

TI Designs: TIDA-01635

Backlight and LCD Bias Reference Design for 90-Hz Refresh-Rate Virtual / Augmented Reality Displays



Description

This reference design describes the power solution for LCD displays in wearable devices, especially in augmented-reality (AR) and virtual reality (VR) headsets. The high current accuracy backlight driver is achieved by LP8556, which provides high current during small duty cycle synchronized with refresh rate. The LCD bias power driver is provided by TPS65132, which is simple to use and has a small package. The detailed design theory, component selection, and test results are also discussed.

Resources

| | |
|----------------------------|----------------|
| TIDA-01635 | Design Folder |
| LP8556 | Product Folder |
| TPS65132 | Product Folder |
| TPS61089 | Product Folder |
| TPS563201 | Product Folder |

Features

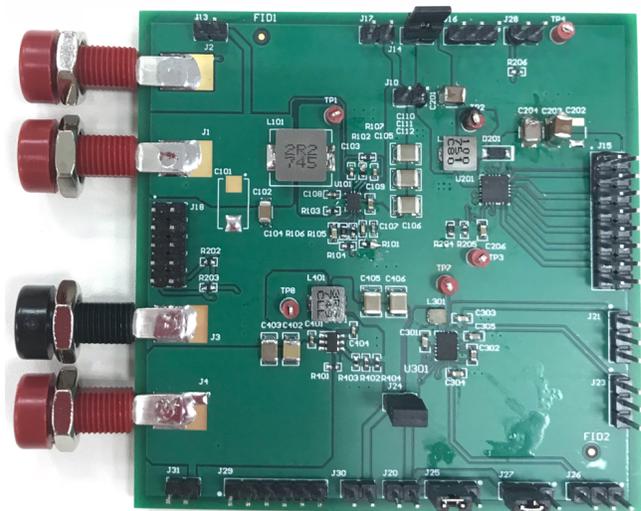
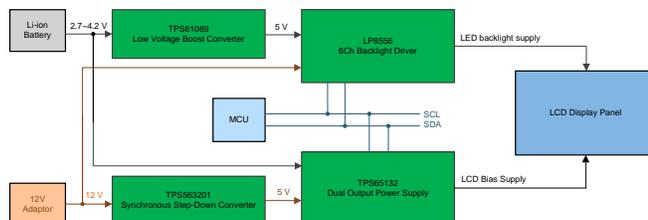
- Strobe Backlight With 90 Hz
- Supports 50 mA With 6 Channels
- Backlight on With 10% Duty Burst Mode
- Supports One Li-ion Battery Input or 12-V Adaptor Input

Applications

- [Virtual and Augmented Reality Headsets and Glasses](#)
- [Handset: Smartphone](#)
- [STB and 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

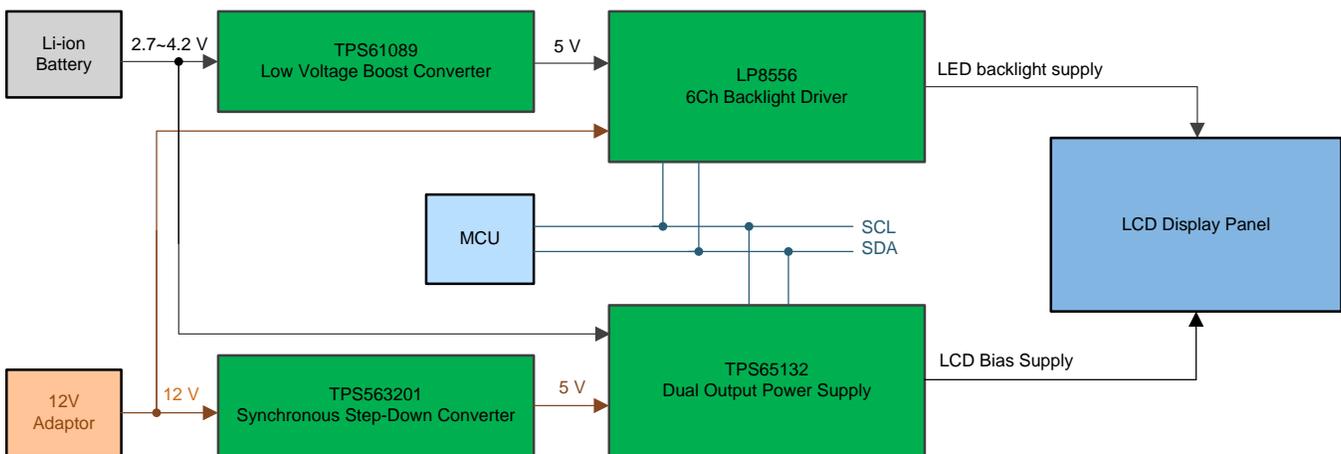
Table 1. Key System Specifications

| 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

Figure 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 I²C 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-m Ω main power switch and a 27-m Ω 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.

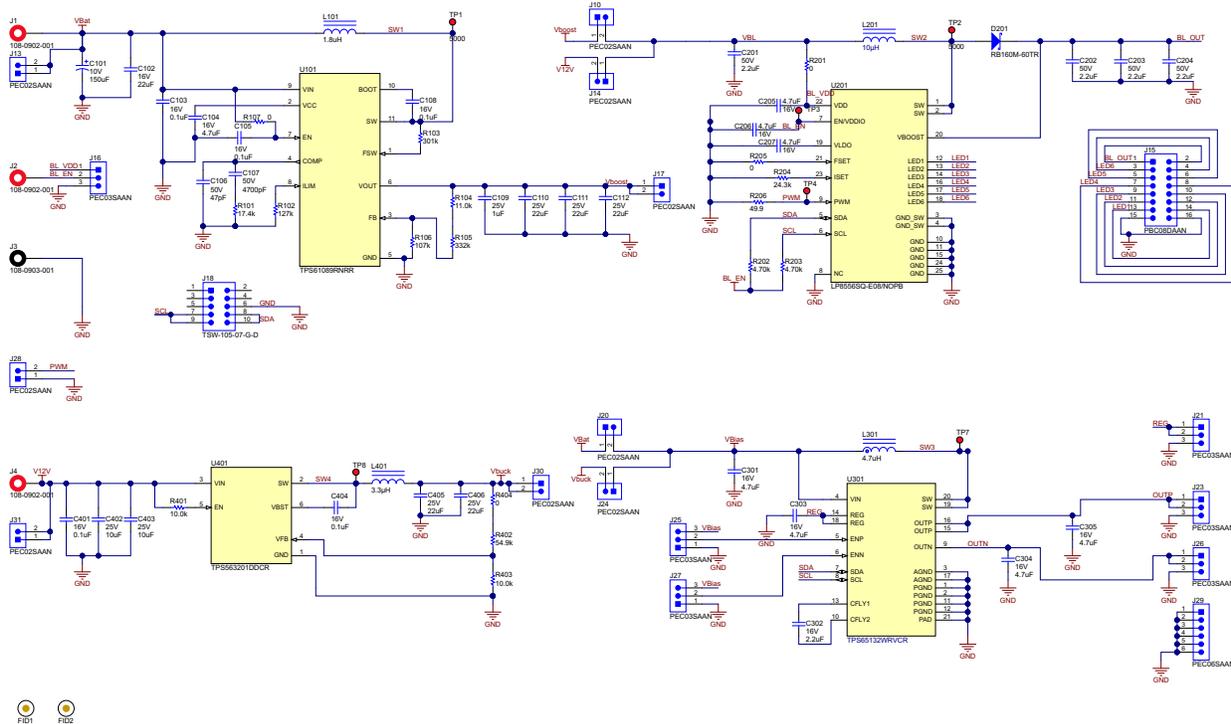
2.3.4 TPS563201

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.

Figure 2. TIDA-01635 Schematic



2.4.1 Backlight Driver Design

Requirements for the backlight driver:

Table 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 (V_f) | 3.5 V |
| Schottky diode forward voltage (V_d) | 0.49 V |

2.4.1.1 Boost Inductor Selection

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

$$I_{pp} = 1L \times F_{sw} \times (1V_{out} + V_f - V_{in} + 1V_{in})$$

where

- $V_{IN} = 5$ V
- $L = 10$ μ H
- $f_{SW} = 1250$ 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 Equation 2:

$$C_{out} = I_{out} \times V_{out} - V_{in} F_{sw} \times V_{out} \times \Delta V_{out}$$

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 [Table 3](#).

Table 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:

Table 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 [Equation 3](#):

$$L_{\text{boost}} = 1 I_{\text{in}} \times 0.2 \times f_{\text{SW}} \times (V_{\text{out}} - V_{\text{in}}) / \Delta I_{\text{in}}$$

where

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

I_{IN} is the average input current, which is calculated in [Equation 4](#), taking η 0.75 as the efficiency

$$I_{\text{in}} = V_{\text{out}} \times I_{\text{out}} / \eta \times V_{\text{in}}$$
(4)

With equation [Equation 3](#) and [Equation 4](#), use an inductor value of 2.2 μH to calculate the peak-to-peak current in inductor:

$$I_{\text{pp}} = 1 L \times f_{\text{sw}} \times (V_{\text{out}} - V_{\text{in}}) / \Delta I_{\text{in}}$$
(5)

Thus, the peak inductor current is $I_{\text{IN}} + 0.5 \times I_{\text{PP}}$, which is 5.5 A.

2.4.2.2 Output Capacitor Selection

Similar to [Section 2.4.1.2](#), the boost output capacitor is selected by considering the output voltage ripple. Three 22- μF 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 [Equation 6](#) and [Equation 7](#) to calculate R101 and C107 in [Figure 1](#):

$$R_{101} = 2\pi \times V_{\text{out}} \times R_{\text{sense}} \times f_{\text{c}} \times C_{\text{out}1} \times D \times V_{\text{ref}} \times \text{GEA}$$
(6)

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

where

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

The value of C106 can be calculated by [Equation 8](#):

$$C_{106} = \text{RESR} \times C_{\text{out}1} \times R_{101}$$
(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 [Table 5](#):

Table 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 [Table 2](#) in the TPS563201 data sheet.

The peak-to-peak current in filter inductor can be calculated by [Equation 9](#):

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

where

- $V_{IN} = 12 \text{ V}$
 - $V_{OUT} = 5 \text{ V}$
 - $f_{SW} = 580 \text{ kHz}$
 - $L_{BUCK} = 3.3 \text{ } \mu\text{H}$
- (9)

The output peak current in inductor is:

$$I_{peak} = I_{out} + I_{pp} / 2$$
(10)

[Equation 10](#) yields a 1.8-A peak current.

The RMS current is:

$$I_{rms} = \sqrt{I_{out}^2 + \frac{1}{3} I_{pp}^2}$$
(11)

[Equation 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 lithium-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 resistors 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.*

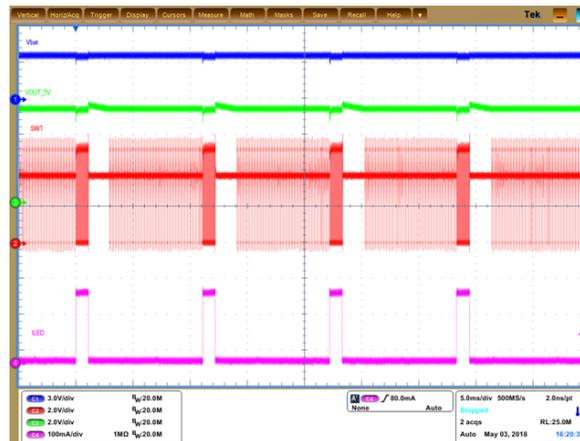
A six strings of eight LEDs in series are loaded by the backlight driver LP8556 and connected to J15. To configure LP8556 with required LED current and settings, USB2ANY is connecting to J18 to communicate between GUI and device.

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. [Figure 3](#), [Figure 4](#), [Figure 5](#), [Figure 6](#), [Figure 7](#), and [Figure 8](#) show the operations waveforms.

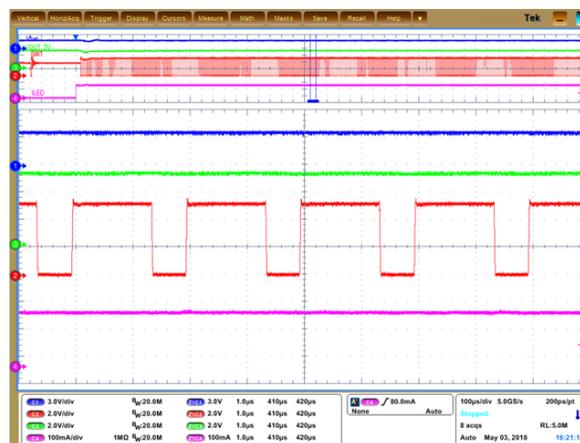
Figure 3. TIDA-01635 Boost Waveforms



CH1: input voltage
CH2: TPS61089 output 5 V

CH3: TPS61089 switching waveform
CH4: LP8556 output current

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



CH1: input voltage
CH2: TPS61089 output 5 V

CH3: TPS61089 switching waveform
CH4: LP8556 output current

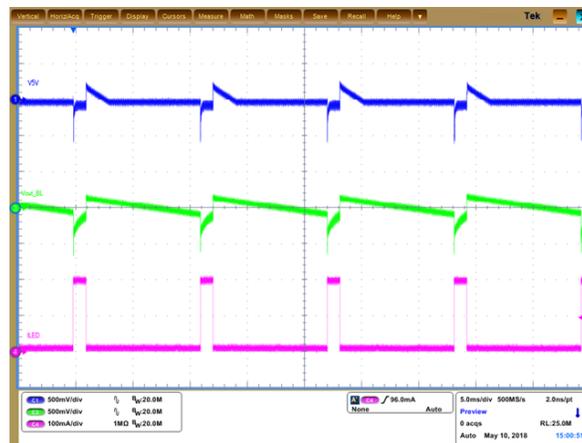
Figure 5. TIDA-01635 LP8556 Backlight Driver Waveforms



CH1 TPS61089 output 5 V
CH2: LP8556 backlight output voltage

CH3: LP8556 backlight switching waveform
LP8556 output current

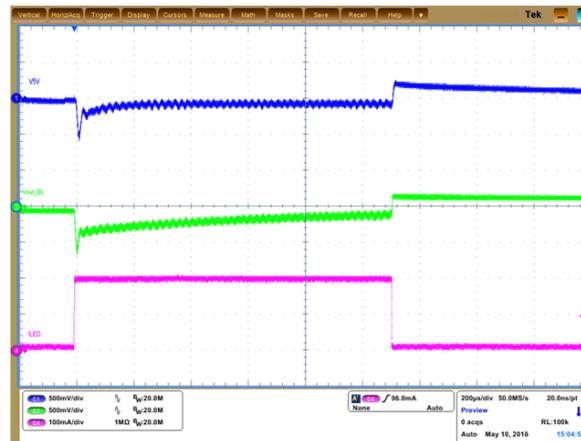
Figure 6. TIDA-01635 Voltage-Ripple Waveforms



CH1 TPS61089 output 5 V
CH4: LP8556 output current

CH3: LP8556 backlight output voltage

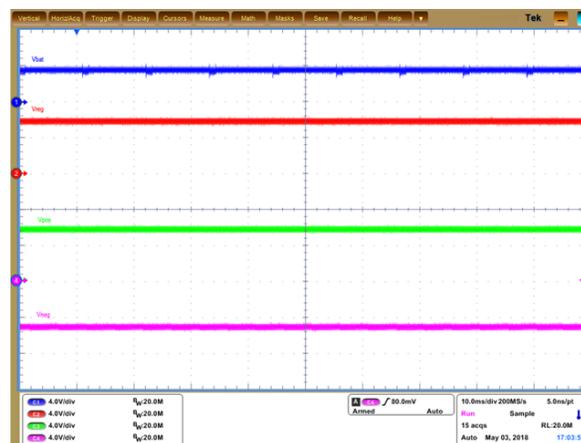
Figure 7. Voltage-Ripple Waveforms (Zoomed In)



CH1: TPS61089 output 5 V
CH4: LP8556 output current

CH3: LP8556 backlight output voltage

Figure 8. TIDA-01635 TPS65132 Waveforms



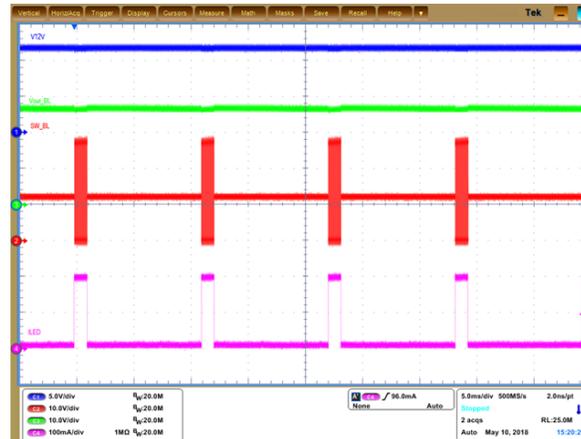
CH1: input voltage
CH2: regulated voltage

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. Figure 9, Figure 10, Figure 11, Figure 12, and Figure 13 show the waveforms of operations.

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



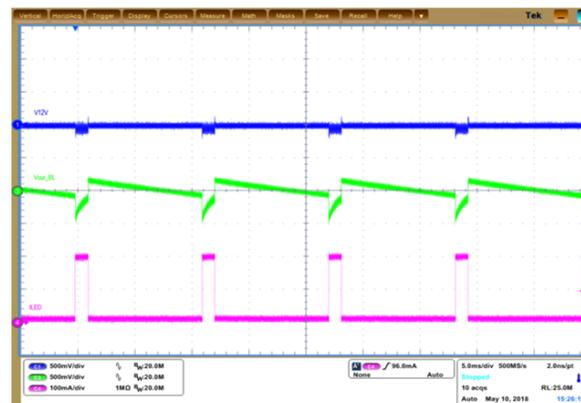
CH1 12-V input voltage

CH2: LP8556 backlight output voltage

CH3: LP8556 backlight switching waveform

CH4: LP8556 output current

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



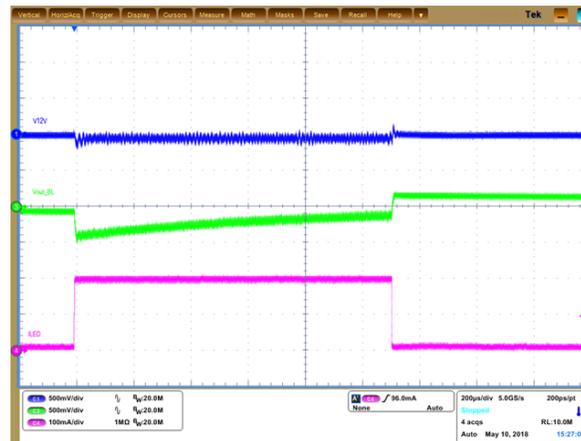
CH1 12-V input voltage

CH2: LP8556 backlight output voltage

CH3: LP8556 backlight switching waveform

CH4: LP8556 output current

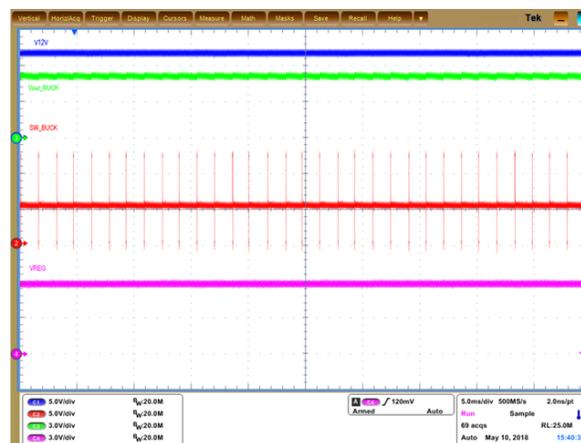
Figure 11. TIDA-01635 Voltage-Ripple Waveforms (Zoomed In) at 12 V_{IN}



CH1 12-V input voltage
CH2: LP8556 backlight output voltage

CH3: LP8556 backlight switching waveform
CH4: LP8556 output current

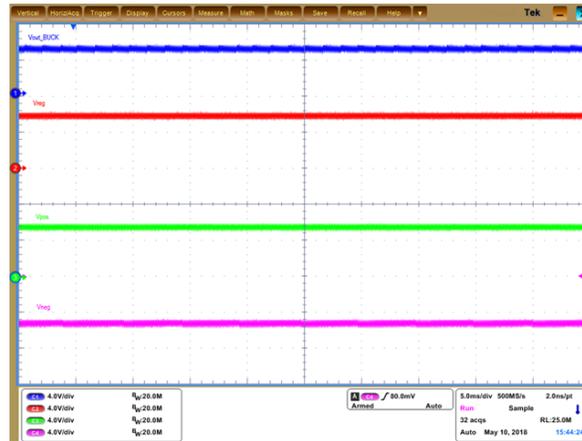
Figure 12. TIDA-01635 Buck Waveforms



CH1 12-V input voltage
CH2: TPS563201 5-V output

CH3: TPS563201 switching waveform
CH4: TPS65132 output voltage

Figure 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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