Application Note

Functional Safety Turn Light Design

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ABSTRACT

Functional safety is more and more popular in the automotive applications. Not only BMS, traction converter, but also brake and turn lights because they are also safety related. This application note provides the method to design an ASIL-B level brake and turn LED light with quality managed devices, TPS57140-Q1 and TPS92611-Q1. This method can fan out to other functional safety designs.

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Trademarks

1 Functional Requirement

1.1 Functionality

1. Operation temperature range is –40 to 85°C.
2. Input 9 V to 18 V.
3. Output 3 LEDs in one series and total 5 parallel, so total 5 parallels by 3 series.
4. Each series is 135 mA.
5. Voltage drop of LED is 2.2-V typical, 2.65-V maximum.
6. The interface between turn light and BCM is power supply and its ground and one high active fault signal named FAULT_OUT.
7. All of the 15 LEDs must be turned on or off at the same time.

1.2 Diagnostics

1. If one single LED or one series LEDs or all LEDs cannot be turned on, this failure must be reported to BCM.
2. One-fail-all-fail is not needed.
3. The customer needs an open drain LOW that indicates fault.
4. System level ASIL-B.

1.3 Application Hours

1. Time of operation per year is 200 hours.
2. Total vehicle operation time is 15 years.
3. Percentage of operation for dual point fault computation is 1%.
4. Operation time for dual point fault computation is 3000 hours.

1.4 Safety Goal and Safe State

The key safety function for turn light is to avoid not turning on the turn indicator when intending to turn it on. The safe state is driver notification, ASIL-B level, FTTI is 280 ms.

1.5 Functional Safety Requirement

1. LED power supply no output voltage must be detected.
2. LED power supply thermal shutdown must be detected.
3. LED driver no current output must be detected.
4. LED driver thermal shutdown must be detected.
5. LED open must be detected.
6. LED short must be detected.

1.6 Technical Safety Concept

1.6.1 Architecture Description

1. The turn indicator module generates constant current for the LED.
2. The module has five LED strings, each string driven by its own linear LED driver.
3. To improve efficiency, the module has wide VIN buck regulator to step down battery voltage and generate power to each linear LED driver. The step voltage is 8 V.
4. The 8-V output from the buck regulator is used to power the fault aggregator circuit.
5. The fault aggregator circuit aggregates the FAULT signal from all linear LED drivers and generates turn indicator fault output.
6. The buck regulator and the LED drivers have built-in safety mechanisms which are used in the system.

1.6.2 Safety Mechanisms

SM1 LED open-circuit or LED short-to-battery detection implemented in TPS92611-Q1, fault asserted

SM2 LED short-to-ground detection implemented in TPS92611-Q1, FAULT asserted

SM3 Overtemperature protection implemented in TPS92611-Q1, FAULT asserted

SM4 Power good output in TPS57140-Q1, if VSENSE pin is between 94% and 107%, PWRGD de-asserted

SM5 Overvoltage transient protection in TPS57140-Q1, output voltage is clamped

SM6 Thermal shutdown implemented in TPS57140-Q1

SM7 Fault aggregator circuit keeps FAULT_OUT pin high impedance

1.6.3 TPS57140-Q1 Failure Mode Effects

1. No PH output: no voltage output, which is indicated by assertion of PWRGD signal.
2. PH output not in specification – voltage or timing: PWRGD signal is asserted.
3. PH high side FET stuck on: voltage output is high which causes LED driver to shut down because of temperature increase.
4. PWRGD false trip or fails to trip: no indication or false indication of fault.
5. Short-circuit any two pins: must analyze Pin FMEA.

1.6.4 TPS92611-Q1 Failure Mode Effects

1. OUT no output (HIZ): FAULT pin is asserted.
2. OUT output not in specification current or timing: FAULT pin is asserted.
3. OUT stuck off (GND): FAULT pin is asserted.
4. OUT stuck on: FAULT pin is asserted.
5. FAULT fails to trip or false trip: no indication or false indication of fault.
6. Short-circuit any two pins: must analyze Pin FMEA.

1.6.5 Fault Aggregator Circuit

1. The TPS92611 fault aggregator circuit is powered from the output of the buck regulator.
2. The TPS92611 fault aggregator circuit is such that when one device fails, only that device shuts down.
3. Aggregate TPS57140 fault output with TPS92611 fault output.

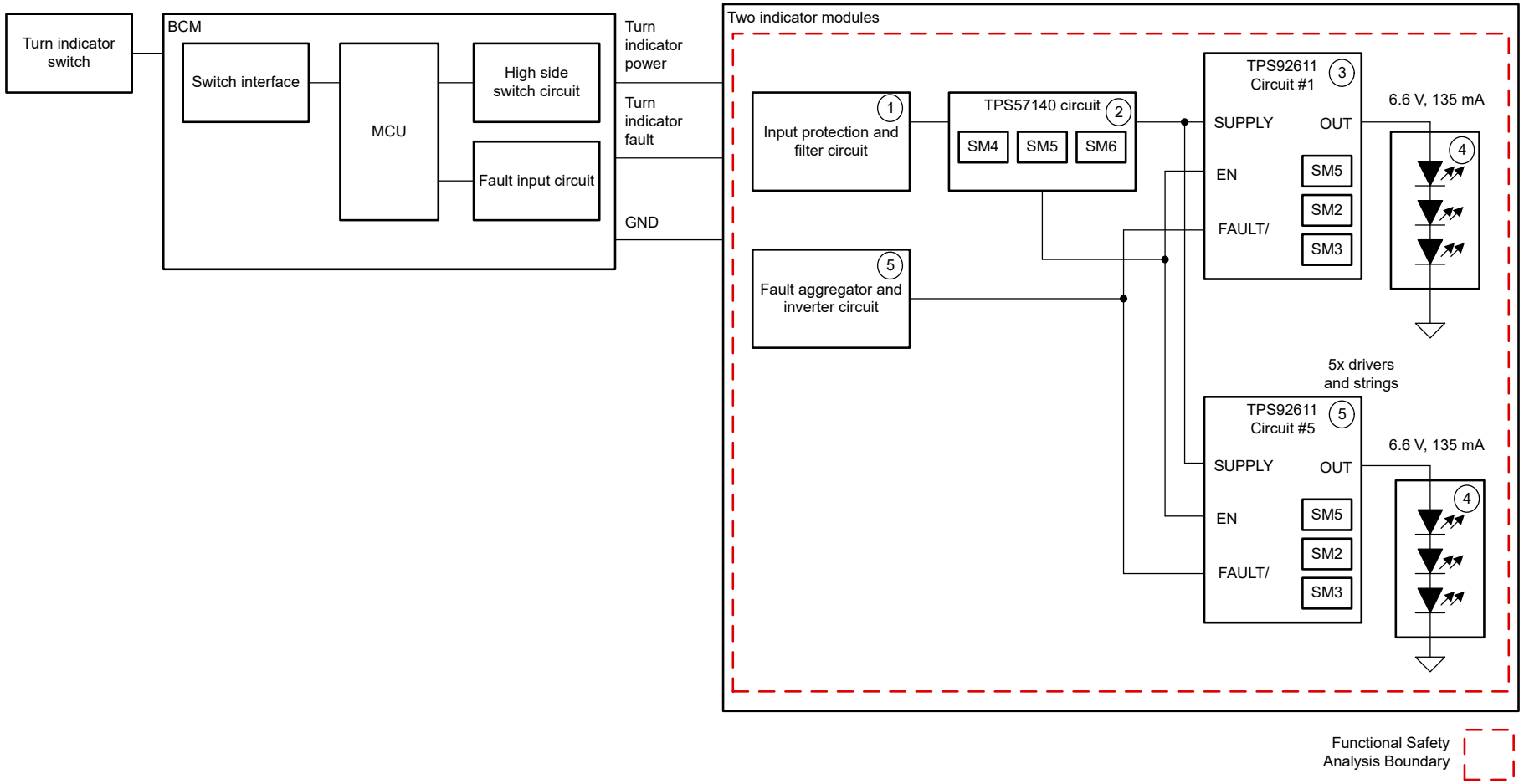

Figure 1-1. System Block Diagram

Table 1-1. Basic Safety Mechanisms

No.	Element	Type	Function	Fault Model	Impact on Safety Function	Measure to Control and Detect Fault	Resulting Requirement
1	Input protection	ASIL-B	Protects against reverse voltage and filters DC/DC converter switching noise to mitigate conducted emissions.	DC fault model	Incorrect function of turn indicator because the turn indicator module does not have power.	Fault in this element can result in no power to the rest of the module. In such case, fault aggregator circuit keeps FAULT_OUT pin high impedance.	FAULT_OUT keeps high impedance to indicate the fault.
2	LED power supply	ASIL-B	Generates regulated step down voltage for the LED driver to help improve efficiency of the linear LED driver.	DC fault model	If LED power supply output voltage is too low, LEDs do not turn ON violating the safety goal. If LED power supply output voltage is too high, LED driver junction temperature can result in thermal shutdown, causing LEDs to not turn ON.	If the fault results in no output voltage, then LED drivers do not have power. In such case, the fault aggregator circuit keeps the FAULT_OUT pin high impedance. The PWRGD output of the LED power supply device can be used to detect limited number of source of fault. If output voltage is out of range, then diagnostics in LED driver detect either through thermal shutdown or current out of range.	FAULT_OUT keeps high impedance to indicate the fault or use PWRGD to generate fault output low to the fault aggregator and keeps FAULT_OUT impedance high to indicate the fault.
3	LED drivers	ASIL-B	Generates regulated current for the LEDs.	The current output is out of regulation.	If the LED driver output current is too low, LEDs are not bright enough to be visible. If the LED driver output current is too high, the LEDs can be damaged or be visible.	LED driver monitors output voltage. Further the LED driver has thermal shutdown to prevent overheating.	Use LED driver to generate fault output low.
4	LEDs	ASIL-B	Check of multiple hardware parameter.	LEDs are either shorted or open.	If one or more LEDs either open or short fault, the LED driver detects the faults.	Diagnostics by the LED driver.	Use LED driver to generate fault output low.
5	Fault reporting	ASIL-B	Fault aggregator	False fault	No impact	If this circuit has fault and the LEDs also have a fault, then the turn indicator module indicates false fault. No monitoring is implemented.	None for the turn indicator.

Table 1-2. System FMEA

Component	Fault	Fault Effect	Potential Failure Cause	Safety Goal Violated	Safety Mechanism	How Does Safety Mechanism Handle the Fault
TPS57140 circuit	No PH output	No supply to LED driver and fault aggregation circuit.	TPS57140 failure	Yes	SM7	No power to the fault aggregator circuit, fault indicated by low side FET.
	PH output not in specification – voltage or timing	No supply to LED driver and fault aggregation circuit.	TPS57140 failure	Yes	SM4, SM7	PWRGD asserted low, LED drivers in sleep mode, Fault indicated by low side FET.
	PH high side FET stuck on	Supply to LED driver is VIN.	TPS57140 failure	Latent fault	SM3	Supply voltage to LED driver is high, which causes higher power dissipation in the LED driver. This event causes die temperature to rise causing thermal shutdown. FAULT of TPS92611 indicated.
	PWRGD false trip	LED driver not enabled.	TPS57140 failure	False trigger	SM4, SM7	PWRGD asserted low, LED drivers are in sleep mode, fault is indicated by low side FET.
	PWRGD fails to trip	LED driver enabled	TPS57140 failure	Latent fault	SM3	LED driver can report the failure.
	BOOT open	No output voltage because boot capacitor is not charged, so pass transistor is always off.	Internal circuit open	Yes	SM4, SM7	No output so PWRGD is asserted low, LED drivers are off. No power to fault aggregator, fault Indicated by low side FET.
	VIN open	No output voltage because device is always off. Potential for damage from static.	Internal circuit open	Yes	SM4, SM7	No output so PWRGD is asserted low, LED drivers are off. No power to fault aggregator, fault indicated by low side FET.
	EN open	Output voltage overshoot at power ON and input inrush current. Normal Operation.	Internal circuit open	No	None	Normal operation.
	SS/TR open	Output voltage overshoot at power ON and input inrush current. Normal Operation.	Internal circuit open	No	None	Normal operation.
	RT/CLK open	Very low switching frequency.	Internal circuit open	Yes	SM4	Output can be abnormal, PWRGD is asserted low, LED drivers in sleep mode.
	PWRGD open	Output voltage is present, but communication about status of output voltage is lost. Normal operation.	Internal circuit open	Latent fault	None	No SM to detect failure. No status of output voltage but normal operation.
	VSENSE open	No predicted duty cycle and potential of damage from static. Unregulated output.	Internal circuit open	Yes	SM4	Output voltage is out of control so PWRGD is asserted low, LED drivers in sleep mode.
	COMP open	Potential for unstable output due to lack of compensation. Unstable operation.	Internal circuit open	Yes	SM4	Output voltage is out of control so PWRGD is asserted low, LED drivers in sleep mode.
	GND open	No output because device is off. No output.	Internal circuit open	Yes	SM4	No output, PWRGD is asserted low, LED drivers are in sleep mode. No power to fault aggregator, fault indicated by low side FET.

Table 1-2. System FMEA (continued)

Component	Fault	Fault Effect	Potential Failure Cause	Safety Goal Violated	Safety Mechanism	How Does Safety Mechanism Handle the Fault
	PH open	No output voltage because PH pin is disconnected from output LC filter.	Internal circuit open	Yes	SM4	No output, PWRGD is asserted low, LED drivers are in sleep mode. No power to fault aggregator, fault indicated by low side FET.
TPS92611 circuit	EN open	TPS92611 enters the sleep mode because of internal pull-down resistor on EN pin.	EN pin internal circuit open	Yes	Enters sleep mode and FAULT of TPS92611 is asserted	When TPS92611 is disabled, the FAULT output of TPS92611 is HIZ and asserted.
	DIAGEN open	Floating pin. Diagnostics function can be false.	DIAGEN pin internal circuit open	Latent fault	None	No SM to detect this failure. Open-load diagnostics disable. Device cannot report LED open fault when DIAGEN pin is in low level.
	PWM open	Floating pin. Output current can be turned off.	PWM pin internal circuit open	Latent fault	None	No SM to detect this failure. Diagnostics are disabled and fault not indicated.
	Fault open	TPS92611 operates normally but without fault reporting function.	/FAULT pin internal circuit or external / FAULT circuit open	False Trigger	SM7	Normal operation and fault indicated by low side FET.
	GND open	Missing ground. Device is not functional.	GND pin internal circuit or external GND circuit open	Yes	SM7	Fault indicated by low side FET.
	Out open	No LED current.	OUT pin internal circuit or external OUT open	Yes	SM1	LED open circuit, FAULT of TPS92611 indicated.
	IN open	No current path for internal MOSFET. Device no output.	IN pin internal circuit or external IN open	Yes	SM1	LED open circuit, FAULT of TPS92611 indicated.
	SUPPLY open	No power supply for device. Device is not functional.	SUPPLY pin internal circuit or external SUPPLY circuit open	Yes	SM7	Fault indicated by low side FET.
	Output over current	LEDs are too bright and can be heated and damaged.	TPS92611 internal current monitoring circuit or Rsns failure	Yes	SM1, SM2, SM3	TPS92611 can be over temperature and report FAULT, or LEDs can be burned to open or short circuits then be detected by SM1 or SM2 of TPS92611 and reported by FAULT of TPS92611.
	Output under current	LEDs are too dark.	TPS92611 internal current monitoring circuit or Rsns failure	No	None	No SM to detect this failure except human eyes.
	OUT No output (HIZ)	No LED current.	TPS92611 failure	Yes	SM1	LED open circuit detected, FAULT of TPS92611 indicated.
	OUT output out of specification, current or timing	Little or big LED current.	TPS92611 failure	Yes	SM1	LED open or short circuit detected, FAULT of TPS92611 indicated.
	OUT stuck off (GND)	No LED current.	TPS92611 failure	Yes	SM1	LED open circuit detected, FAULT of TPS92611 indicated.

Table 1-2. System FMEA (continued)

Component	Fault	Fault Effect	Potential Failure Cause	Safety Goal Violated	Safety Mechanism	How Does Safety Mechanism Handle the Fault
	FAULT fails to trip	Operates normally but does not indicate fault.	TPS92611 failure	Latent fault	None	No SM to detect this failure.
	FAULT false trip	Fault is indicated.	TPS92611 failure	False Trigger	SM7	Fault indicated by low side FET.
LEDs	LED Open	LED string is not able to be on.	LED	Latent fault	SM1	If one string fails and other strings are functional, the turn indicator is still functional. However, if all LED strings fail, the turn indicator violates the safety goal.
	One LED short	Reduced brightness.	LED	Latent Fault	None	If one LED fails and other LEDs are functional, the turn indicator is still functional.
	One string LED short	LED string is not able to be on.	LED	Latent fault	SM2	Other strings are still functional, fault is asserted.
Inverter	Input open	Pin is floating, can change output state and cause excessive current from VCC to GND.	Internal or external circuit open.	Latent fault	None	No SM to detect this fault. Fault can be reported incorrectly.
	Output open	Normal operation.	Internal or external circuit open.	False Trigger	SM7	No output of inverter causes the low side FET to open, indicating fault to BCM.
	VCC open	Device not powered.	Internal or external circuit open.	Latent fault	SM7	No output of inverter causes the low side FET to open, indicating fault to BCM.
	GND open	Device not powered.	Internal or external circuit open.	Latent fault	SM7	No output of inverter causes the low side FET to open, indicating fault to BCM.

2 Hardware Schematic

This reference design has two stages. As shown in Figure 2-1, the first stage is the buck TPS57140-Q1 which converts the battery input 9 V to 18 V down to 8 V, 1 A, which is the input power supply of the five pieces of paralleled linear LED drivers, TPS92611-Q1, to provide higher system efficiency. The second stage is the five pieces of paralleled TPS92611-Q1 which drives the LEDs directly. Each LED serial has three LEDs and their current is 135 mA.

The fault aggregator and inverter function block proposes a fault detection and aggregation circuit for the five pieces of TPS92611. We can connect the five fault pins together and connect to the base of Q1 to achieve only-failed-channel-off.

The input protection and filter circuit function block is proposed for the input power supply for better system EMI and BCI performance.

2.1 Introduction to TPS57140-Q1

The TPS57140-Q1 device is a 42-V, 1.5-A step-down regulator with an integrated high-side MOSFET. Current-mode control provides simple external compensation and flexible component selection. A low-ripple pulse-skip mode reduces the no-load, regulated output supply current to 116 µA. When the enable pin is in the low state, the shutdown current is reduced to 1.5 µA. Undervoltage lockout is internally set at 2.5 V, but can be increased using the enable pin. The output voltage startup ramp is controlled by the slow-start pin that can also be configured for sequencing or tracking. An open-drain power-good signal indicates the output is within 92% to 109% of its nominal voltage. A wide switching-frequency range allows optimization of efficiency and external component size. Frequency foldback and thermal shutdown protect the part during an overload condition.

To provide higher power efficiency, we use the TPS57140-Q1 as the buck device to convert the input 9-V to18-V battery power supply to 8 V, which is the input of the TPS92611-Q1.

2.2 Introduction to TPS92611-Q1

The TPS92611-Q1 device is one of a family of single-channel linear LED drivers. The family provides a simple solution for automotive LED applications. Different package options in the family provide a variety of current ranges and diagnostic options. The TPS92611-Q1 supports LED open-circuit detection and short-to-ground detection.

2.3 Introduction to the Fault Aggregator Circuit

The fault aggregator circuit contains three parts. See details in Figure 2-1 schematic:

1. R10 + Q1 + R8 implements the non-one-fail-all-fail. All of the faults output of TPS92611-Q1 are connected together. If one TPS92611-Q1 reports fault, it weakly pulls the relevant FAULT output LOW by a typical 750-uA current. Because of the R10 and Q1, the voltage on the FAULT pin is 5 V – 750 uA × 2 KOhm = 3.5 V, which is higher than the FAULT logic input high threshold 2 V, so other normal TPS92611-Q1 still output normally. In this case, Q1 is turned ON so the input voltage of U4 is HIGH.
2. The SN74LVC1G04QDBVRQ1 is a single channel inverter logic. In above case its output is LOW.
3. MOSFET Q2 is a key logic to convert the above logic LOW to FAULT_OUT high impedance and FAULT_OUT is pulled HIGH at BCM side, so FAULT_OUT reports a logic high to indicate fault.

The power supply 5 V is generated by D16 to meet the power supply range requirement of U4.

The PWRGD signal of TPS57140-Q1 is aggregated to the EN of TPS92611-Q1. When PWRGD is triggered LOW, it disables TPS92611-Q1 such TPS92611-Q1 triggers FAULT pin LOW.

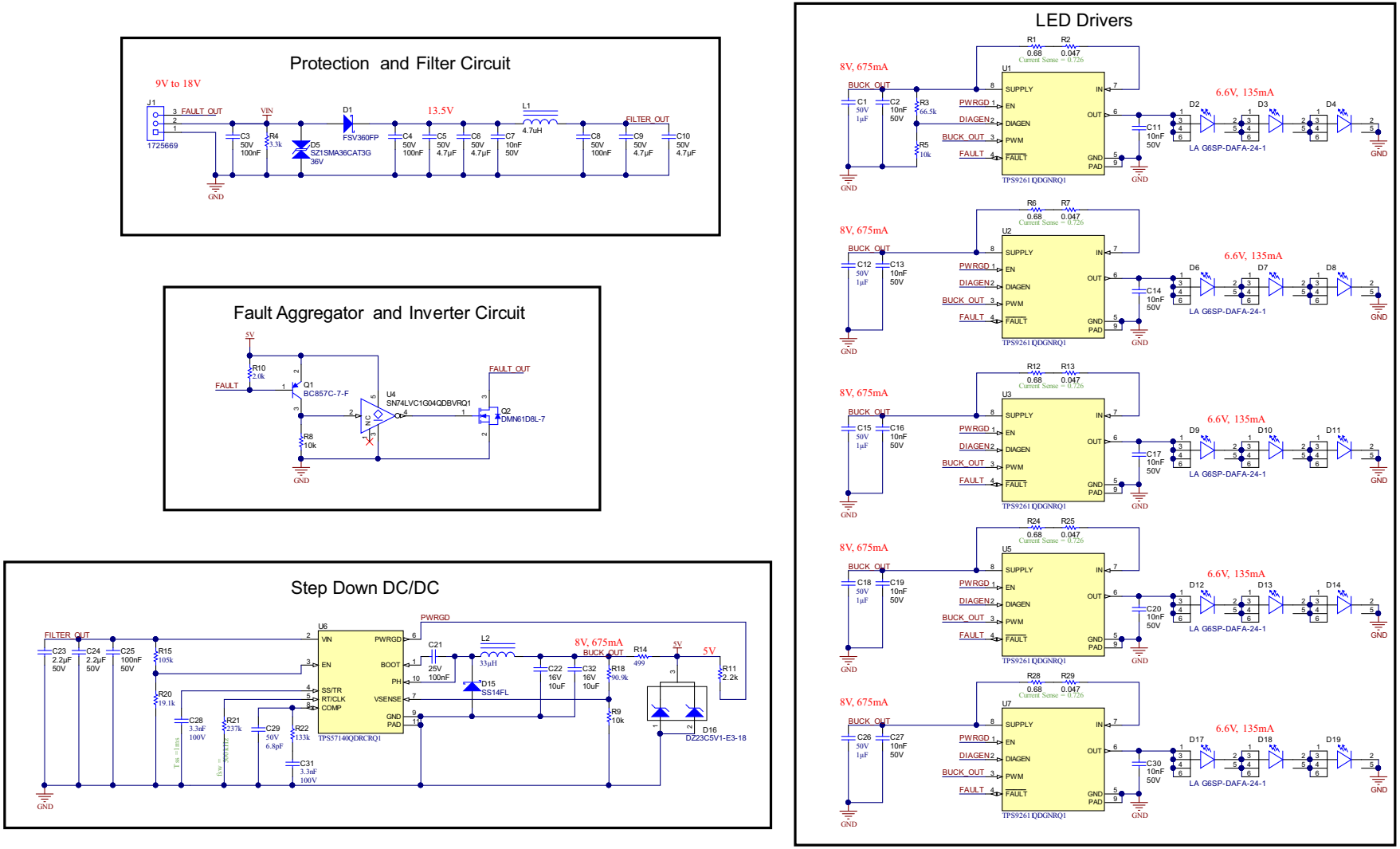

Figure 2-1. Schematic

3 References

- Texas Instruments, *TPS92611-Q1 Automotive Single-Channel Linear LED Driver* data sheet
- Texas Instruments, *TPS57140-Q1 1.5-A 42-V Step-Down DC-DC Converter With Eco-mode™ Control* data sheet
- Texas Instruments, *TPS54xx0-Q1 and TPS57xx0-Q1 Pin Open and Short Test Results* application report
- Texas Instruments, *Functional Safety FIT Rate, Failure Mode Distribution TPS92611-Q1*

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (March 2021) to Revision A (April 2022)	Page
• Updated text throughout publication for clarification	2
• Updated the *TPS92611-Q1 Failure Mode Effects* section	3
• Updated the *References* section	11

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