TI Designs

EMC Compatible Automotive LED Rear Lamp With Sequential-Turn Animation Reference Design

Design Overview

This design is an analog solution for automotive rear lamps with sequential turn animations. This design is compatible with the TL81000 RI and the BCI test in a third-party EMC lab. This design also illustrates full automotive diagnostic with low quiescent current during fault mode.

Design Resources

TIDA-01007	Design Folder
TPS92638-Q1	Product Folder
TPS7A6650-Q1	Product Folder
TLC555-Q1	Product Folder
SN74LV164A	Product Folder
Other EVMs / TI Designs	Tools Folder

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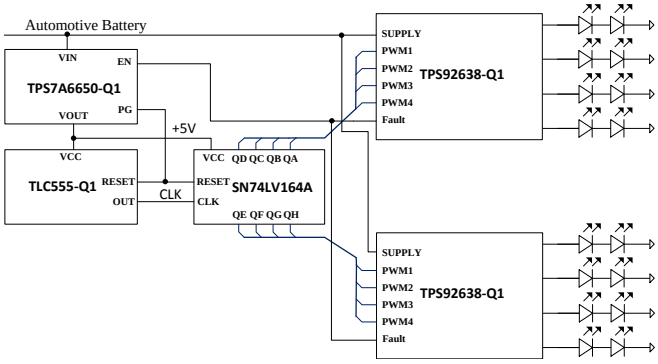
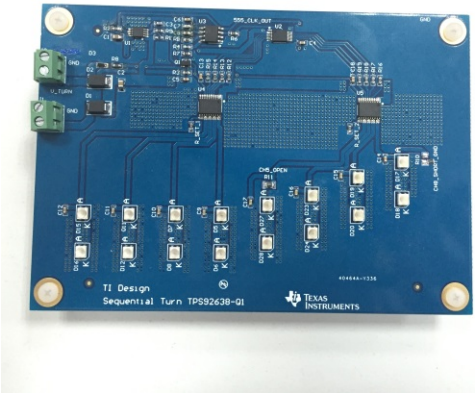
Design Features

- Automotive Battery Direct Connection
- Compliance With TL81000 RI and BCI
- Sequential Turn Animation Without MCU
- Full Diagnostic and Protection
- One-Fail-and-All-Fail (OFAF) Function
- Low-Quiescent Current During Fault Mode

Featured Applications

- Automotive Rear Light (RCL)
- Sequential-Turn Rear Lamp





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1 Key System Specifications

Table 1 shows the key system specifications for this TI Design.

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Input voltage range	9 V to 16 V
Output current	48.8 mA per Channel
Delay time for string on during sequential turn animation	22 ms
LED number	2s8P
LED type	LA E63F, OSRAM
Fault-mode current	< 10 mA

2 System Description

The TIDA-01007 TI Design is for an automotive rear light with sequential-turn animations and full diagnostics. The reference board passes the TL81000-RI and the BCI-test standards in a third-party EMC lab. In this design, linear light-emitting diode (LED) drivers (TPS92638-Q1) drive the LEDs with constant current.

The fault pins of two TPS92638-Q1s are connected together and implement a One-Fail-and-All-Fail (OFAF) function. The TPS7A6650-Q1 works as the power supply of the TLC555-Q1 and the SN74LV164A. The EN pin is controlled by the Fault Bus signal, then the LED fault turns off the low dropout (LDO) and decreases the fault-mode consumption current of the system. The TPS7A6650-Q1 PG pin controls the TLC555-Q1 and the SN74LV164A RESET pin to ensure the two devices reset during every power down. The TLC555-Q1 generates a PWM as the clock of the SN74LV164A and generates the delay time between LED-string turnon. The SN74LV164A generates eight PWM on signal to control the corresponding LED-string turnon sequence.

3 Block Diagram

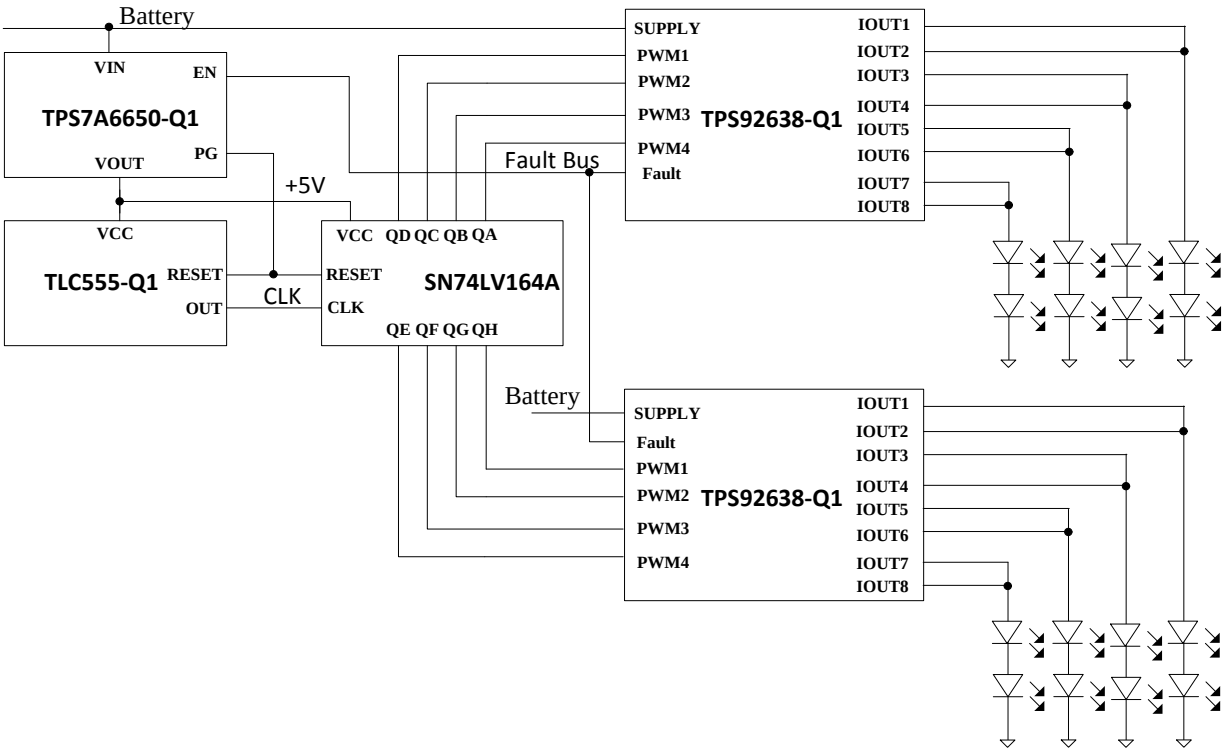

Figure 1. TIDA-01007 System Block Diagram

3.1 Highlighted Products

Section 3.1.1, Section 3.1.2, Section 3.1.3, and Section 3.1.4 outline the key features and highlight the products used in this reference design. Refer to the complete details of the highlighted-device data sheets in Section 8.

3.1.1 TPS92638-Q1—Eight-Channel Linear LED Driver

The TPS92638-Q1 is an 8-channel device with analog- and PWM-dimming controls (linear LED driver). This device is similar to the TPS92630-Q1, but the output current per channel is smaller (70 mA per channel maximum). The device can output a large current (560-mA maximum) with all outputs in parallel. The device is optimized for automotive stop lights and tail lights, and the current of these lights can be set by independent resistors. The TPS92638-Q1 contains four PWMs and each PWM controls two output channels. The TPS92638-Q1 offers complete system-protection features such as LED open, LED short, current foldback, and thermal shutdown, which improve reliability and simplify the design.

3.1.2 TPS7A6650-Q1—High Voltage, Low I_Q, and LDO

The TPS7A6650-Q1 is an LDO regulator designed for up to 40-V V_{IN} operations. The TPS7A6650-Q1 is suitable for standby MCU systems because it has a 12-µA quiescent current at no load, especially in automotive applications. The device features include integrated-short circuit and overcurrent protection. The device uses stable reset and regulation.

Program the delay with an external capacitor. A low voltage-tracking feature allows for a smaller input capacitor and can eliminate the need for a boost converter during cold-crank conditions.

3.1.3 TLC555-Q1—Timer

The TLC555-Q1 device generates a PWM input for the high driver. The TLC555-Q1 is a monolithic-timing circuit, which is fabricated using TI LinCMOS™ technology. The timer is fully compatible with a complementary metal-oxide semiconductor (CMOS), transistor-transistor logic (TTL), MOS logic, and operates at frequencies of up to 2 MHz. This device uses smaller timing capacitors than the capacitors used by the NE555 because of its high-input impedance. As a result, more accurate time delays and oscillations are possible. Power consumption is low across the full range of power-supply voltage.

3.1.4 SN74LV164A—8-Bit Parallel-Out Serial Shift Registers

The SN74LV164A devices are 8-bit parallel-out serial-shift registers designed for 2- to 5.5-V V_{CC} operation.

4 System Design Theory

The reference design uses two TPS92638-Q1s to drive 8-channel amber LED strings, and the current of each string is set to 24.4 mA. When input V-HAZARD connects to a battery, the LED strings work in stop function, and all of the strings turn on at approximately the same time with short delay. The STOP function of the TPS92638-Q1 can be disabled. Users can use the STOP function and switch the LED current to a higher level to implement the STOP function according to individual system requirements.

When input V-TURN connects to a battery, the LED strings turn on by sequence with an adjustable delay time to enable sequential-turn animation. The TLC555-Q1 is used to generate a PWM as a clock of the SN74LV164A and to decide the delay time between LED string turnon. The SN74LV164A generates eight PWMs to control the corresponding LED-string turnon in sequence.

4.1 Linear LED Driver Design

4.1.1 LED Current Design

Consider the thermal design when using a linear LED driver. When the input voltage and ambient temperature are high, the junction temperature of the device must be kept lower than 150°C to limit the output current.

Table 2 shows a design example.

Table 2. Thermal Design Parameters

PARAMETERS	SPECIFICATION
Input voltage range	9 V to 16 V
LED number	2s8P
LED type	LA E63F, OSRAM VF = 2.1 V
Ambient temperature, $T_{AMBIENT}$	85°C
PCB	Two-layer, 1 oz
θ_{JA}	37.8°C/W

The following list details the method to calculate the maximum output current of the LED driver (solution with the TPS92638):

1. Calculate the total LED-forward voltage using Equation 1.

   total LED-forward voltage = 2 × 2.1 = 4.2 V (1)

2. Calculate the total device power using Equation 2.

   total device power = (150 – $T_{AMBIENT}$) / θ_{JA} = 1.720 W (2)

3. Calculate the maximum current per channel using Equation 3.

   maximum current per channel = 1.720 / (16 – 4.2) / 8 = 18.2 mA, choose 18 mA per channel (3)

4. Calculate the reference resistor using Equation 4.

   reference resistor = 1.222 × 200 / 0.018 = 13.58 kΩ (4)

NOTE: θ_{JA} is determined by the PCB layout and material; in this example, the value for θ_{JA} is based on the JEDEC condition.

The board supports 24.4 mA per channel, as a result the board of θ_{JA} is lower than 37.8 °C/W.

4.1.2 LED Fault Design

As Figure 2 shows, connecting the fault pins together allows the system to use the OFAF function without a MCU in the system. The TPS92638-Q1 FAULT-pin design supports the connection of up to 30 TPS92638-Q1 devices in one system. When one or more LED strings have errors, their corresponding FAULT pins go low and pull down the connected FAULT-bus signal and shut down all device outputs. The TPS7A6650-Q1 EN pin connects to the FAULT-bus signal. When a fault occurs, the TPS7A6650-Q1 turns off the output and recover when the FAULT bus signal goes high again. Because the TPS9A6650-Q1 I_Q is 2 µA when the EN pin is low, the current consumption of the TPS92638-Q1 is 1.15 mA maximum per device. The total fault-mode current is 2.3 mA.

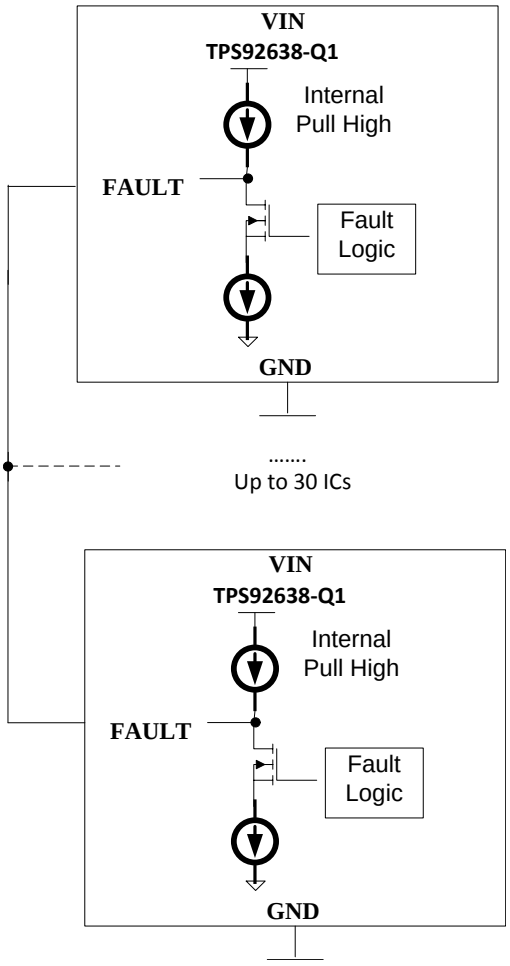

Figure 2. Fault Bus

4.1.3 PWM Input Design

The TPS92638-Q1 features four independent PWM-bank dimming-control pins. Each pin controls one bank consisting of two channels. The TLC555-Q1 and SN74LV164 generate the on signal to control the TPS92638-Q1 PWM pin and turn on the LED string by sequence.

4.2 CLK and Delay-Time Design

To implement eight separated PWMs with adjustable-shift delay times, the SN74LV164A works for 8-bit parallel-out serial-shift registers. Connect pin A and pin B to VCC directly so the Qx high-shift time depends on the CLK. In Figure 3, the TLC555-Q1 device is used to generate the CLK input signal.

Use Equation 5, Equation 6, Equation 7, and Equation 8 to set the CLK period and duty cycle.

$$t_H = 0.693 \times (R_4 + R_5) \times C_7 \quad (5)$$

$$t_H = 0.693 \times (R_5) \times C_7 \quad (6)$$

$$\text{period} = t_H + t_L = 0.693 \times (R_4 + 2R_5) \times C_7 \quad (7)$$

$$T_{delay1} = 0.693 \times (10 + 2 \times 150) \times 10^3 \times 2.2 \times 10^{-9} = 0.47 \text{ ms} \quad (8)$$

Use Equation 9 when V Turn is high so eight LED strings turn on with a 21.9-ms shift delay by sequence.

$$T_{delay2} = 0.693 \times (10 + 2 \times 150) \times 10^3 \times (0.0022 + 0.1) \times 10^{-6} = 21.96 \text{ ms} \quad (9)$$

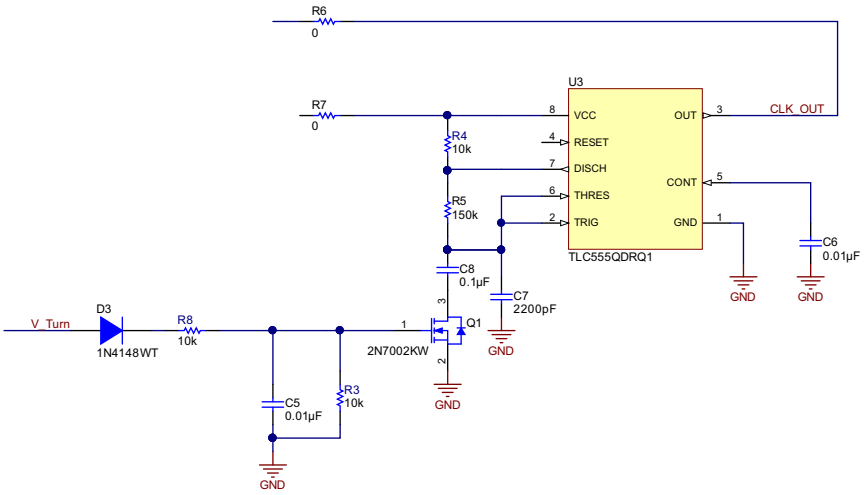

Figure 3. CLK Generator

4.3 Low I_Q in Fault Mode

Connect the TPS7A6650-Q1 EN pin to the FAULT pin-bus signal (see Figure 4). When a fault occurs, the TPS7A6650-Q1 turns off the output. No current is consumed from the TLC555-Q1 or the SN74LV164A. Recover when the FAULT bus signal goes high again.

Because the TPS9A6650-Q1 I_Q is 2 µA when the EN pin is low, the current consumption of the TPS92638-Q1 is 1.15-mA maximum per device (see Figure 5). The total fault-mode current is 2.3 mA.

NOTE: When an open fault occurs, the LED open fault cannot auto recover because the TPS7A6650-Q1 and the fault channel turn off. The LEDs remain off if users reconnect the open string. To auto-recover the LEDs, remove R9 and solder R1 with 0R, shown in Figure 4. The system must sacrifice a higher fault-mode current.

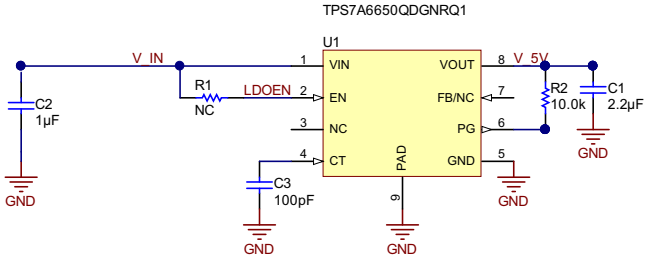

Figure 4. TPS7A6650-Q1

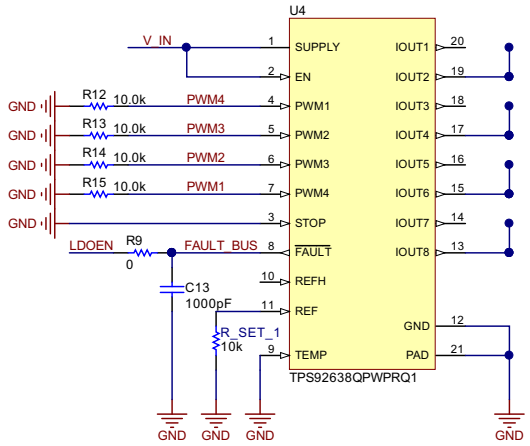

Figure 5. Low I_Q of Fault Mode

4.4 Sequential-Turn Function Effective in Every Power on

The sequential-turn function must be effective during every power on. The RESET pins of the SN74164A and the TLC555-Q1 must go low when the power is off. Because the pins are connecting directly to the battery, the system may not drop the VIN pin to the GND every time. The RESET pins must connect to the PG pin to ensure the RESET pin discharges to the GND when the battery is lower than 4.5 V.

5 Getting Started Hardware

Connecting a 12-V DC supply to the onboard-input connector (J1) lights up the LED in tail mode. Connecting a 12-V DC supply through the PWM mode high-side driver with a 0.5-s on and a 0.5-s off to the onboard-input connector (J2) lights up the LED sequential-turn animation. See Figure 6 for the input voltage in turn mode.

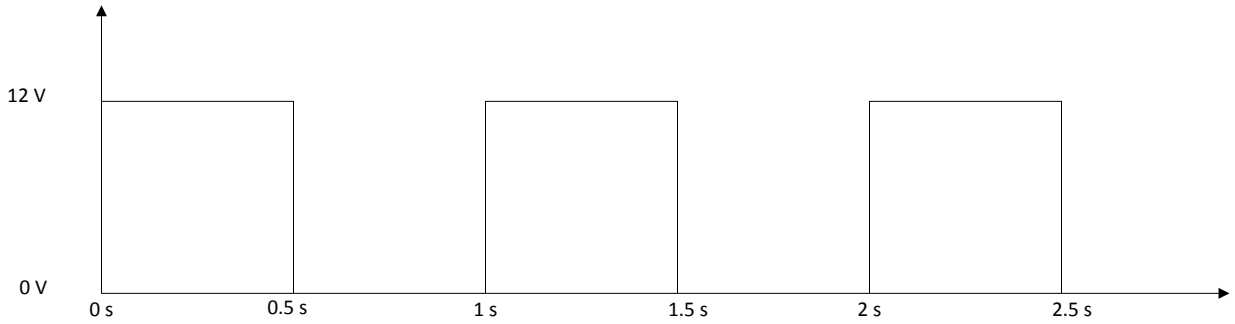

Figure 6. Input Voltage of Turn Mode

6 Test Data

6.1 Subsection

Figure 7 shows the input relation during the tail mode. CH1 is CLK, CH2 is PWM2, CH3 is PWM2, and CH4 is PWM8. All channels turn on within 4 ms so the user cannot detect the strings turnon by sequence.

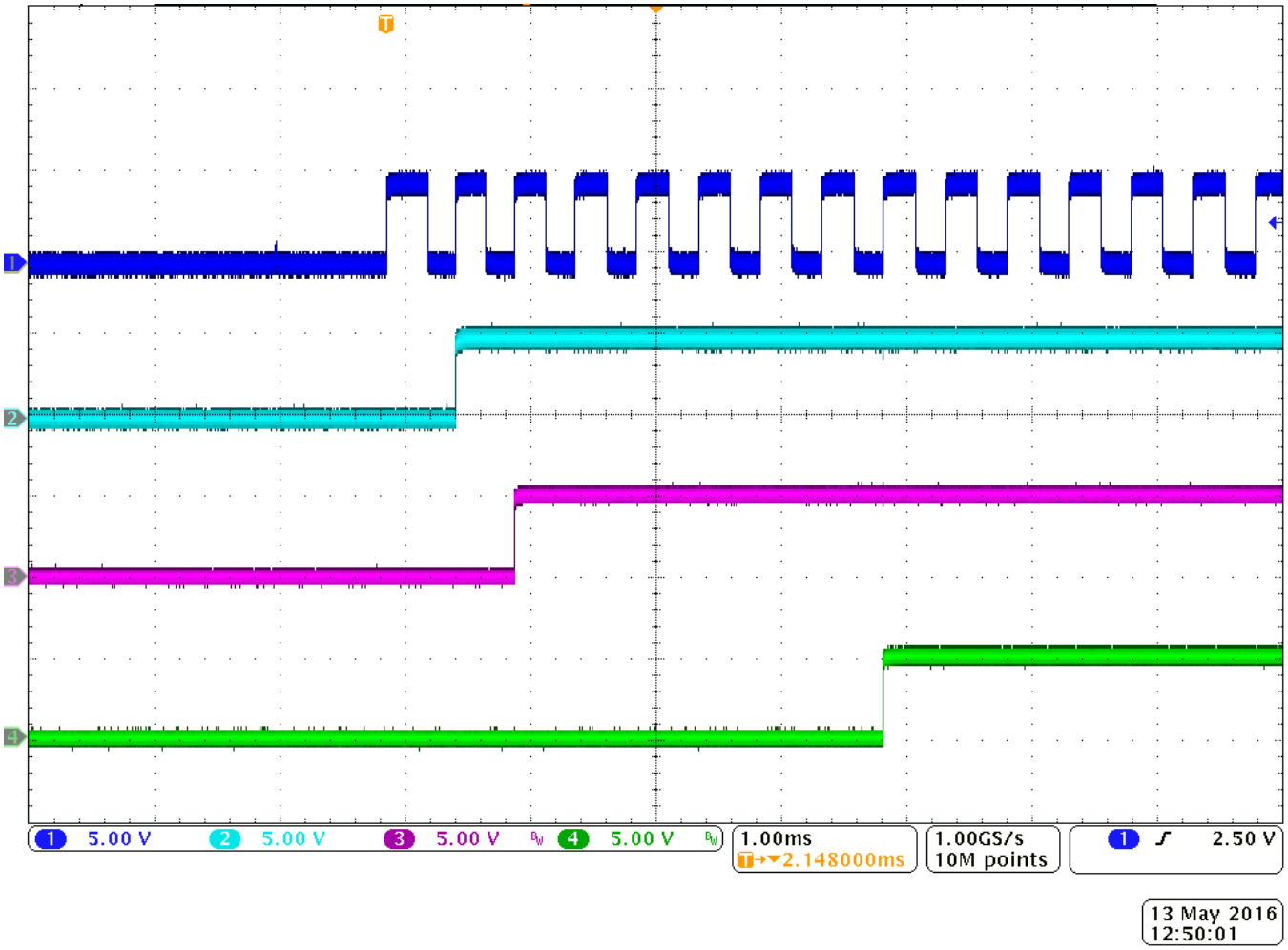

Figure 7. PWM Turnon Timing in Tail Mode

Figure 8 shows the CLK and PWM input during the sequential-turn mode. CH1 is CLK, CH2 is PWM2, CH3 is PWM2, and CH4 is PWM8. All channels turn on in 22-ms shift delays, and all channels turn on within 160 ms so the user can detect the strings turnon by sequence and consistent regulations. Users can adjust the CLK with the RC value based on system requirements.

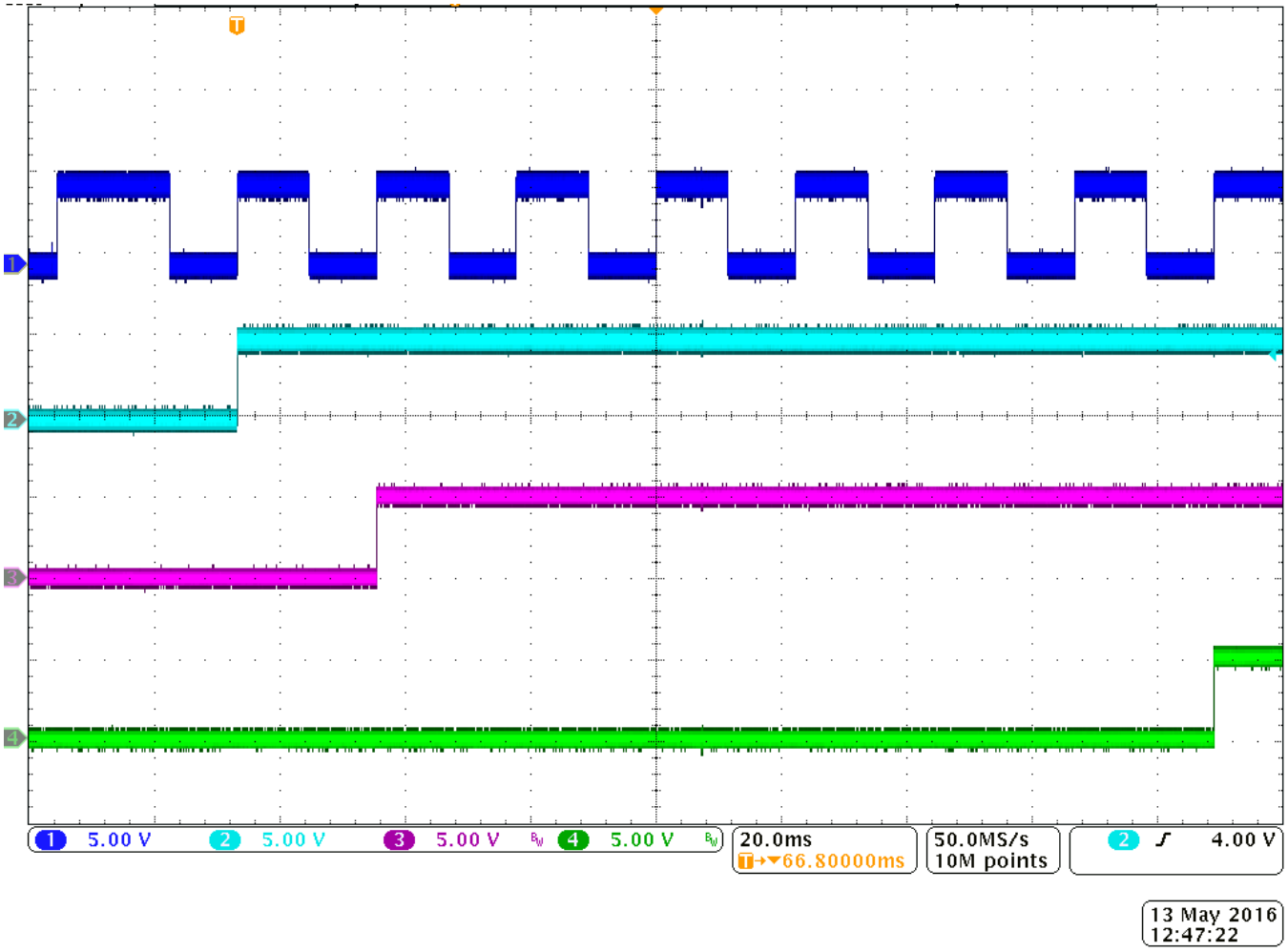

Figure 8. PWM Turnon Timing of Sequential Turn Mode

6.2 Fault-Mode Consumption Current

Table 3 shows the fault-mode consumption current with the following test condition: V_{IN} = 12 V, free-air temperature.

Table 3. Board Consumption Current of Fault Mode

FAULT	I_Q WITH SHUTDOWN LDO	I_Q WITHOUT SHUTDOWN LDO
One LED open	2.254 mA	6.56 mA
One LED string short	2.254 mA	6.56 mA

7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDA-01007.

7.2 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at TIDA-01007.

7.3 PCB Layout Recommendations

The layout process is an important step for the use of a linear LED driver. If the layout is not carefully designed, the driver may not deliver enough output current because of the thermal limitation. To improve the thermal performance of the device and maximize the current output at high-ambient temperatures, TI recommends spreading the thermal pad as wide as possible and placing a sufficient number of thermal vias on the thermal pad.

7.3.1 Layout Prints

To download the layout prints for each board, see the design files at TIDA-01007.

7.4 Altium Project

To download the Altium project files for each board, see the design files at TIDA-01007.

7.5 Gerber Files

To download the Gerber files for each board, see the design files at TIDA-01007.

7.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at TIDA-01007.

8 References

1. Texas Instruments, *TPS92638-Q1 8-Channel Linear LED Driver With PWM Dimming*, TPS92638-Q1 data sheet (SLVSCK5)
2. Texas Instruments, *TPS7A66xx-Q1 High-Voltage Ultra-Low IQ Low-Dropout Regulator*, TPS7A66xx-Q1 data sheet (SLVSBL0)
3. Texas Instruments, *TLC555-Q1 LinCMOS™ TIMER*, TLC555-Q1 data sheet (SLFS078)
4. Texas Instruments, *SN74LV164A 8-Bit Parallel-Out Serial Shift Registers*, SN74LV164A data sheet (SCLS403)

9 About the Author

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