Innovating in Automotive Lighting with OpAmps

Matt Sullivan & Michael Helmlinger

Automotive Systems – Body Electronics and Lighting

Detailed agenda

- Automotive Lighting Overview
- TIDA-01183: Single Stage DRL with Accurate Timer
  - 555 Timer feedback and filter
- TIDA-01382: Single Stage DRL with Thermal Foldback
  - Analog signal conditioning for temperature-based current limiting
- TIDA-01581: Single Stage DRL design with
  - Multi-String Current Balancing
  - Fault Detection
  - Thermal Foldback
- TIDA- 01520: Dual Stage (Boost + Buck) Headlight Design
  - Pre-boost control using dynamic headroom feedback

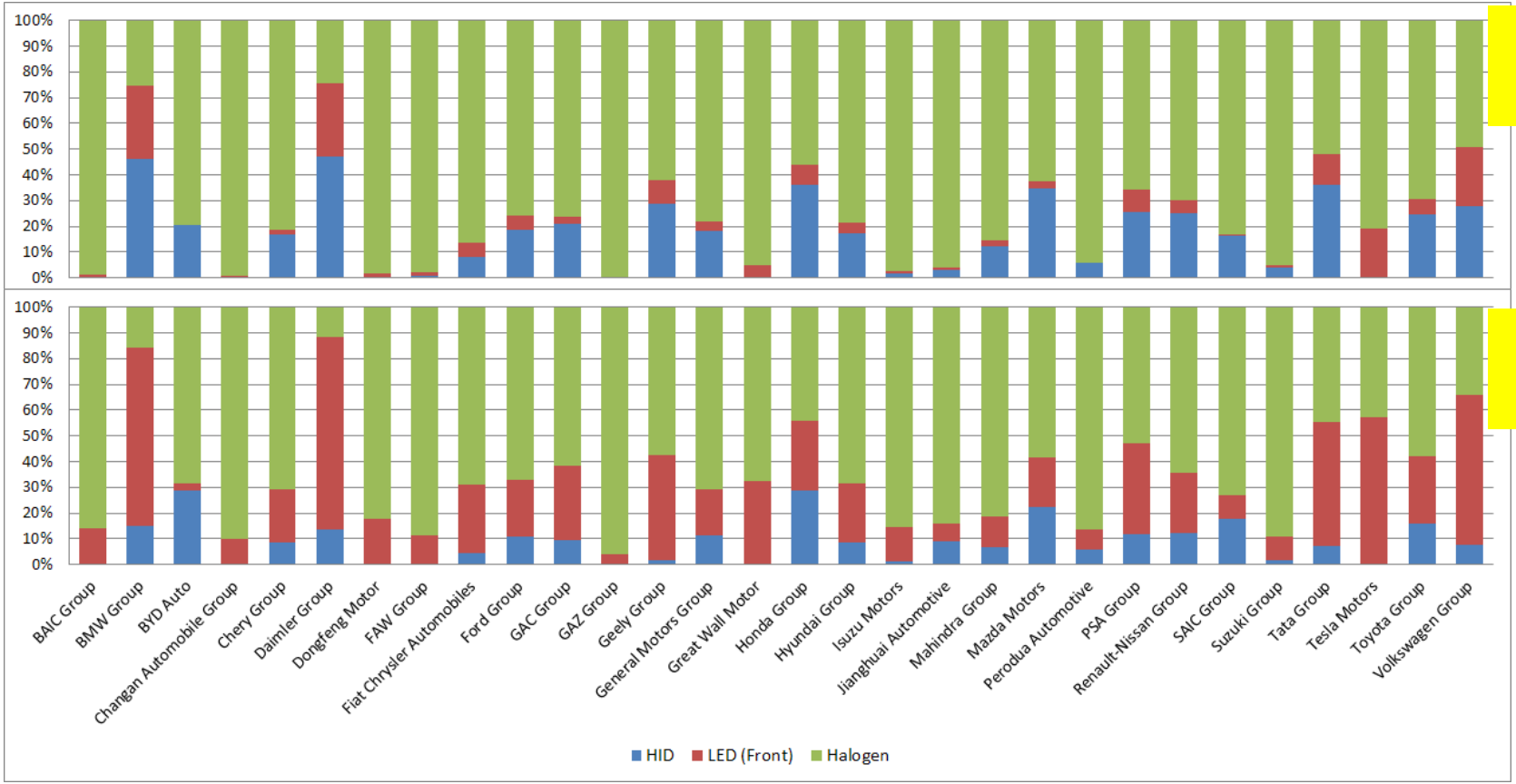
Automotive lighting overview

- Existing LED Driver portfolio with customizable discrete circuitry allows for a flexible design to meet specific needs
- OpAmp building blocks help realize complex and flexible lighting solutions
- TI Designs enable customer to realize LED lighting solutions quickly

Automotive lighting overview

END EQUIPMENT	#Project SBE-2	#Project EE	#Accounts SBE-2	#Accounts EE	Socket WIN %	% ID	SBE-2 Pending Amount	SBE-2 Lost Amount	SBE-2 Win Amount
Exterior Lighting - Fog Light	5	28	4	14	50%	**18%**	$0.00	$338.76k	$1.61M
Exterior Lighting - Headlight	147	468	24	46	65%	**31%**	$4.56M	$9.64M	$8.91M
Exterior Lighting - Rear Light	76	211	18	32	60%	**36%**	$2.30M	$2.23M	$4.05M
Exterior Lighting - Small Light	7	32	6	15	65%	**22%**	$10.02k	$464.10k	$318.33k
Interior Lighting	5	76	4	26	83%	**7%**	$228.15k	$0.00	$34.82k

Automotive lighting overview



2017: 88M

2022: 102M

Systems-level problem solving

Four problems to be solved:

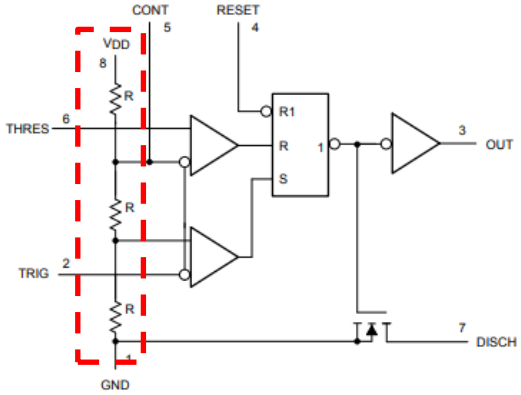
1. Timer inaccuracy for improved dimming
2. Thermal inaccuracies and runaway of LEDs
3. Inefficiencies due to multi-stage LED drivers
4. Proper brightness balancing for multi-string designs

Accurate PWM dimming

Timer inaccuracy

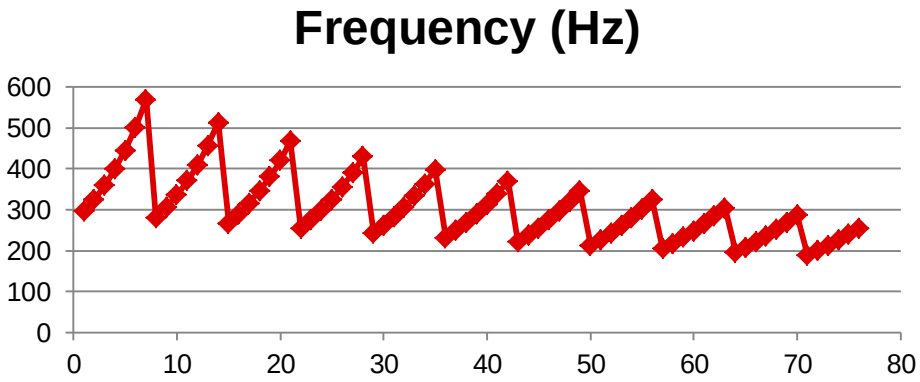
PROBLEM

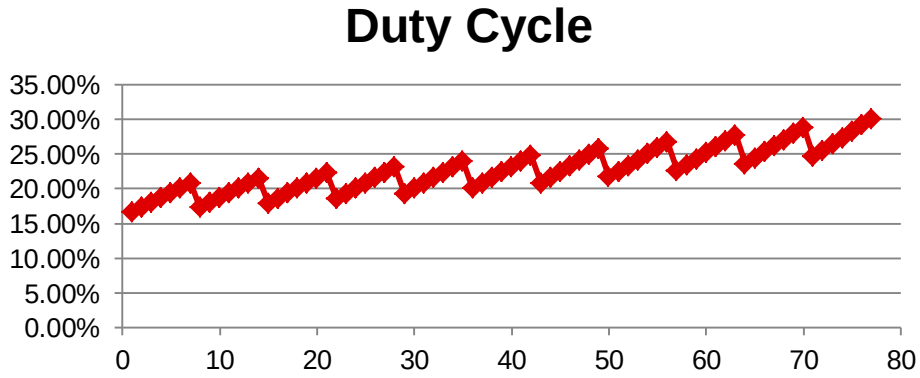
- TLC555-Q1 provides analog PWM for LED dimming without using an MCU
- Several levels of inaccuracy
  - Propagation delay
  - ON-state resistance process variation
  - Internal resistor divider-based reference process variation



THRES Ref Voltage @25C:
2.8V to 3.8V

TRIG Ref Voltage @25C:
1.36V to 1.96V

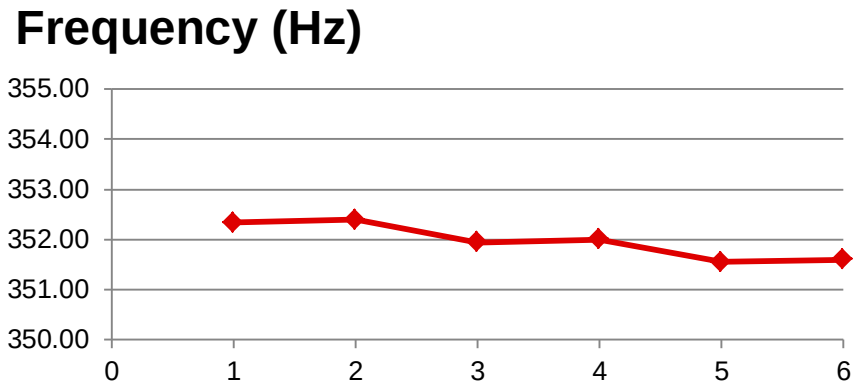


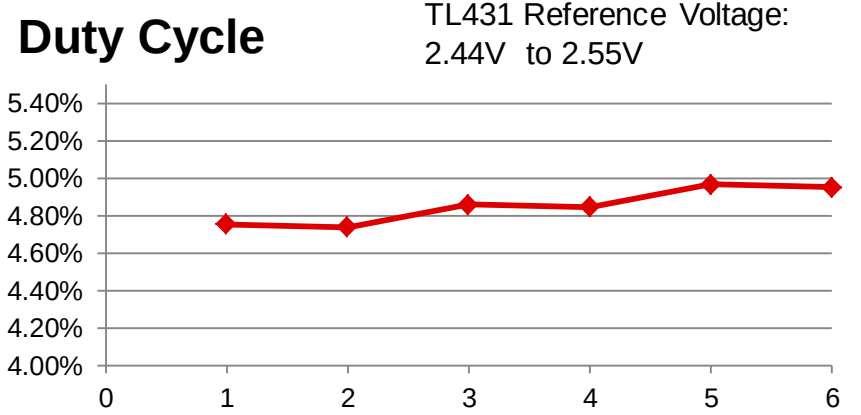


Timer inaccuracy

SOLUTION

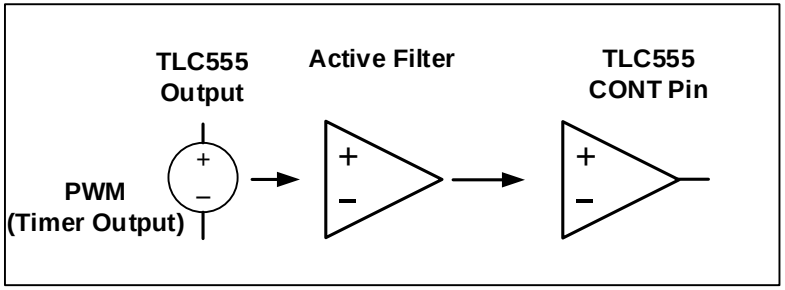
- External accurate reference to avoid 555 reference inaccuracy
- Filtered duty cycle of TLC555 examined with 0.5% accurate TL431 reference
- Resultant output fed back to CONT controls TRIG and THRES reference voltages and removes internal process variance
- Opamp Feedback compensates for additional external RC variance





Accurate timer

PWM filtering

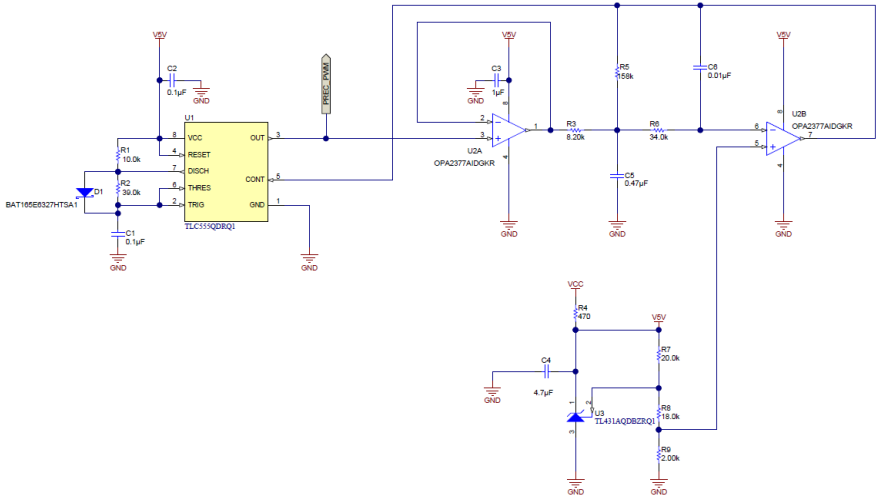


Questions to ask:

- Do you need improve the accuracy of a TLC555 Timer?

Select Op Amp Based on:

- Low voltage, rail-to-rail input and output
- Good CMRR and PSRR, low Vos



Recommended Op Amps:

- **OPA2377-Q1**

TIDA-01183

Accurate PWM Generation with TLC555 for DRL/PSTN

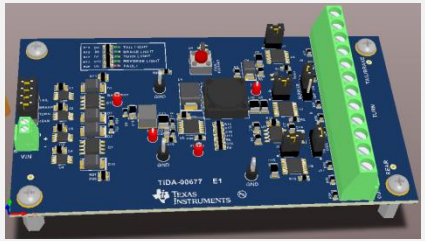
Design Features

- Operates from Automotive Battery (6V to 45V)
- PWM dimming range 5% to 80%
- Buck/Boost topology (470kHz)
- Operates through cold crank, jump start, and load dump (IEC61000-4)
- Reverse battery protected
- EMI Filter

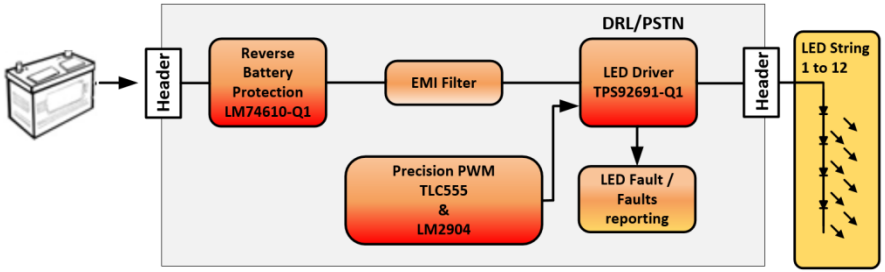
Design Benefits

- Accurate PWM +/- 2% Dimming
- Cost-effective no uC needed
- Small form factor
- CISPR25 Class 3 compliant
- ISO 11452-4 Bulk Current Injection Tolerant

Tools & Resources



- **TIDA-01183 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis



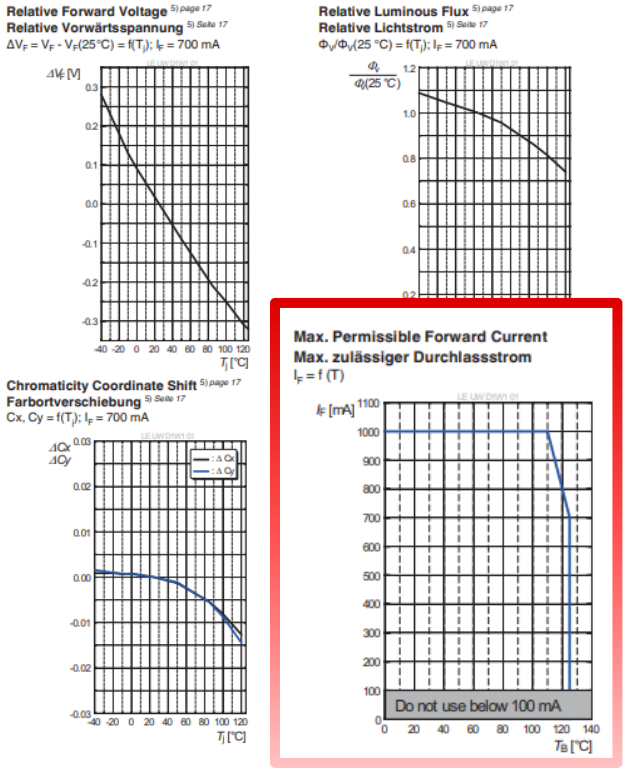
LED thermal stability

LED thermal stability

PROBLEM

- LEDs in an automotive environment can quickly exceed rated maximum temperatures
- Current needs to be limited dependent on temperature

OSRAM OSTAR Headlamp LED
Model: LE UW D1W1 01

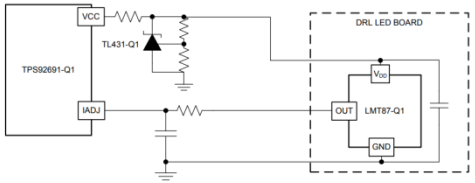


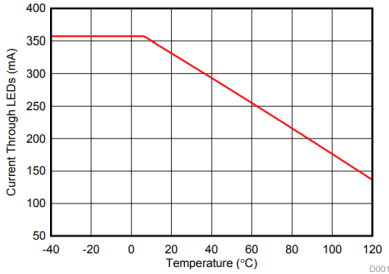
LED thermal stability

SOLUTION

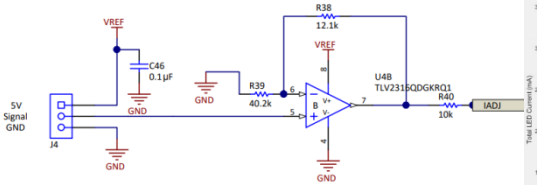
- Modern LED drivers like the TPS92691 utilize a IADJ pin to set the current limit
- Thermal foldback through use of temp sense device (LMTxxx, NTC, etc) and opamp can control the IADJ pin with a slope to lower as temperature rises
- Opamp Gain settings control slope for customization

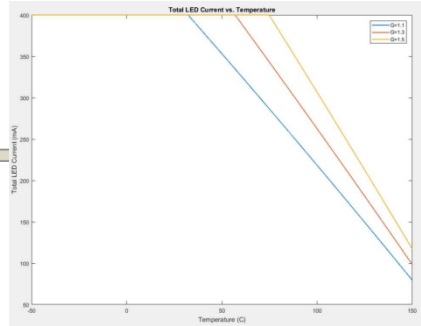
Foldback with LMT87 and no additional slope control





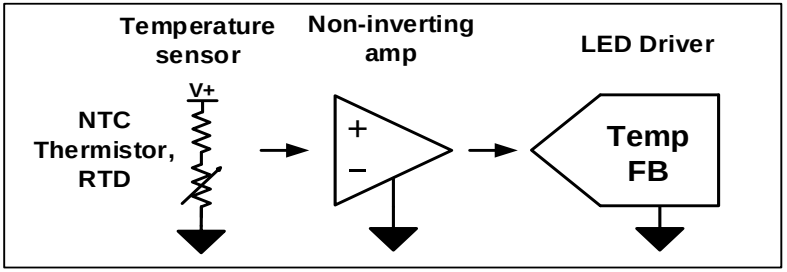
Foldback with LMT87 with opamp slope control





Thermal foldback

NTC sensing and signal conditioning

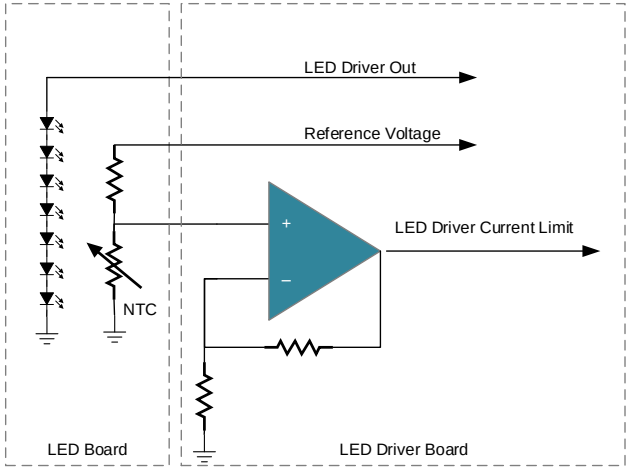


Questions to ask:

- Does the LED driver use an NTC or RTD for thermal foldback?
- Do you need to condition an NTC signal for measurement?

Select Op Amp Based on:

- Low voltage
- Rail-to-Rail input and output



Recommended Op Amps

- **OPA317-Q1**
- **OPA377-Q1**
- **LMV931-Q1**

TIDA-01382

Automotive DRL LED Driver Reference Design with Linear Thermal Foldback

Design Features

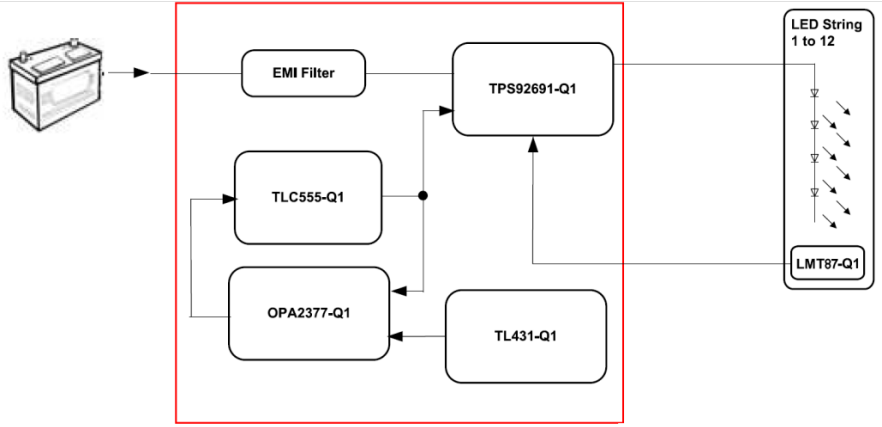
- Operates from Automotive Battery (6V to 45V)
- Boost topology (470kHz)
- Operates through cold crank, jump start, and load dump
- Reverse battery protected
- EMI Filter

Design Benefits

- Accurate Temperature +/- 2.7°C
- Small form factor
- CISPR25 Class 3 compliant
- ISO 11452-4 Bulk Current Injection Tolerant

Tools & Resources

- **TIDA-01382 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files

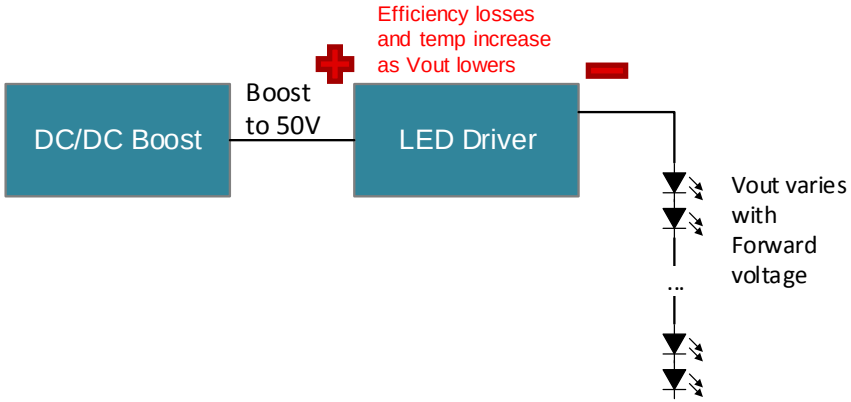


Dual stage LED driver efficiency

Dual stage driver efficiency

PROBLEM

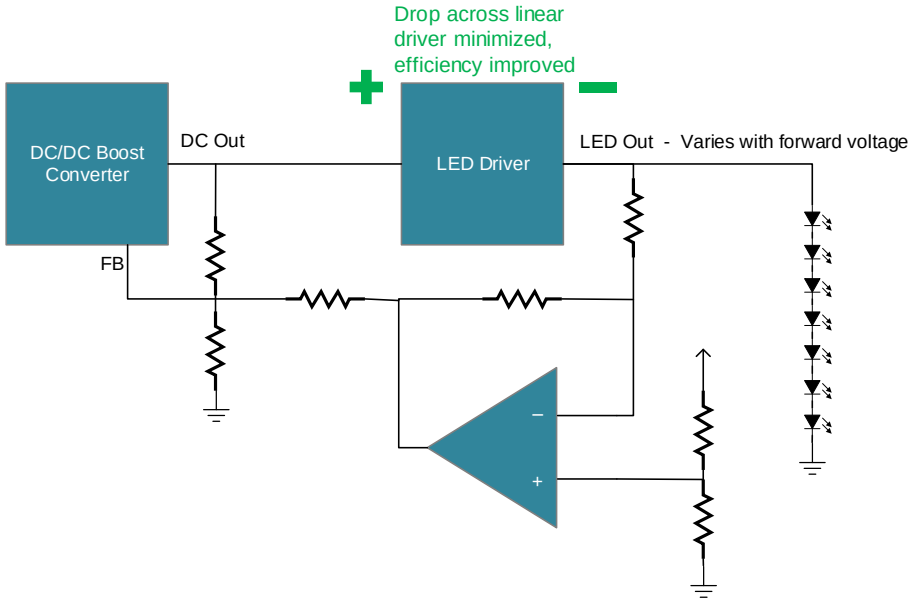
- The main power loss in Linear LED drivers is simply the LED current times the voltage drop on the LED driver
- To keep the losses and temperature at a low level the voltage drop should be kept small
- Since the LED forward voltage is varying with process, temperature and current the voltage drop on the Linear driver is changing



Dual stage driver efficiency

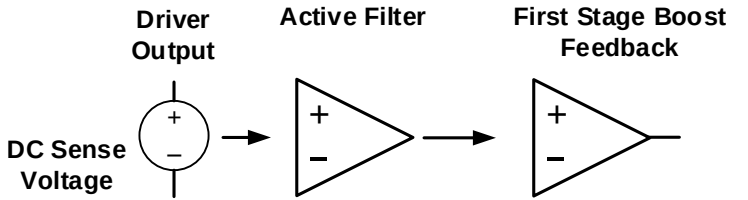
SOLUTION

- To keep the voltage drop at a minimum headroom control can be used
- Dual stage LED driver systems (boost + Linear or buck + linear) can be regulated dynamically based on the varying forward voltage



Dynamic Headroom Control

Voltage Sensing

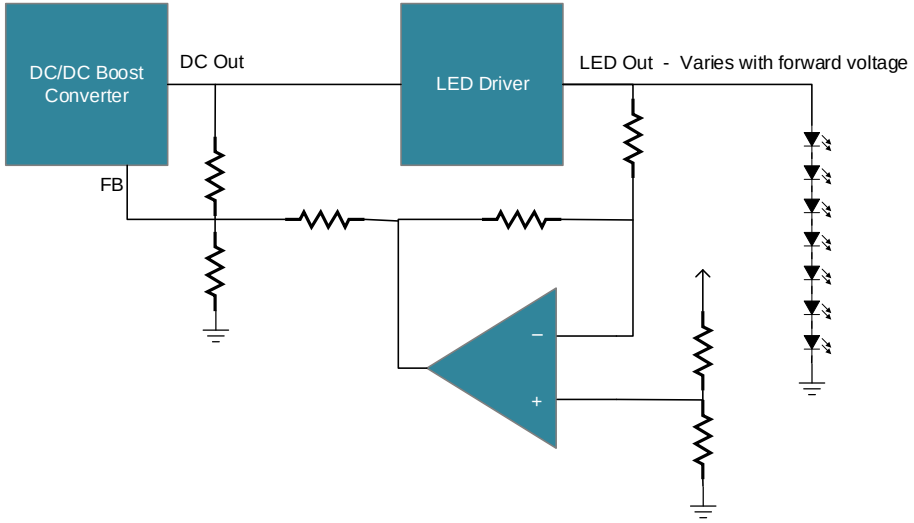


Questions to ask:

- Do you have concerns for efficiency in your LED Driver?
- Do you need to compensate for changes in forward voltage?

Select Op Amp Based on:

- DC accuracy requirements (V_{OS}, V_{OS} drift)
- Wide input common mode range



Recommended Op Amp

- **OPA2377-Q1**

TIDA-01520 50W Dual Stage LED driver for automotive headlights

Features

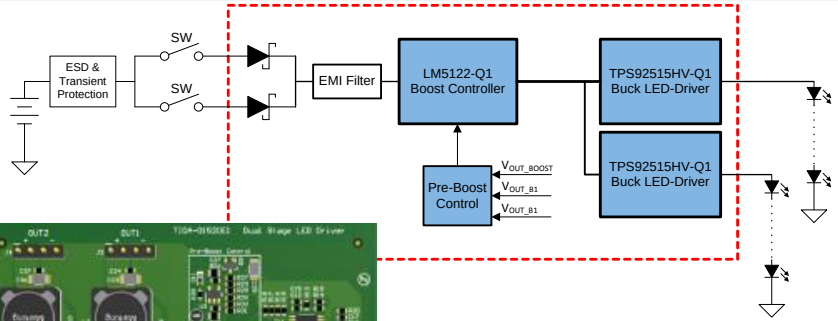
- Wide input voltage range: 13.5V Typical, 6-18V Continuous
- Supports dynamic loads
- Dual Stage: Boost + 2 Buck LED drivers
- Each channel up to 14 LED's @ 25W
- 1A output current per string
- Reverse battery protection
- CISPR25 Class 3 compliant

Benefits

- Adaptable to Different System Power Requirements
  - Flexible number of Buck LED driver's
  - Boost with optional dual phase operation
- Automatic output voltage adaption of boost controller to longest LED string used
- Enables customer to realize LED lighting solution quickly (no SPI programming, no uC necessary, cost effective)

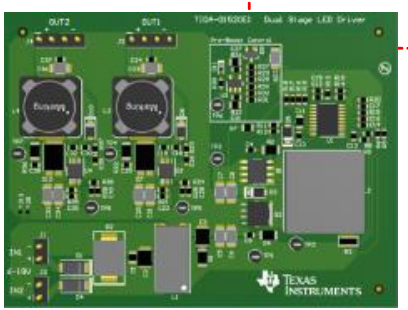
Applications

- Automotive Headlight



Tools & Resources

- **TIDA-01520 Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.
- **Device Datasheets:**
  - LM5122-Q1
  - TPS92515HV-Q1

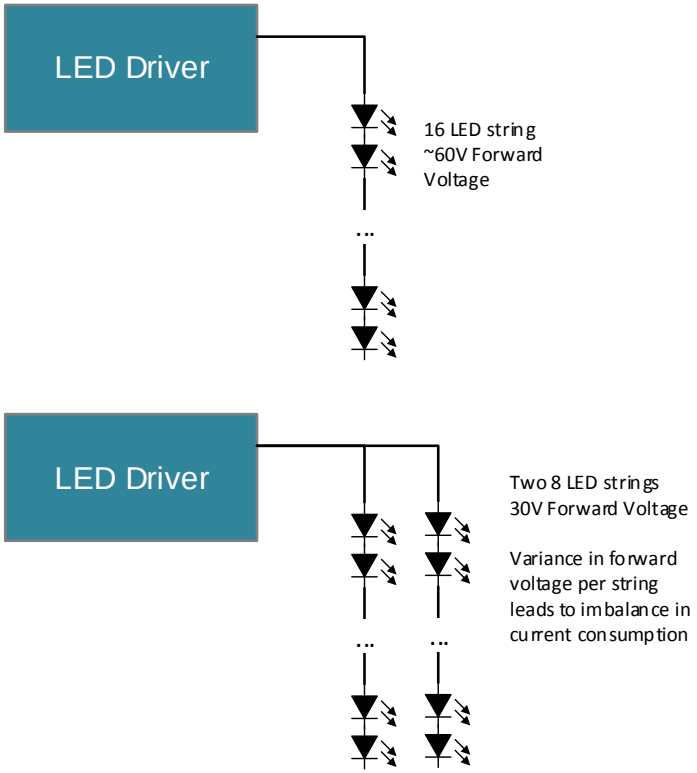


Multi-string current balancing and protection

Multi-String current balancing and protection

PROBLEM

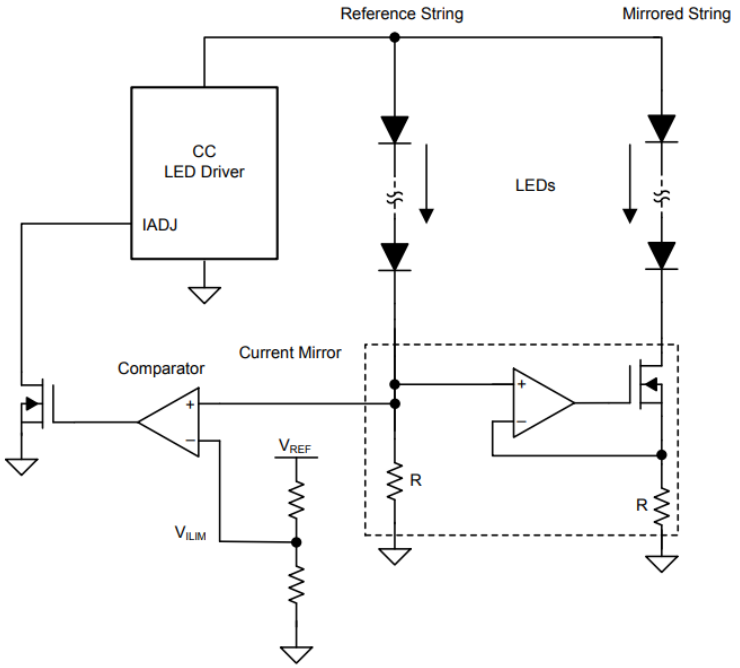
- To drive a long LED string like in a Daytime running light high voltage is required
- Single String solution with 10-15 LED would require 50-60V at output of LED driver
- Multi-string solutions with a single LED driver need additional regulation and protection



Multi-String current balancing and protection

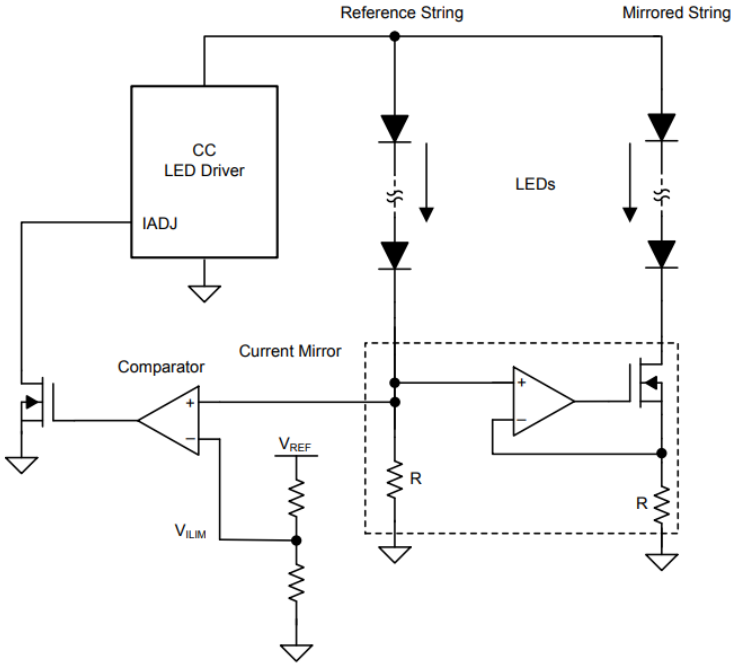
SOLUTION

- Opamp-based current mirror for balancing
- String currents at the same level independent of process and temperature variations and minimizes maximum voltage requirements
- Comparator-based protection circuitry allows for current limiting in cases where one string exhibits a fault condition to prevent overheating and overcurrent conditions



Current Balancing LED Strings

Low Side Sensing and Current Mirror Control



Questions to ask:

- Do you need to balance the current between multiple LED Strings?
- Are there concerns for process and temperature variation between multiple LED strings?

Select Op Amp Based on:

- Input common-mode voltage range (should include ground)
- DC accuracy requirements (Ib, Vos, Vos drift)

Recommended Op Amps:

- **TLV316-Q1**
- **OPA377-Q1**

TIDA-01581 Automotive Daytime Running Light Dual String LED Driver Reference Design with Current Balancing and Adjustable Thermal Foldback

Features

- Wide Input Voltage 4.5 V to 65 V
- High Accuracy LED Current Balancing (<1%)
- Adjustable Thermal Foldback
- 'Position' and 'DRL' Lighting Modes Using PWM
- Current Limiting Incase of Open Circuit Failure
- Spread Spectrum Frequency Modulation
- CISPR25 Class 5 EMI Tested

Benefits

- Requires a single LED controller
- Lower driving voltage can be used
- Ensures equal brightness of LED strings
- Open/short circuit failure over current protection
- Thermal protection
- Operates without a microcontroller

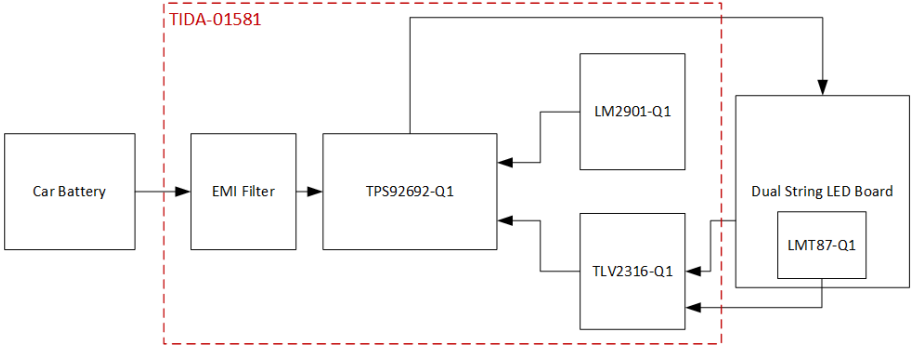
Applications

- Daytime Running Lights (DRL)
- Rear Lighting
- Front Lighting

Tools & Resources

- **TIDA-01581 and/or Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.

- **Device Datasheets:**
  - TPS92692-Q1
  - TLV2316-Q1
  - LMT87-Q1
  - LM2901-Q1



Summary

- OpAmp Building Blocks help drive innovation and improve Automotive lighting designs!

- For more information on Automotive Body and Lighting and details on these TI Designs, please see TI.com/body

THANK YOU!

Summary

- OpAmp Building Blocks help drive innovation and improve Automotive lighting designs!
- SEM will continue to help Find More, Win More and increase the ID% for our building block parts!
- For more information on Automotive Body and Lighting and details on these TI Designs, please see TI.com/body