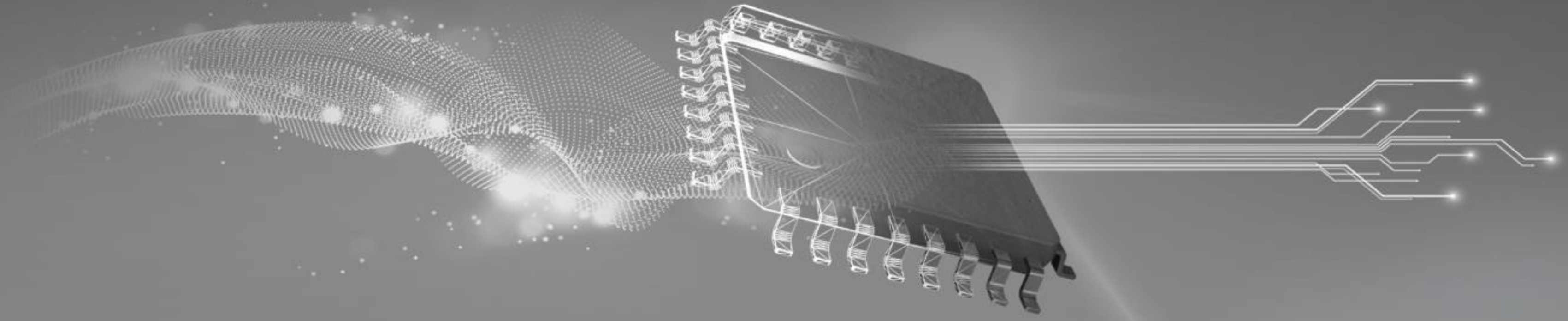
TI TECH DAYS



Automotive LED exterior lighting design considerations

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Exterior lighting requirements in automotive

Rear light

- Tail lamp ★
- Stop lamp
- Turn ★
- Back-up light (reverse)
- Fog lamp

Front light

- Low beam
- High beam ★
- Turn indicator ★
- DRL/position ★
- Fog lamp / Corner
- Side markers

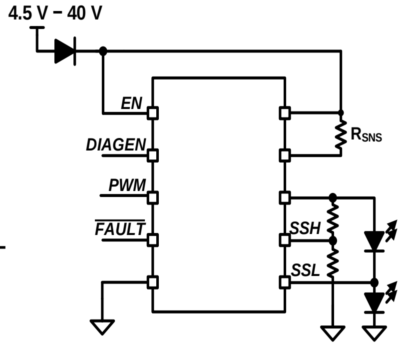
Design challenges in Automotive LED lighting

- **Fault and diagnostics**
  - ✓ One fail all fail : if one LED fails (open or short), all other LEDs in lamp turn off
  - ✓ N-1 : if one LED or string fail in the lamp, remaining LEDs can meet photometric requirement
  - ✓ Output short to ground and open protection
  - ✓ Over temperature protection
- **Thermal management**
  - ✓ Max ambient temperature test (55C) without reduction in lumen output at nominal battery level or 16V
  - ✓ 24V, 1min test at 25C ambient (with or without dimming)
- **Control large number of LEDs in DRL and tail lamp**
- **Animated solutions for two wheeler and four wheeler exterior lighting**
- **Safety and quality requirements**
- **Common issues in LED drivers including**
  - ✓ Thermal management and PCB copper area
  - ✓ EMI/EMC - RE, CE, RI, Bulk current injection
  - ✓ Behavior during Transient tests, Load dump, input ripple test
  - ✓ How to debug them
- **Summarize the topic with resources like**
  - ✓ Functional safety documentation
  - ✓ Reference design and application report on TI LED drivers

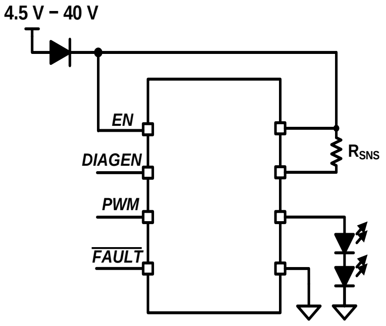
TPS9261x-Q1 40-V single channel LED driver

- Ease of use in multiple applications
- Cost competitive against discrete solution
- Reliable off-board LEDs control
- Full diagnostics and protection features
- PWM signal is required for dimming

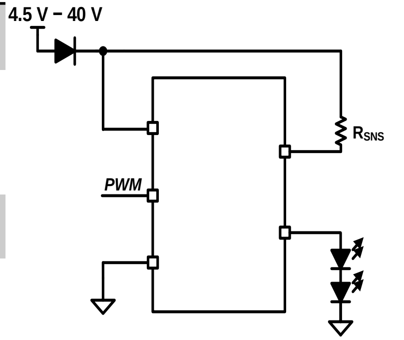
Device	Iout per ch X # of channels	Diagnostics & Protection	Package	RΘJA C/W
TPS92613-Q1	600mA X 1	Open, Short	TO-263	28.4
TPS92610-Q1	450mA X 1	Open, Short, Single LED short	HTSSOP-14	52.4
TPS92611-Q1	300mA X 1	Open, Short	MSOP-8	60
TPS92612-Q1	150mA X 1	Short Protection (no FAULT output)	SOT23-5	200.7



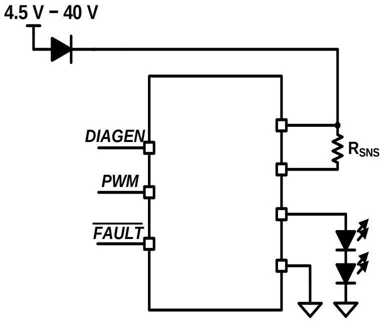
TPS92610-Q1



TPS92611-Q1

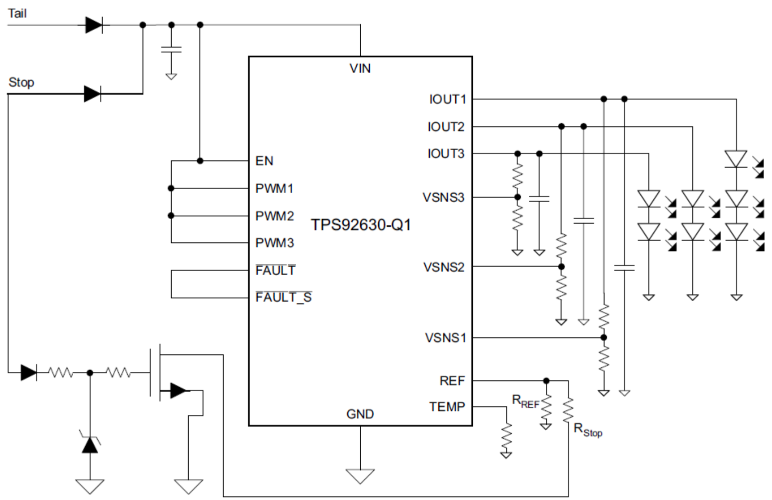


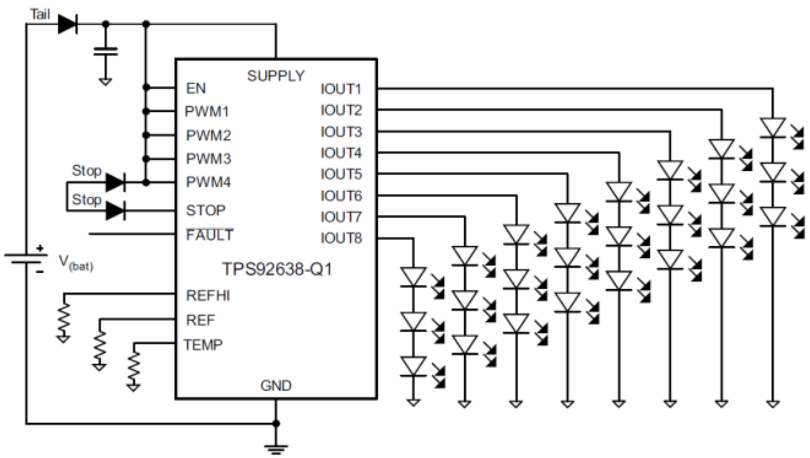
TPS92612-Q1



TPS92613-Q1

TPS9263x-Q1 40-V multi channel LED driver





Changing output current on-the-go is very easy!

Device	Iout per ch X # of channels	Diagnostics & Protection	Package	RΘJA
TPS92630-Q1	150mA X 3	Open, Short, Single LED short, thermal foldback	HTSSOP-16	41.5C/W
TPS92638-Q1	70mA X 8	Open, Short, Thermal foldback	HTSSOP-20	37.8C/W

Thermal calculations for linear driver [1] [2] [3] [4]

[2] TPS92611-Q1 PCB Thermal Budget Design for Maximum Output Current

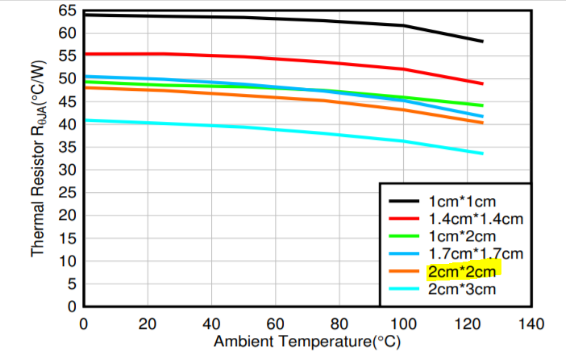


Figure 1. $R_{\theta JA}$ with Copper Area Varies

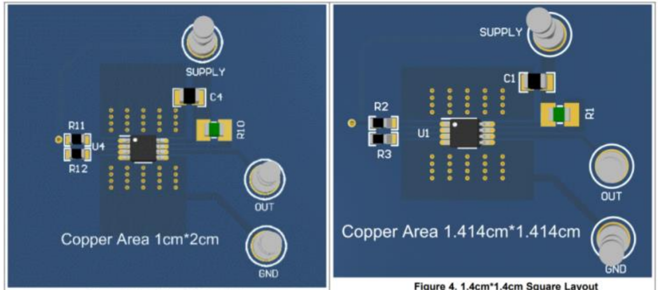
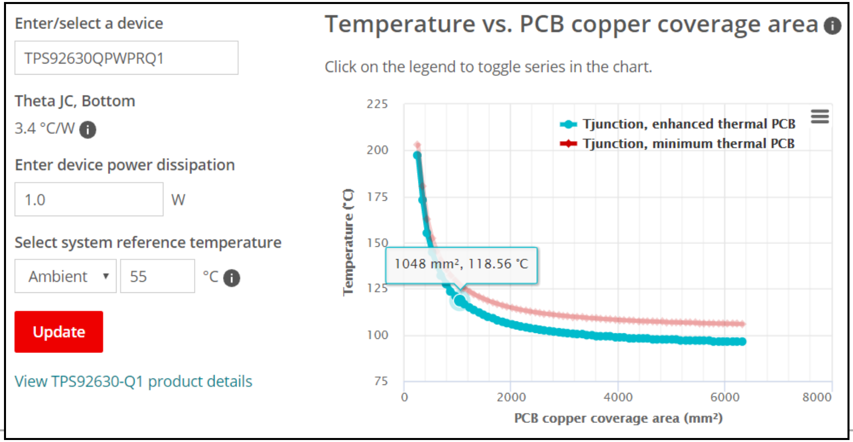


Figure 3. 1cm*2cm Rectangle Layout

Figure 4. 1.4cm*1.4cm Square Layout

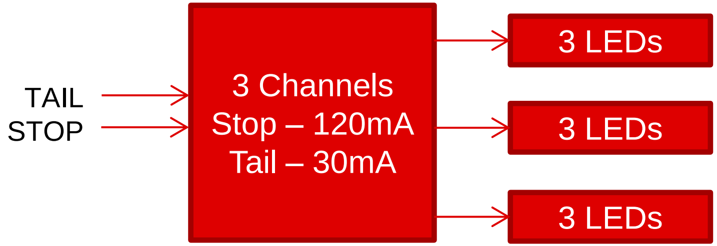
[4] TPS92630-Q1 online PCB thermal calculator



Case Study

Problem statement for Stop/Tail lamp

- Need to drive 9 RED LEDs with N-1
  - 120mA in STOP mode
  - 30mA in TAIL mode (dimming required)
- 9V to 16V operation @ 55C with required lumen
- 24V operation @ 25C for 1min
- Total PCB size available for driver section – 5cmX5cm
- LED forward voltage, VF : 2Vmin to 2.65V max



Solution:

It is obvious to make 3 strings of 3 LED each. **Which approach would you pick for the requirement ?**

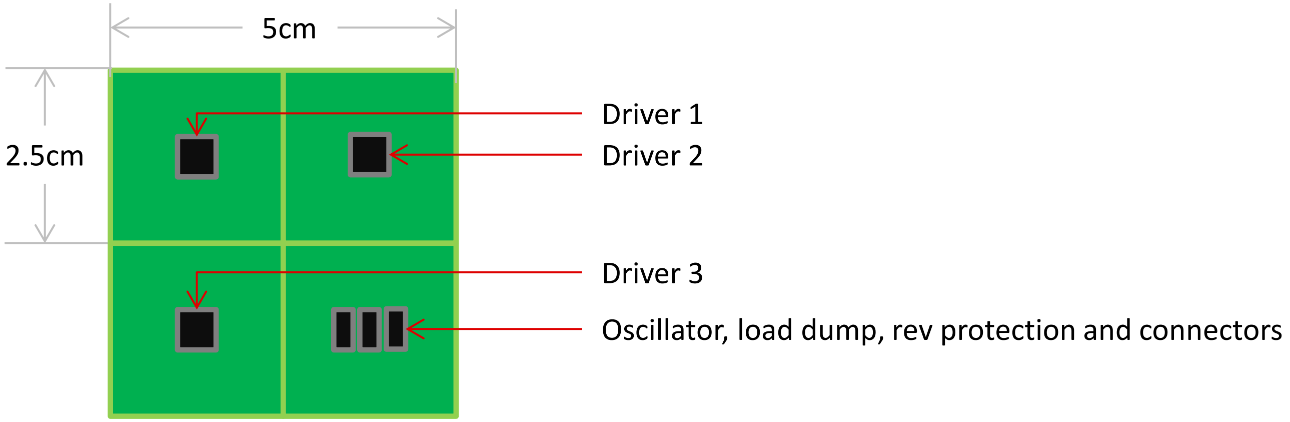
Approach	#1	#2	#3
LED driver options	TPS92630-Q1	3X TPS92611-Q1	TPS92638-Q1

Case Study

	Criteria	Approach		
		#1	#2	#3
1	Drivers	TPS92630-Q1	3X TPS92611-Q1	TPS92638-Q1
2	Output current per channel X number of channel	150mA X 3	300mA X 3	70mA X 8
3	Partial failure	N-1 1-fail-all-fail	N-1	N-1
4	Current setting and Use of LED with multiple intensity bins	Use REF resistor	Use RSNS	Use REF resistor
5	Stop to tail mode dimming	Use REF pin with BJT	LM2903B-Q1 for PWM	Use one additional diode
6	Power dissipation in each driver at 16V	3.6W	1.2W	3.6W
7	Junction temp rise of driver above ambient @16V	149C	72C	136C
9	1ku cost	$0.8	$1.1	$1.1

PCB thermal estimation with approach #2:

1. PCB form factor= 5cm X 5cm
2. Divide this area in 4 rectangle with 2.5cmX2.5cm area as shown below
3. With below arrangement each driver gets 2.5cmX2.5cm
4. This is equivalent to or better than 2cmX2cm – 2 layer, 1oz PCB for which we have practically measured RϴJC data available



From TPS92611-Q1 PCB Thermal Budget Design for Maximum Output Current [2]

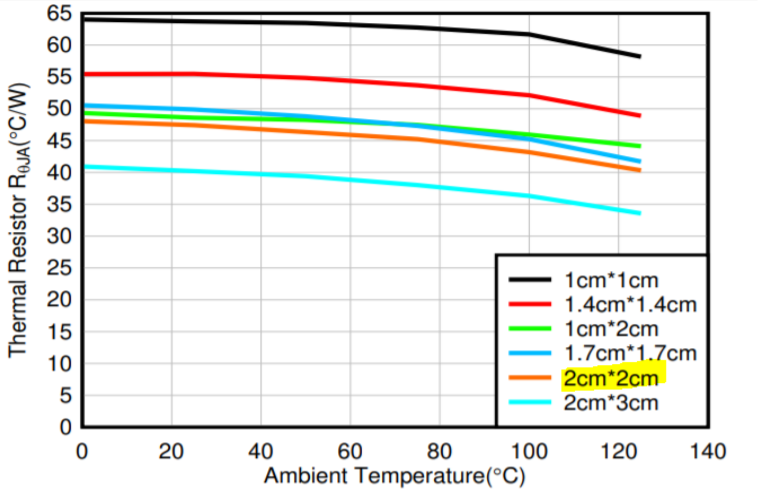


Figure 1. $R_{\theta JA}$ with Copper Area Varies

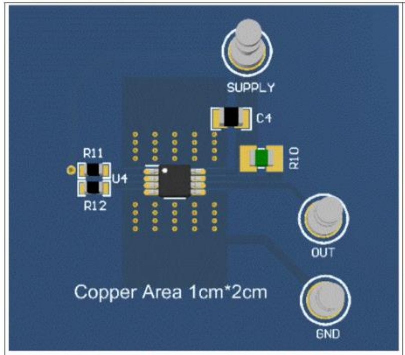


Figure 3. 1cm*2cm Rectangle Layout

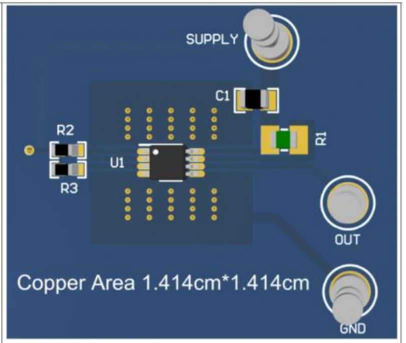
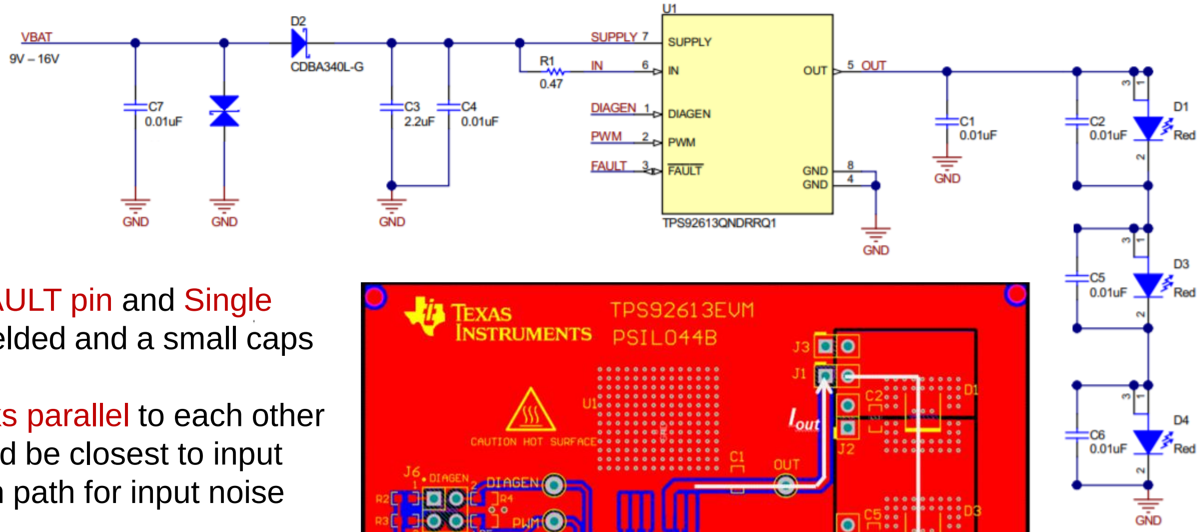


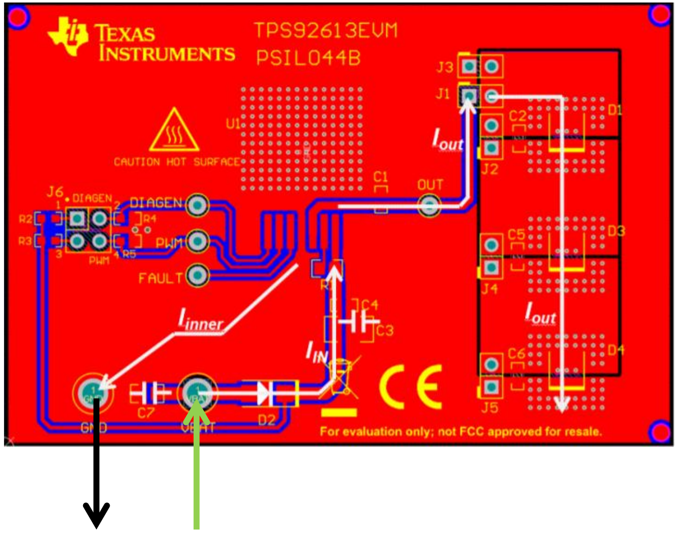
Figure 4. 1.4cm*1.4cm Square Layout

Ambient (C)	Vin (V)	Dissipation per driver (W)	RΘJA (C/W) (1oz, 2 layer, 2cmX2cm PCB)	Driver junction temperature (C)
55	16	1.2	46	110.2
25	24	2.16	47	126.52

No need to have thermal fold-back or dimming for 24V

Recommendations to pass EMI/EMC for linear drivers [8]



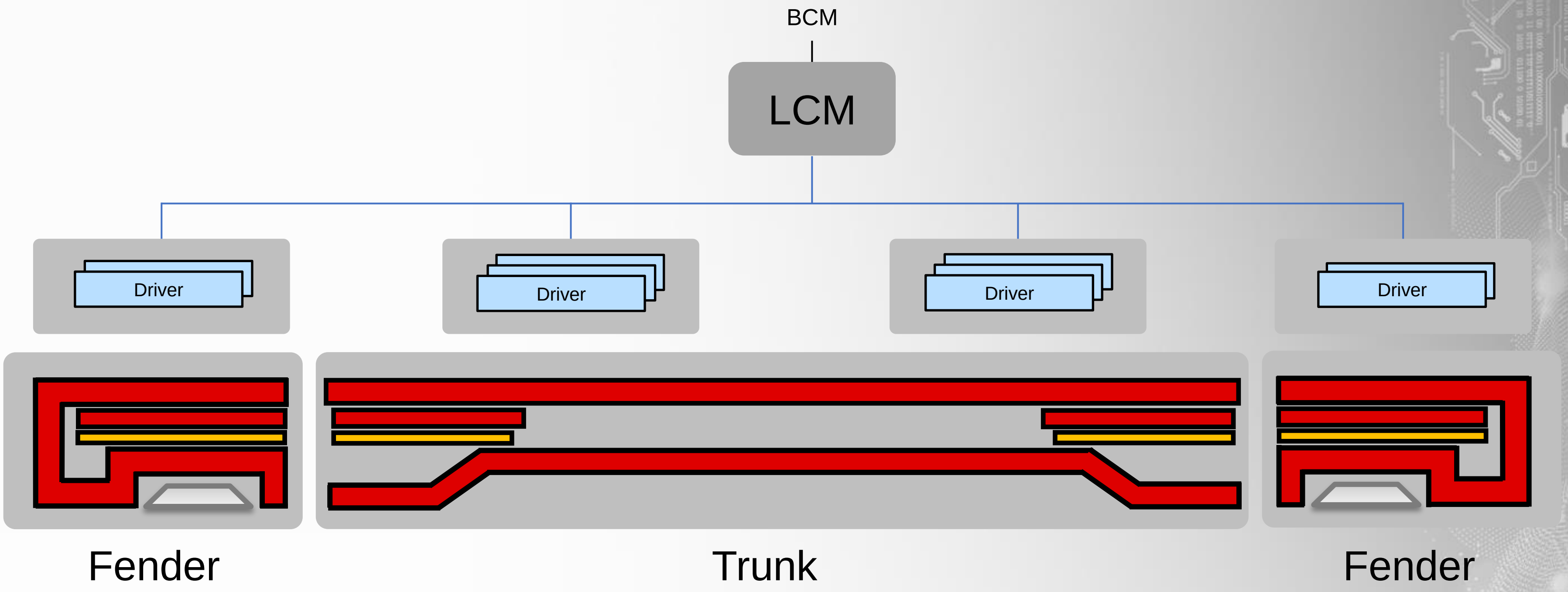


1. Shielding noise sensitive traces (FAULT pin and Single LED short detection) should be shielded and a small caps (<100pF) can be used
2. Avoid routing input and output tracks parallel to each other
3. Input capacitor C7 (and TVS) should be closest to input connector to provide shortest return path for input noise (BCI)

Other points-

1. Supply/decoupling caps C3 +C4 and R1should be closest to IC pin
2. 10nF cap on OUT pin is more than sufficient.
3. Individual LEDs / LED strings should have small caps in parallel
   - for gradual rise and fall of LED current
   - Sometime LEDs are on separate PCB
4. Ground layer plays important role wrt EMI/EMC as well as thermal performance

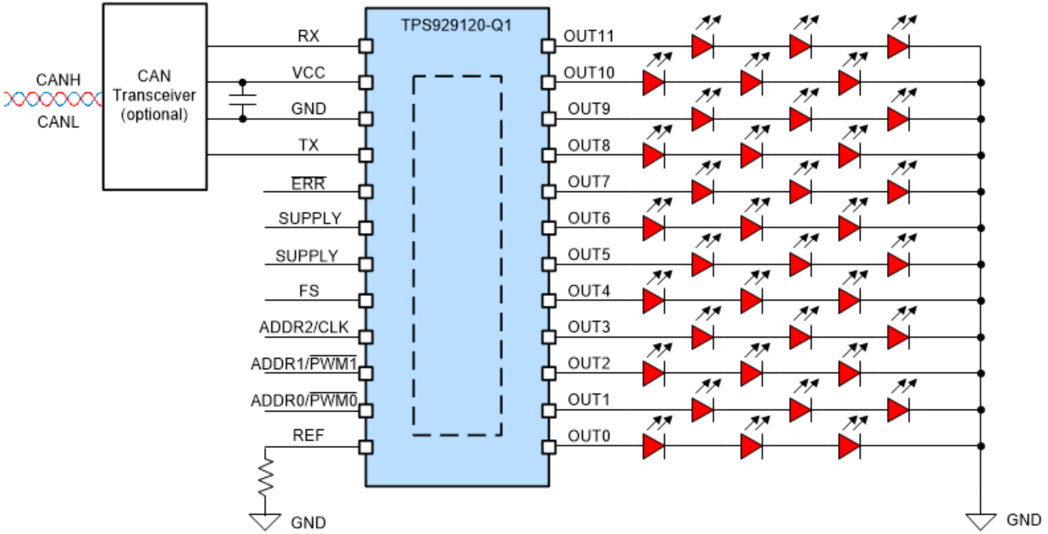
Managing large number of LEDs and Animation with LED Lighting



TPS929120-Q1

Features

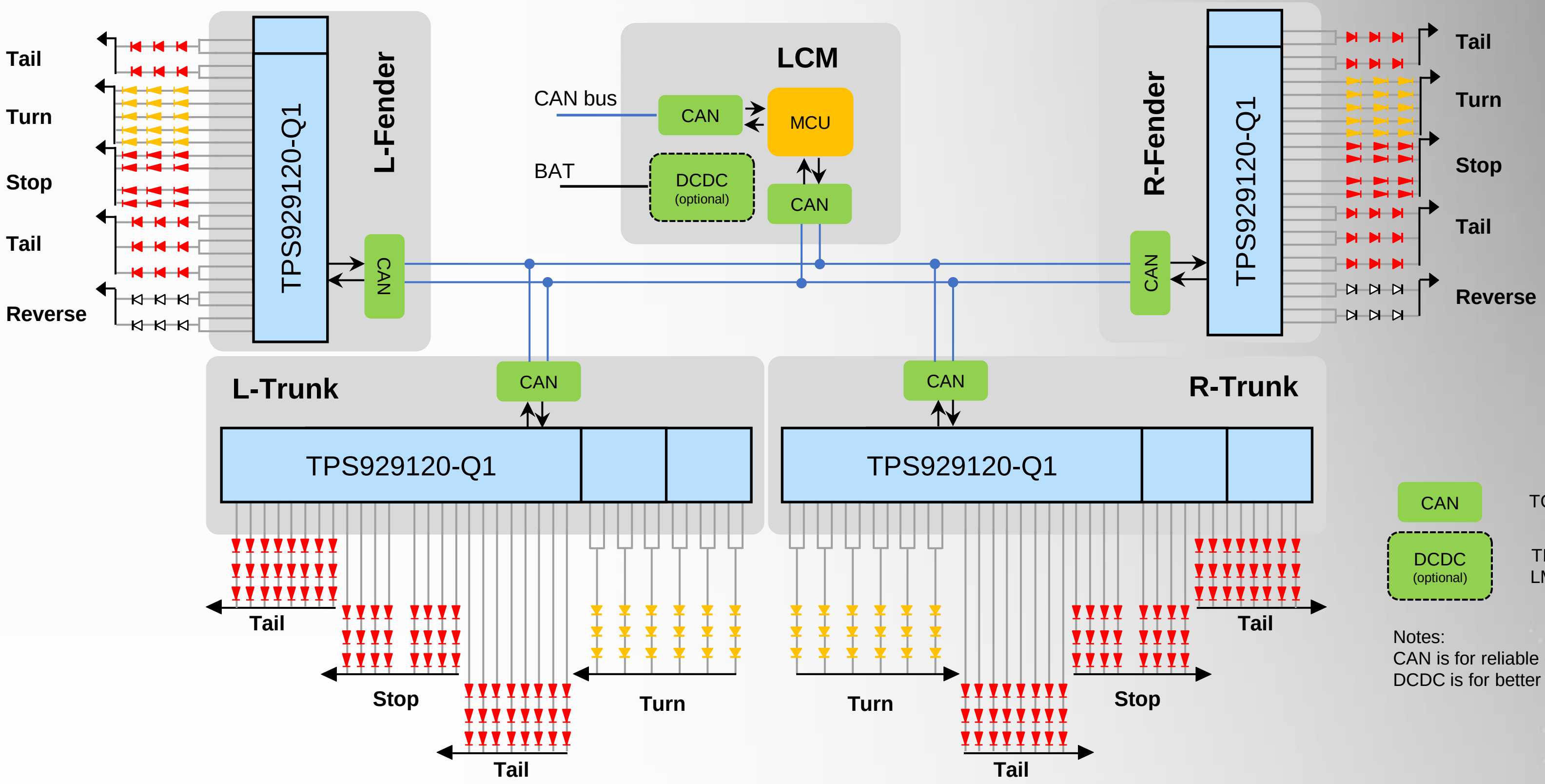
- **AEC-Q100 Qualified (Grade 1: T_A -40C to +125C)**
- **12-Ch Precision High-side Current Output**
  - Up to 75mA channel current set by resistor
  - Low voltage drop 500mV @ 50mA
  - Programmable PWM frequency up to 20KHz
- **FlexWire Control Interface**
  - Up to 1-MHz clock frequency
  - Max. 16 devices on one FlexWire bus
  - Burst Mode for max. 8 Bytes of data throughput
  - 5V LDO output to supply CAN transceiver
- **Protection and Diagnostics**
  - Programmable fail-safe state in EEPROM
  - LED open-circuit and short-circuit detection
  - Single-LED short-circuit diagnostic
  - Programmable low-supply detection
  - Open-drain ERR for fault indication
  - Watchdog and CRC for FlexWire interface
  - 8-bit ADC for pin voltage measurement
  - Overtemperature protection
- **HTSSOP-24 Package (PWP)**



Key Parameter Overview

Output Current Resolution	6+2	bit
PWM Dimming Resolution	12	bit
Output Current Accuracy	< ±5%	
Supply Voltage	4.5 - 40	V

Flexwire Animation Lighting



CAN	TCAN1042-Q1
DCDC (optional)	TPS92682-Q1 LMR33630-Q1

Notes:
CAN is for reliable off-board communication
DCDC is for better thermal performance

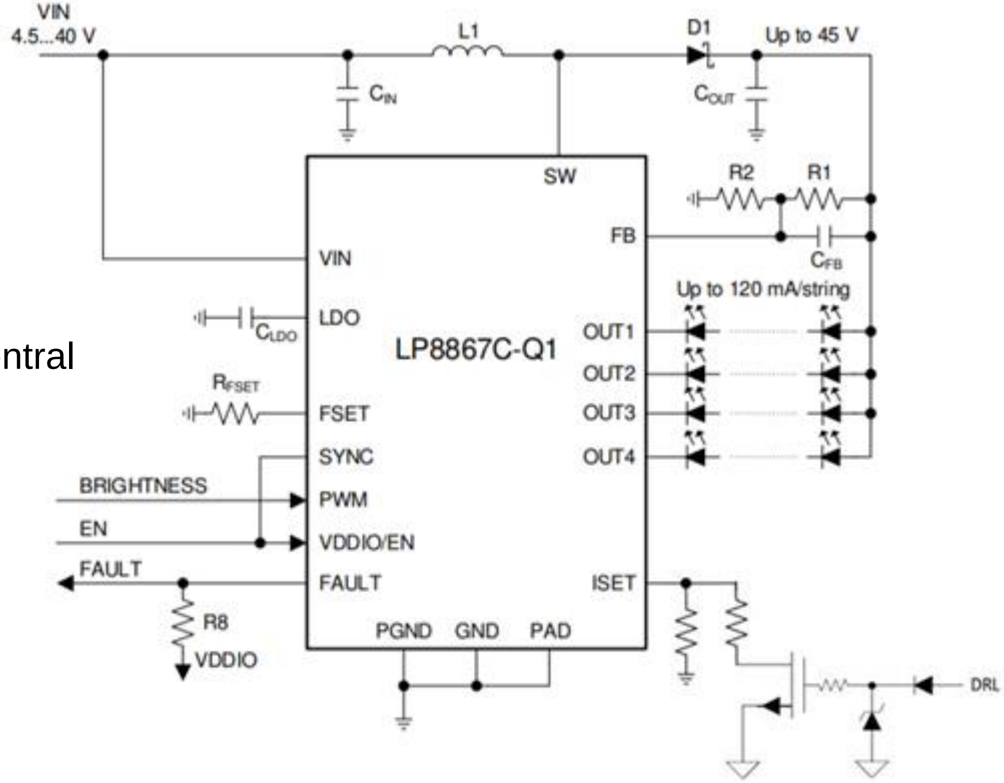
Using BUCK pre-regulator with linear drivers

	TPS560430-Q1	LMR33620-Q1/ LMR33630-Q1	LMR63615-Q1/ LMR63625-Q1	LMR34206-Q1/ LMR34215-Q1
Iout max	0.6A	2A / 3A	1.5	0.6A / 1.5A
VIN max	36V	36V	36V	42V
Switching frequency	2.1MHz fixed	400kHz fixed / 1.4MHz fixed / 2.1MHz fixed	Adjustable	400kHz fixed / 2.1MHz fixed
Spread spectrum	No	No	Yes	Yes
Package	SOT23- 6 (2.9mm X 1.6mm)	VQFN (2mmX3mm)	HTSSOP-16 (5mm X 4mm) WSON -12 (3mm X3mm)	VQFN (2mmX3mm)
Components to pass CISPR25 Class 5 EMI	2.2uH + FB + caps (refer to SNVA886)	3.3uH + FB + caps (refer to datasheet)	1.5uH + FB + caps (refer to datasheet)	83H9652 FB + caps (refer to datasheet)

BOOST / SEPIC pre-regulator + Linear drivers

LP8869C-Q1 and LP8867C-Q1

- 3 or 4 channels : 120mA/channel
- Boost or SEPIC implementation
- Integrated 3.3A FET (3.7A typ)
- Adaptive output voltage for best efficiency
- Spread spectrum for low EMI (±3% from central frequency, 1-kHz modulation frequency)
- Protection and fault detection
  - – Fault output
  - – Boost OVP (adjustable through FB)
  - – SW OVP (internally fixed at 49V)
  - – LED Open and short fault detection
  - – Thermal shutdown (165C typ)



Adaptive Boost / SEPIC voltage control

7.8 Current Sinks Electrical Characteristics

Limits apply over the full operation temperature range −40°C ≤ T_A ≤ +125°C , unless otherwise speicified, V_{IN} = 12V.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{LOW_COMP}	Low comparator threshold			0.9		V
V_{MID_COMP}	Mid comparator threshold			1.9		V
V_{HIGH_COMP}	High comparator threshold		5.6	6	7	V

- **<u>Boost efficiency of >92% with 400kHz switching frequency</u>**
- **<u>Boost efficiency of >87% with 2.1MHz switching frequency</u>**

- **<u>LED Open Condition</u>**
  - Boost/SEPIC voltage is raised to maximum level set through FB &
  - V(OUTx) < 0.9V.

- **<u>LED Short Condition</u>**
  - If V(OUTx) – V(OUTy) > ~5V

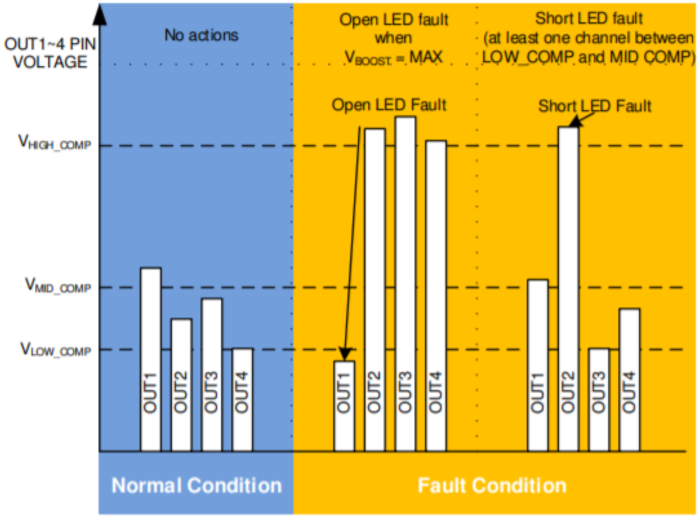
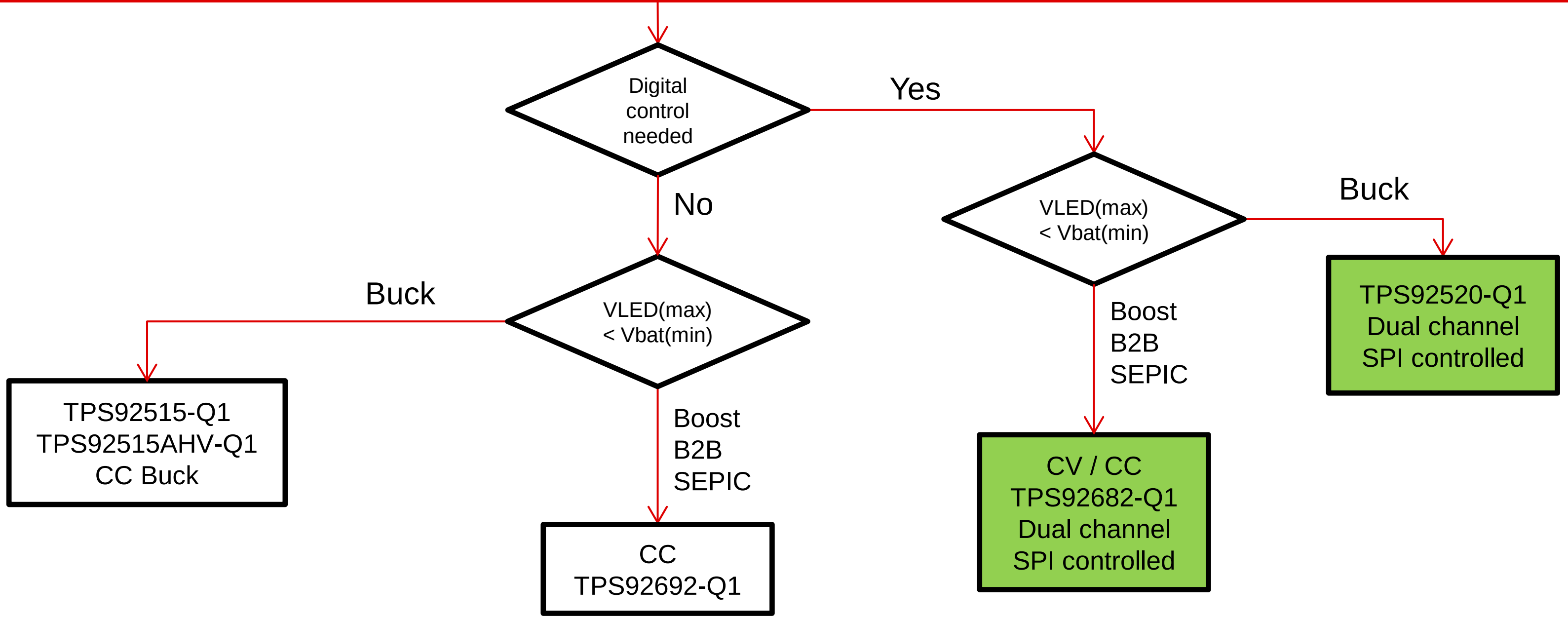
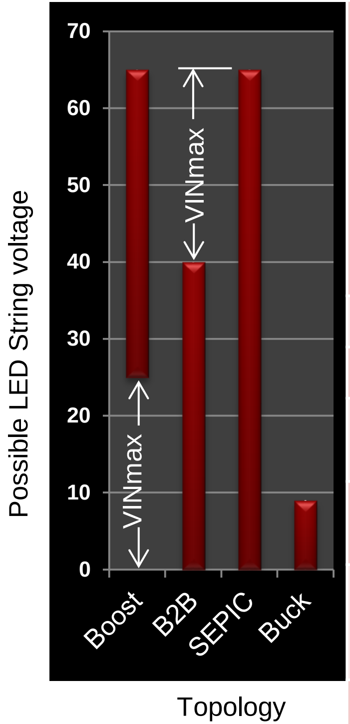


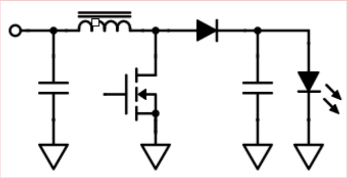
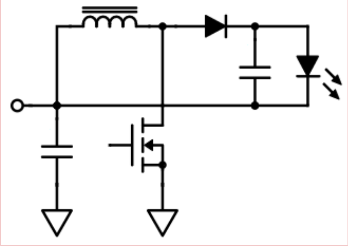
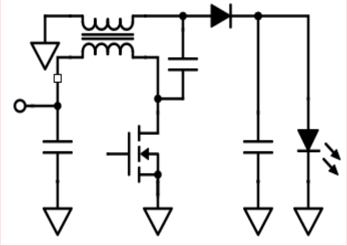
Figure 15. Protection and DC-DC Voltage Adaptation Algorithms

Switching LED drivers

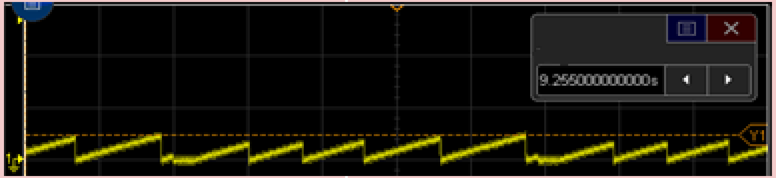
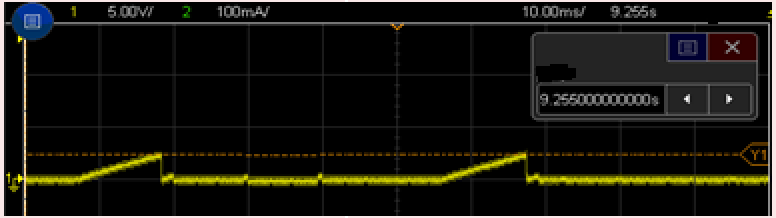


When to use B2B v/s Boost v/s SEPIC?

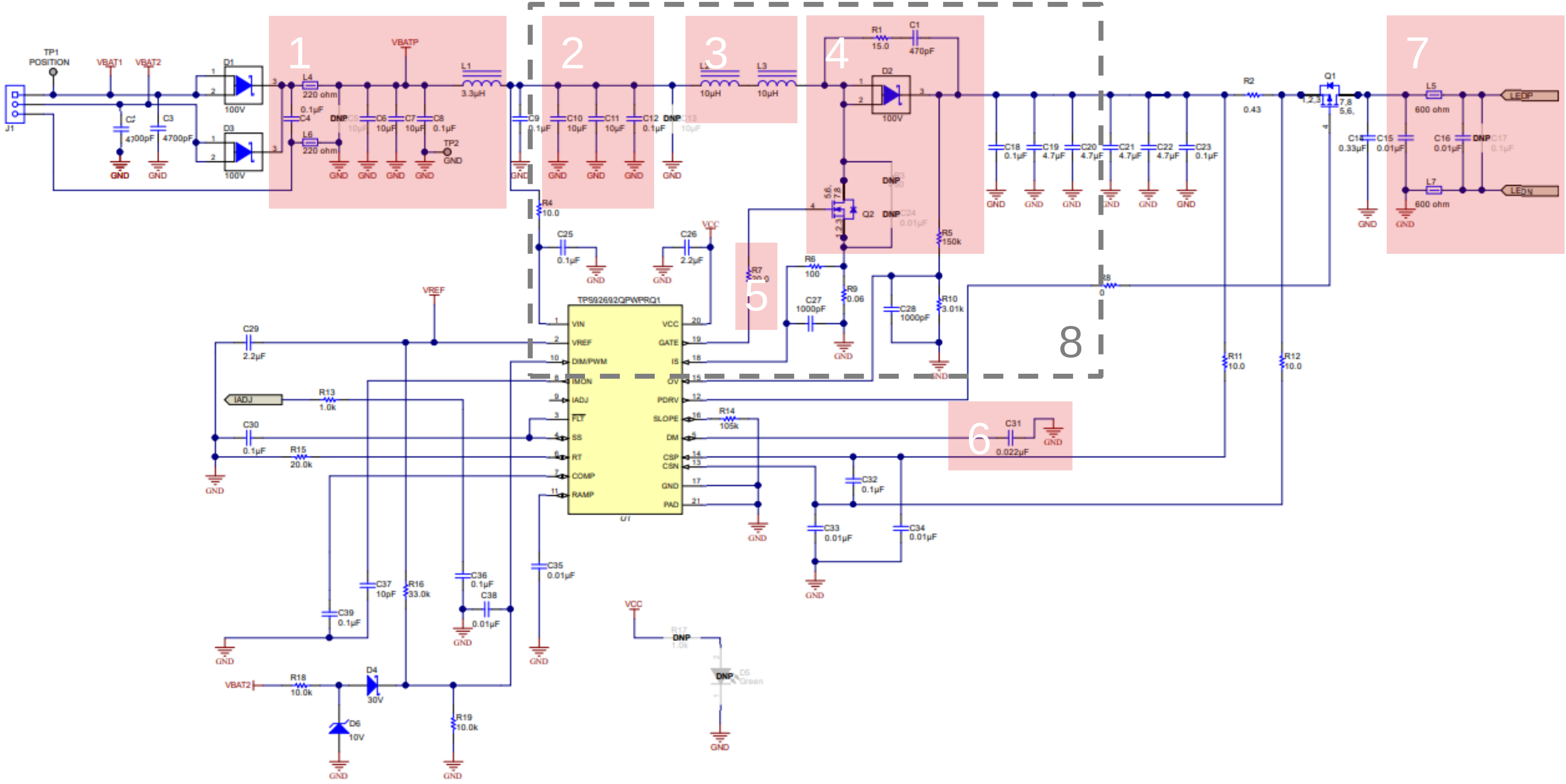


	Boost	B2B	SEPIC
Power stage schematic			
LED string voltage	>Max VIN & <65V	< (65V – Max VIN)	<65V
LED Cathode connection	GND	VIN	GND
Output short to GND protection	Requires PFET	Requires PFET	Self protected
Driving multiplexed loads Eg. DRL + TURN driver	Easy using N-FET in GND path	Complex due to level shifting need	Easy using N-FET in GND path
BoM differences	Single inductor FET with VOUT rating	Single inductor FET with VIN+VOUT rating	Coupled inductor Cap with higher IRMS FET with VIN+VOUT rating
Max output voltage wrt GND	VLEDmax	VINmax + VLEDmax	VLEDmax

TPS92692-Q1 : Decoding fault behavior
(FLT and SS pin shorted together)

<table>
<tr><th>Observation</th><th>Waveform</th><th>FAULT</th><th>Corrective action</th></tr>
<tr><td rowspan="3">Dimmed output</td><td rowspan="3">Sawtooth waveform on SS pin

</td><td>Output OV protection
VOV > 1.228V</td><td>If LED voltage is as expected-
• Reduce value of Rov1
Or
• Increase value of Rov2</td></tr>
<tr><td>Observed at lower input voltage: Switch current limit, VIS > 250 mV</td><td>• Populate R-C filter on IS pin not already done
• Decrease RIS value</td></tr>
<tr><td>Observed at higher input voltage</td><td>• Check combination of switching frequency, inductor, RIS and Slope resistor</td></tr>
<tr><td rowspan="2">LED string blinking at Time interval >35mS</td><td rowspan="2">Sawtooth waveform on SS pin with 35ms of low period

</td><td>LED overcurrent
IMON > 1.5*ADJ</td><td>• This may occur during start up, input transient test, digital dimming or while switching LED current
• need to correct compensation / slope / output cap
• Input capacitor may be insufficient for input transient test</td></tr>
<tr><td>Output UV protection
VOV < 100mV</td><td>• Check for short between output (LED+) to GND
• Check if Rov2 is open
• Check if Rov1 is shorted</td></tr>
</table>

TPS92692-Q1 : Managing EMI / EMC (TIDA-01581)



References

PCB thermal : Applications notes

[1] TPS92610-Q1 PCB Thermal Budget Design for Maximum Output Current - link

[2] TPS92611-Q1 PCB Thermal Budget Design for Maximum Output Current - link

[3] How to Calculate TPS92630-Q1 Maximum Output Current for Automotive Exterior Light - link

[4] For TPS92630-Q1 online PCB thermal calculator

Safety and Quality Analysis : Technical documents

[5] TPS92611-Q1 Functional Safety FIT Rate and Failure Mode Distribution - link

[6] TPS92610-Q1 Functional Safety FIT Rate and Failure Mode Distribution - link

[7] TPS92613-Q1 Functional Safety FIT Rate and Failure Mode Distribution – link

EMI/EMC : Application note

[8] TPS92613-Q1 Typical Application to Achieve High Immunity to BCI – link

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