFICATION	VALUE
Input voltage (V_{IN})	5 V
Output current (I_{LED})	95 mA per string
Output LED configure	8 LEDs × 2 strings
LED maximum forward voltage (Vf)	3.5 V
Schottky diode forward voltage (Vd)	0.49 V

2.4.1.1 Boost Inductor Selection

After considering efficiency, inductor ripple current, and component form factor, a 10-µH inductor was chosen, and the driver is operating at 1250 kHz. The inductor peak-to-peak current can be calculated by 公式 1:

$$I_{pp} = \frac{1}{L \times F_s \times \left(\frac{1}{V_{out} + V_f - V_{in}} + \frac{1}{V_{in}} \right)}$$

where

- V_{IN} = 5 V
- L = 10 µH
- f_{SW} = 1250 kHz
- 8 LEDs output with V_{OUT} of 28 V
- V_F = 0.49 V (1)

The peak-to-peak current is 0.33 A, and the average input current is 1.08 A. The boost inductor then has a peak current 1.41 A. The LP8556 device current limit register is chosen maximum 2.8 A to leave some margin and allow output capacitors to charge up quickly. The inductor must have a higher saturation current than the LP8556 current to prevent current increasing suddenly due to inductor saturation.

2.4.1.2 Output Capacitor Selection

Select the output capacitor to meet requirements for output voltage ripple and loop stability of the whole system. The output capacitor can be calculated by 公式 2:

$$C_{out} = \frac{I_{out} \times (V_{out} - V_{in})}{F_s \times V_{out} \times \Delta V_{out}}$$

where

- ΔV_{OUT} is the output ripple voltage
- I_{OUT} is the total LED current, 190 mA (2)

Take care when evaluating the capacitance under DC bias. The DC bias can reduce the capacitance significantly so that the remaining valid capacitance is smaller than rated value.

2.4.1.3 Register Settings

The LP8556 device is available in two packages: DSBGA and QFN. TI recommends the QFN package for its thermal dissipation and large current capability, and it is the package used in this reference design. Additionally, LP8556 has various EPROM versions to differentiate configurations with many features. E09 version is selected in this reference design because it is allowed to use all of the 6 channels at first place. Actually, if I2C bus is available in the system, EPROMs can be rewritten all the time on line.

A few settings to consider:

1. Both large current limit range and large output voltage range are selected.
2. 95 mA is spread in 3 channels, so each channel outputs approximately 32 mA. The maximum current bits choose 50 mA and adjust the 12 bits in A0h and A1h registers to get 32 mA.
3. Output strobe current follows input the PWM signal, which is 90 Hz and 10% duty. The LP8556 device is set to direct PWM dimming mode by simply connecting PWM pin to ground.

Recommended register settings used in this reference design are shown in 表 3.

表 3. LP8556 Register Settings

ADDRESS	VALUE
98H	0x98[7]=1b
9EH	0x22
A0H	0x21
A1H	0xFA
A2H	0x29
A3H	0x02
A4H	0x72
A5H	0xF4
A6H	0x80
A7H	0xFE
A8H	0x04
A9H	0xE0
AAH	0x0F
ABH	0x00
ACH	0x00
ADH	0x00
AEH	0x0E

2.4.2 Boost Converter Design

Requirements for the boost converter:

表 4. Design Parameters

SPECIFICATION	VALUE
Minimum input voltage	2.7 V
Output current	2 A
Output voltage	5 V

2.4.2.1 Boost Inductor Selection

The inductance is primarily selected by output power and ripple current. Generally, the inductor ripple current is 20% of its average current, and the inductor value can be derived by 公式 3:

$$L_{boost} = \frac{1}{I_{in} \times 0.2 \times f_{SWw} \times \left(\frac{1}{V_{out} - V_{in}} + \frac{1}{V_{in}} \right)}$$

where

- f_{SW} is the switching frequency 500 kHz
- V_{OUT} = 5 V,
- V_{IN} = 2.7 V, (3)

I_{IN} is the average input current, which is calculated in 公式 4, taking h 0.75 as the efficiency

$$I_{in} = \frac{V_{out} \times I_{out}}{\eta \times V_{in}} \quad (4)$$

With equation 公式 3 and 公式 4, use an inductor value of 2.2 µH to calculate the peak-to-peak current in inductor:

$$I_{pp} = \frac{1}{L \times F_{sw} \times \left(\frac{1}{V_{out} - V_{in}} + \frac{1}{V_{in}} \right)} \quad (5)$$

Thus, the peak inductor current is I_{IN} + 0.5 × I_{PP}, which is 5.5 A.

2.4.2.2 Output Capacitor Selection

Similar to 节 2.4.1.2, the boost output capacitor is selected by considering the output voltage ripple. Three 22-uF ceramic capacitors are used in this reference design to provide steady output voltage for backlight driver input.

2.4.2.3 Compensation Design

The COMP pin is the output of the internal trans-conductance error amplifier. Use 公式 6 and 公式 7 to calculate R101 and C107 in 图 1:

$$R_{101} = \frac{2\pi \times V_{out} \times R_{sense} \times f_c \times C_{out}}{(1 - D) \times V_{ref} \times G_{EA}} \quad (6)$$

$$C_{107} = \frac{R_{out} \times C_{out}}{2 \times R_{101}}$$

where

- R_{SENSE} is the equivalent internal current sense resistor (0.08 Ω)
- D is the duty cycle by (V_{OUT} – V_{IN}) / V_{OUT}
- C_{OUT} = output capacitor
- GEA is the error amplifier's trans-conductance (GEA = 190 µA/V) (7)

The value of C106 an be calculated by 公式 8:

$$C_{106} = \frac{R_{ESR} \times C_{out}}{R_{101}} \quad (8)$$

As the output capacitor is the ceramic capacitor, the ESR is relatively small, so that C106 is very small. In this reference design, a 47-pF capacitor is used to filter the noise on COMP pin.

2.4.3 Buck Converter Design

Requirements for the buck converter as shown in 表 5:

表 5. Design Parameters

SPECIFICATION	VALUE
Input voltage	12 V
Output current	1 A
Output voltage	5 V

2.4.3.1 Output Filter Selection

Design the output LC filter of buck converter to achieve a robust system. Choose the inductor and capacitor of the LC filter according to 表 2 in the TPS563201 data sheet.

The peak-to-peak current in filter inductor can be calculated by 公式 9:

$$I_{pp} = \frac{V_{out}}{V_{in}} \times \frac{V_{in} - V_{out}}{L_{buck} \times F_{sw}}$$

where

- V_{IN} = 12 V
- V_{OUT} = 5 V
- f_{SW} = 580 kHz
- L_{BUCK} = 3.3 µH (9)

The output peak current in inductor is:

$$I_{peak} = I_{out} + \frac{I_{pp}}{2} \tag{10}$$

公式 10 yields a 1.8-A peak current.

The RMS current is:

$$I_{rms} = \sqrt{I^2_{out} + \frac{1}{12} I^2_{pp}} \tag{11}$$

公式 11 yields 1.1 A.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

This reference design is applicable to either a lithumi-ion battery or a 12-V adaptor. In the test, a DC power supply is used to provide power supply. Take care that only one supply input is connected once. The battery and adaptor cannot be connected together.

As for the load of this reference design, a LED load board is used for LP8556 output, and 2 resisters are used as the load of TPS65132.

3.1.2 Software

The LP8556 GUI and TPS65132 GUI can be downloaded for use with this reference design.

3.2 Testing and Results

3.2.1 Test Setup

This reference design can be applied to two kinds of input voltage source. One is single cell lithium-ion battery, connecting to J1 and J3 (GND); the other is 12-V adaptor, connecting to J4 and J3 (GND). *Take care that J1 and J4 are not connected at the same time*.

A six strings of eight LEDs in series are loaded by the backlight driver LP8556 and connected to J15. To configure LP8556 with required LED current and settings, USB2ANY is connecting to J18 to communicate between GUI and device.

3.2.2 Test Results

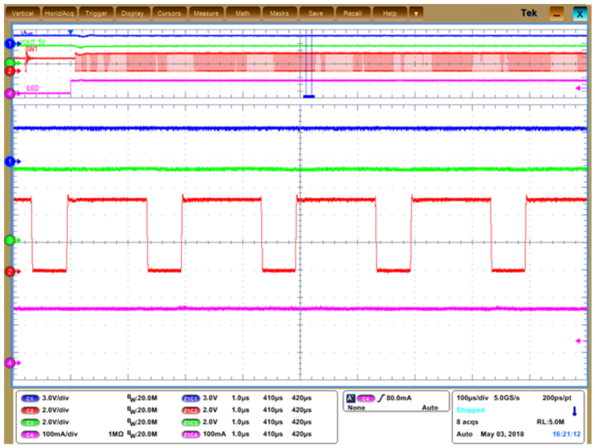
3.2.2.1 Battery Input

With a battery voltage source input, TPS61089 and LP8556 operate to drive the backlight LEDs. TPS65132 is powered by a battery directly to drive the bias. A power source with 3.7 V is used to simulate battery voltage. 图 3, 图 4, 图 5, 图 6, 图 7, and 图 8 show the operations waveforms.

图 3. TIDA-01635 Boost Waveforms

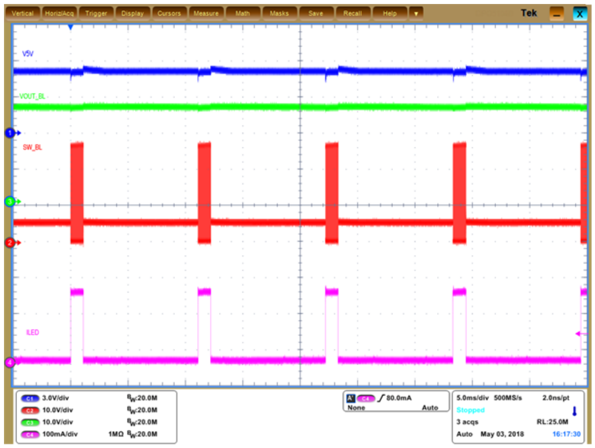
CH1: input voltage
CH2: TPS61089 output 5 V
CH3: TPS61089 switching waveform
CH4: LP8556 output current

图 4. TIDA-01635 Boost Waveforms (Zoomed In)



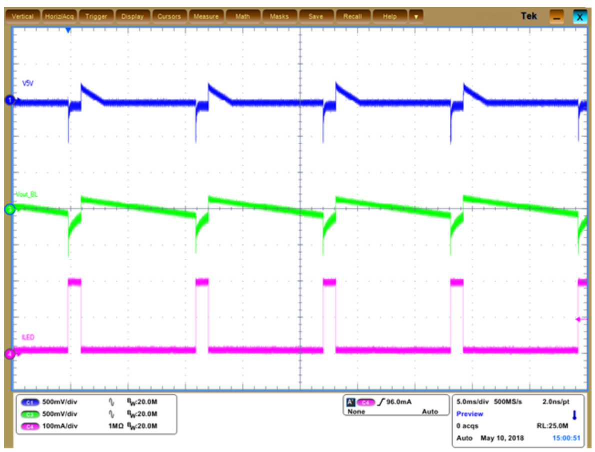
CH1: input voltage
CH2: TPS61089 output 5 V
CH3: TPS61089 switching waveform
CH4: LP8556 output current

图 5. TIDA-01635 LP8556 Backlight Driver Waveforms



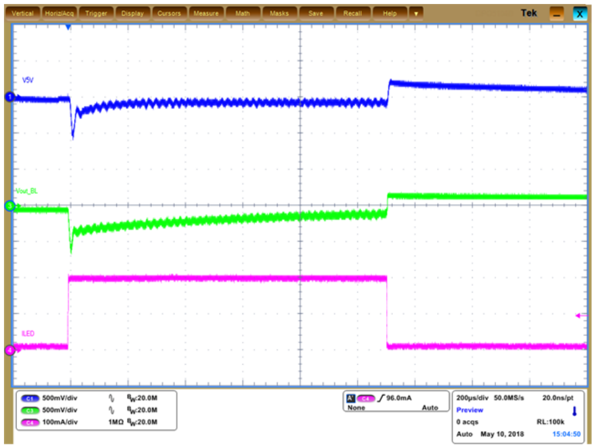
CH1 TPS61089 output 5 V
CH2: LP8556 backlight output voltage
CH3: LP8556 backlight switching waveform
LP8556 output current

图 6. TIDA-01635 Voltage-Ripple Waveforms



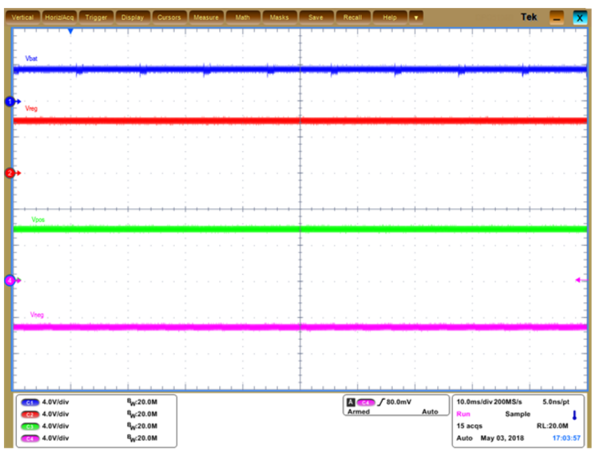
CH1 TPS61089 output 5 V
CH4: LP8556 output current
CH3: LP8556 backlight output voltage

图 7. Voltage-Ripple Waveforms (Zoomed In)



CH1: TPS61089 output 5 V
CH3: LP8556 backlight output voltage
CH4: LP8556 output current

图 8. TIDA-01635 TPS65132 Waveforms

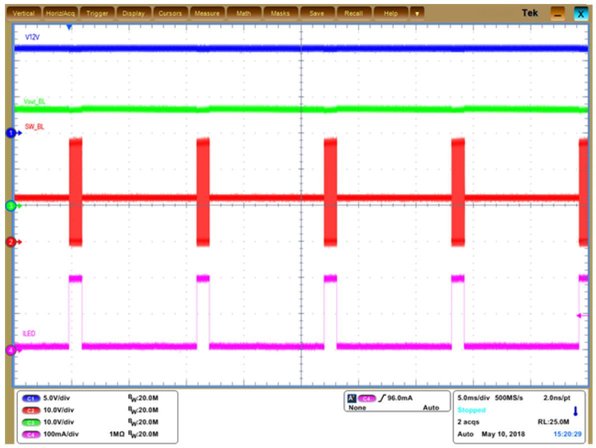


CH1: input voltage
CH2: regulated voltage
CH3: positive output voltage
CH4: negative output voltage

3.2.2.2 12-V Input

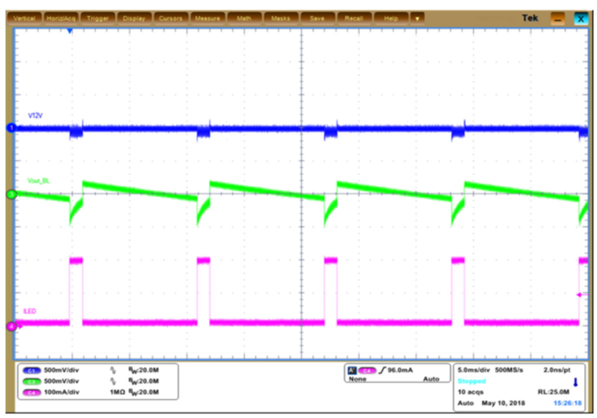
A 12-V adaptor voltage is applied to LP8556 directly to drive the backlight LEDs. The TPS563201 device is used to step down 12 V to 5 V and then applied to bias driver TPS65132. 图 9, 图 10, 图 11, 图 12, and 图 13 show the waveforms of operations.

图 9. TIDA-01635 LP8556 Backlight Driver Waveforms at 12 V_{IN}



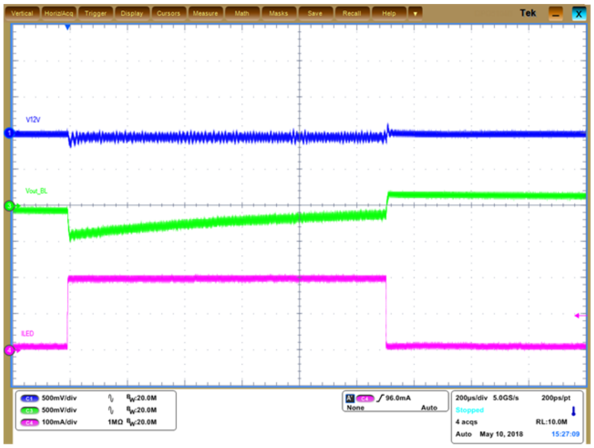
CH1 12-V input voltage
CH2: LP8556 backlight output voltage
CH3: LP8556 backlight switching waveform
CH4: LP8556 output current

图 10. TIDA-01635 Voltage-Ripple Waveforms at 12 V_{IN}



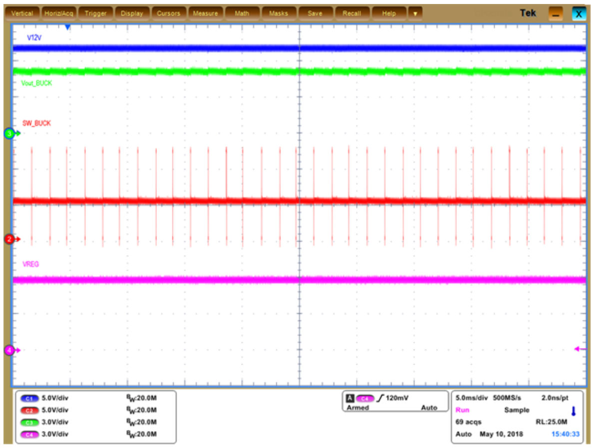
CH1 12-V input voltage
CH2: LP8556 backlight output voltage
CH3: LP8556 backlight switching waveform
CH4: LP8556 output current

图 11. TIDA-01635 Voltage-Ripple Waveforms (Zoomed In) at 12 V_{IN}



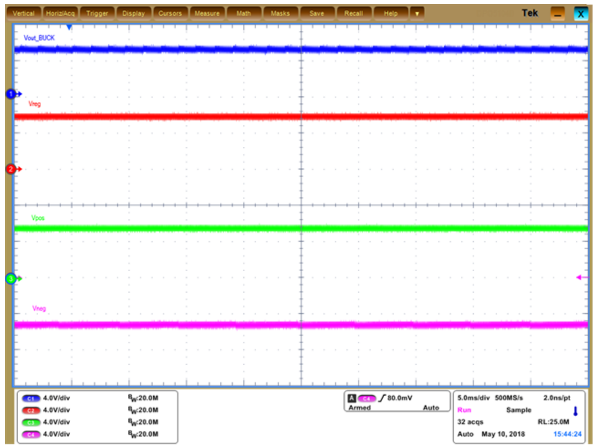
CH1 12-V input voltage
CH2: LP8556 backlight output voltage
CH3: LP8556 backlight switching waveform
CH4: LP8556 output current

图 12. TIDA-01635 Buck Waveforms



CH1 12-V input voltage
CH2: TPS563201 5-V output
CH3: TPS563201 switching waveform
CH4: TPS65132 output voltage

图 13. TIDA-01635 TPS65132 Waveforms at 12 V_{IN}



CH1: output voltage of buck converter
CH2: regulated voltage
CH3: positive output voltage
CH4: negative output voltage

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01635.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01635.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01635.

4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-01635.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01635.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01635.

5 Software Files

To download the software files, see the design files at TIDA-01635.

6 Related Documentation

1. *LP8556 High-Efficiency LED Backlight Driver for Tablets*
2. *TPS65132 Single Inductor - Dual Output Power Supply*
3. *TPS56320x 4.5-V to 17-V Input, 3-A Synchronous Step-Down Voltage Regulator in SOT-23*

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7 About the Author

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