Application Note

Typical Design Guideline for TPS92633-Q1 Parallel Channels in High Current Application

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ABSTRACT

The TPS92633-Q1 is a linear three-channel constant-current LED driver designed for high brightness LEDs in automotive rear light applications. As requirements continue to evolve in the rear light market, LED drivers are expected to achieve greater flexibility and more comprehensive functionality. This application note provides some design guidelines on how to use TPS92633-Q1 device to achieve a higher output current by paralleling output channels and make sure normal operation while maintaining diagnostic functions.

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1 Introduction

The TPS92633-Q1 three channel LED driver includes an unique thermal management design to reduce temperature rising on the device. This device can output full current loads up to 150mA per channel and each channel can be independently controlled. External shunt resistors are used to share the output current and power dissipation of the device. Both SUPPLY control and EN/PWM control are supported by this device to turn LED on or off. TPS92633-Q1 also has full diagnostic capabilities, including LED short-to-GND, LED open-circuit, single-LED-short and auto-recovery function. See Figure 1-1.

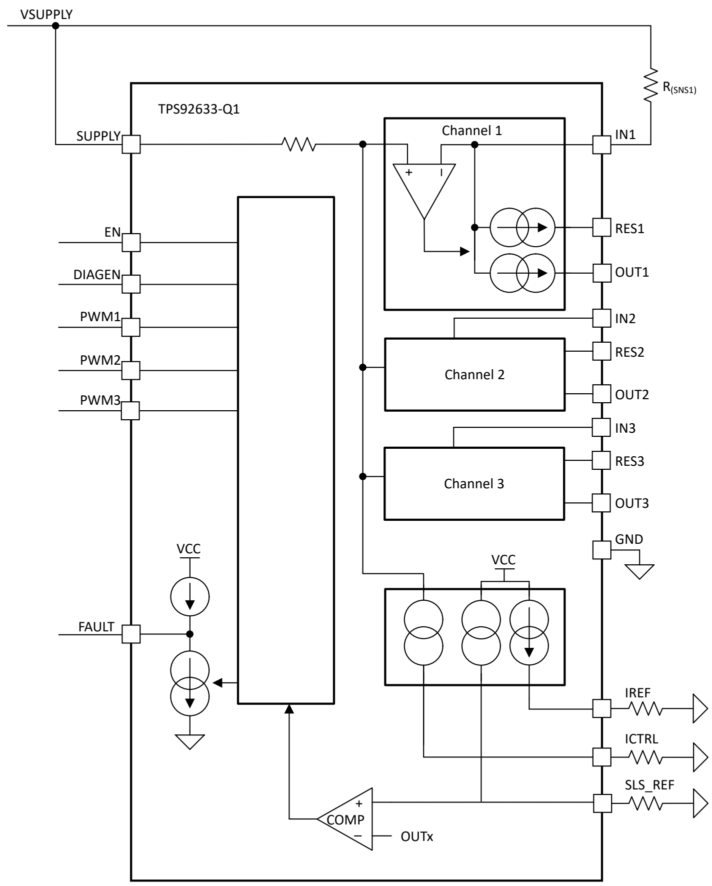

Figure 1-1. Functional Block Diagram

This device can output full current loads up to 150mA per channel and each channel can be independently controlled. If there is a higher current requirement for the LED string, it is easy to achieve that by connecting all output channels together and making all channels perform the same signals . See Figure 1-2

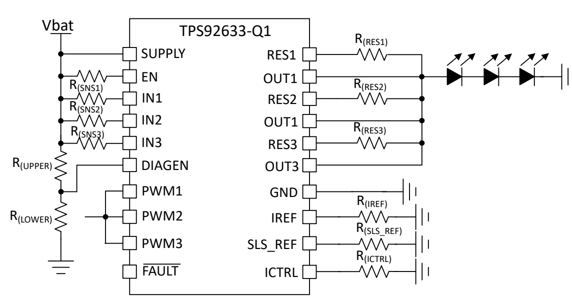

Figure 1-2. TPS92633-Q1 Typical Schematic for Higher Output Current

2 TPS92633-Q1 Design Considerations

2.1 Setting the Output Current

The TP92633-Q1 can set the output current I(OUTx_Tot) at each channel independently through regulating the voltage drop $V_{(CS\_REG)}$ on the external high-side current-sense resistors $R_{(SNSx)}$. When the output current is in regulation, the current value can be calculated through Equation 1.

$$I_{(OUTx\_Tot)} = \frac{V_{(CS\_REG)}}{R_{(SNSx)}} \quad (1)$$

where

- V_{CS_REG} is variable according to Equation 2.
- x = 1, 2 or 3 for output channel 1, 2, or 3.

The TPS92633-Q1 supports analog constant current for all three channels through adjusting the $V_{(CS\_REG)}$. As depicted in Figure 2-1. The device outputs a constant current $I_{(ICTRL)}$ on the ICTRL pin and measures the voltage $V_{(ICTRL)}$ on the ICTRL pin to determine the $V_{(CS\_REG)}$. The $I_{(ICTRL)}$ current is 10 times of the current $I_{(IREF)}$ on the IREF pin.

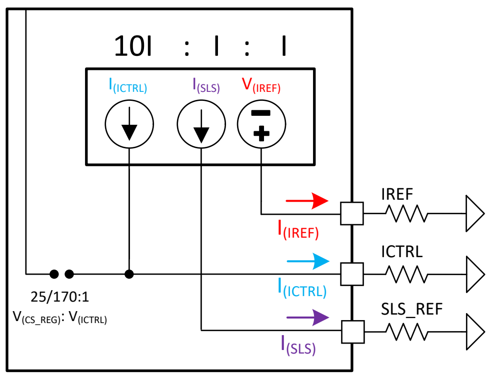

Figure 2-1. Internal Block Diagram of IREF, ICTRL and SLS_REF pins

The $V_{(CS\_REG)}$ value can be changed following Equation 2

$$V_{(CS\_REG)} = \frac{V_{(IREF)} \times R_{(ICTRL)} \times 25}{R_{(IREF)} \times 17} \quad (2)$$

where

- $V_{(IREF)}$ = 1.235V
- $R_{(IREF)}$ is in kΩ unit
- $R_{(ICTRL)}$ is in Ω unit

The desired output current of each channel can be calculated by Equation 3 which is a combination of Equation 1 and Equation 2

$$I_{(OUTx\_Tot)} = \frac{V_{(IREF)} \times R_{(ICTRL)} \times 75}{R_{(IREF)} \times R_{(SNSx)} \times 17} \quad (3)$$

where

- $V_{(IREF)}$ = 1.235V
- $R_{(ICTRL)}$ is in Ω unit
- $R_{(IREF)}$ is in kΩ unit
- $R_{(SNSx)}$ is in Ω unit

Seeing how the three channels are connected in parallel and then the total output current can be calculated by Equation 4.

$$I_{(OUT\_Parallel\_Tot)} = I_{(OUT1\_Tot)} + I_{(OUT2\_Tot)} + I_{(OUT3\_Tot)} \quad (4)$$

The previous calculation and the value selection of peripheral component parameters can be done with the assistance of *TPS92633-Q1 External Component Calculation Tool*.

2.2 Single-LED-Short Diagnostic

The TPS92633-Q1 is able to provide full diagnostics and protection to keep the system operating reliably, including the LED short-to-GND, LED open-circuit, and thermal shutdown protection, specially, this device supports single-LED-short(SLS) diagnostic to flexibly fit different diagnostic requirements. After the fault is removed, this device can recover to normal operation automatically. The one-fails-all-fail function is supported by this device to meet the system design requirement. The LED open-circuit and single-LED-short functions can be disabled through setting an accurate threshold of DIAGEN pin. Once the TPS92633-Q1 has asserted a LED fault on the LED string, the device turns off the faulty channel and auto-retries with a retry current.

In high current application, the retry currents of each channel are combined together if all three channels are connected together. For LED-string short-to-GND and LED open-circuit fault, the device keeps the same fault behavior. But since the diagnostic mechanisms of single-LED-short function are different from others and more complicated, some special deign considerations are required to make sure the device is working properly as expected.

2.2.1 Single-LED-Short Detection

The TPS92633-Q1 can support a single-LED-short detection by monitoring the output voltage when the output current is enabled and the DIAGEN input signal is high. The scale down output voltage $V_{(OUTx)}$ of each channel is internally compared with a programmable reference voltage $V_{(SLS\_th\_falling)}$ set by $R_{(SLS\_REF)}$ on the SLS_REF pin to detect a SLS fault. When the $V_{(OUTx)}$ falls below $V_{(SLS\_th\_falling)}$ longer than the deglitch time, the device asserts the fault and pulls low the FAULT pin. Combined with Figure 2-1, the $V_{(SLS\_th\_falling)}$ can be calculated by Equation 5.

$$V_{(SLS\_th\_falling)} = \frac{N_{(OUT)} \times R_{(SLS\_REF)} \times V_{(IREF)} \times N_{(SLS\_REF)}}{R_{(IREF)}} \quad (5)$$

where:

- $V_{(IREF)}$ = 1.235(Typical)
- $R_{(IREF)}$ = 12.3kΩ recommended
- $R_{(SLS\_REF)}$ is in kΩ unit
- $N_{(OUT)}$ = 4 (typical)
- $N_{(OUT)}$ = 1 (typical)

More information is referred to the detailed description in the*TPS92633-Q1 Three-Channel Automotive High-Side LED Driver with Thermal Sharing and Off-Board Binning*.

The TPS92633-Q1 can support the maximum output current of 450mA when all channels are tied together, the $V_{(SLS\_th\_falling)}$ is adjusted according to the number of LED and the total output current. Generally, to achieve the single-LED-short detection, the $V_{(SLS\_th\_rising)}$ needs to be kept within the bounds following relationship from Equation 6.

$$V_{F\_max} \times (N - 1) < V_{(SLS\_th\_falling)} < V_{F\_min} \times N \quad (6)$$

where:

- N is the number of LED in the LED string.
- V_{F_max} is the maximum forward voltage of the LED used at the given current.
- V_{F_min} is the minimum forward voltage of the LED used at the given current.

2.2.2 Single-LED-Short Auto-Recovery

After the single-LED-short fault is asserted and the devices starts, an auto-recover process. During retrying, the device sources full current from IN to OUT to pull up the LED loads every 10ms for 300us period when the PWM input is logic high for the faulty channel. Once the device detects $V_{(OUTx)}$ risng above $V_{(SLS\_th\_rising)}$, the single-LED-short fault is cleared and the device resumes to normal operation automatically. The $V_{(SLS\_th\_rising)}$ is 2.5% higher the $V_{(SLS\_th\_falling)}$, therefore, it can be easily obtained according to Equation 5. The total retry current $I_{(Retry\_Tot)}$ is the addition of the retry currents of the paralleled channels, which can be calculated from Equation 7.

$$I_{(Retry\_Tot)} = I_{(Retry\_Out1)} + I_{(Retry\_Out2)} + I_{(Retry\_Out3)} \quad (7)$$

Where

- $I_{(Retry\_Out1)}$ is the retry current of channel 1.
- $I_{(Retry\_Out2)}$ is the retry current of channel 2.
- $I_{(Retry\_Out3)}$ is the retry current of channel 3.

In this high current application, there is a special situation if PWM dimming feature is required. Since the fault detection and auto-retry processes for each channel are independent, if all three channels are working in PWM mode, the time difference of each channel can be accumulated with more PWM cycles, eventually leading to a possibility that the retry current of each channel becomes out of sync when PWM is operating for a long time with a high PWM frequency, which is shown in the Figure 2-2. The output voltage triggered by this out-of-sync retry current cannot rise above the designed $V_{(SLS\_th\_rising)}$, in this situation, the device cannot be able to recover even the single-LED-short fault is removed. To make sure the desired behavior of auto-recovery, the retry current of all channels needs to be synchronized to maintain a full retry current and meet the threshold setting, there are some steps that need to be considered during the design process.

Figure 2-2. Out of Sync Retry Currents

Step 1: Evaluate the $V_{(SLS\_th\_rising)}$

Set $V_{(SLS\_th\_rising)}$ to a level in which the device can recover under the situation of out-of-sync retry currents.

Considering the worst case - the retry current of the three channels are completely separated. In this condition, the retry current of single channel needs to be used in the calculation. In addition to meet the Equation 6, the $V_{(SLS\_th\_rising)}$ needs to be within the bounds of the following Equation 8.

$$V_{I_F = I_{Retry\_Tot}} \times (N - 1) < V_{(SLS\_th\_rising)} < V_{I_F = I_{Retry\_Outx}} \times N \quad (8)$$

The equation means that the threshold must be lower than the forward voltage of the LED string at the given retry current of single channel. If the calculation can be applied under any circumstance, the device is able to work normally. But if the evaluation results show that the target range is difficult to achieve, the step 2 needs to be followed.

Step 2: Recommended External Circuit to Sync All Retry Currents

According to the auto-recovery mechanism, the device retries the LED load every 10ms for 300us period until the fault is removed. To avoid the accumulation of time difference, a wait synchronization interval of no less than 10ms is designed to synchronize the retry current of different channels.

The synchronization can be easily accomplished by controlling PWM pins and FAULT pin. After a single-LED-short fault is reported out, the PWM pins are pulled low for a certain time interval, then the PWM inputs can be held high until the fault is removed and the FAULT pin is released. The designed waveforms are depicted in Figure 2-3. In this way, time differences are not introduced with PWM cycles during the fault state.

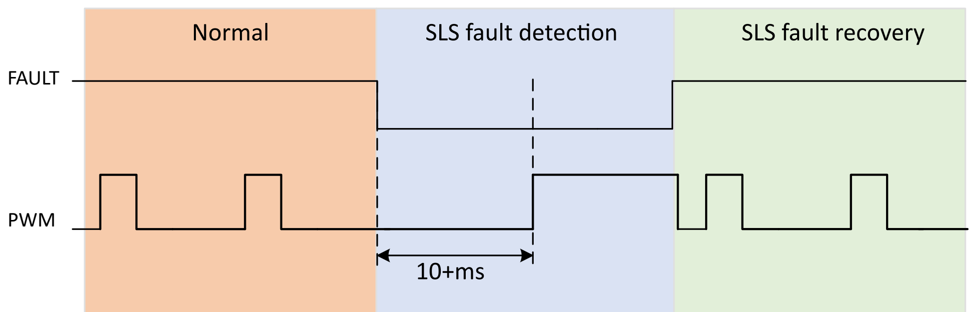

Figure 2-3. Designed Waveforms to Sync all Retry Currents

A recommended synchronization circuit to sync all retry current is shown in Figure 2-4.

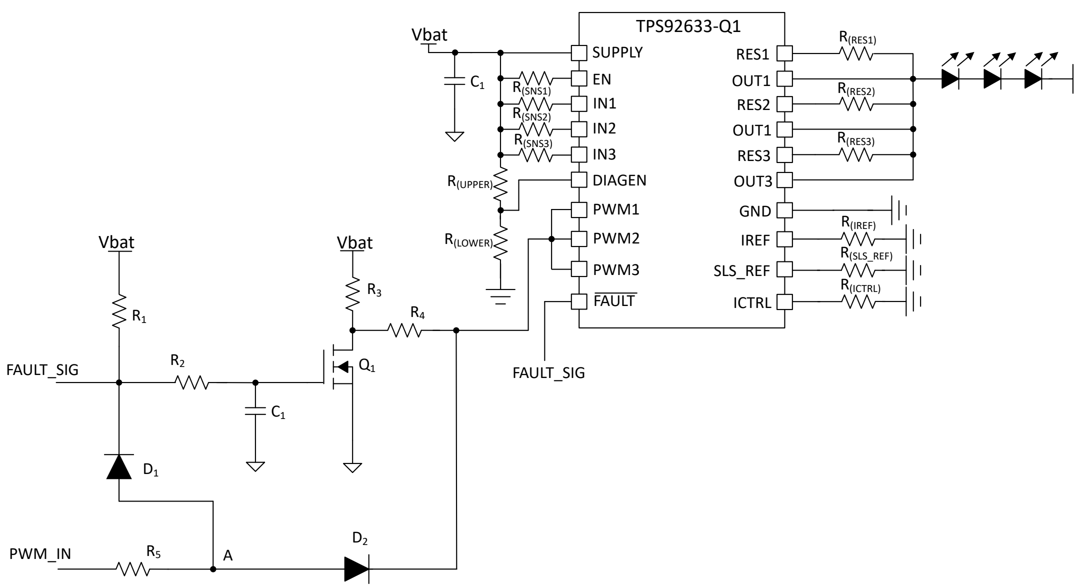

Figure 2-4. Recommended Synchronization Circuit for TPS92633-Q1 Parallel Channels

The FAULT pin is internally pulled low when the device detects a single-LED-short fault, due to the presence of the diode, the PWM pins can be clamped to a low voltage level until Q1 is turned off, the PWM pins return to a constant high voltage level after a designed discharge time. Once this fault is cleared, the device detects the output voltage rising above $V_{(SLS\_th\_rising)}$, the FAULT pin is released and the device resumes to normal operations.

To make sure the circuitry can work as expected, the pullup resistor R_1 must be large enough that can cover the range of Vbat and keep the FAULT pin is always below 0.4V when fault is triggered, otherwise the FAULT pin can not be pulled down correctly. In addition, the R_2 and C_1 need to be chosen appropriately for the given threshold voltage of Q_1 and the designed PWM pull-low time interval.

2.2.2.1 Implementation Results

The application results with the recommended circuit implemented is shown in Figure 2-5 and Figure 2-6. Table 2-1 shows the components values.

Table 2-1. Component Values

R_1	R_2	R_3	R_4	R_5	C_1
100kΩ	10kΩ	100kΩ	100kΩ	100kΩ	1uF

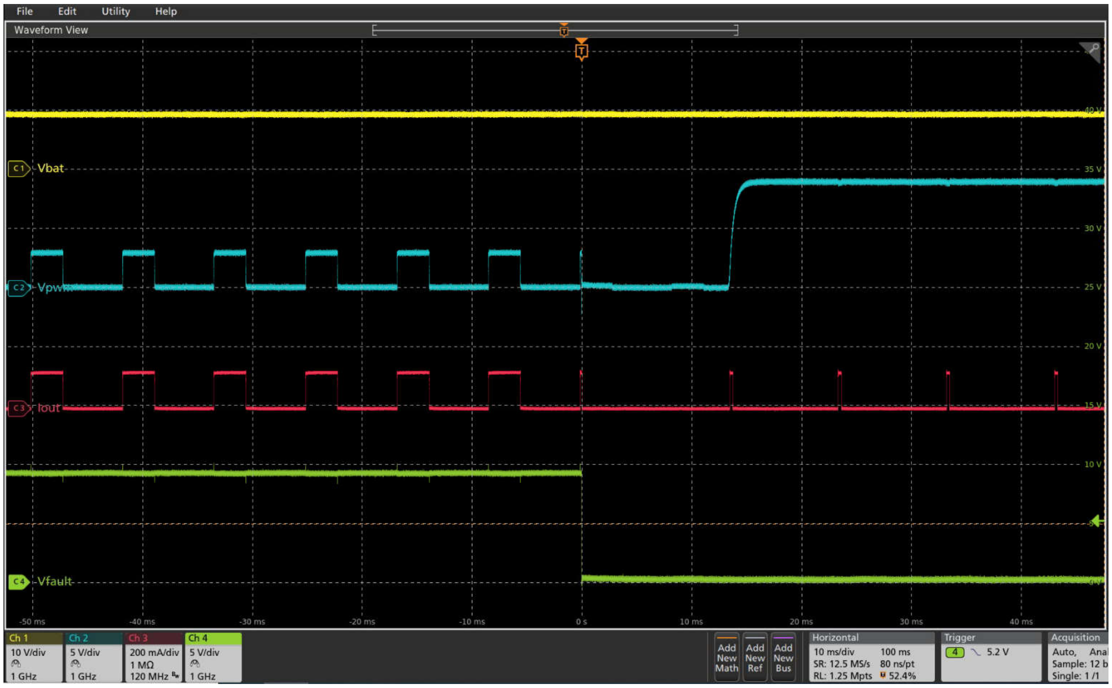

Figure 2-5. Parallel Channels Exposed to SIngle-LED-Short Condition Detection

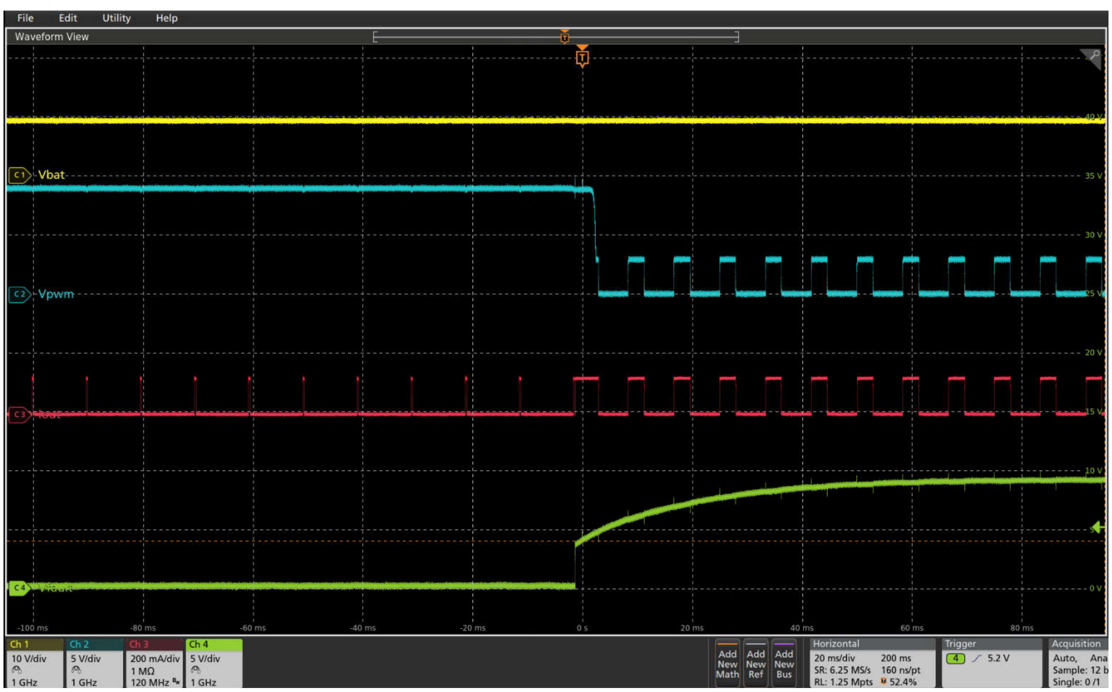

Figure 2-6. Parallel Channels Exposed to Single-LED-Short Condition Auto-Recovery

For a supply voltage of 10V, and 5V PWM pulse of 120Hz at 35% duty cycle, if a single-LED-short fault occurs, the FAULT pin is pulled down internally, then the PWM pins are pulled low. After a time interval of 13ms, the PWM pins are pulled up until the fault is removed. The FAULT pin is released and the output current can recover to normal operation.

Step 3: Use a MCU to Sync All Retry Currents

If a MCU is available in this system and can be used to control the PWM pins and the FAULT pin, it is easy to achieve this retry current synchronization, which can be seen in Figure 2-7. The same functionally can be achieved as the retry current sync circuit above.

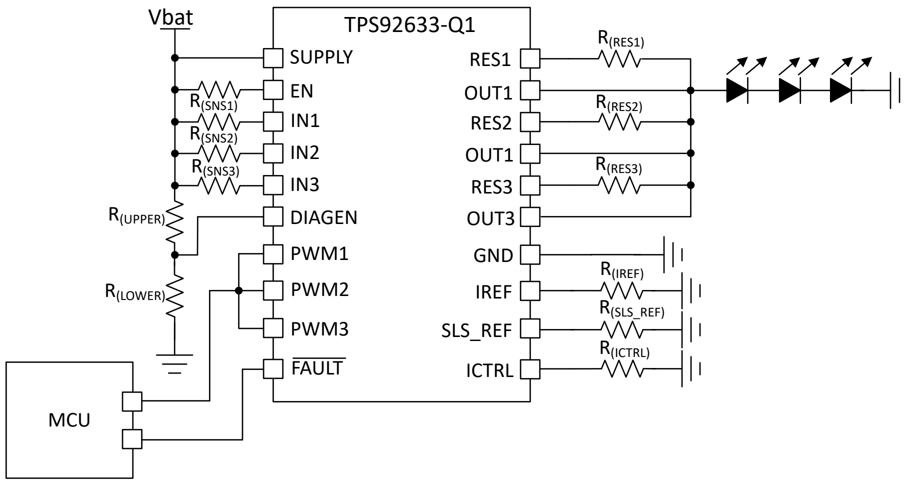

Figure 2-7. MCU Connection for TPS92633-Q1 Parallel Channels

3 Summary

This application note introduces the typical design requirements and considerations for the TPS92633-Q1 parallel channels in automotive rear lamp applications to achieve a high performance and more flexible current capability as expected.

4 References

- Texas Instruments, *TPS92633-Q1 Three-Channel Automotive High-Side LED Driver with Thermal Sharing and Off-Board Binning*, data sheet.

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