TI 设计：TIDA-01348
适用于汽车 LED 照明系统的 CISPR 25 5 类 7.5W 额定功率尾灯参考设计

说明

TIDA-01348 TI 设计详细展示了一款用于汽车尾灯应用的解决方案。该设计 采用 同步降压转换器 (LM53601-Q1) 供电的 TPS92638-Q1 线性 LED 驱动器，该转换器直接通过汽车电池电压供电。该设计无需共模扼流线圈 (CMCC) 滤波器即可符合 CISPR 25 5 类传导发射和辐射发射标准，且能够提高解决方案效率。

资源

TIDA-01348	设计文件夹
LM53601-Q1	产品文件夹
TPS92638-Q1	产品文件夹
TLC2274A-Q1	产品文件夹

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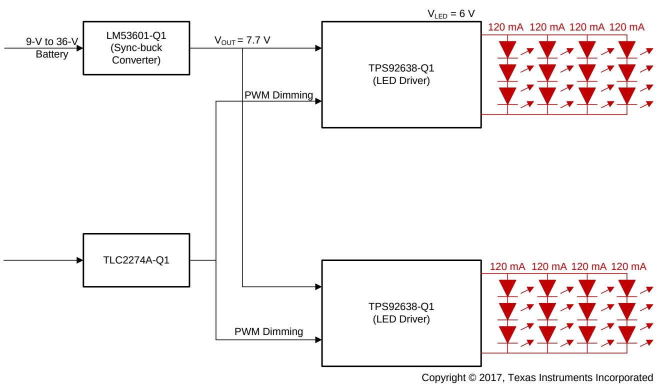
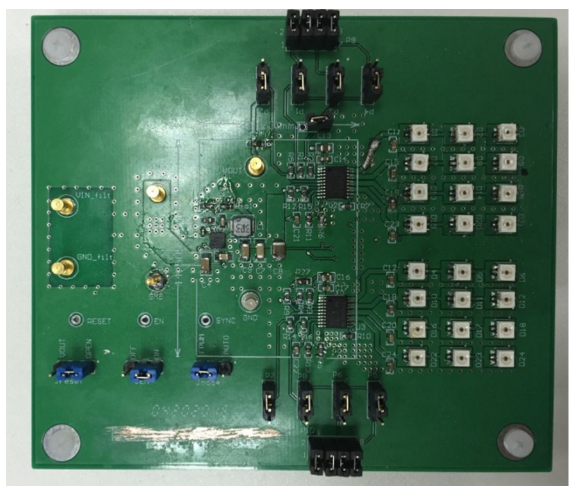
特性

- 9V 至 36V 输入、八通道 LED 照明和 7.5W 总输出
- 具有频率为 2.1MHz 的同步降压转换器
- 符合 CISPR 25 5 类传导发射标准；无需 CMCC 滤波器即可通过 AM 和 FM 无线电频带测试
- 具有方便易用的内置补偿
- 解决方案大小：42.5mm × 32.6mm；覆铜 1 盎司的四层电路板

应用

- 汽车 LED 照明





该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

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

表 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

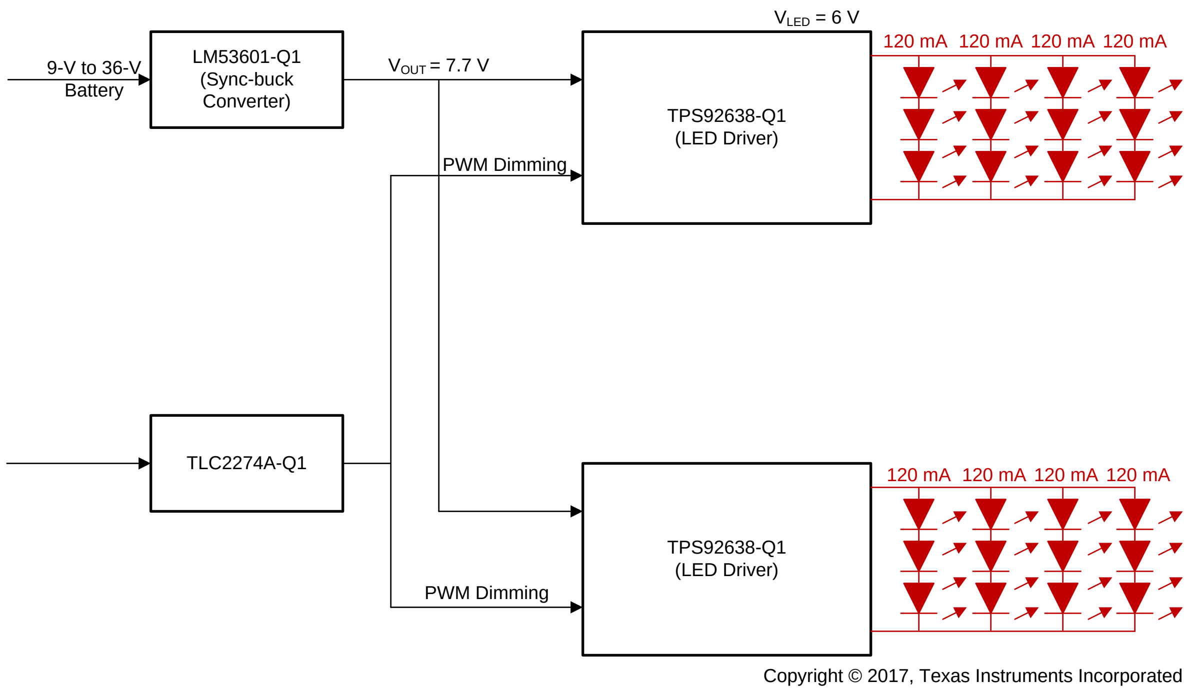


图 1. TIDA-01348 Block Diagram

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 μV_{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 公式 1.

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

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 公式 2:

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

Choose L_f = 4.7 µH.

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

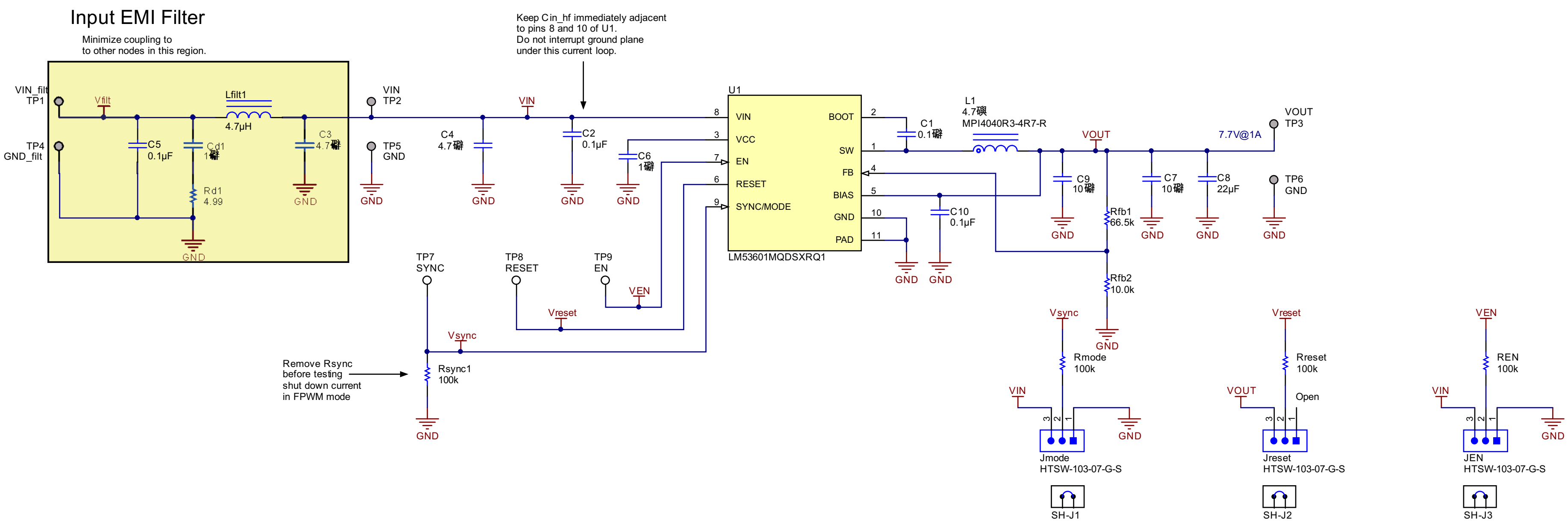


图 2. Buck Converter LM53601 Schematic

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.

公式 3 and 公式 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)

图 3 shows the schematic of the LED driver part.

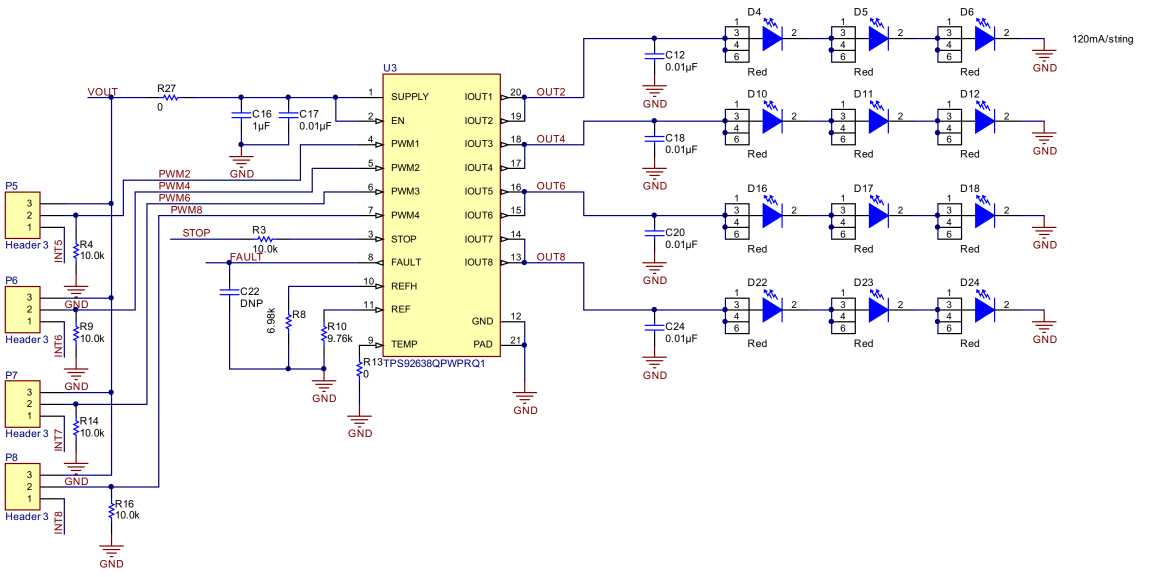


图 3. TPS92638 LED Driver Schematic

3.3 PWM Generation Design

This design uses the TLC2274A to generate PWM to control the LED driver dimming. 图 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 2V_{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 公式 5.

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

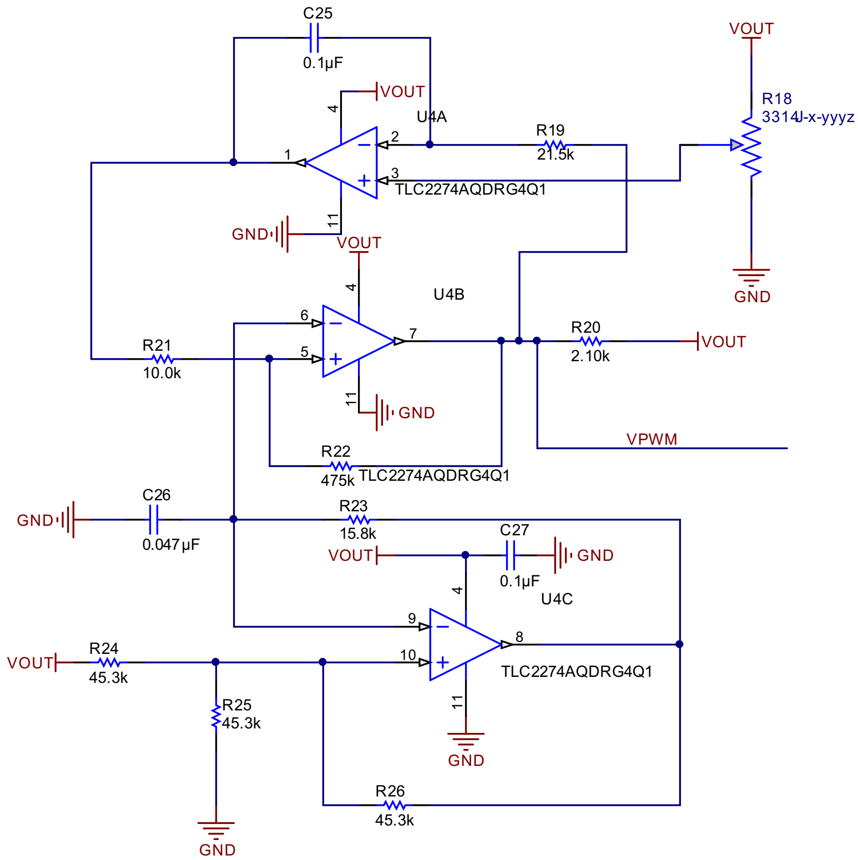


图 4. TLC2274A-Q1 PWM Generation Schematic

4 Test Results

4.1 Thermal Data

The infrared thermal images in 图 5 and 图 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.

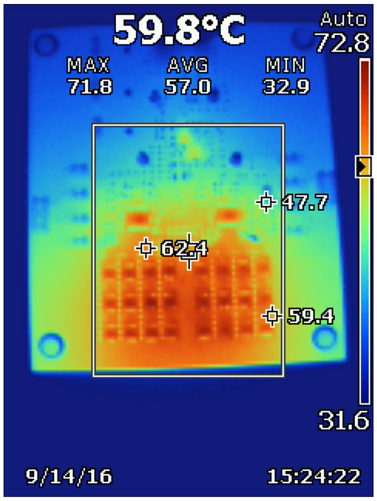


图 5. Thermal Data at 9 V_{IN}

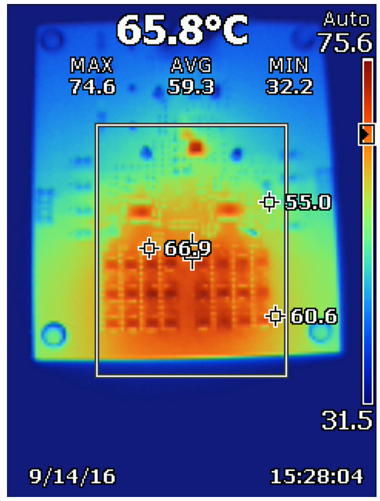


图 6. Thermal Data at 24 V_{IN}

4.2 Efficiency Data

图 7 shows the efficiency at various input conditions.

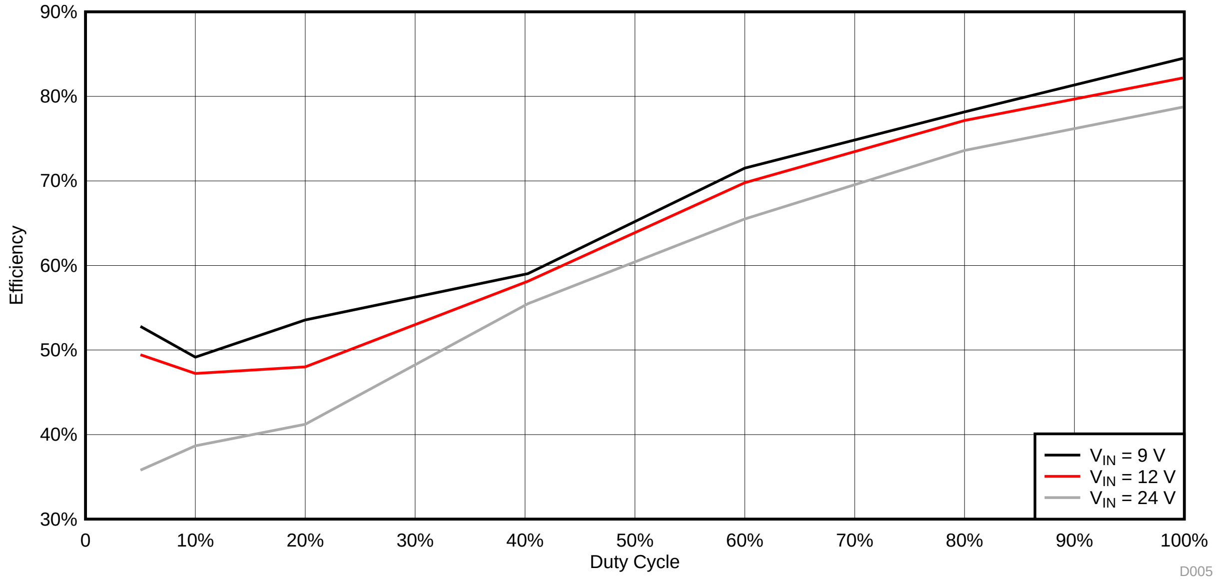


图 7. Efficiency versus Duty Cycle at Various Input Voltages

表 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

表 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

表 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

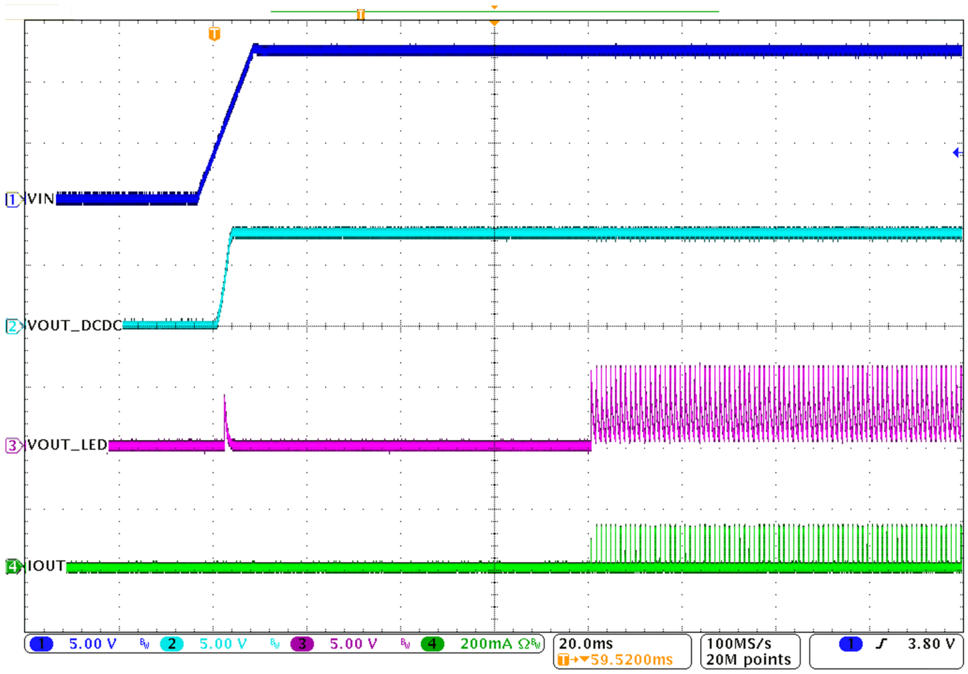


图 8. Start-Up: V_{IN} = 12 V, Duty Cycle = 5%

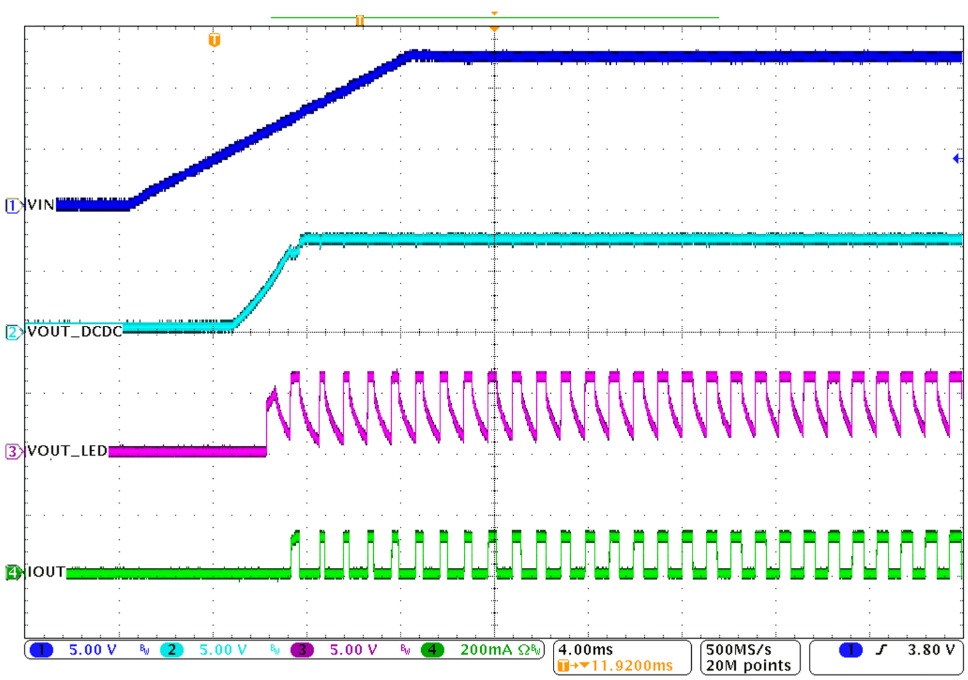


图 9. Start-Up: V_{IN} = 12 V, Duty Cycle = 50%

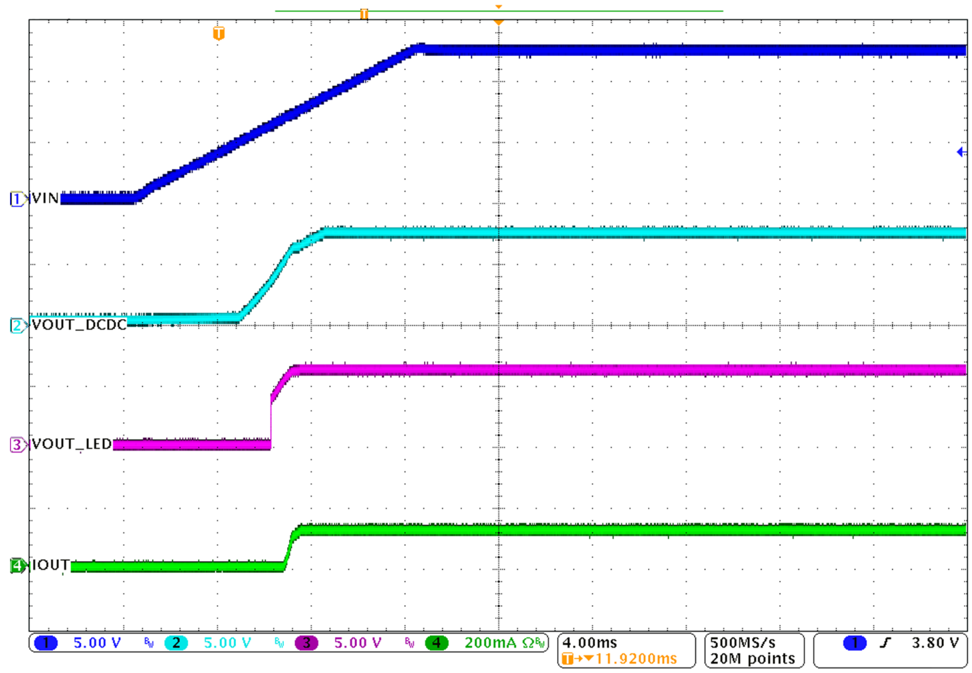


图 10. Start-Up: V_{IN}= 12 V, Duty Cycle = 100%

5.2 Shut Down

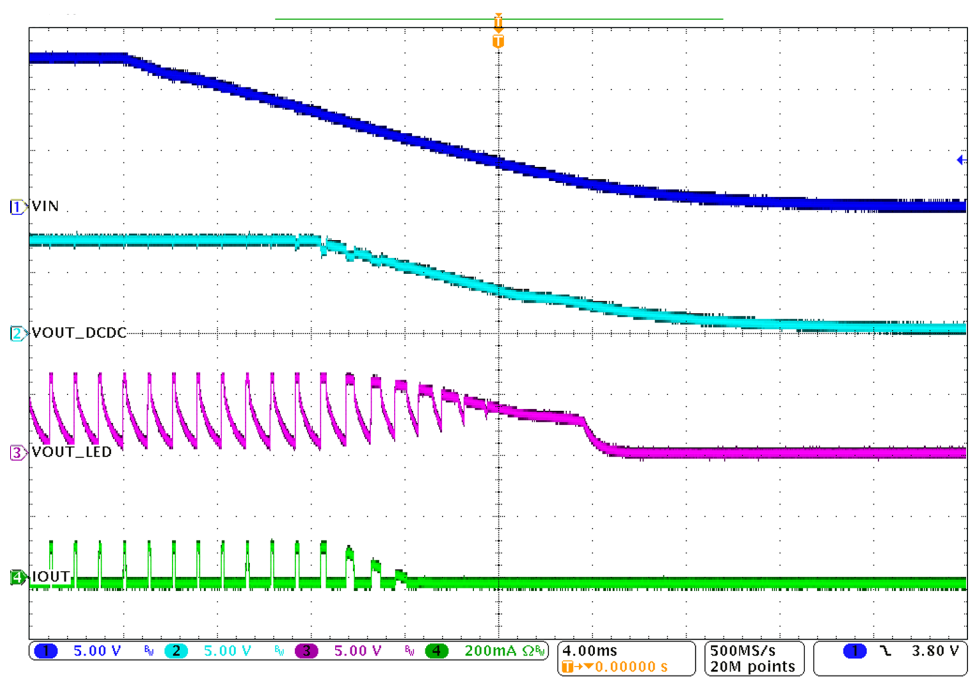


图 11. Shut Down: V_{IN} = 12 V, Duty Cycle = 5%

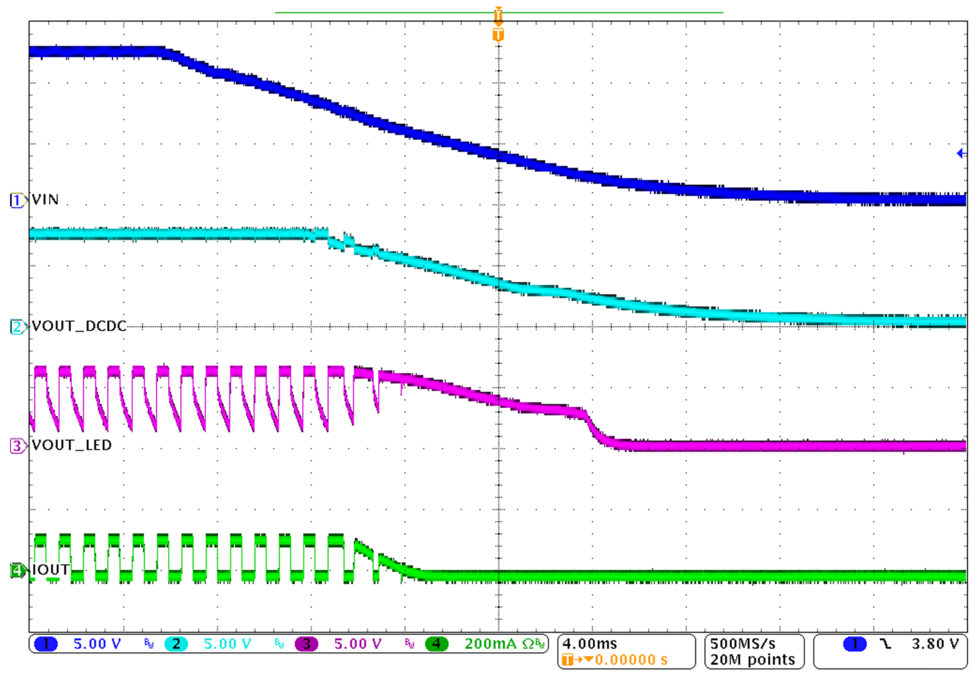


图 12. Shut Down: V_{IN} = 12 V, Duty Cycle = 50%

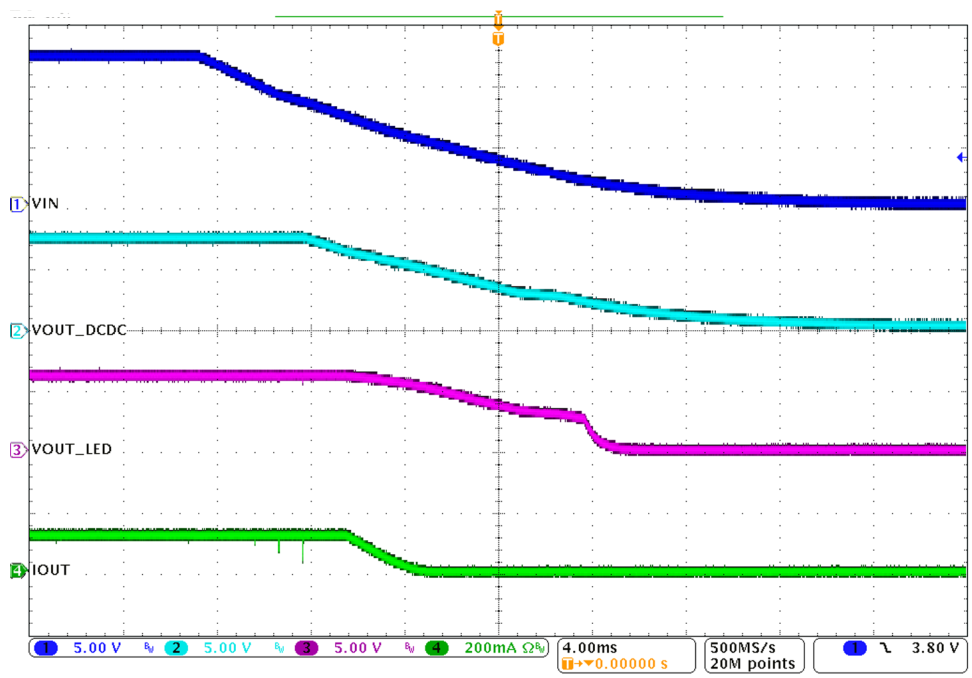


图 13. Shut Down: V_{IN} = 12 V, Duty Cycle = 100%

5.3 Steady State

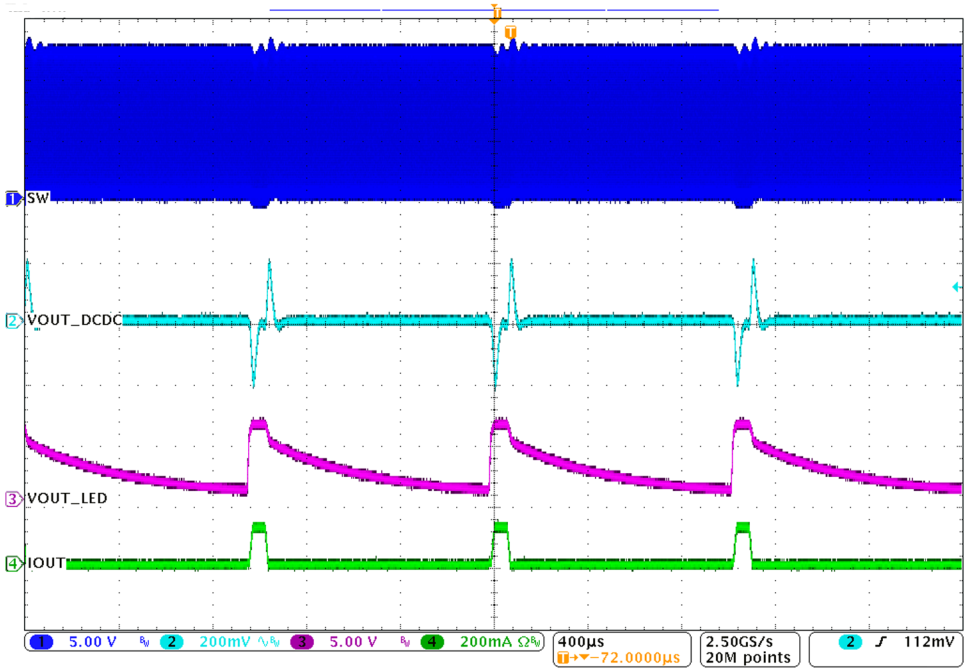


图 14. Steady State: V_{IN} = 12 V, Duty Cycle = 5%

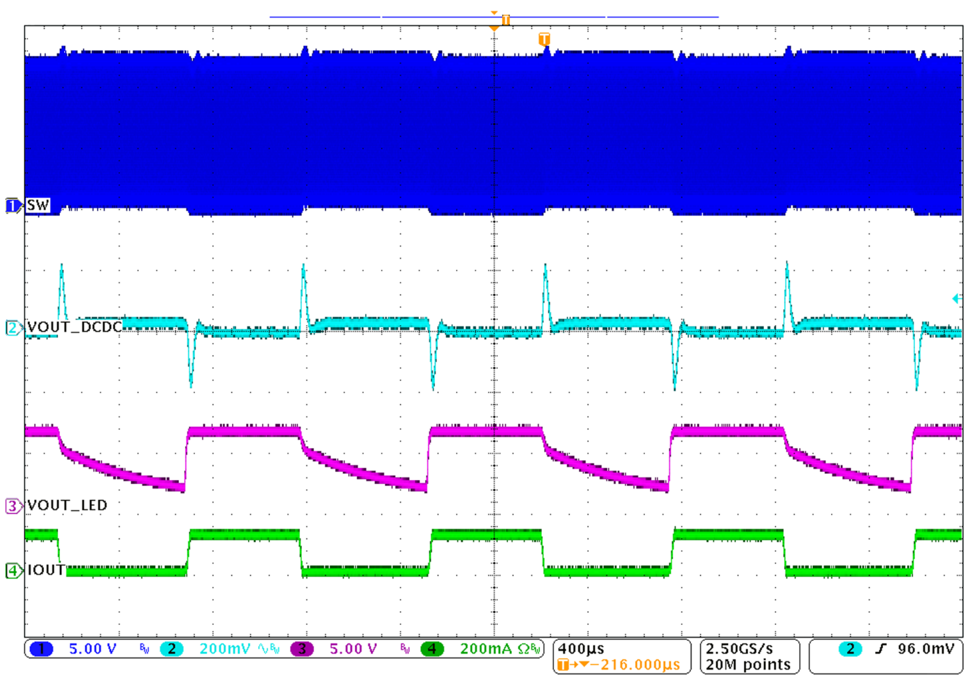


图 15. Steady State: V_{IN} = 12 V, Duty Cycle = 50%

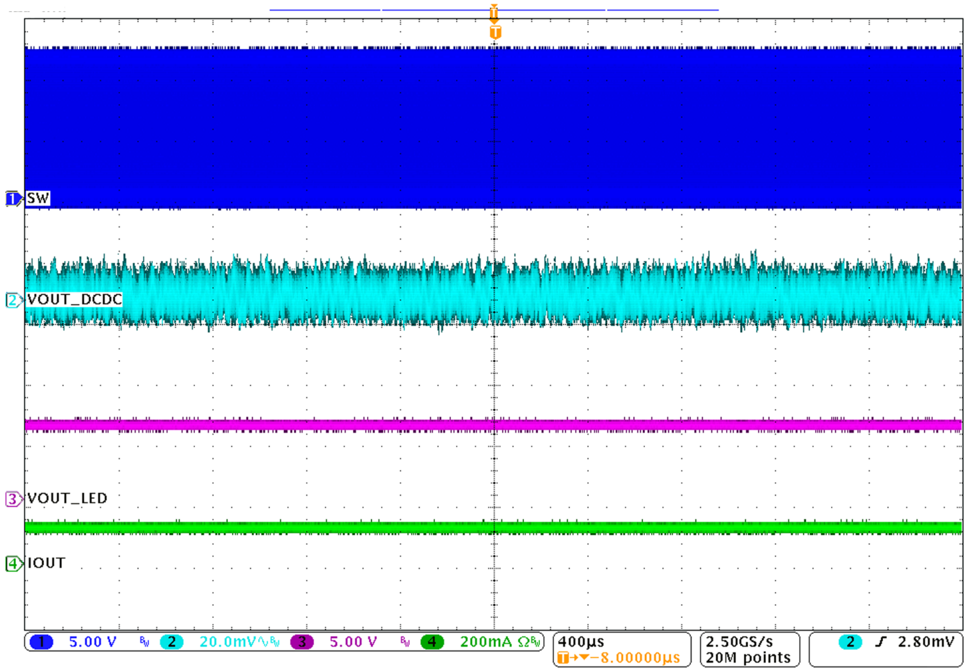


图 16. Steady State: V_{IN} = 12 V, Duty Cycle = 100%

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.

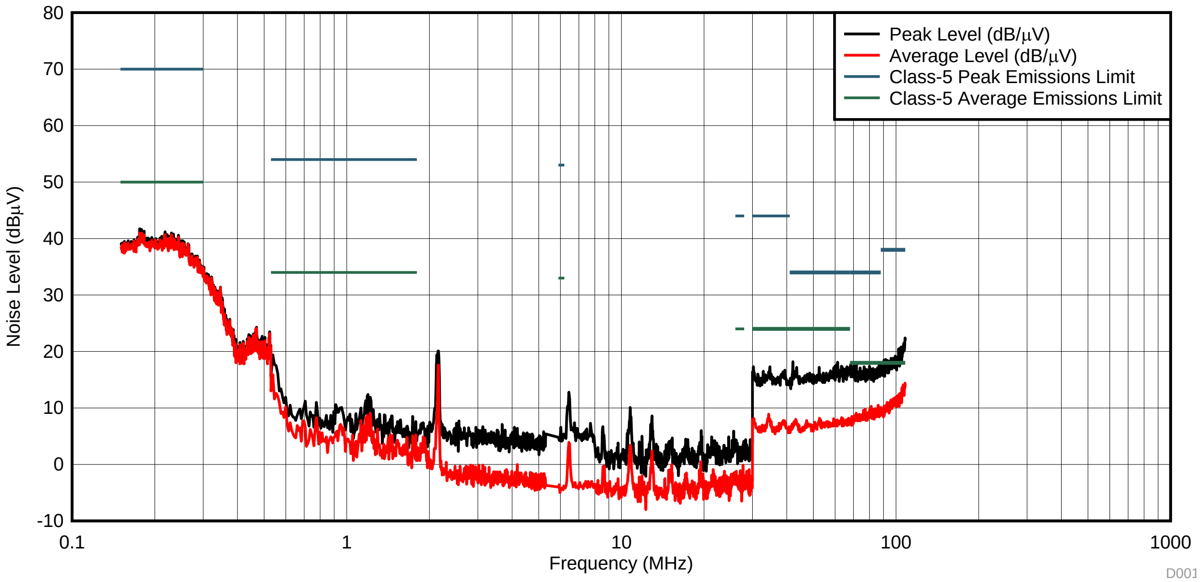


图 **17. Conducted Emissions Positive**

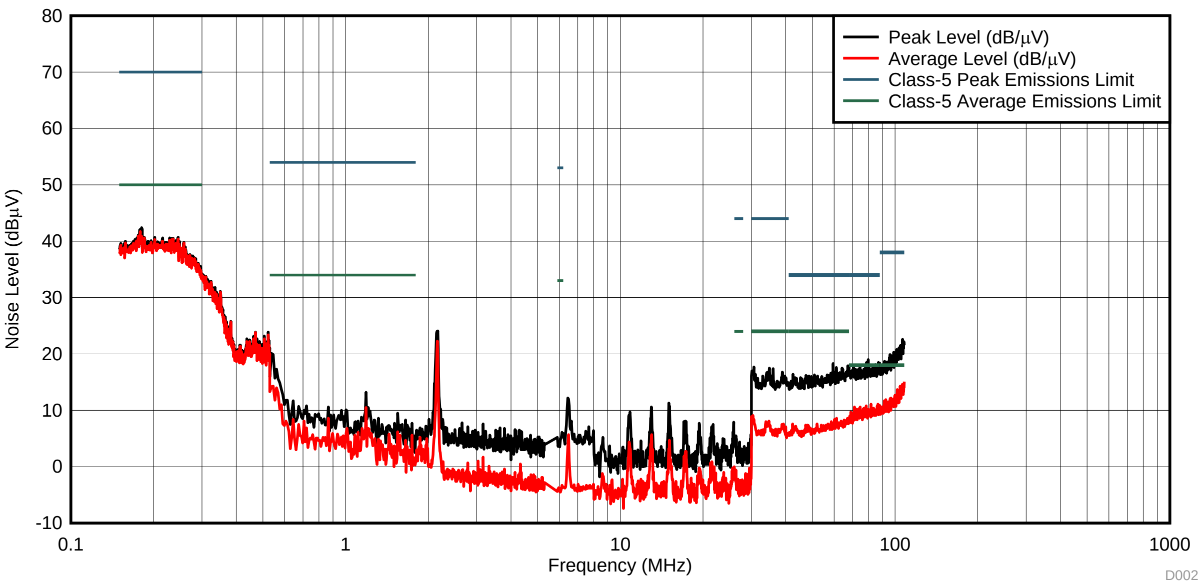


图 **18. Conducted Emissions Negative**

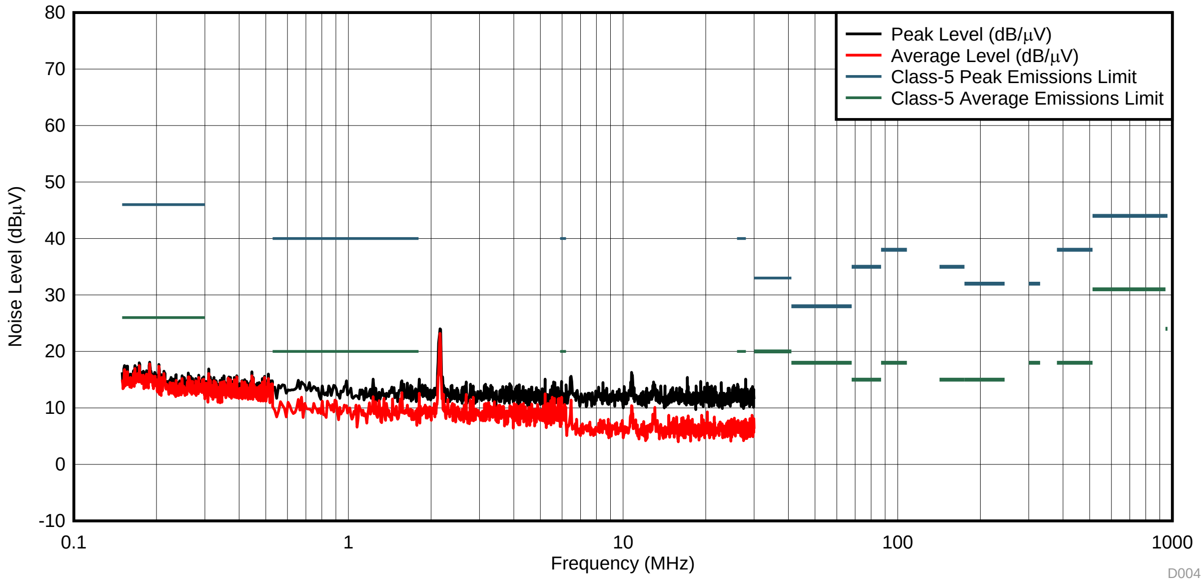


图 19. Radiated Emissions of 150 kHz to 30 MHz

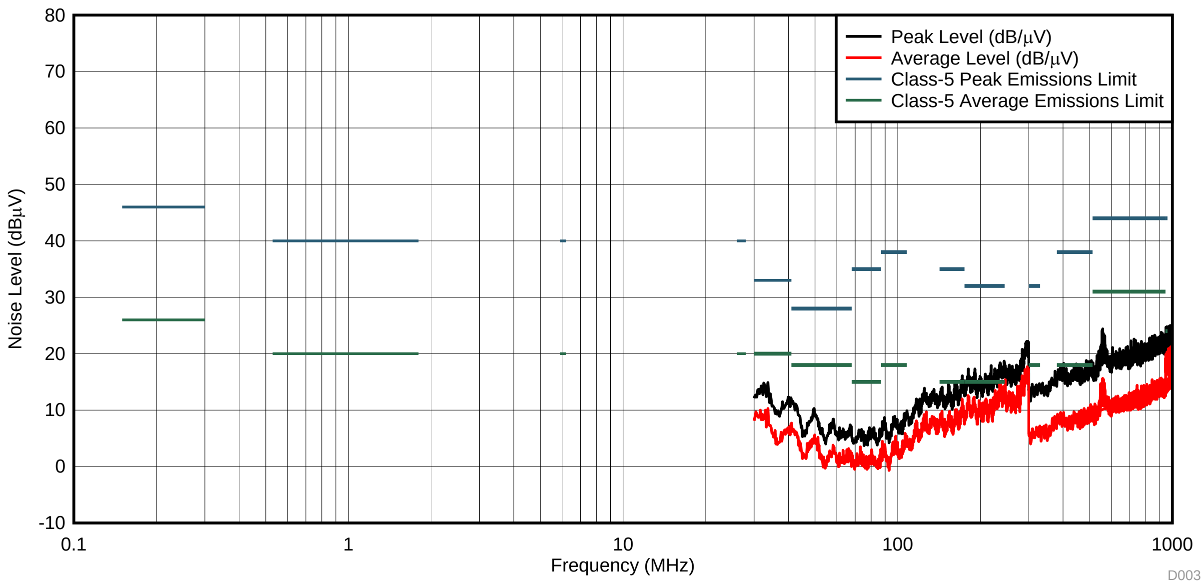


图 20. Radiated Emissions of 30 MHz to 1000 MHz

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 商标

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