TI’s intelligent LED drivers in automotive cluster systems

Shirley He
LED Drivers
Outline

• Automotive instrument cluster system trends
• Automotive LED indicator
• Global dimming backlight LED driver
• Local dimming backlight architecture and LED driver
• Aid functional safety cluster system design
• Q&A
Automotive instrument cluster system demand volume

- Hybrid cluster: consists of both analog gauges and a display panel
- Solid state cluster: consists of a single display panel, containing no analog gauges

Source: Strategy Analytics, Automotive Instrument Clusters: Moving Towards Cockpit Integration and 3D Displays, May 2020
LED drivers in instrument clusters

- Hybrid cluster:
  - backlight LED driver (low/mid power)
  - LED indicator

- Solid state cluster:
  - backlight LED driver (mid/high power)
  - LED indicator for tell-tales (optional)
# Multi-channel automotive LED indicator family

<table>
<thead>
<tr>
<th>New Generation (TPIC2810)</th>
<th>Old Generation (TPIC6596)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TLC6C598/12-Q1</strong></td>
<td><strong>TLP6596</strong></td>
</tr>
<tr>
<td>- Shift Register Power Logic</td>
<td>- Shift Register Power Logic</td>
</tr>
<tr>
<td>- 40V Breakdown Voltage</td>
<td>- 33V Breakdown Voltage</td>
</tr>
<tr>
<td>- Vcc = 3 ~ 5.5V</td>
<td>- Vcc = 4.5 ~ 5.5V</td>
</tr>
<tr>
<td>- Cont. &lt;50mA per channel (8/12 ch)</td>
<td>- Cont. &lt;100mA per channel (8 ch)</td>
</tr>
<tr>
<td>- Thermal Shutdown Protection</td>
<td>- ( \text{Vcc} ) = 3 ~ 5.5V</td>
</tr>
</tbody>
</table>

| **TLC6C5816-Q1**        | **TLP5968**               |
| - Shift Register Power Logic | - I2C Power Logic |
| - 40V Breakdown Voltage | - 40V Breakdown Voltage |
| - Vcc = 3 ~ 5.5V | - Vcc = 3 ~ 5.5V, Serial I/F |
| - Cont. <50mA per channel (16 ch) | - Cont. <120mA/ch (8/16 ch) |
| - 2 PWM Input | - 8 bit Global Dot Correction |
| - LED Open & Short Diagnostic | - OT, LED Open |
| - Deactivated LED Fault Detection | - LED Short (7 only) |

| **TLC6C5712-Q1** | **TLP5716** |
| - Const. Current Sink | - Const. Current Sink |
| - 7V Breakdown Voltage | - 7V Breakdown Voltage |
| - Vcc = 3 ~ 5.5V, SPI | - Vcc = 3 ~ 5.5V, Serial I/F |
| - Cont. <75mA/ch (12 ch) | - Cont. <50mA/ch (24/16 ch) |
| - 8 bit Dot Correction | - 7 bit Dot Correction, 8 bit BC |
| - 6 Ext. PWM arbitrary mapping | - 12/10/8 bit Int. Ind. PWM |
| - Full Diagnostic & Protection | - Full Diagnostic & Protection |
| - Deactivated LED Fault Detection | - Deactivated LED Fault Detection |

| **TLC6C5716/24-Q1** | **TLP5712** |
| - Const. Current Sink | - Const. Current Sink |
| - 7V Breakdown Voltage | - 17V Breakdown Voltage |
| - Vcc = 3 ~ 5.5V, Serial I/F | - Vcc = 3 ~ 5.5V, Serial I/F |
| - Cont. <50mA/ch (24/16 ch) | - Cont. <120mA/ch (16 ch) |
| - 7 bit Dot Correction, 8 bit BC | - 8 bit Global Dot Correction |
| - 12/10/8 bit Int. Ind. PWM | - 8 bit Int. Ind. PWM |
| - Full Diagnostic & Protection | - Full Diagnostic & Protection |
| - Deactivated LED Fault Detection | - Deactivated LED Fault Detection |

## Topology

- **V\text{BAT}: 9-18V**
- **V\text{CC}: 3.3-5.5V**

- No Diagnostic
- Simple ON/OFF
- Requires Parallel wires from MCU

- Diagnostic
- Constant Current w/ Rsense
- MCU Serial I/F & Daisy Chain Option
**TLC6C5816-Q1**

**Applications**
- Instrumentation Cluster
- HVAC / Head-unit Faceplate
- Center Stack HMI
- Electronic Gear Shifter

**Features**
- AEC-Q100 Qualified for Automotive Applications
- **16 Channel Power DMOS Transistor Outputs**
  - Open drain output up to 50mA/channel
  - Rdson 6.2 Ohm (25C Junction, typ)
  - Rdson 13.5 Ohm (150C Junction, worst case)
  - 40V Output for load dump, support load directly connect to battery
  - Optimized slow slew rate helps reduce EMI
- **Serial Interface & PWM inputs**
  - Shift register compatible with 596/598/5912
  - Fault register readback with RCK high
  - 2 PWM inputs, each control 8 outputs.
- **Diagnostic & Protection**
  - Over Temperature Protection
  - 8 Channel On-demand LED Open / Short Diagnostics
  - Serial Interface Communication Error Detection
  - Open-drain error output for MCU interruption
- **Package**
  - HTSSOP-28

**Benefits**
- 16 channels in one chip for more cost efficient to power each LED
- On-demand LED Short & Open Detection to easy fulfill diagnostics and save system cost
- Optimized Slew Rate helps reduce EMI
- Dual PWM input to support two different dimming scenarios
- SPI Checksum readback to enhance SPI communication reliability

**Key Parameter Overview**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vcc operating voltage</td>
<td>3 ~ 5.5</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage maximum rating</td>
<td>40</td>
<td>V</td>
</tr>
<tr>
<td>Channel output maximum current</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Rdson (on) typical</td>
<td>6.2</td>
<td>Ω</td>
</tr>
</tbody>
</table>

**Diagram**

Battery 5 V - 40 V

3 V – 5.5 V
TLC6C5712-Q1

Features

- AEC-Q100 Qualified for Automotive Applications
- 12 Channel Power DMOS Transistor Outputs
  - Constant current up to 75mA, set via external resistor
  - Breakdown voltage up to 7V
  - Max drop-out voltage: 0.75V @ 50mA/ch, 1.2V @ 75mA/ch
  - Configurable slew rate for optimized EMI performance
- Precision Constant Current
  - Channel-Channel difference < ±3%
  - Device-Device difference < ±3%
  - 8-bit, 256-step linear dot correction for each channel
- Serial Interface & PWM inputs
  - 6 PWM Inputs with frequency supervision
  - Programmable PWM mapping capability via SPI interface
- Diagnostic & Protection
  - Open-load, Short-to-GND, Shorted-LED detection for both activated and deactivated states
  - LED Weak Supply Detection
  - Adjacent Pin Short Detection
  - Reference Resistor Open/Short Detection & Protection
  - Thermal Prewarning and Shutdown
  - Input PWM Timeout Monitoring
  - Open-drain Error reporting
  - Force Error for SPI Integrity Diagnostics
  - SPI register lock for content protection
- Small & thermal effective package
  - 28 HTSSOP (PowerPAD)

Benefits

- Output current high accuracy ensure whole system close to zero deviation in LED Display
- Full Programmable via SPI to offer the flexibility for various applications
- Complete Diagnostic and Protection to meet high functional safety requirements

Applications

- Instrumentation Cluster
- HVAC / Head-unit Faceplate, Center Stack HMI, Electronic Gear Shifter
- Local Dimming Display
- RGB Ambient Lighting

Key Parameter Overview

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vcc operating voltage</td>
<td>3 ~ 5.5 V</td>
</tr>
<tr>
<td>Output voltage maximum rating</td>
<td>7 V</td>
</tr>
<tr>
<td>Full range output current</td>
<td>75 mA</td>
</tr>
<tr>
<td>Output current accuracy</td>
<td>±3 %</td>
</tr>
</tbody>
</table>
TLC6C5716/24-Q1

Features

• AEC-Q100 Qualified for Automotive Applications
• 24/16 Channel Outputs
  • Constant current up to 50mA, set via external resistor
  • Breakdown voltage up to 7V
• Precision Constant Current
  • Channel to Channel: ±8%
  • Device to Device: ±2%
  • 7-bit, 128-step Dot correction for each channel
  • 8-bit, 256-step Brightness Control for each color group
• Serial Interface & PWM Dimming
  • up to 4MHz SCK and 8MHz GCLK frequency, optimized for Automotive application
  • 12/10/8 Bits internal PWM dimming configurable by each channel
  • EMI friendly with programmable Output Channel Turn On/Off Slew Rate
  • Grouped Delay to Prevent Inrush Current
• Diagnostic & Protection
  • LED open error (LOD), LED short error (LSD), Output pin short to GND error (OSD)
  • LOD/LSD detection circuit failure, LOD/LSD register failure
  • PWM operation error, GCLK signal missing error
  • Adjacent pin short error (APS)
  • Thermal Prewarning (TPW), Thermal error and Shutdown (TEF)
  • IREF resistor open failure (IOF), IREF resistor short failure (ISF)
• Small & thermal effective package
  • 38 HTSSOP (PowerPAD)

Benefits

• High system reliability by fault detection and readback, including PWM error, GCLK missing, etc
• Suitable to drive eight RGB color mixing LED lamps
• Mixed LED Binning with DC/BC compensation and high accuracy of constant current
• EMI friendly with low inrush current and group delay

Applications

• Instrumentation Cluster
• HVAC / Head-unit Faceplate, Center Stack HMI, Electronic Gear Shifter
• Local Dimming Display
• RGB Ambient Lighting

Key Parameter Overview

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vcc operating voltage</td>
<td>3 ~ 5.5</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage maximum rating</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Full range output current</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Output current accuracy</td>
<td>±8</td>
<td>%</td>
</tr>
</tbody>
</table>
TFT LCD architecture

Mostly used in Local Dimming

Mostly used in Global Dimming
LP8866-Q1 / LP8866S-Q1

Benefits
- High brightness and big size LCD panel support with
  - 6 * 200/150 mA LED output
- Good Cold cranking behavior with
  - Input Voltage Operating Range 3 V to 48 V
- Good EMI Performance with
  - Phase shifted LED outputs
  - Boost converter Spread Spectrum
  - Hybrid Dimming (Linear + PWM)
  - Boost synchronization input
- Ease Customer design with
  - Resistor configuration for PWM /Boost frequency/LED configuration/Dimming mode
  - Integrated Discharge function

Features
- AEC-Q100 Qualified for Automotive Applications (Grade 1: T_A -40C to +125C)
- Six High-Precision Current Sinks
  - Output Current up to 200/150 mA/Channel
  - Current Matching 1% (typical)
  - Up to 16-bit LED Dimming Resolution
  - Individual LED String Brightness Control
  - Dimming Ratio 32,000:1 @ 152Hz PWM
  - I2C, PWM Brightness Control Modes
  - 8 configurable LED strings configuration
  - Automatically adjusts phase shift for number of LED strings
- Boost Controller for LED String Power
  - Input Voltage Operating Range 3 V to 48 V
  - Switching Frequency 100 kHz to 2.2 MHz
  - Boost SYNC input to set boost switching frequency from an external clock
  - Spread Spectrum for lower EMI
  - Adaptive Voltage Control for Power Optimization
  - Output voltage automatically discharged when boost is disabled
- Full Protection and Diagnostic Features
  - Open, Shorted, Short-to-GND LED Fault Detection
  - Boost Output OVP and OCP
  - Boost Input UVLO, OVP and OCP
  - External Resistor Fault/Charge Pump Fault/CRC Errors
  - VDD UVLO and Thermal Shutdown
- HTSSOP-38 Package (DCP)

Applications
- Backlight for:
  - Automotive Infotainment
  - Automotive Instrument Clusters
  - Smart Mirrors
  - Heads-Up Displays (HUD)
  - Central Information Displays (CID)
  - Audio-Video Navigation (AVN)
The LP8866-Q1 contains several diagnostic registers that can be read with the I2C interface for debugging or additional device information.
LED SHORT_TO_GND

- Support the industry's quickest detection of LED short to GND fault
- Avoid the glare when LED is short to GND
  - Risk of blinding driver at night
## Full fault detection and handling

<table>
<thead>
<tr>
<th>Supply Fault</th>
<th>Boost Fault</th>
<th>LED Fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN undervoltage</td>
<td>Boost OVP low</td>
<td>Open LED string</td>
</tr>
<tr>
<td>VIN overvoltage</td>
<td>Boost OVP high</td>
<td>Shorted LED</td>
</tr>
<tr>
<td>VIN overcurrent</td>
<td>Boost overcurrent</td>
<td>LED short to GND fault</td>
</tr>
<tr>
<td>VDD undervoltage</td>
<td>LEDSET detection fault</td>
<td>Invalid LED string detected</td>
</tr>
<tr>
<td>Charge pump fault</td>
<td>MODE detection fault</td>
<td></td>
</tr>
<tr>
<td>Charge pump components missing</td>
<td>FSET detection fault</td>
<td></td>
</tr>
<tr>
<td>Boost sync clock invalid fault</td>
<td>ISET resistor fault</td>
<td></td>
</tr>
<tr>
<td>Internal Register CRC Fault</td>
<td>Thermal shutdown</td>
<td></td>
</tr>
</tbody>
</table>

- The Interrupt Fault Status registers can be read back in three fault registers.

- Fault in red means critical fault which will make the chip enter into fault recovery state. It will shutdown all the modules and retry periodically.
### High reliability & diagnostic coverage

LP8866-Q1 could survive (no damage) when any pin is OPEN/Short to GND or short with adjacent pin.

<table>
<thead>
<tr>
<th>Name</th>
<th>Open</th>
<th>Short to GND</th>
<th>Adjacent pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD</td>
<td>No</td>
<td>No</td>
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</tr>
<tr>
<td>EN</td>
<td>No</td>
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<td>No</td>
</tr>
<tr>
<td>C1N</td>
<td>No</td>
<td>No</td>
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</tr>
<tr>
<td>C1P</td>
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</tr>
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</tr>
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<td>ISET</td>
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<tr>
<td>FB</td>
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<td>DISCHARGE</td>
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<tr>
<td>SD</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Local dimming architecture

<table>
<thead>
<tr>
<th></th>
<th>Global Dimming</th>
<th>Local Dimming</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCON</td>
<td>Process Video stream only</td>
<td>Process both Video stream and backlight control signal</td>
</tr>
<tr>
<td>LED Backlight Unit</td>
<td>Mostly edge-lit</td>
<td>Direct lit only. Each zone contains at least one LED</td>
</tr>
<tr>
<td>LED Driver</td>
<td>Channel current output, global controlled</td>
<td>Channel current output, individually controlled, Digital interface cascaded</td>
</tr>
</tbody>
</table>

1. System Board
2. Timing Controller (TCON) HX8880
3. LED Driver

Video Stream

Connected to:
- LCD Panel
- LED Backlight Unit
- LED Driver
Channel individual control LED driver (direct)

- All the LEDs are driven at the same time in parallel
- One backlight zone needs one LED driver’s channel
Channel individual control LED driver (scan)

- The backlight LEDs are driven sequentially in groups.
- One LED driver’s channel could cover multiple zones (depending on multiplexing config).
- High peak current for each LED and LED driver’s channel since each LED could be only on in a duty cycle (25% in the 4:1 multiplexing example below).
Direct Drive

- Feasible to put chip on LED board

Scan

- Higher LED power consumption and higher LED driver power consumption
- Higher PCB thermal peak
- Unfeasible to put chip on LED board
Direct vs. scanning LED driver placement

**Direct Drive** *(Drivers on board)*
- LED drivers & LEDs
- TCON/MCU
- Power

**Integrated Scanning** *(Drivers on external board)*
- LEDs only
- LED Drivers
- TCON/MCU
- Power

Bigger connectors & more PCB space
Local dimming roadmap

**TLC5941-Q1**
- 16 CH Const. Current Sink
- 17V breakdown Voltage
- Vcc = 3 ~ 5.5V, 30MHz Serial I/F
- 60mA/ch
- 6 bit Dot Correction
- 12 bit Int. Ind. PWM
- OT, LED Open
- HTSOP-28, 4.4 mm* 9.7 mm

**TLC6C5716/24-Q1**
- 16/24 CH Const. Current Sink
- 8V breakdown Voltage
- Vcc = 3 ~ 5.5V, 4MHz Serial I/F
- 50mA/ch
- 7 bit Dot Correction, 8 bit BC
- 12/10/8 bit Int. Ind. PWM
- OT, LED Open/Short/Short-to-GND
- HTSOP-38, 6.2 mm* 12.5 mm

**TLC6C5748-Q1**
- 48 CH Const. Current Sink
- 11V breakdown Voltage
- Vcc = 3 ~ 5.5V, 25MHz Serial I/F
- 32mA/ch
- 7 bit Dot Correction, 7 bit BC
- 3 bit MC, Integrated IREF
- 16 bit Int. Ind. PWM, ES-PWM
- OT, LED Open/Short
- HTSOP-56, 6.1 mm * 14 mm

Lower cost per channel
TLC6C5748-Q1
48ch, 16bit PWM LED Driver with low headroom voltage and high output voltage

Features

- 48 Outputs with 7bit DC for each output
- 16bit PWM Constant-Current with 7bit Brightness Control and 3bit Max Current Control for 31.9mA, no external RREFERENCE resistor
- IC Supply Voltage Range: 3.0 – 5.5V
- LED Breakdown Voltage: 11V
- Precise Constant Current Regulation:
  - Channel-to-Channel: ± 2% (typ)
  - Device-to-Device: ± 2% (typ)
- Low Headroom Voltage: 0.25V@19mA
- LED Open/Short Detection
- Over Temperature Detection
- Power Save Mode: 7uA consumption
- HTTSSOP-56 Package (DCA) 6.1 mm * 14 mm
- Operating Junction Temperature Range: -40 C to +125C

Benefits

- Best to drive 48 LED zones with uniformity
- Perfect solution for chip-on-LED-board architecture
- Direct daisy chain interface with TCON controller
- Max 3 single-junction LEDs/ 1 dual-junction LED in series
- Reduces system power consumption
- Reduces system cost
- Unlimited device cascading

Applications

- Automotive Local Dimming Backlight
- Automotive Pixel Lamp
- Automotive RGB display
XTIDA-020036 384-Zone 12” Local Dimming Backlight Reference Design

Features

- 384 zones & LEDs
  - 12x32 matrix; 1S1P
  - 0.9 cm pitch
- PCB Specifications
  - Direct driver on back of PCB
  - 2 layer PCB
- SPI control for 8x daisy-chain
- 8x 48-ch low-side LED drivers
- Compatible with local dimming TCONs
- LED Specifications
  - OSRAM Mini TOPLED White 120° SMD
  - Size : 2.3mm x 1.9mm (91mil x 75mil)
  - Single junction @ 3.05V forward voltage
  - 20mA per LED

Tools & Resources

- TIDA-020036 Folder
- Design Guide
- Design Files: Schematics, BOM, Gerbers, Software, etc.

- Device Datasheets:
  - TLC6C5748-Q1
  - SN74LVC2G17
  - LCW MVSG.EC-BXEX

- TOP

- BOTTOM

- ~500mV headroom
- 30C temperature
- increase

- Area
- Mark: 55.4°C
- Avg: 38.0°C
- 35°C temperature increase
Aiding Functional Safety cluster system designs

- TI offers **Functional Safety-Capable** LED drivers to aid system-level functional-safety cluster system design

- Documentation we can provide:
  - **Functional safety FIT rate**
    - Based on IEC TR 62380 or SN 29500 standards
    - Calculated at a 90% confidence interval for safety-related rate estimation in compliance with IEC 61508 and ISO 26262
  - **Failure mode distribution (FMD)**
  - Pin FMA *
  - Diagnostic description and fault handling routine *

* Available for select products
Q&A
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