# TI Designs: TIDA-01348
# CISPR 25 Class-5 Rated 7.5-W Tail-Light Reference Design for Automotive LED Lighting System

## Description

The TIDA-01348 TI Design details a solution for an automotive tail-light application. The design features the TPS92638-Q1 linear LED driver powered by a synchronous buck converter (LM53601-Q1) that is directly supplied from the automotive-battery voltage. This design helps pass CISPR 25 Class-5 conduct emission and radiated emission without a common-mode choke coils (CMCC) filter and also optimizes the solution efficiency.

## Resources

| | |
|---|---|
| TIDA-01348 | Design Folder |
| LM53601-Q1 | Product Folder |
| TPS92638-Q1 | Product Folder |
| TLC2274A-Q1 | Product Folder |

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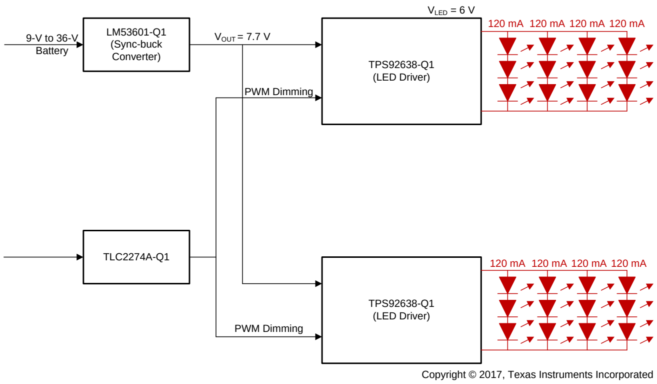
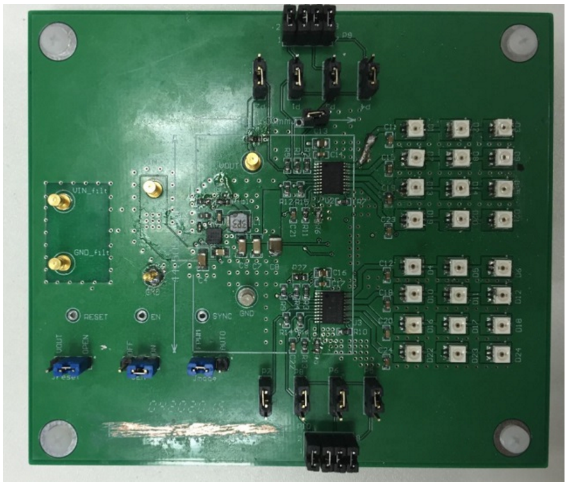
## Features

- 9-V to 36-V Input, Eight-Channel LED Lighting, and 7.5-W Total Output
- Synchronous Buck Converter With 2.1 MHz
- In Compliance With CISPR 25 Class-5 Conducted Emissions Standard; Passes both AM and FM Radio Band Tests Without CMCC Filter
- Internal Compensation for Ease of Use
- Solution Size 42.5 mm × 32.6 mm; Four-Layer Board, 1-oz Copper Layer

## Applications

- Automotive LED Lighting



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# 1 System Description

The TIDA-01348 is a CISPR 25 Class-5 rated 7.5-W tail-light reference design which features the TPS92638-Q1 linear light-emitting diode (LED) driver powered by a synchronous buck converter (LM53601) that is directly supplied from the automotive-battery voltage. This design applies to automotive high-brightness lighting such as headlights and taillights and also interior LED lighting systems. This design passes CISPR 25 Class-5 conducted emissions and radiated emissions without a CMCC filter and also optimizes the solution efficiency.

## 1.1 Key System Specifications

**Table 1. Key System Specifications**

| PARAMETER | COMMENTS | SPECIFICATION |
|---|---|---|
| $V_{IN}$ minimum | Minimum input voltage | 9-V DC |
| $V_{IN}$ maximum | Maximum input voltage | 36-V DC |
| $V_{OUT\_Buck}$ | Buck output voltage | 7.7-V DC |
| $V_{OUT\_LED}$ | LED output voltage | 6 V (max) |
| $I_{OUT}$ | Output current | 1 A |
| $I_{LED}$ | LED drive current (per channel) | 120 mA |
| $f_s$ J5 | Buck switching frequency | 2.1 MHz |
| $I_{Dim}$ J7 | LED dimming | 0 mA to 120 mA |

# 2 System Overview

## 2.1 Block Diagram

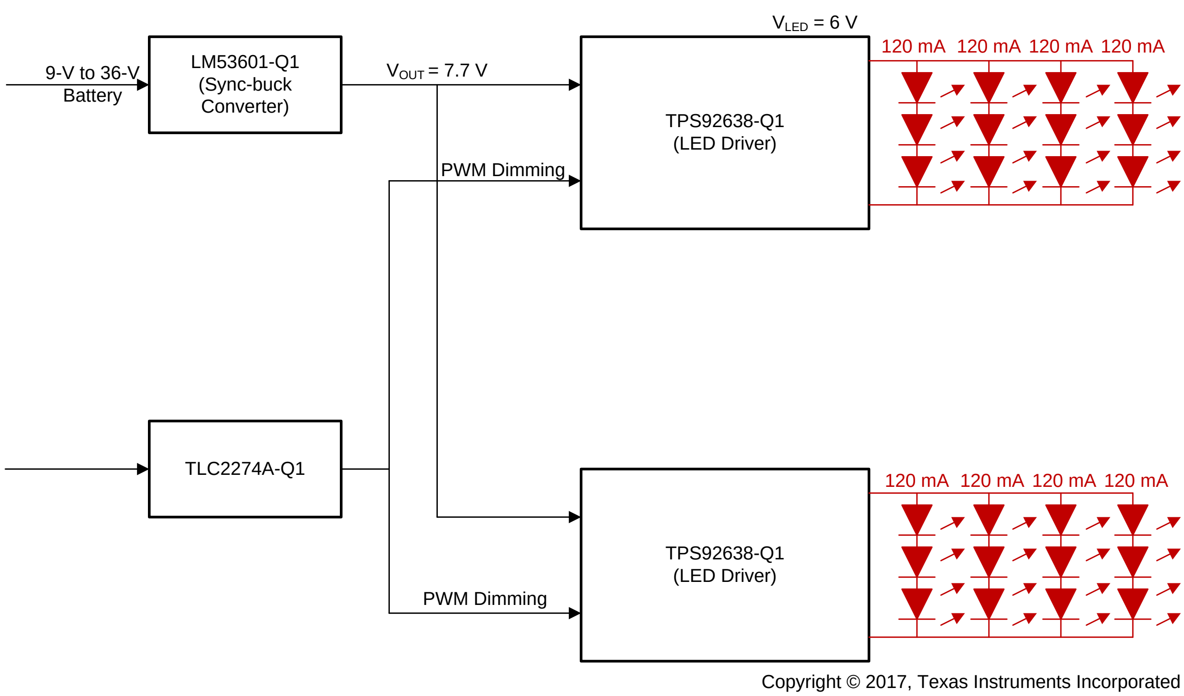


**Figure 1. TIDA-01348 Block Diagram**

## 2.2 Highlighted Products

### 2.2.1 LM53601-Q1

- AEC-Q100 qualified with –40°C to 125°C ambient operating temperature range
- Wide operating input voltage: 3.55 V to 36 V (with transient to 42 V)
- Spread spectrum option available
- 2.1-MHz fixed switching frequency
- Low output voltage noise: 25 $\mu V_{RMS}$
- Pin-selectable forced pulse-width modulation (PWM) mode
- External frequency synchronization
- Internal compensation
- 10-lead, 3-mm x 3-mm SON package with wettable flanks

### 2.2.2 TPS92638-Q1

- AEC-Q100 qualified with –40°C to 125°C ambient operating temperature range
- Eight-channel LED driver with analog and PWM
- Four-bank PWM dimming to control eight channels
- Open- and shorted-LED detection with deglitch
- Single resistor for stop-current set point
- Single resistor for tail-current set point
- Package: 20-pin thermally enhanced PWP package (PDSO)

### 2.2.3 TLC2274A-Q1

- AEC-Q100 qualified with –40°C to 125°C ambient operating temperature range
- Output swing includes both supply rails
- Low noise: 9 $nV/\sqrt{Hz}$ typical at f = 1 kHz
- Fully specified for both single-supply and split-supply operation
- Common-mode input voltage range includes negative rail
- High-gain bandwidth: 2.2 MHz typical
- High slew rate: 3.6 V/µs typical

# 3 System Design

## 3.1 Buck Converter Design

The LM53601 is available in 3.3-V or 5.0-V fixed and adjustable versions, which can be programmed using a resistor divider and feedback voltage. With a red LED, each maximum drop voltage is about 2.0 V. A 1.5-V drop out between $V_{IN}$ and $V_{OUT}$ of LED driver is required to deliver 120 mA per channel.

When setting the output voltage of the LM53601 device at 7.7 V and $R_{fb2}$ = 10 kΩ, $R_{fb1}$ can be derived using Equation 1.

$$R_{fbl} = \left( \frac{V_{OUT\_BUCK}}{V_{REF}} - 1 \right) \times R_{fb2} = 67\ k\Omega \quad (1)$$

where,

- $V_{REF}$ is the reference voltage of LM53601 and is equal to 2 V.

In the buck converter, the ripple of the inductor enlarges with the input voltage rising. During a 7.7-$V_{OUT}$ condition, the minimum ON time has not been triggered. Setting the ripple at a 36-$V_{IN}$ is an 80% ratio of the output current, for which the inductance can be calculated using Equation 2:

$$L_f = \frac{V_{OUT\_BUCK} \times \left( 1 - \frac{V_{OUT\_BUCK}}{V_{IN\_MAX}} \right)}{0.4 \times I_{OUT} \times f_s} = 3.6\ \mu H \quad (2)$$

Choose $L_f$ = 4.7 µH.

Figure 2 shows a schematic of the DC-DC converter.

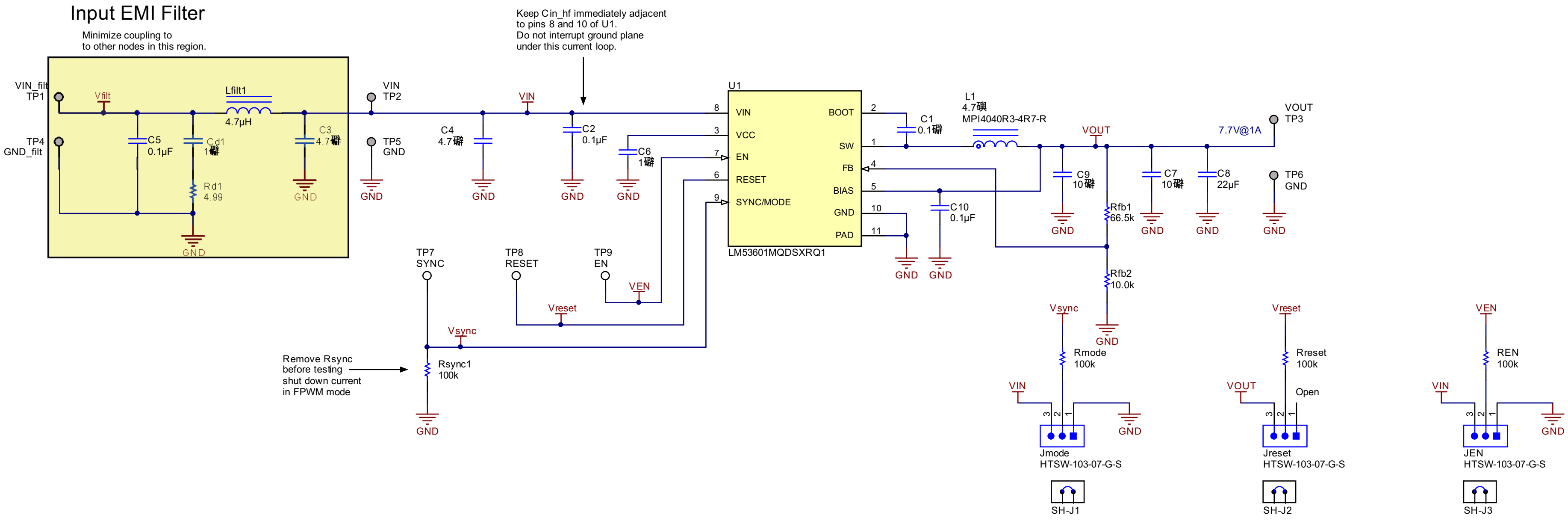




**Figure 2. Buck Converter LM53601 Schematic**

### 3.2 LED Driver Design

The TPS92638-Q1 is an eight-channel linear LED driver with PWM dimming control. Independent linear current regulators control the eight LED output channels. Global external resistors set the current of each channel. The device also features two current levels, which are intended for stop and tail applications.

The internal current reference, $I_{REF}$, has two possible values depending on the state of the STOP input: When STOP is low, REF, which is the current drawn from the REF pin, controls the output current. When STOP is high, the sum of the currents drawn from the REFHI pin and REF pin controls the output current.

Equation 3 and Equation 4 calculate values for the current-setting resistors.

**When STOP = low**:

$$I_{OUT\_TAIL} = \frac{V_{REF\_LED} \times G_{(I)}}{R_{REF}}$$

$$R_{REF} = \frac{V_{REF\_LED} \times G_{(I)}}{I_{OUT\_TAIL}} = 9.76\ k\Omega$$

where

- $V_{REF\_LED}$ = 1.222 V is the internal reference voltage of TPS92638
- $G_{(I)}$ = 200 is the ratio of output current to reference current
- $I_{OUT\_TAIL}$ = 25 mA is the tail current of each channel. (3)

**When STOP = high**:

$$I_{OUT\_STOP} = \frac{V_{REF\_LED} \times G_{(I)}}{R_{REF}} + \frac{V_{REF\_LED} \times G_{(I)}}{R_{REFHI}}$$

$$R_{REFHI} = \frac{V_{REF\_LED} \times G_{(I)}}{I_{OUT\_STOP} - \frac{V_{REF\_LED} \times G_{(I)}}{R_{REF}}} = 6.98\ k\Omega$$

where

- $I_{OUT\_STOP}$ = 60 mA is the stop current of each channel. (4)

Figure 3 shows the schematic of the LED driver part.

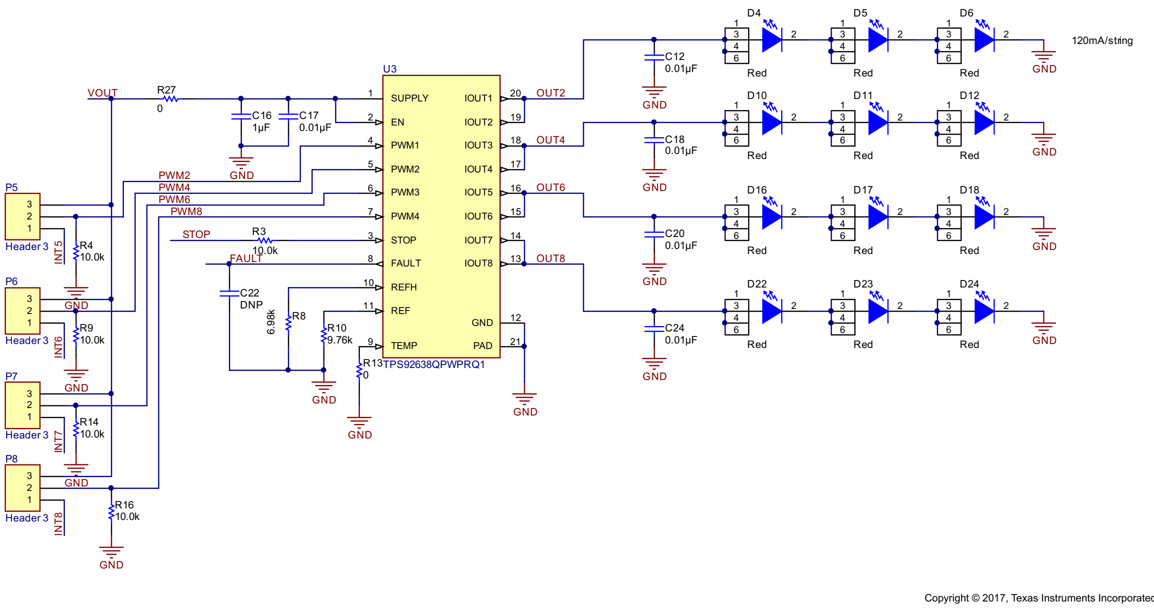


**Figure 3. TPS92638 LED Driver Schematic**

### 3.3 PWM Generation Design

This design uses the TLC2274A to generate PWM to control the LED driver dimming. Figure 4 shows a schematic of the TLC2274A-Q1.

In this schematic, U4C works as an amplifier and is capable of generating a similar triangle waveform at pin 9. The minimum and maximum voltage is relatively $V_{OUT}$ / 3 and 2$V_{OUT}$ / 3. The period is: (2R23 × C26 × ln2). U4B works as a comparator: When pin 3 voltage rises, pin 1 voltage also rises, which generates a larger duty cycle PWM through U4B. As R19 and C25 work as an RC filter, the crossover frequency must be smaller than one-tenth of the PWM frequency, which means that R23, C26, R19, and C25 must be calculated as shown in Equation 5.

$$\frac{1}{2\pi \times R_{19} \times C_{25}} \leq \frac{1}{10} \times \frac{1}{2R_{23} \times C_{26} \times \ln 2} \tag{5}$$

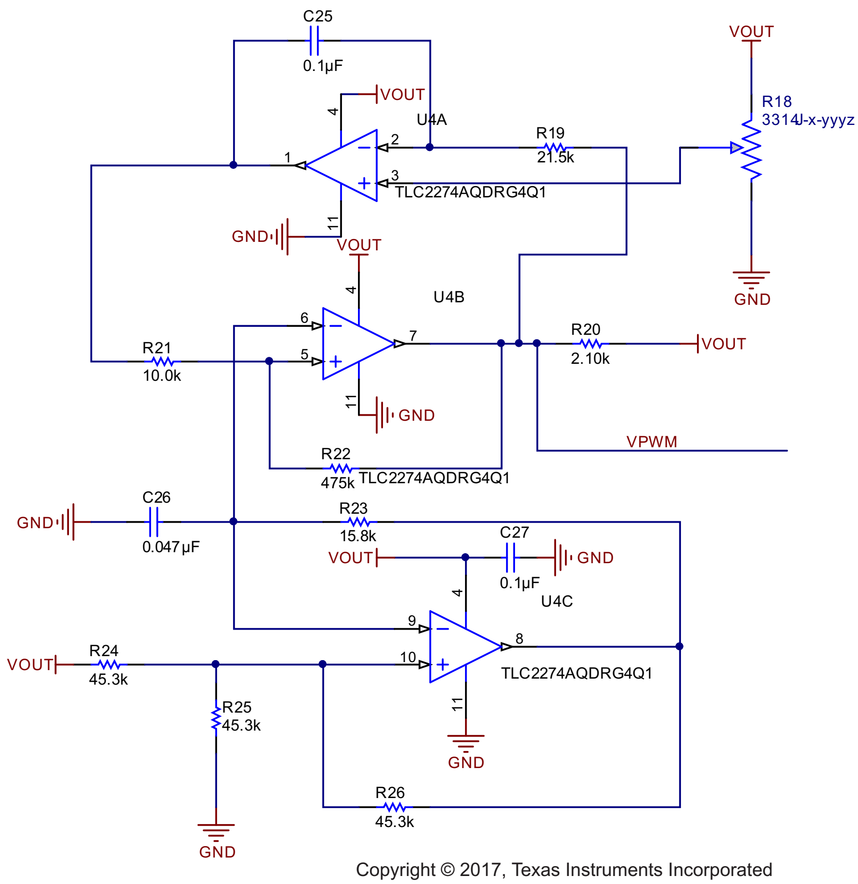


**Figure 4. TLC2274A-Q1 PWM Generation Schematic**

# 4 Test Results

## 4.1 Thermal Data

The infrared thermal images in Figure 5 and Figure 6 were taken at a steady state at STOP = high, duty cycle = 100%, and $V_{IN}$ = 9 V and 24 V for two minutes with no airflow.

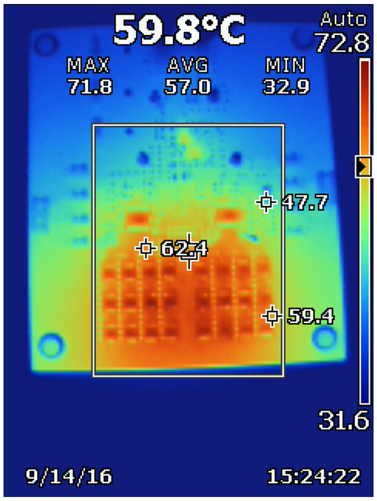


**Figure 5. Thermal Data at 9 $V_{IN}$**

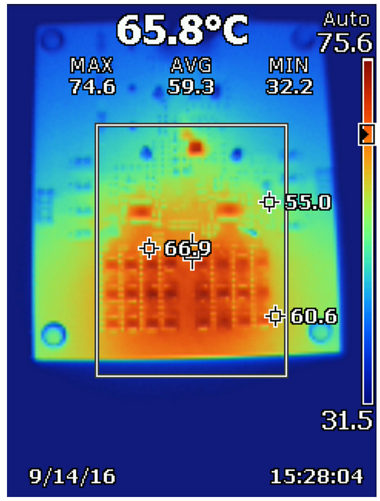


**Figure 6. Thermal Data at 24 $V_{IN}$**

## 4.2 Efficiency Data

Figure 7 shows the efficiency at various input conditions.

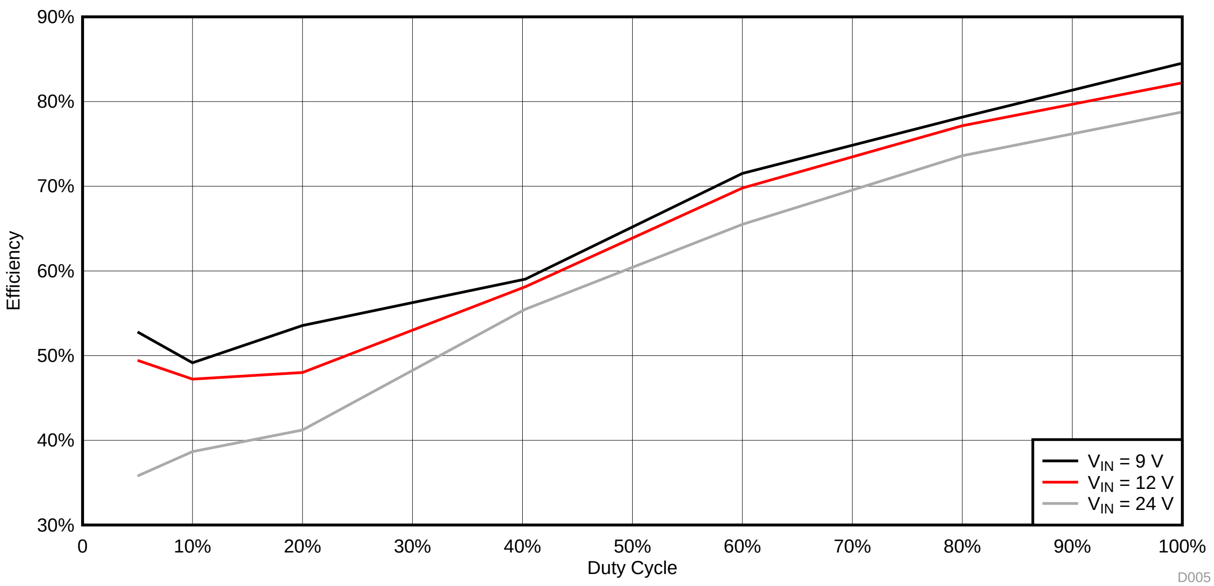


**Figure 7. Efficiency versus Duty Cycle at Various Input Voltages**

**Table 2. Efficiency Data Table at 9 $V_{IN}$**

| $V_{IN}$ (V) | $I_{IN}$ (A) | $I_O$ (mA) | DUTY | $V_O$ (V) | EFFICIENCY (%) |
|---|---|---|---|---|---|
| 9.056 | 0.0693 | 17.7 | 0.05 | 2.34 | 52.80 |
| 9.045 | 0.1244 | 25.8 | 0.10 | 2.68 | 49.16 |
| 9.030 | 0.1834 | 36.0 | 0.20 | 3.08 | 53.56 |
| 9.098 | 0.3695 | 60.8 | 0.40 | 4.08 | 59.03 |
| 9.062 | 0.5472 | 89.8 | 0.60 | 4.94 | 71.51 |
| 9.029 | 0.7071 | 112.0 | 0.80 | 5.57 | 78.16 |
| 8.995 | 0.8701 | 139.0 | 1.00 | 5.95 | 84.52 |

**Table 3. Efficiency Data Table at 12 $V_{IN}$**

| $V_{IN}$ (V) | $I_{IN}$ (A) | $I_O$ (mA) | DUTY | $V_O$ (V) | EFFICIENCY (%) |
|---|---|---|---|---|---|
| 12.012 | 0.0543 | 17.3 | 0.05 | 2.33 | 49.44 |
| 12.073 | 0.0974 | 26.0 | 0.10 | 2.67 | 47.23 |
| 12.063 | 0.1554 | 35.7 | 0.20 | 3.15 | 48.01 |
| 12.037 | 0.2852 | 61.2 | 0.40 | 4.08 | 58.13 |
| 12.011 | 0.4215 | 89.4 | 0.60 | 4.94 | 69.79 |
| 12.089 | 0.5403 | 113.0 | 0.80 | 5.57 | 77.15 |
| 12.065 | 0.6627 | 138.0 | 1.00 | 5.95 | 82.21 |

**Table 4. Efficiency Data Table at 24 $V_{IN}$**

| $V_{IN}$ (V) | $I_{IN}$ (A) | $I_O$ (mA) | DUTY | $V_O$ (V) | EFFICIENCY (%) |
|---|---|---|---|---|---|
| 24.201 | 0.0382 | 17.6 | 0.05 | 2.35 | 35.79 |
| 24.197 | 0.0598 | 26.2 | 0.10 | 2.67 | 38.68 |
| 24.191 | 0.0885 | 35.1 | 0.20 | 3.14 | 41.22 |
| 24.180 | 0.1533 | 63.0 | 0.40 | 4.08 | 55.47 |
| 24.166 | 0.2210 | 88.4 | 0.60 | 4.95 | 65.49 |
| 24.154 | 0.2831 | 113.0 | 0.80 | 5.57 | 73.60 |
| 24.142 | 0.3462 | 138.0 | 1.00 | 5.96 | 78.77 |

# 5 Waveform

## 5.1 Start-Up

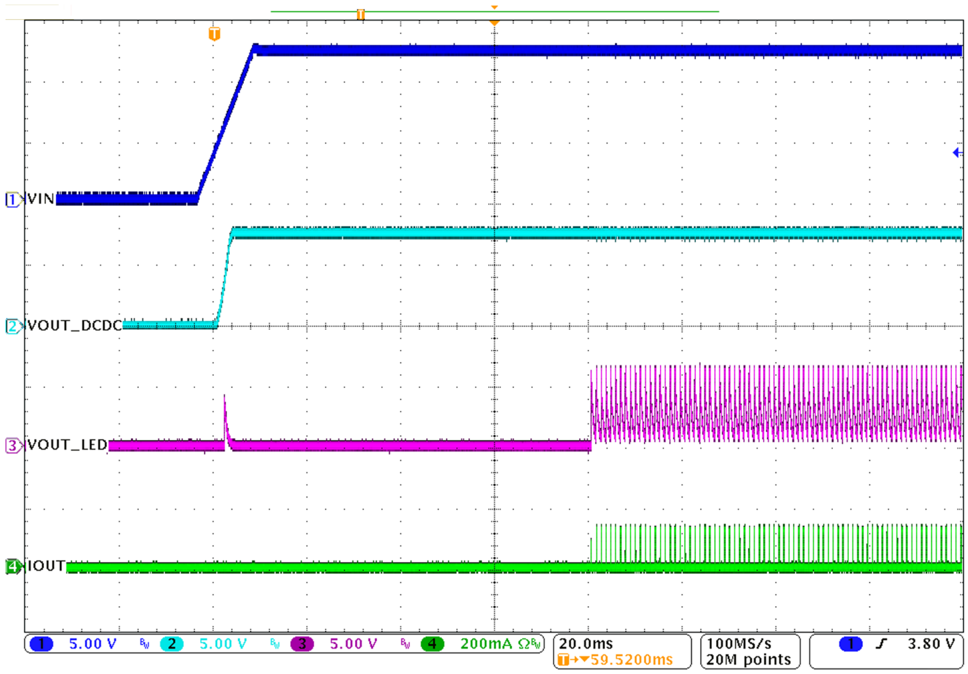


**Figure 8. Start-Up: $V_{IN}$ = 12 V, Duty Cycle = 5%**

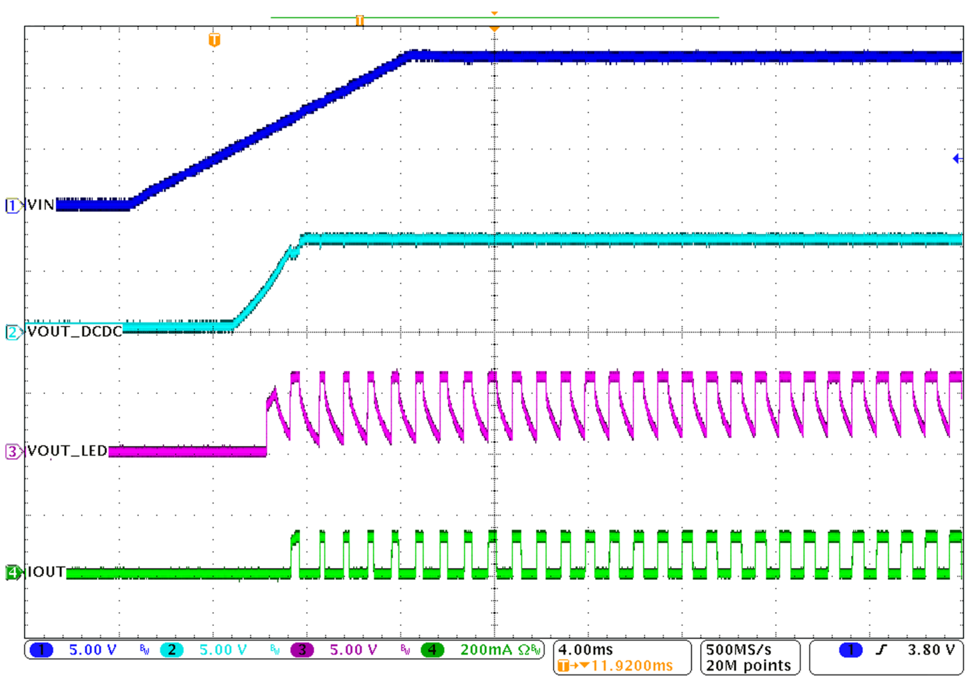


**Figure 9. Start-Up: $V_{IN}$ = 12 V, Duty Cycle = 50%**

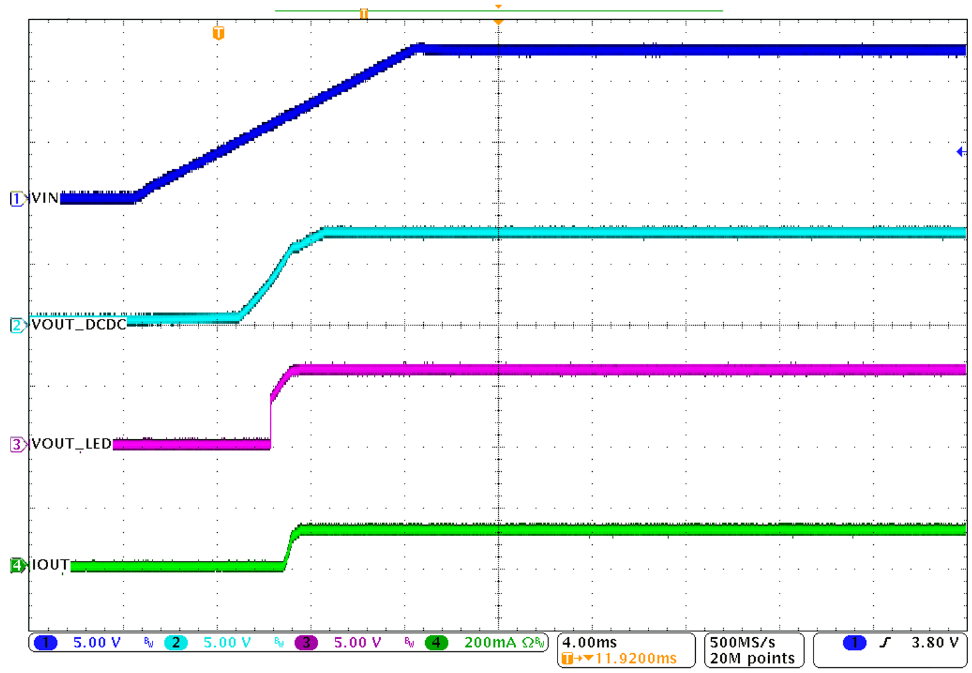


**Figure 10. Start-Up: $V_{IN}$= 12 V, Duty Cycle = 100%**

## 5.2 Shut Down

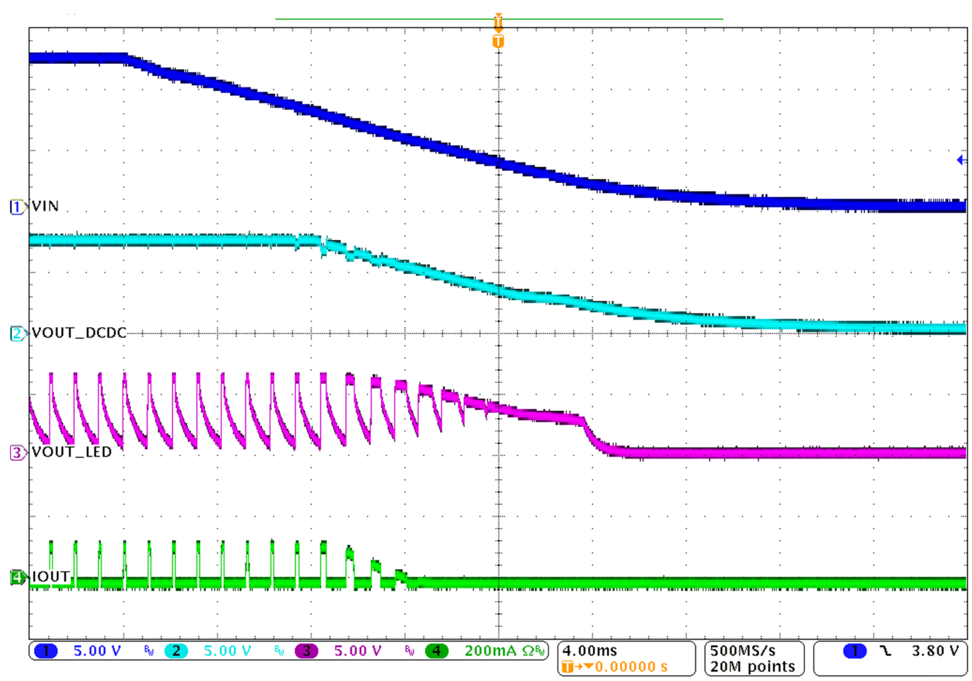


**Figure 11. Shut Down: $V_{IN}$ = 12 V, Duty Cycle = 5%**

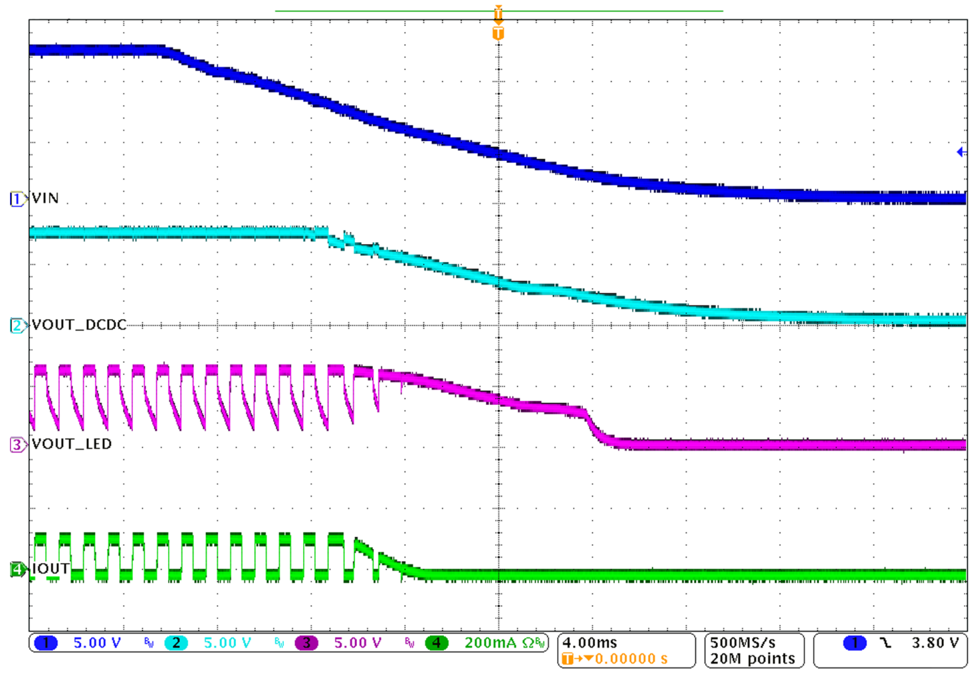


**Figure 12. Shut Down: $V_{IN}$ = 12 V, Duty Cycle = 50%**

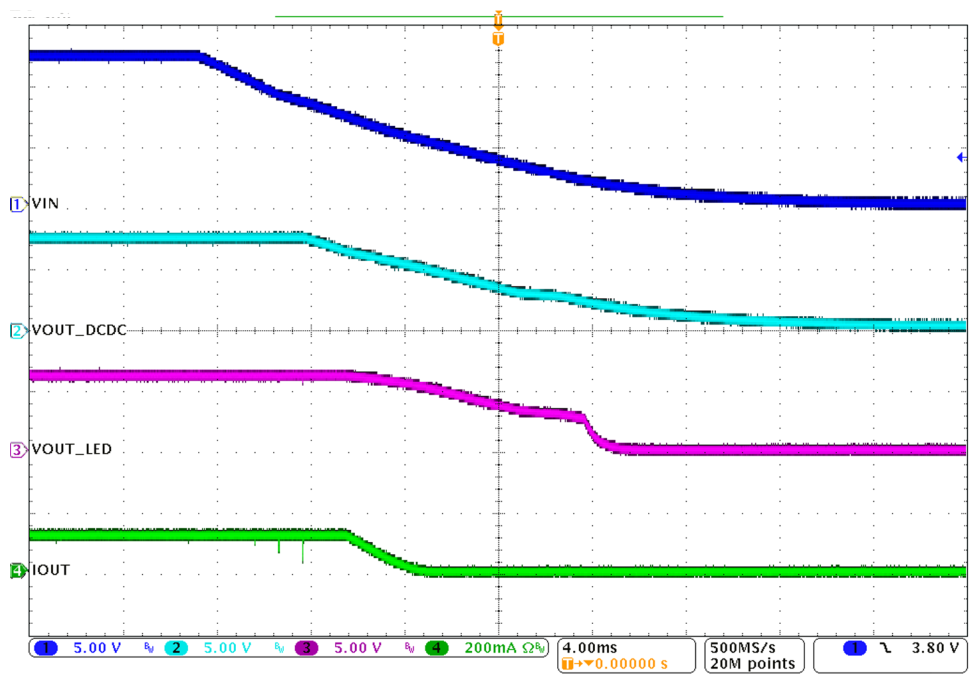


**Figure 13. Shut Down: $V_{IN}$ = 12 V, Duty Cycle = 100%**

### 5.3 Steady State

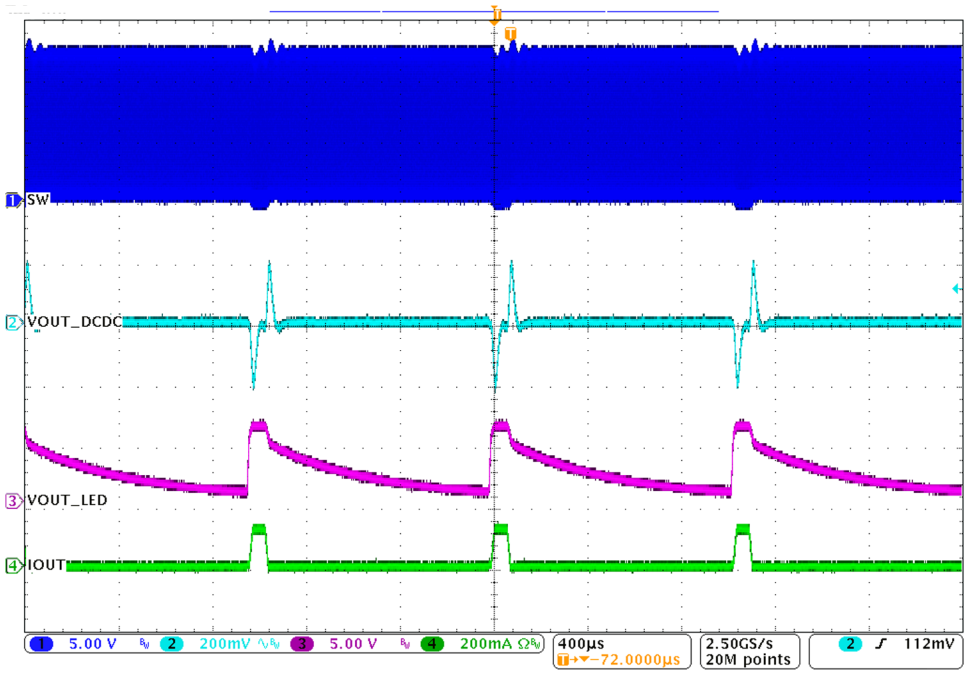


**Figure 14. Steady State: $V_{IN}$ = 12 V, Duty Cycle = 5%**

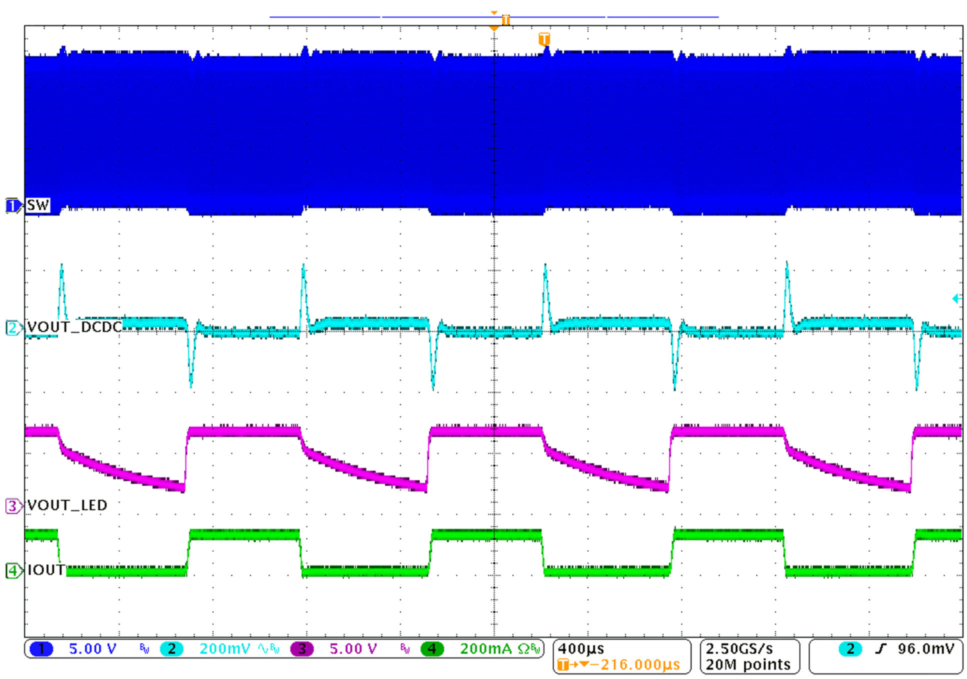


**Figure 15. Steady State: $V_{IN}$ = 12 V, Duty Cycle = 50%**

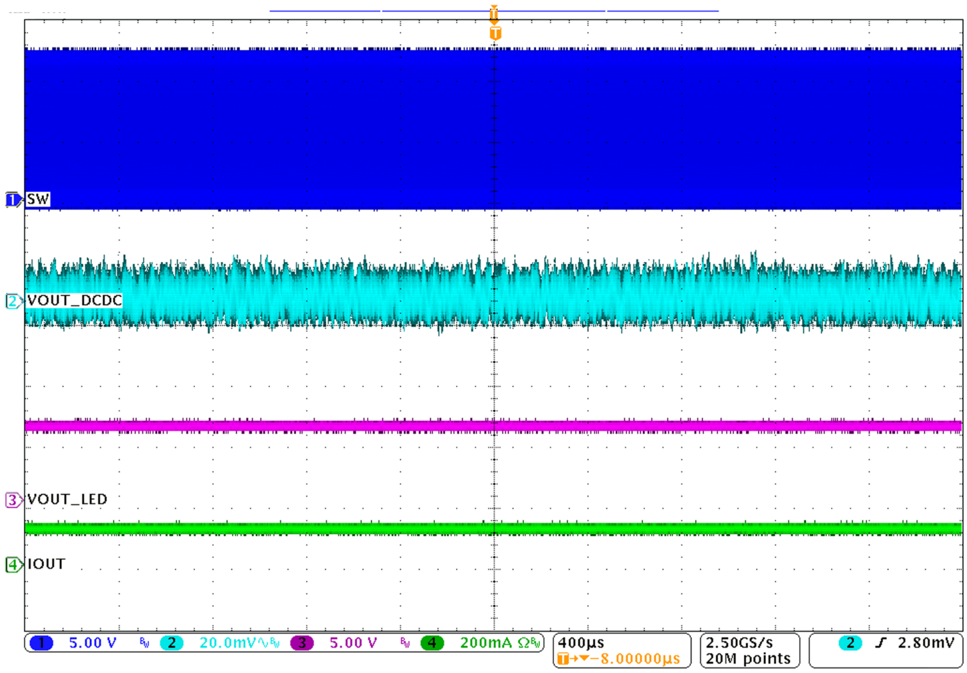


**Figure 16. Steady State: $V_{IN}$ = 12 V, Duty Cycle = 100%**

# 6 EMI Test Results

CISPR 25-EMI testing is completed at a third-party facility. Both conducted and radiated emissions tests are completed. When viewing the results, the blue lines are Class-5 limits for the peak emissions limits and the green lines are the average emissions limits. The following graphs show that the TIDA-01348 design can pass CISPR 25 Class-5 specifications without requiring a CMCC filter.

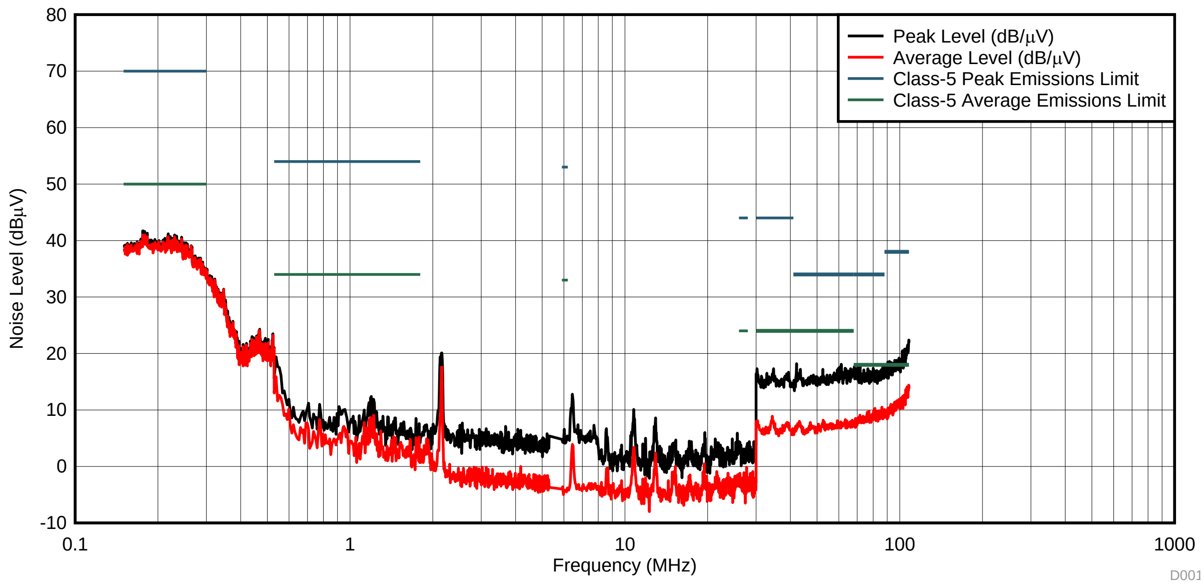


**Figure 17. Conducted Emissions Positive**

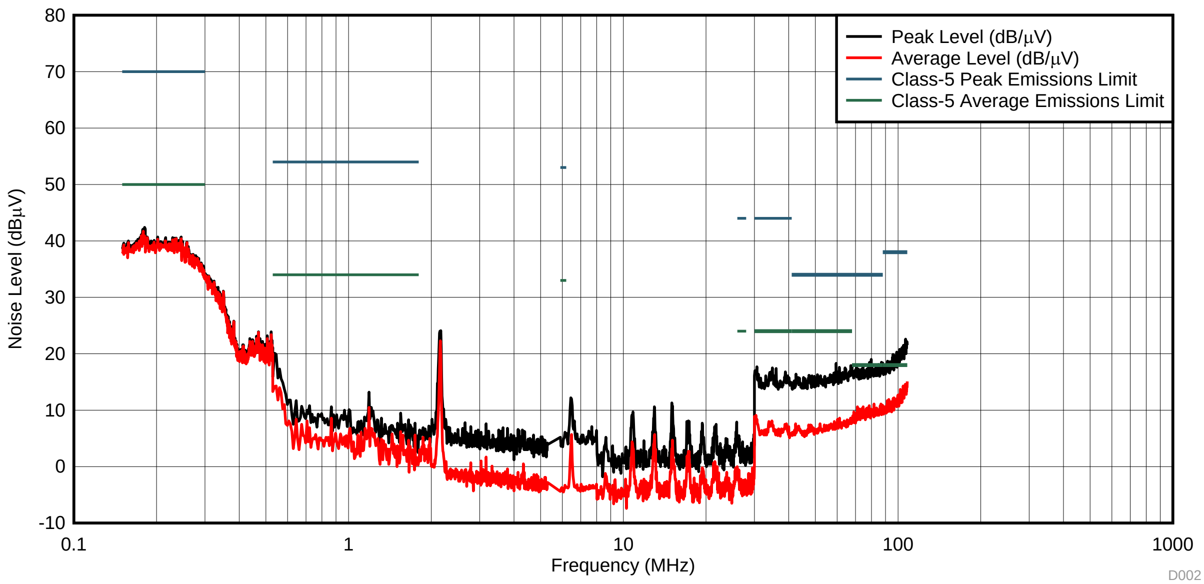


**Figure 18. Conducted Emissions Negative**

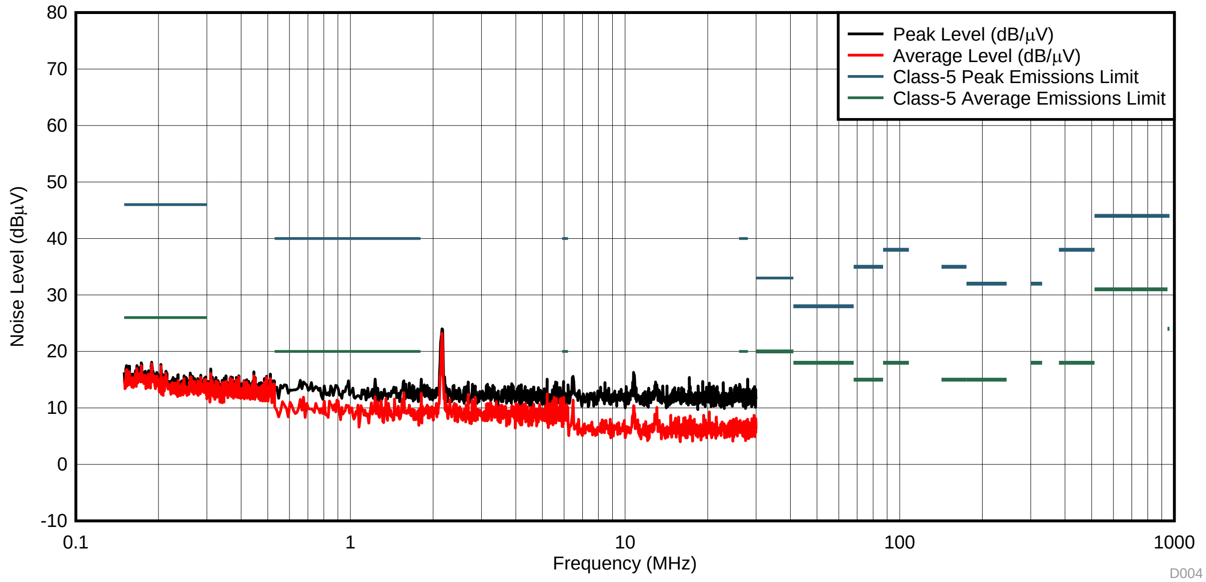


**Figure 19. Radiated Emissions of 150 kHz to 30 MHz**

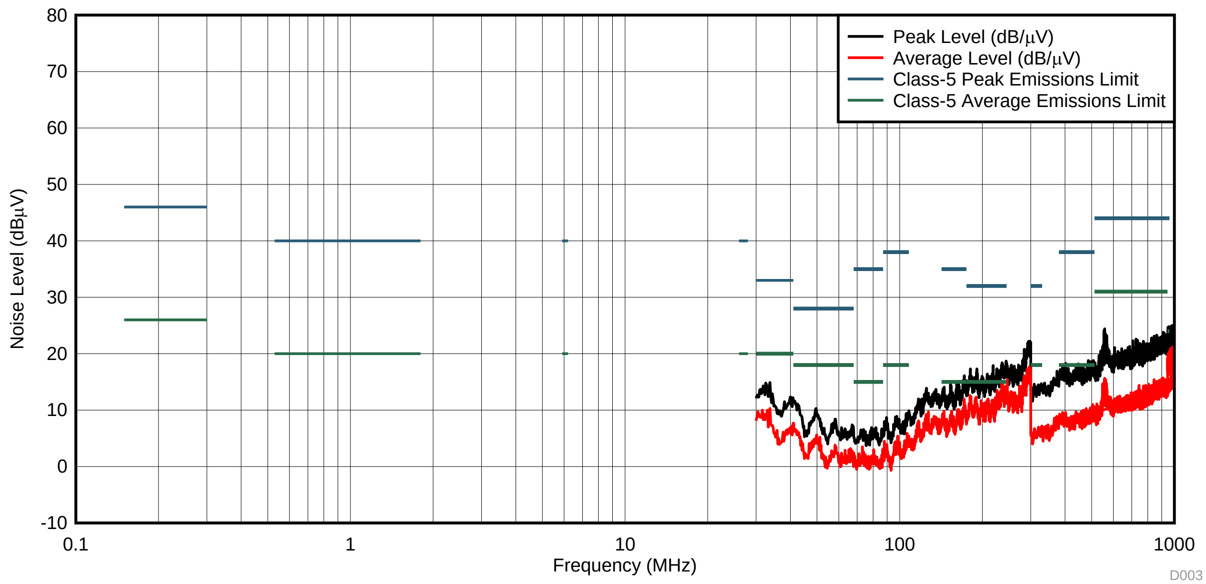


**Figure 20. Radiated Emissions of 30 MHz to 1000 MHz**

# 7 Design Files

## 7.1 Schematics

To download the schematics, see the design files at TIDA-01348.

## 7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01348.

## 7.3 PCB Layout Recommendations

### 7.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01348.

## 7.4 Altium Project

To download the Altium project files, see the design files at TIDA-01348.

## 7.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01348.

## 7.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01348.

# 8 Related Documentation

1. Texas Instruments, *LM53600/01-Q1, 0.65A/1A, 36V Synchronous, 2.1MHz, Automotive Step Down DC-DC Converter*, LM53600-Q1/LM53601-Q1 Data Sheet (SNAS660)
2. Texas Instruments, *TPS92638-Q1 8-Channel Linear LED Driver With PWM Dimming*, TPS92638-Q1 Data Sheet (SLVSCK5)
3. Texas Instruments, *TLC227x-Q1 Advanced LinCMOS ™ Rail-To-Rail Operational Amplifiers*, TLC227x-Q1/TLC227xA-Q1 Data Sheet (SGLS007)

## 8.1 Trademarks

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