

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

Features

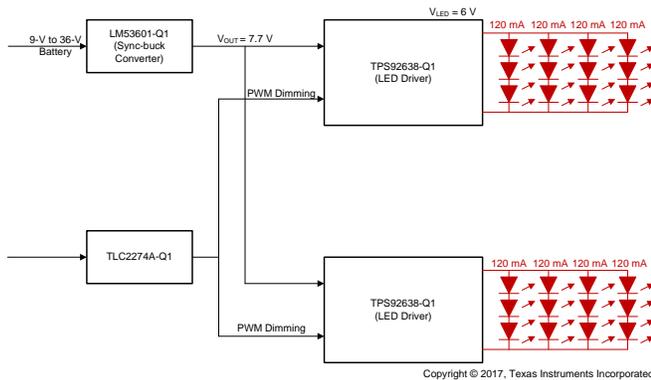
- 9-V to 36-V Input, Eight-Channel LED Lighting, and 7.5-W Total Output
- Synchronous Buck Converter With 2.1 MHz
- In Compliance With CISPR 25 Class-5 Conducted Emissions Standard; Passes both AM and FM Radio Band Tests Without CMCC Filter
- Internal Compensation for Ease of Use
- Solution Size 42.5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

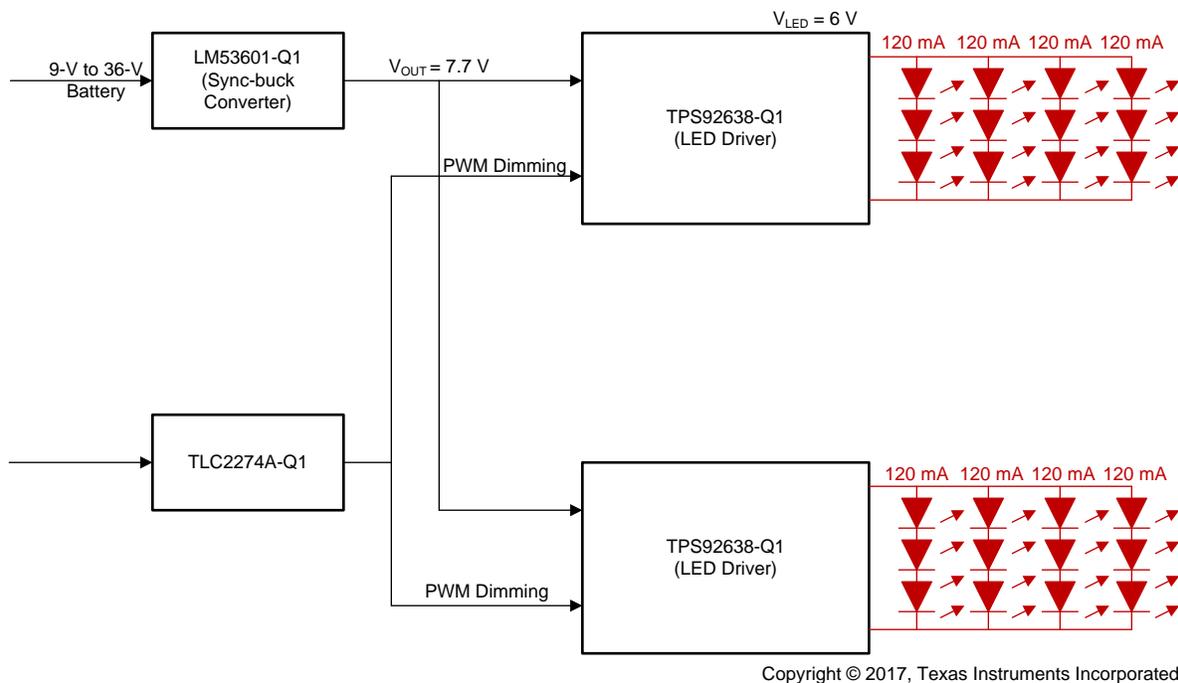
1.1 Key System Specifications

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



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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: $25\ \mu\text{V}_{\text{RMS}}$
- 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: $9\ \text{nV}/\sqrt{\text{Hz}}$ typical at $f = 1\ \text{kHz}$
- 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: $3.6\ \text{V}/\mu\text{s}$ 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 $R_{fb2} = 10 \text{ k}\Omega$, R_{fb1} can be derived using [Equation 1](#).

$$R_{fb1} = \left(\frac{V_{OUT_BUCK}}{V_{REF}} - 1 \right) \times R_{fb2} = 67 \text{ k}\Omega \quad (1)$$

where,

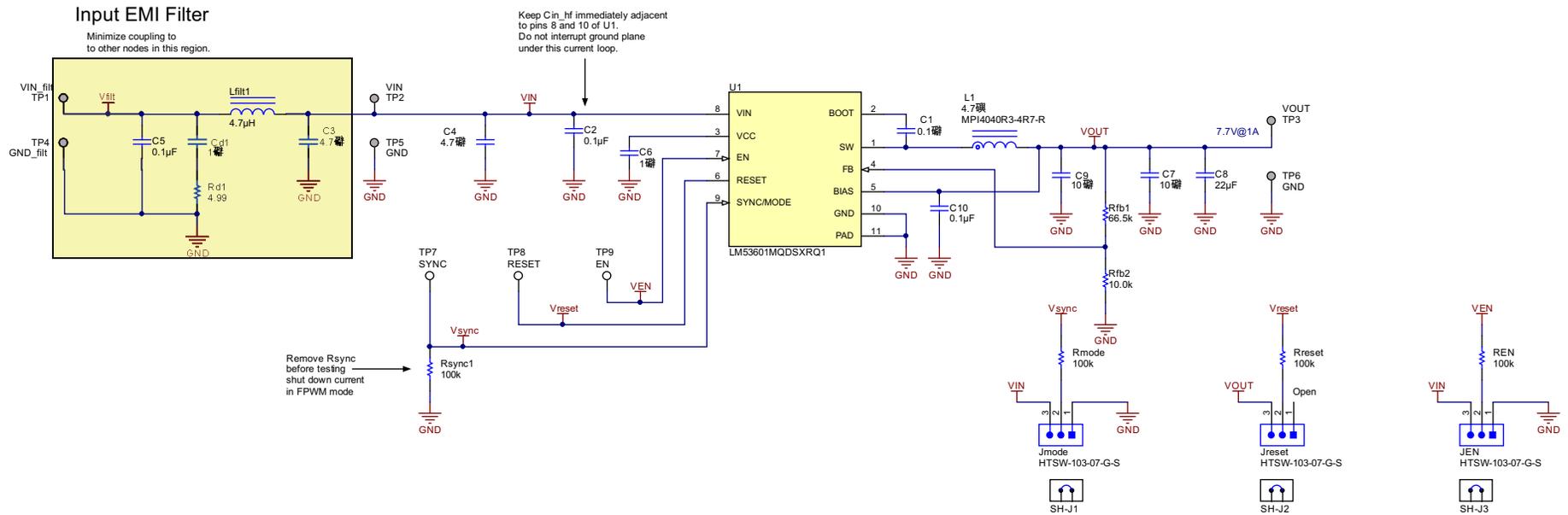
- V_{REF} is the reference voltage of LM53601 and is equal to 2 V.

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](#):

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

Choose $L_f = 4.7 \text{ }\mu\text{H}$.

[Figure 2](#) shows a schematic of the DC-DC converter.



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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:

$$I_{OUT_TAIL} = \frac{V_{REF_LED} \times G_{(I)}}{R_{REF}}$$

$$R_{REF} = \frac{V_{REF_LED} \times G_{(I)}}{I_{OUT_TAIL}} = 9.76 \text{ k}\Omega$$

where

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

(3)

When STOP = high:

$$I_{OUT_STOP} = \frac{V_{REF_LED} \times G_{(I)}}{R_{REF}} + \frac{V_{REF_LED} \times G_{(I)}}{R_{REFHI}}$$

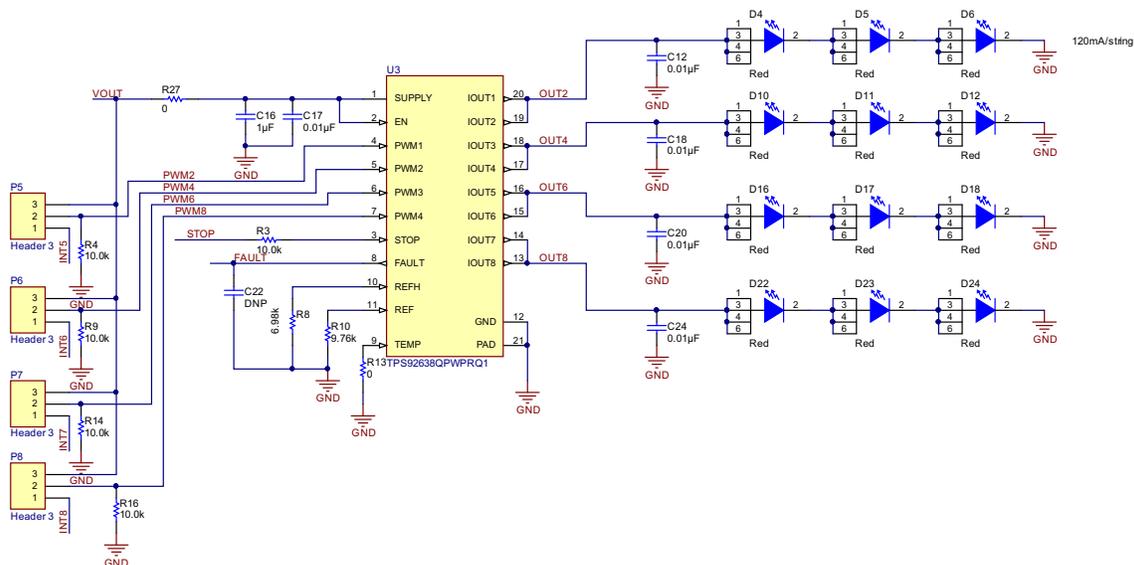
$$R_{REFHI} = \frac{V_{REF_LED} \times G_{(I)}}{I_{OUT_STOP} - \frac{V_{REF_LED} \times G_{(I)}}{R_{REF}}} = 6.98 \text{ k}\Omega$$

where

- $I_{OUT_STOP} = 60 \text{ mA}$ is the stop current of each channel.

(4)

Figure 3 shows the schematic of the LED driver part.



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Figure 3. TPS92638 LED Driver 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.

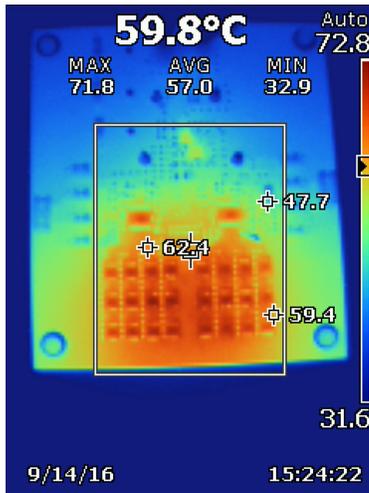


Figure 5. Thermal Data at 9 V_{IN}

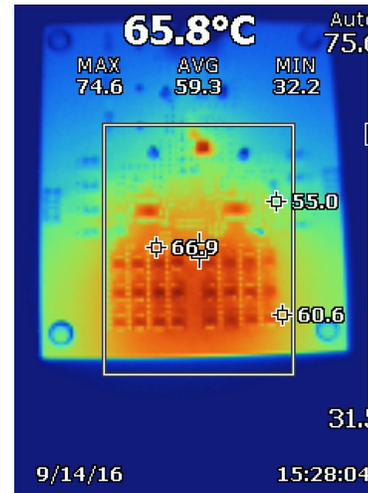


Figure 6. Thermal Data at 24 V_{IN}

4.2 Efficiency Data

Figure 7 shows the efficiency at various input conditions.

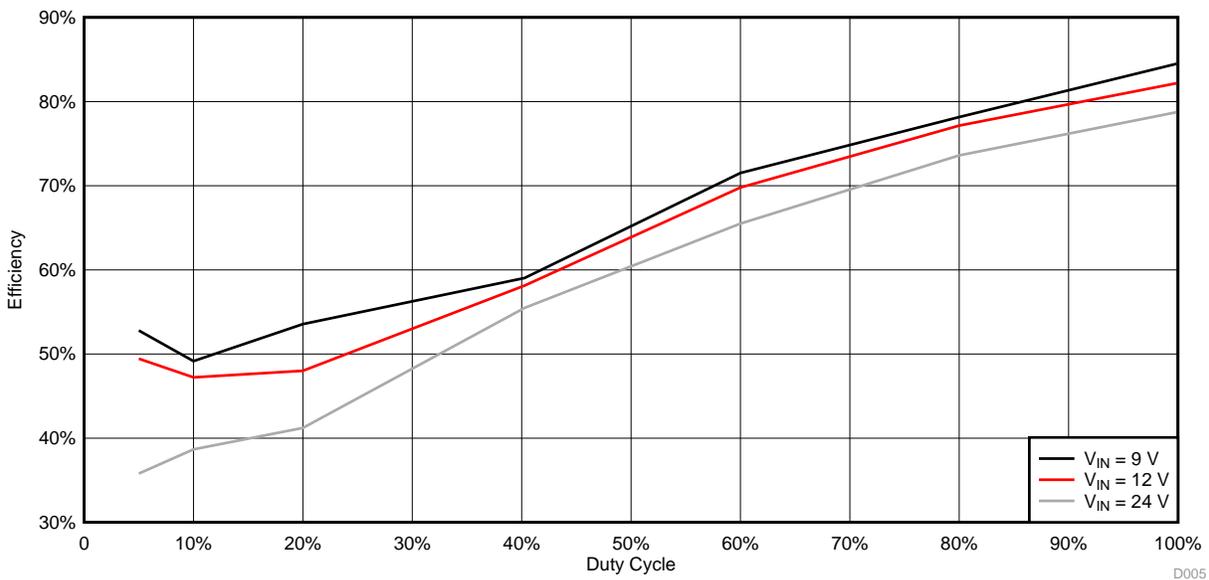


Figure 7. Efficiency versus Duty Cycle at Various Input Voltages

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

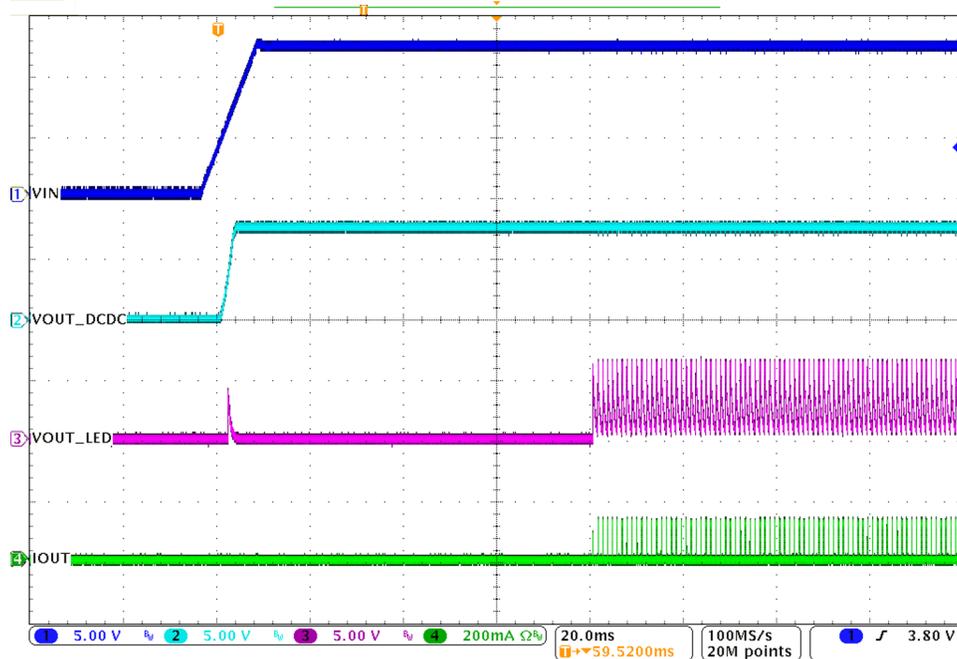


Figure 8. Start-Up: $V_{IN} = 12\text{ V}$, Duty Cycle = 5%

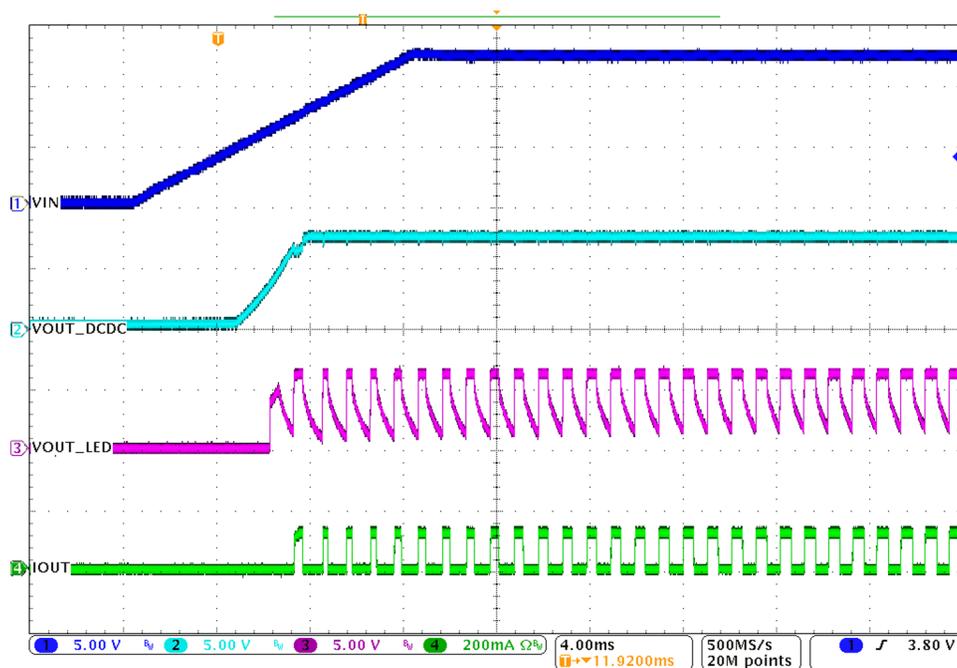


Figure 9. Start-Up: $V_{IN} = 12\text{ V}$, Duty Cycle = 50%

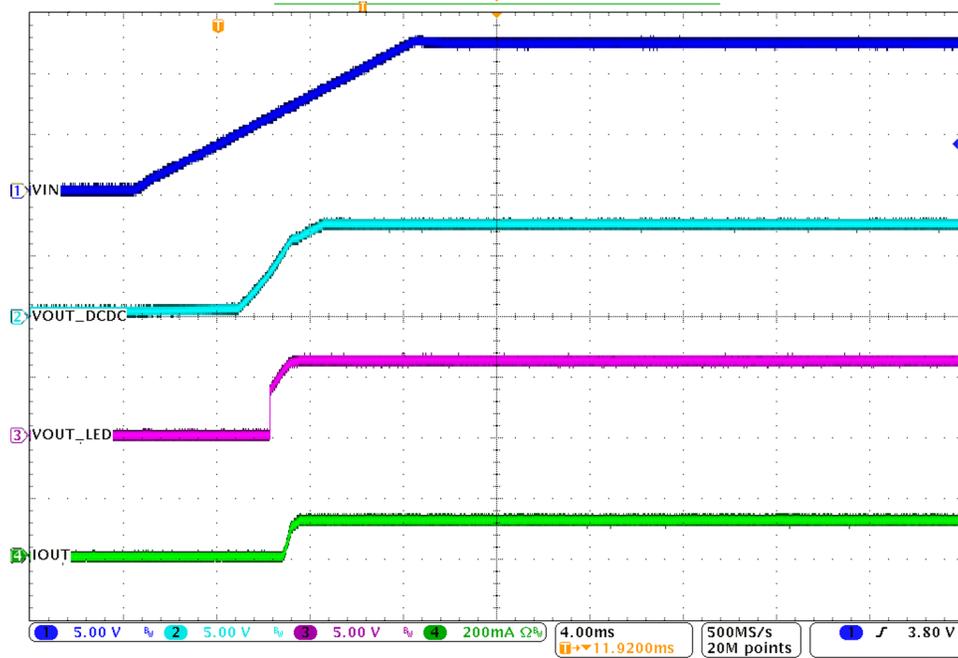


Figure 10. Start-Up: $V_{IN} = 12\text{ V}$, Duty Cycle = 100%

5.2 Shut Down

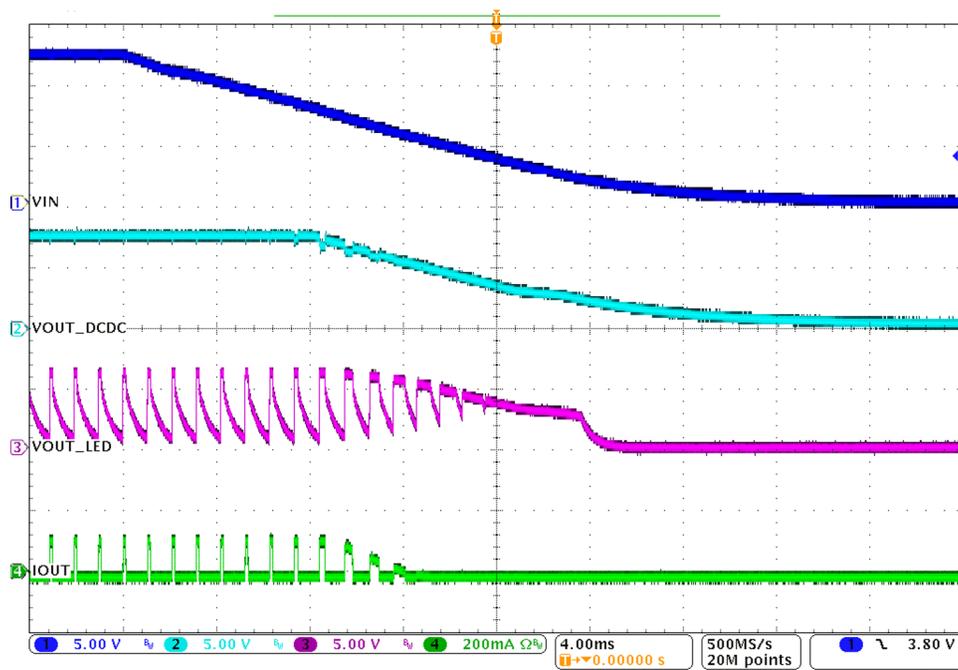


Figure 11. Shut Down: $V_{IN} = 12\text{ V}$, Duty Cycle = 5%

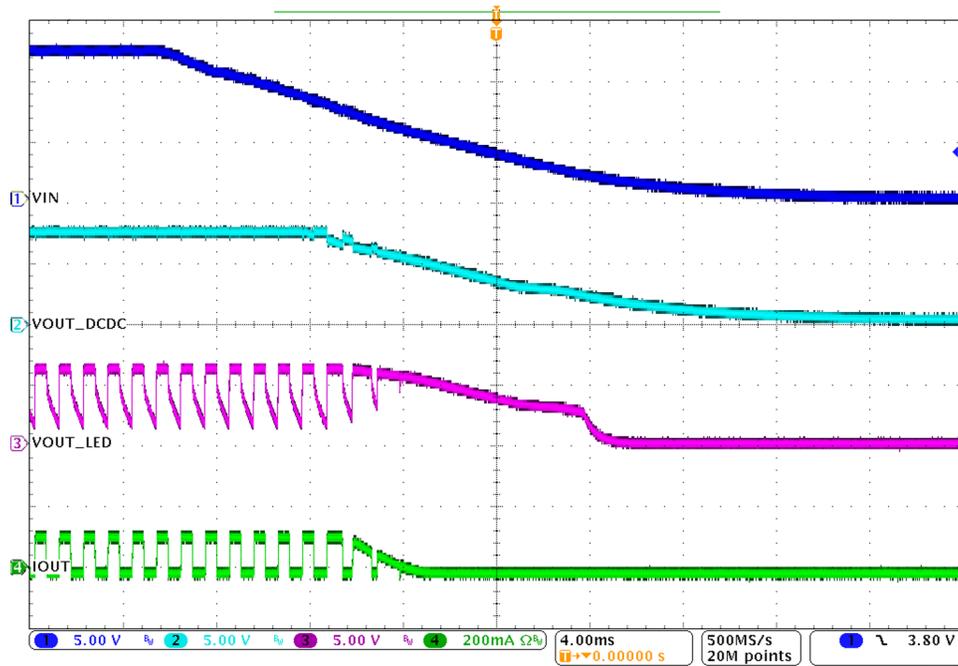


Figure 12. Shut Down: $V_{IN} = 12\text{ V}$, Duty Cycle = 50%

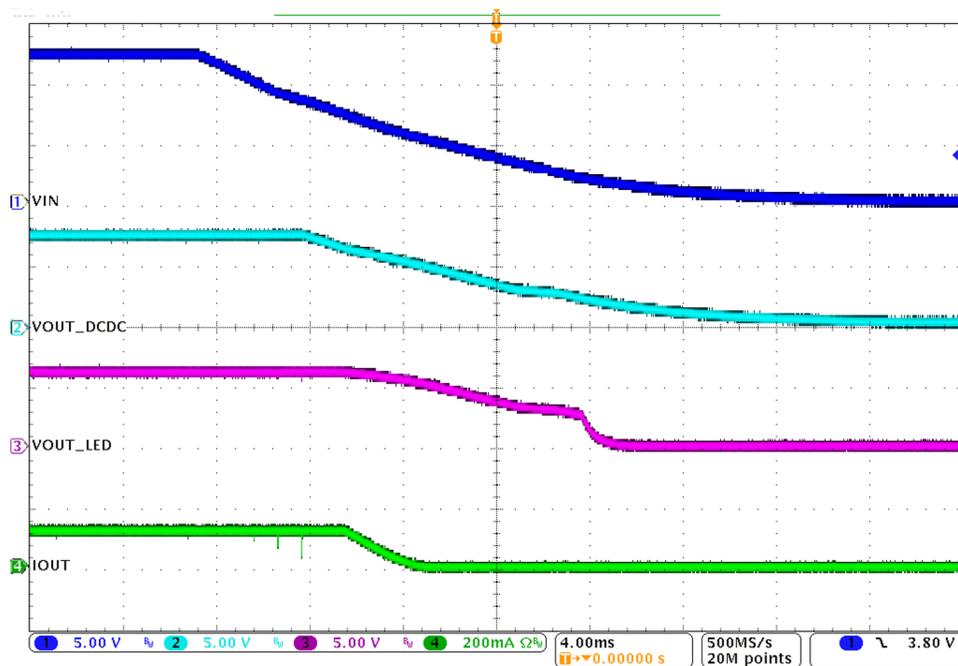


Figure 13. Shut Down: $V_{IN} = 12\text{ V}$, Duty Cycle = 100%

5.3 Steady State

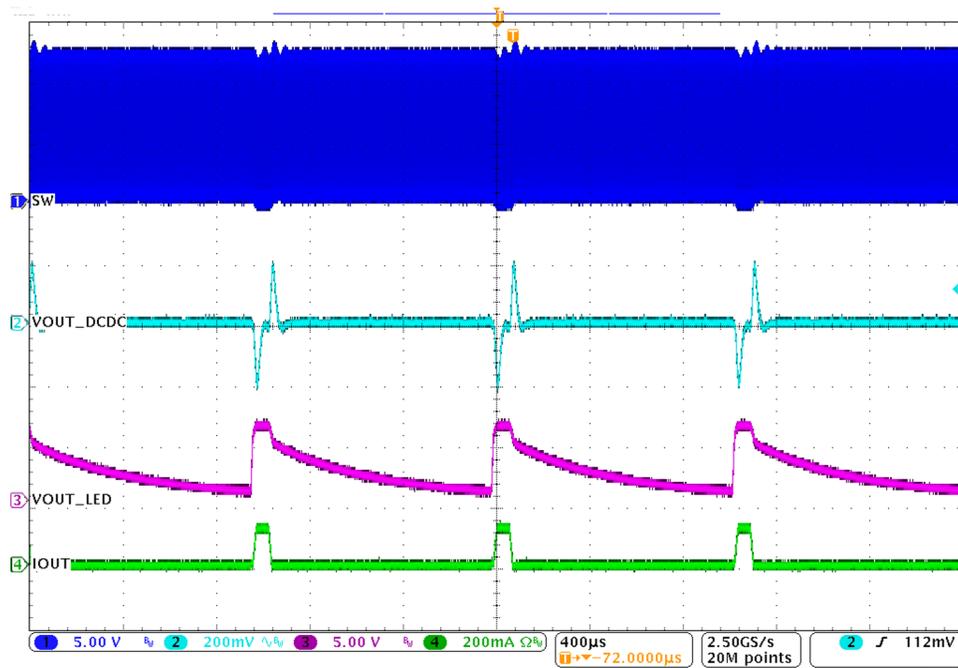


Figure 14. Steady State: $V_{IN} = 12\text{ V}$, Duty Cycle = 5%

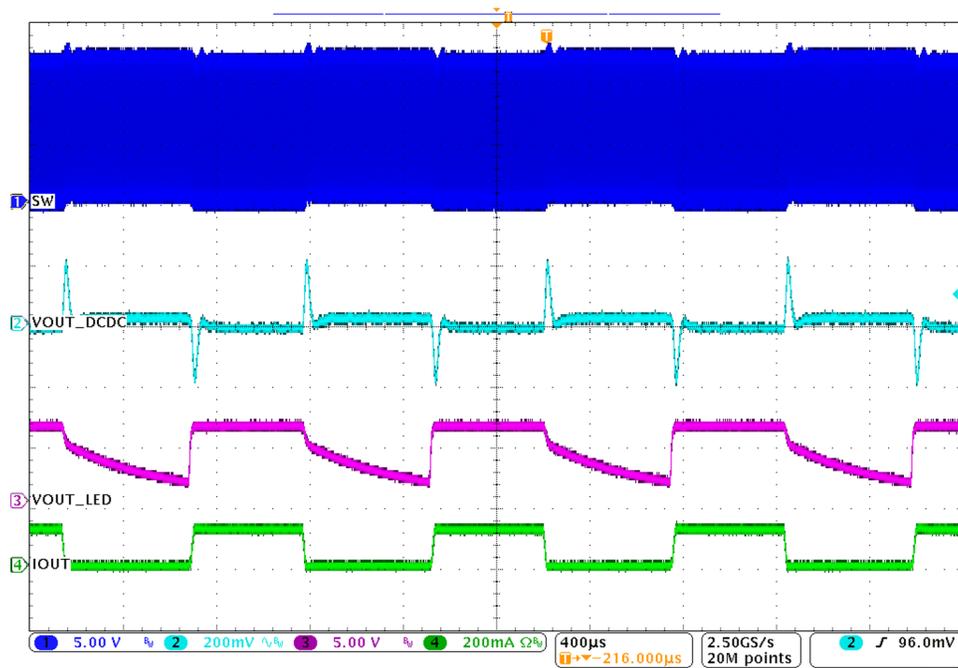


Figure 15. Steady State: $V_{IN} = 12\text{ V}$, Duty Cycle = 50%

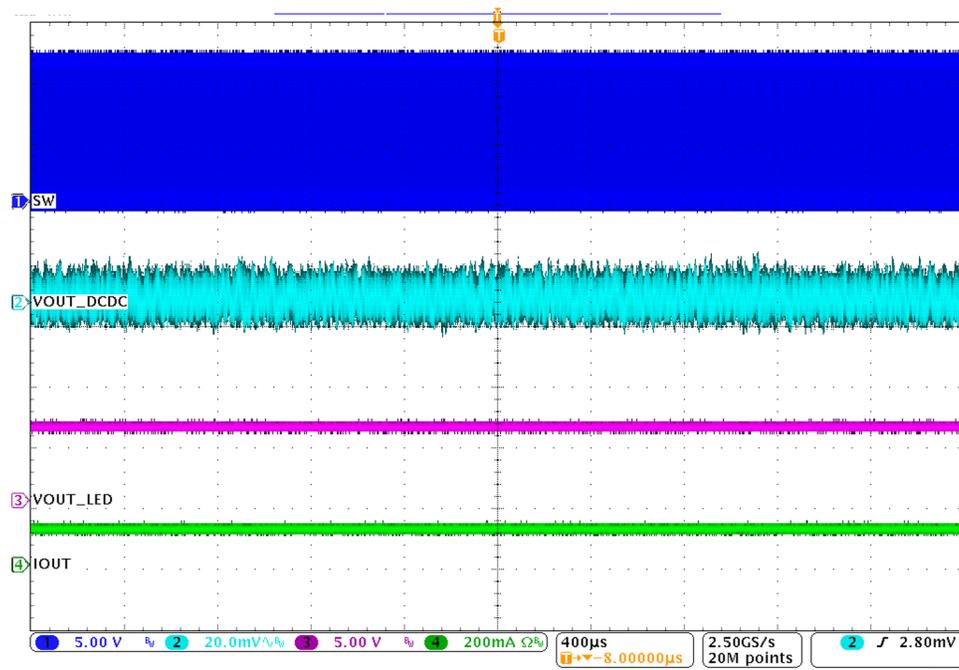


Figure 16. Steady State: $V_{IN} = 12\text{ V}$, Duty Cycle = 100%

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.

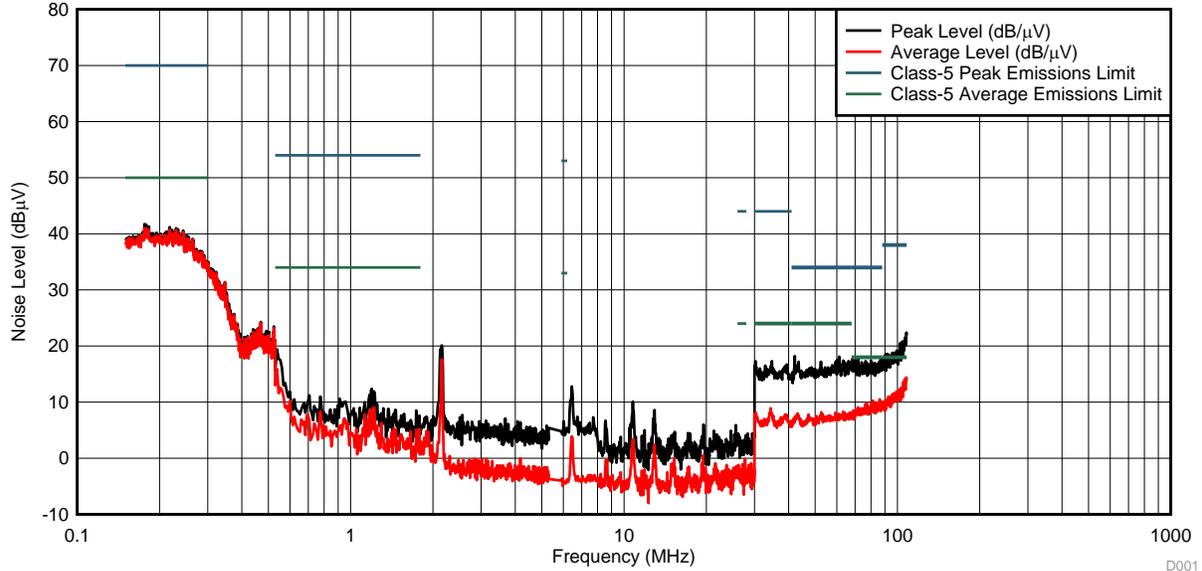


Figure 17. Conducted Emissions Positive

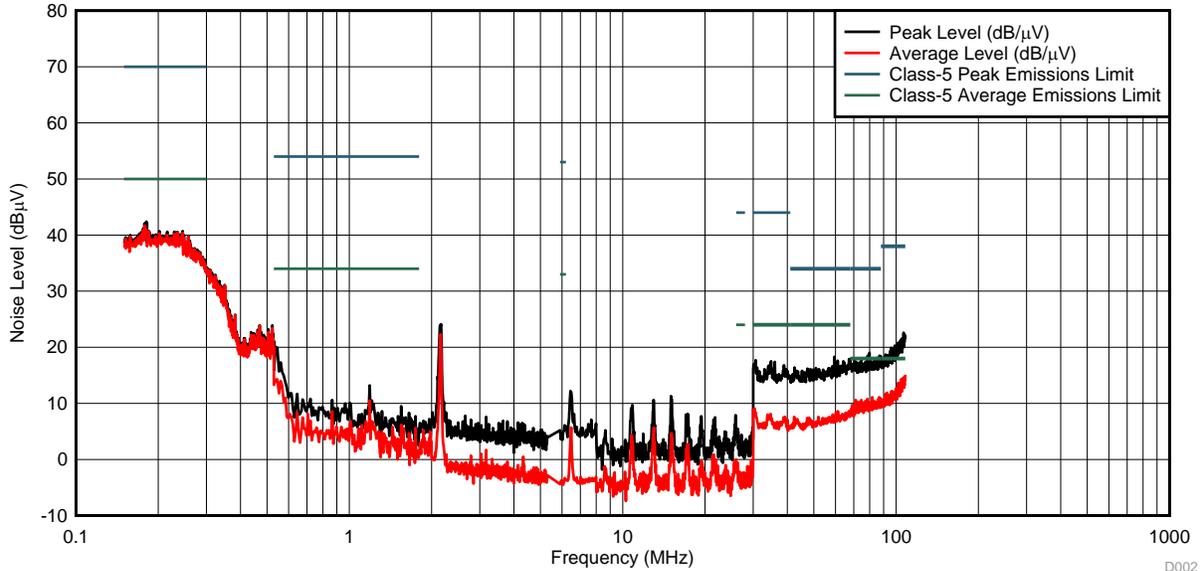


Figure 18. Conducted Emissions Negative

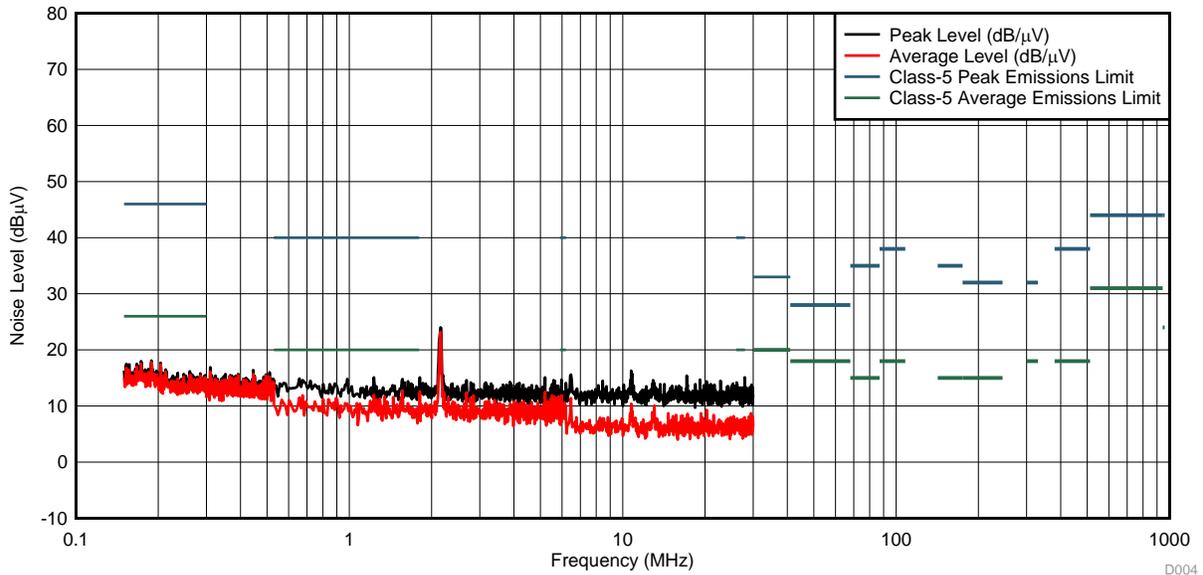


Figure 19. Radiated Emissions of 150 kHz to 30 MHz

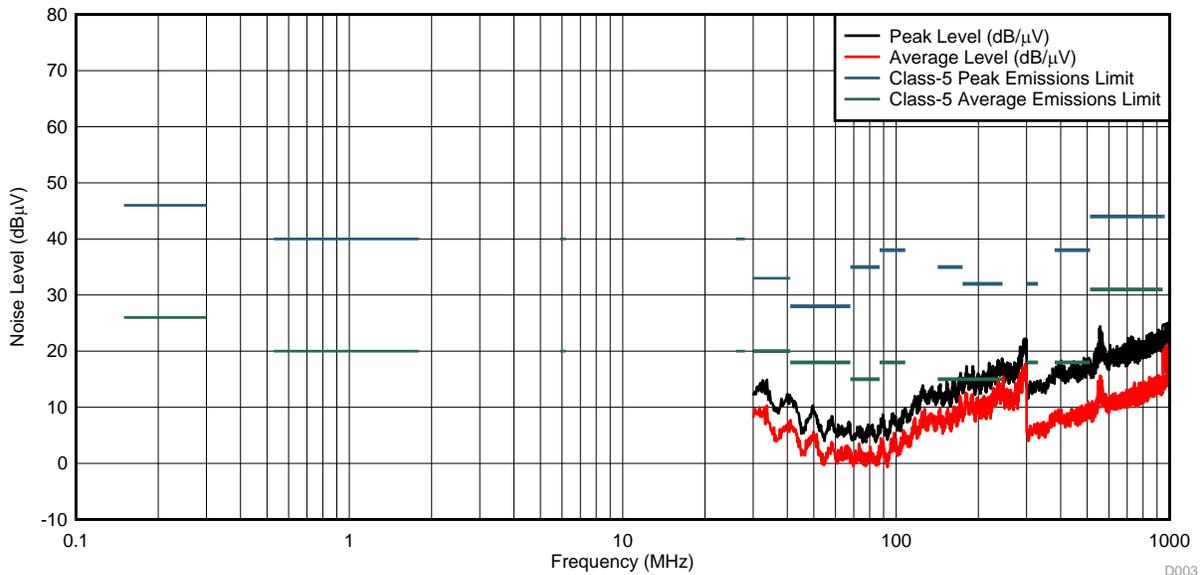


Figure 20. Radiated Emissions of 30 MHz to 1000 MHz

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)

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