



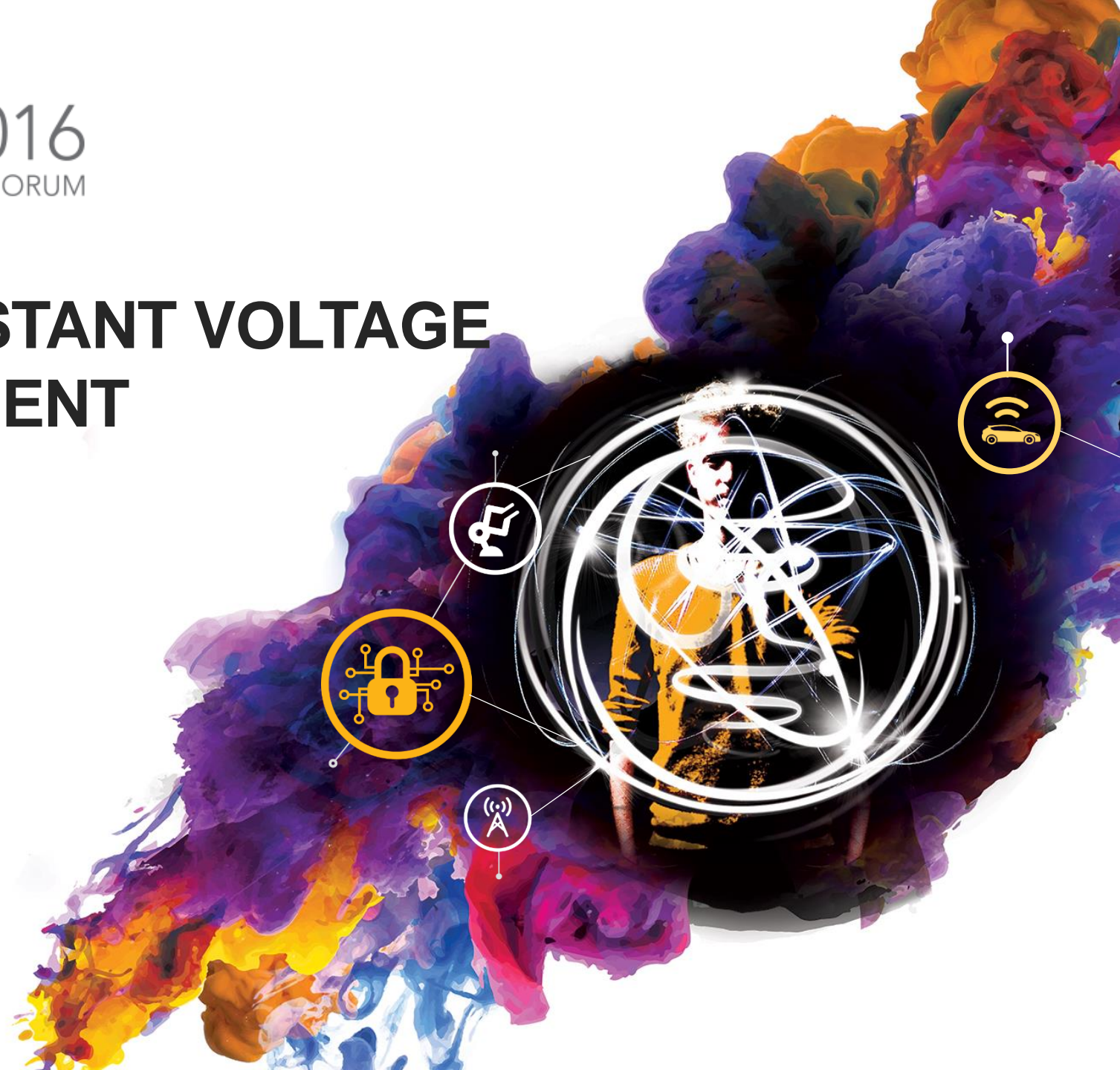
**FTF 2016**  
TECHNOLOGY FORUM

# DRIVING LEDs: CONSTANT VOLTAGE OR CONSTANT CURRENT

**FTF-DES-N1915**

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MAY 17, 2016

PUBLIC USE



# AGENDA

- LED Basics
- LED Driver Considerations
- LED Products Overview/Description
- LED Applications
- Conclusion and Q&A



# LED BASICS

# What is LED

- LED is an abbreviation for Light Emitting Diode
- LED is a special diode as semiconductor electronic component
- LED emits light when an electric current is passed through it and different voltages are necessary to operate the diode in forward bias
- LED light's color depends on the semiconductor material used
- LED lights are extremely energy efficient and long lasting
- LED lights can be used in a wide range of applications
- LED lights contain no mercury or other toxins
- LED lighting can create fascinating worlds of experience

# History of LED

- In 1907, British scientist Henry J. Round discovered the physical effect of electroluminescence, but the light produced was very dim
- In 1962, the first visible spectrum LED light was produced by Nick Holonyak Jr.
- In 1971, the development of new semiconductor materials, LEDs are produced in new colors: green, orange and yellow
- In 1980, the first super bright LED's were developed
- From 1990 the use of LED's became standard in various industrial applications
- For last two decades LED lights have been replacing incandescent globes in homes, businesses and everywhere

# Benefits of LED Lighting

- Low power consumption
- High efficiency level
- Long lifetime (50,000 hours) and superior reliability
- Continuous dimming and robustness
- Immediate light (full brightness) at switching on
- Smallest possible dimensions
- Wide operating temperature range
- High impact and vibration resistance
- No Ultraviolet (UV) or Infrared (IR) radiation
- Smart Lighting with natural color

# LED DRIVER CONSIDERATIONS



# How to Drive LED

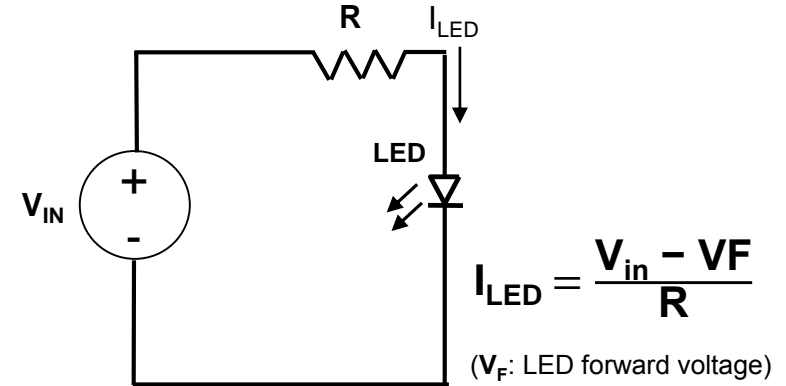
## Voltage Source with Resistor

### Pros:

- Heat is dissipated in the resistor
- Source is independent of heat dissipated
- Good for driving multiple LEDs in series, with different  $V_F$

### Cons:

- Any change in LED forward voltage ( $V_F$ ) or LED supply voltage ( $V_{IN}$ ) create a change in LED current ( $I_{LED}$ )



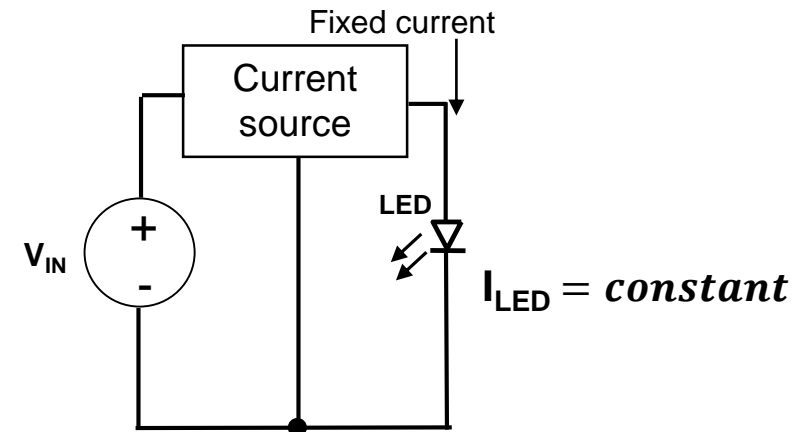
## Constant Current Source without Resistor

### Pros:

- LED light remains constant current regardless of LED supply voltage and LED forward voltage fluctuations

### Cons:

- Heat is dissipated at the current source
- Current source is sensitive to heat dissipation

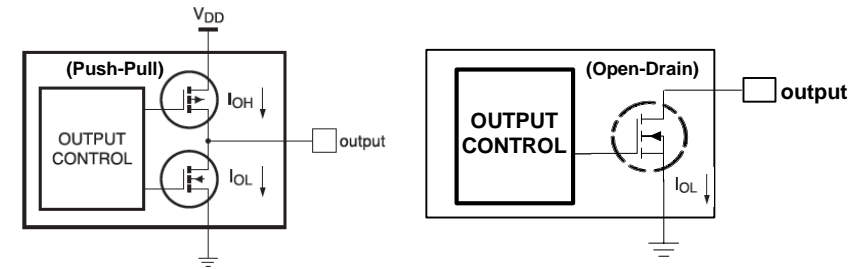




# LED Output Structures

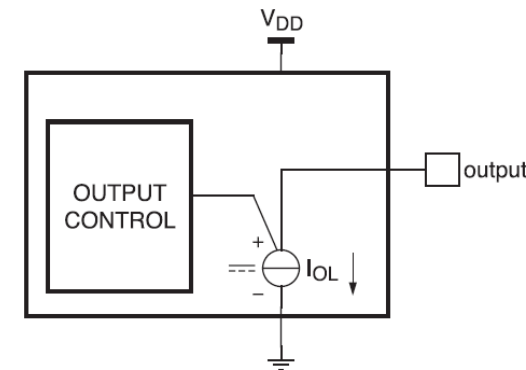
## Voltage switch/source output structure

- Either Push-pull or Open-drain output
- The LED connected to the output by switching the connection to GND or VDD/Open (on or off)
- A series resistor connected between the LED and output to limit the current, and dissipate the heat outside the device



## Constant current source output structure

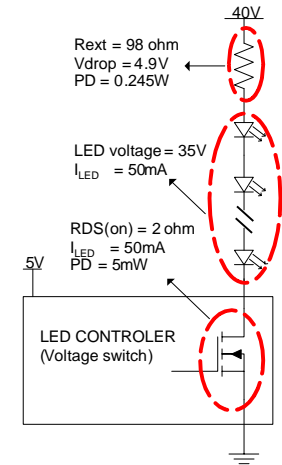
- Open-drain sink current output
- Current-regulated output to drive LEDs
- Remaining constant current with the LED supply-voltage fluctuations
- The higher power dissipation in the device if the LED forwards voltage mismatch



# Two Types of LED Controllers

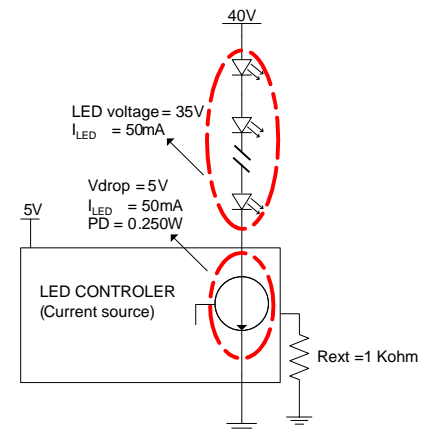
## Voltage switch driver

- Advantages
- Less power dissipation in driver
- Higher I<sub>LED</sub> per channel (up to 100mA)
- Considerations
- Need one R<sub>EXT</sub> per channel to limit current
- I<sub>LED</sub> varies with changes of LED supply voltage and each LED forward voltage



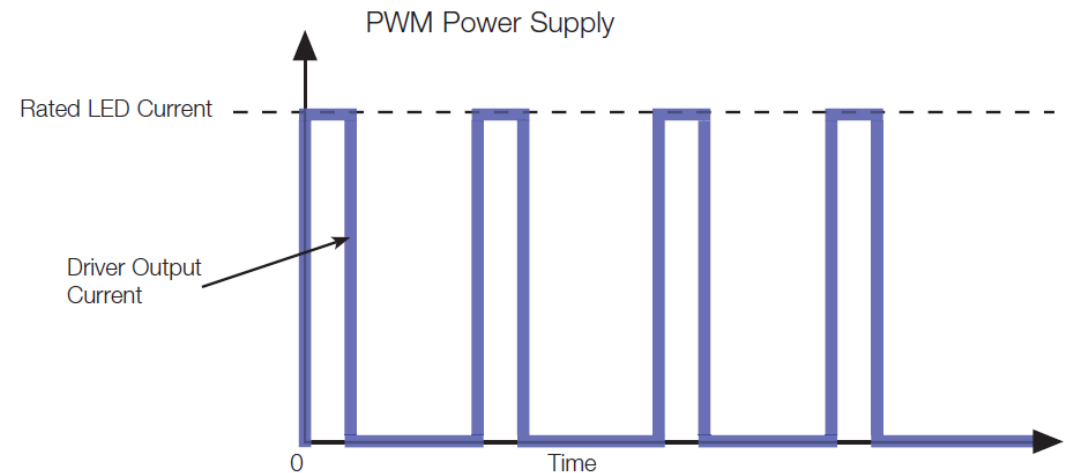
## Current source driver

- Advantages
- One R<sub>EXT</sub> sets I<sub>LED</sub> for all channels
- I<sub>LED</sub> is independent of changes in supply voltage and LED forward voltage
- Considerations
- Higher power dissipation in driver
- Lower I<sub>LED</sub> per channel (up to 57mA)



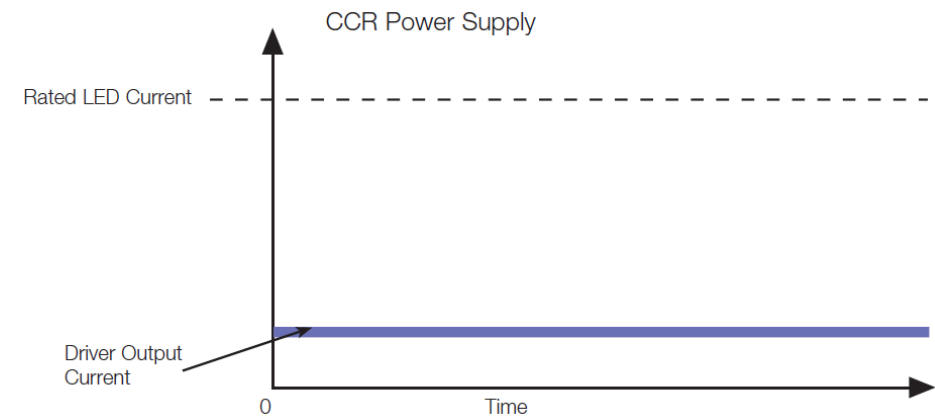
# Dimming LEDs Via PWM

- Use Pulse Width Modulation for LED brightness/contrast adjustment
- Applying full current to the LED at a reduced duty cycle
- PWM signal must be above 100 Hz to avoid blinking to human eye
- Need additional logic to create the PWM digital waveforms
- PWM based drivers can provide a very precise output level
- PWM dimming greatly reduces color changes or shifting
- The discrete switching cycles can cause EMI noise and inrush current in the system
- Voltage switch LED driver always uses PWM for dimming



# Dimming LEDs Via CCR

- Use Constant Current Reduction (CCR) for LED brightness/contrast adjustment
- The current flows continuously at a set amount for a given light level
- The current is reduced to reduce the brightness of the LED
- Applications where long wire runs may exist between the driver and the light engines
- Applications that may have strict EMI requirements, such as medical suites
- Changing the operating current linearly may not result in a linear change in light output
- Inappropriate for applications that require a constant color temperature



# LED PRODUCTS OVERVIEW AND DESCRIPTION



# LED Controllers Overview

- Why used?
  - Reduce I2C-bus traffic and off-load the microcontroller
  - Pre-programmed individual/global dimming, blinking and color mixing
  - Low power consumption and high reliability
- Where used?
  - Status indicator and display for White Goods
  - Keypad and LCD backlighting
  - Color mixing and brightness control for Pachinko/gaming machines
  - Tell-Tales light and Instrument cluster for Automotive
- Why NXP LED Controller?
  - Large selection of LED Controllers in a wide range of packages
  - AEC-Q100 automotive compliant qualification
  - Each LED output can be set to OFF, ON, individual/group PWM control for dimming/blink and color mixing capabilities
  - Low power in standby or sleep mode
  - Minimized surge currents and reduce EMI noise with programmable LED output delay
  - LED Open or Short error detection and Over-temperature protection in real time
  - No external components required

# NXP's LED Controllers Offer a Variety of Features

- Programmable group blinking and dimming mixed capability with individual LED brightness
- Up to 12-bit Pulse-width modulation (PWM) resolution for LED luminous control
- 256 discrete steps for Red/Green/Blue (RGB) Color mixing capabilities
- Up to 40 V for LED supply and adjustable output peak current with 8-bit linear DAC up to 57 mA
- Fast-mode Plus (Fm+) bi-directional communication I2C-bus with data rate up to 1 Mbps
- SPI-compatible 4-wire serial bi-directional daisy-chain interface with data rate up to 25 Mbps
- Different or programmable output drive types (push-pull or open-drain)
- Independent control of LEDs
- Highly reliable thanks to AEC-Q100 compliant automotive qualification
- LED Open or Short status and fault reading
- Gradation control with programmable “breathing” effect
- Over-temperature protection

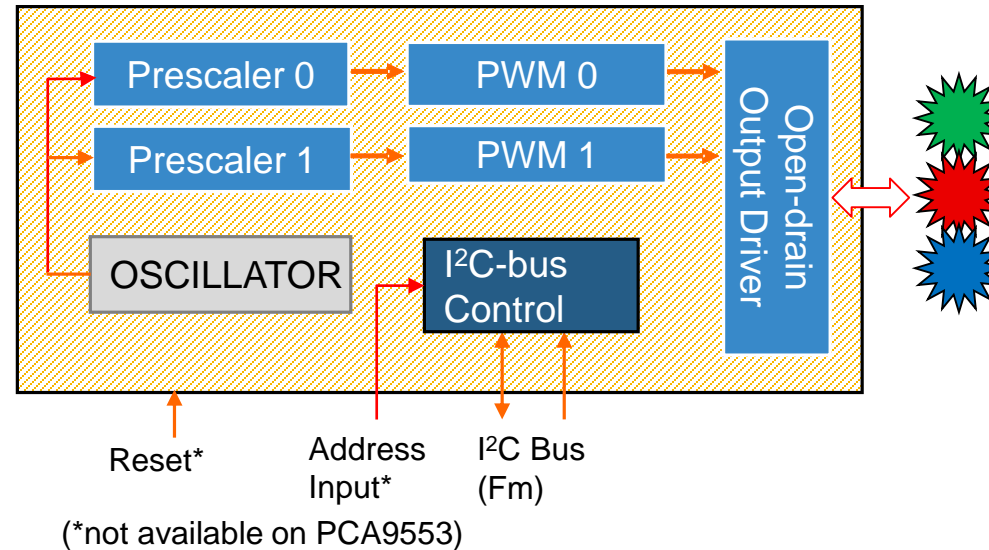


# PCA955x – Simple LED Blinkers

Voltage Switch LED Controllers with Dual PWMs/Prescalers, 25 mA/5 V

## Features

- Device supply voltage 2.3 V to 5.5 V
- Device can be used as regular GPIOs
- Output
  - Open Drain
  - 5 V / 25 mA
- Digital Interface
  - I2C-bus, Fm 400 KHz (bi-directional)
  - Hardware Address Input Pins
- PWM Generator
  - 2x PWM with 256 steps (8-bit)
- Two frequency prescalers for blinking rates between 0.172 Hz and 44 Hz
- Packages offered: SO, TSSOP, HVQFN, HVSON
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 150V MM
- Low standby current



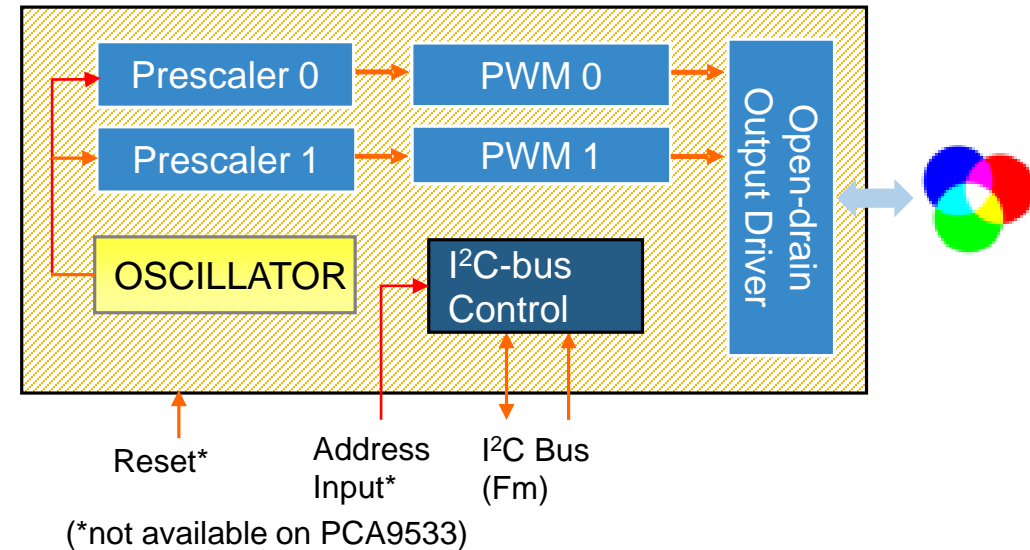
Device	# Channel	Package
PCA9550	2-channel	TSSOP8, SO8, HVSON8
PCA9553	4-channel	TSSOP8, SO8, HVSON8
PCA9551	8-channel	TSSOP16, SO16, HVQFN16
PCA9552	16-channel	TSSOP24, SO24, HVQFN24

# PCA953x – Simple LED Dimmer and Blinker

Voltage Switch LED Controllers with Dual PWMs/Prescalers, 25 mA/5 V

## Features

- Device supply voltage 2.3 V to 5.5 V
- Device can be used as regular GPIOs
- Output
  - Open Drain
  - 5 V / 25 mA
- Digital Interface
  - I2C-bus, Fm 400 KHz (bi-directional)
  - Hardware Address Input Pins
- PWM Generator
  - 2x PWM with 256 steps (8-bit)
- Two frequency prescalers for blinking rates between 0.591 Hz and 152 Hz
- Packages offered: SO, TSSOP, HVQFN
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 150V MM
- Low standby current



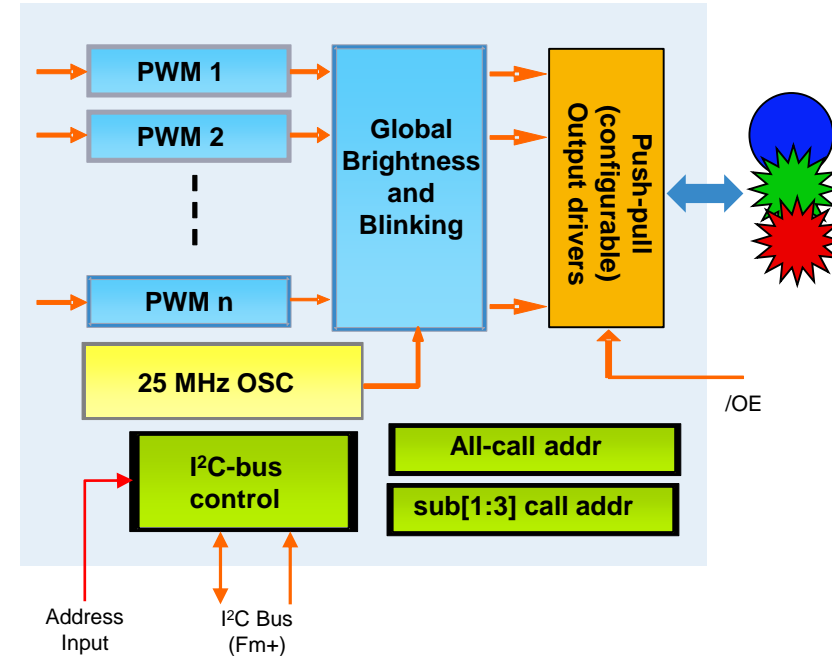
Device	# Channel	Package
PCA9530	2-channel	TSSOP8, SO8
PCA9533	4-channel	TSSOP8, SO8
PCA9531	8-channel	TSSOP16, SO16, HVQFN16
PCA9532	16-channel	TSSOP24, SO24, HVQFN24

# PCA963x – RGBA Color Mixing LED Dimmer and Blinker

Voltage Switch LED Controllers with Individual and Global PWMs, 25 mA/5 V

## Features

- Device supply voltage 2.3 V to 5.5 V
- Output
  - Configurable push-pull or open drain
  - 5 V / 25 mA
- Digital Interface
  - I2C-bus, Fm+ 1 MHz (bi-directional)
  - Hardware Address Input Pins
  - Four programmable all/sub-call addresses
  - Software Reset feature through the I2C-bus
- PWM Generator
  - 256-step individual PWM (97 kHz)
  - 256-step Global PWM 190 Hz dimming and 41 ms to 10.73 S blinking
- Active LOW Output Enable (OE) input
- Packages offered: SO, TSSOP, HVQFN, HVSON
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 200V MM
- PCA9635 is AEC-Q100 automotive compliant qualification
- Low standby current



Device	# Channel	Package
PCA9633	4-channel	TSSOP8/10/16, SO16, HVQFN16, HVSON8
PCA9634	8-channel	TSSOP20, SO20, HVQFN20
PCA9635 <sup>[1]</sup>	16-channel	TSSOP28

[1] PCA9635 is AEC-Q100 compliant

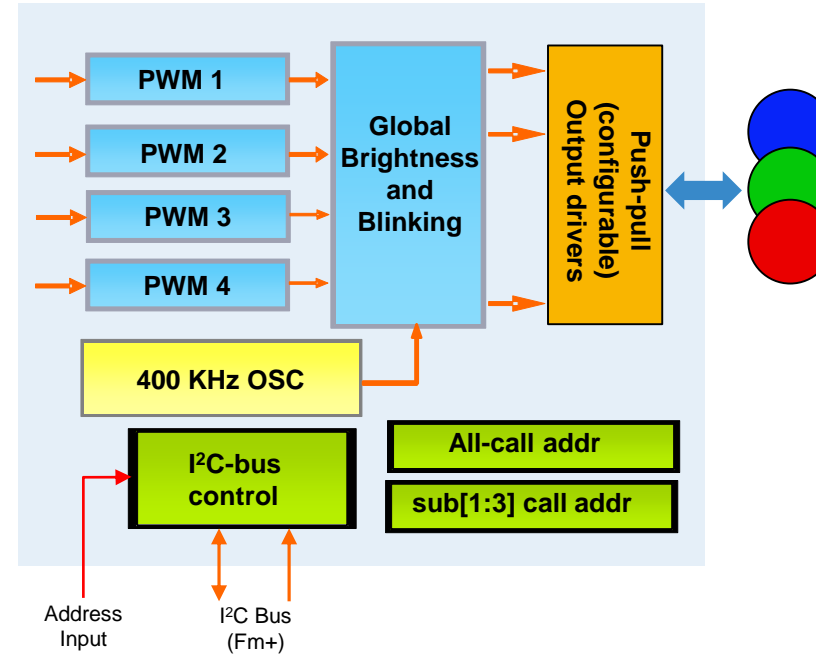


# PCA9632 – RGBA Color Mixing LED Dimmer and Blinker for Mobile

Voltage Switch LED Controllers with Individual & Global PWMs, 25 mA/5 V

## Features

- Device supply voltage 2.3 V to 5.5 V
- Output
  - Configurable push-pull or open drain
  - 5 V / 25 mA
- Digital Interface
  - I2C-bus, Fm+ 1 MHz (bi-directional)
  - Hardware Address Input Pins
  - Four programmable all/sub-call addresses
  - Software Reset feature through the I2C-bus
- PWM Generator
  - 256-step individual PWM (1.56 kHz)
  - 64-step Global PWM 190 Hz dimming and 41 ms to 10.73 S blinking
- Packages offered: TSSOP, HVSON
- -40°C to +85°C operating temperature range
- ESD exceeds 5 kV HBM, 200V MM
- Lowest standby current and 40x power reduction



Device	# Channel	Package
PCA9632	4-channel	TSSOP8/10, HVSON8/10

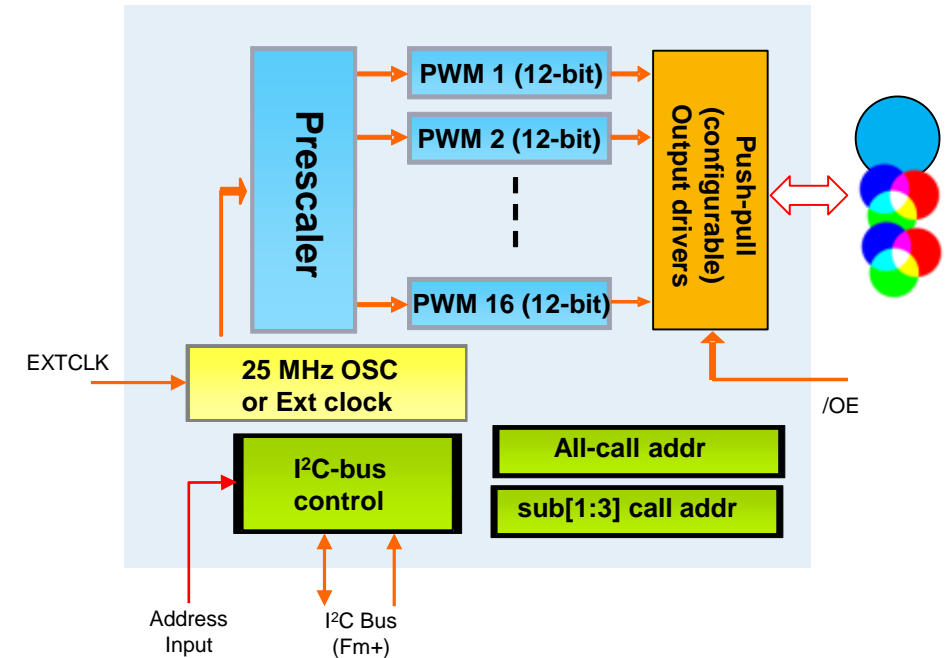


# PCA9685: RGBA Color Mixing LED Dimmer/Blinker, 12-bit PWM

Voltage switch LED Controllers with individual PWMs, 25 mA/5 V

## Features

- Device supply voltage 2.3 V to 5.5 V
- Output
  - Configurable push-pull or open drain
  - 5 V / 25 mA
- Digital Interface
  - I2C-bus, Fm+ 1 MHz (bi-directional)
  - Hardware Address Input Pins
  - Four programmable all/sub-call addresses
  - Software Reset feature through the I2C-bus
- 12-bit PWM Generator
  - 4096-step individual PWM (24 Hz ~ 1526 Hz)
- Active LOW Output Enable (OE) input
- External 50 MHz (max) clock input
- Packages offered: TSSOP, HVQFN
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 200V MM
- AEC-Q100 automotive compliant qualification
- Low standby current



Device	# Channel	Package
PCA9685 <sup>[1]</sup>	16-channel	TSSOP28, HVQFN28

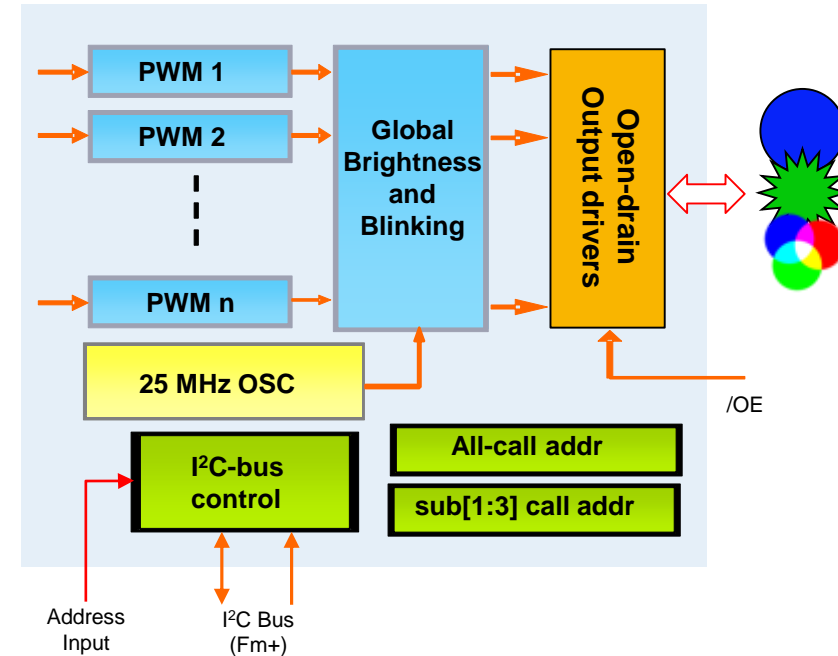
[1] PCA9685 is AEC-Q100 compliant

# PCA962x – RGBA Color Mixing LED Dimmer and Blinker

Voltage Switch LED Controllers With Individual & Global PWMs, 100 mA/40 V

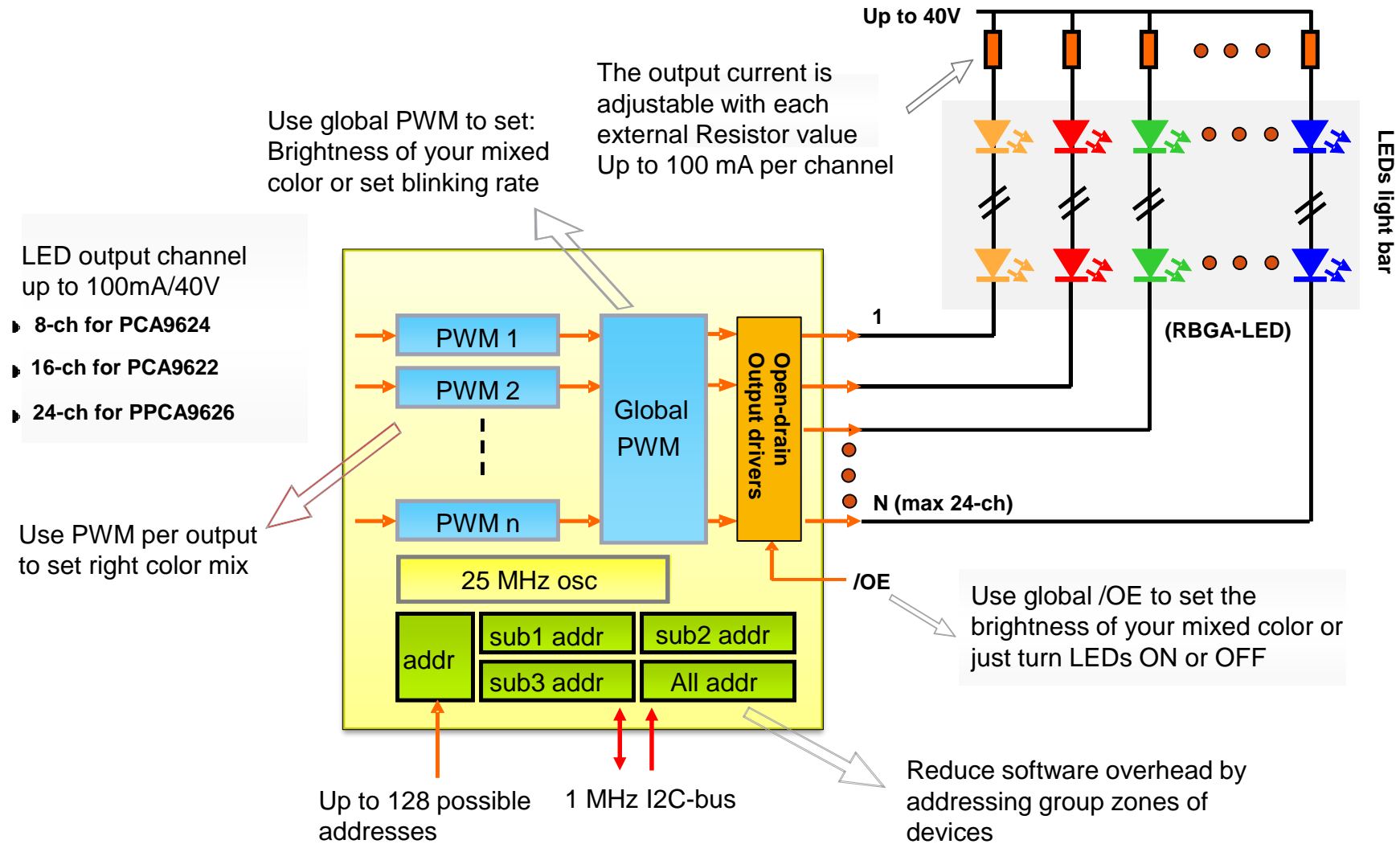
## Features

- Device supply voltage 2.3 V to 5.5 V
- Output
  - Open drain
  - 40 V / 100 mA
- Digital Interface
  - I2C-bus, Fm+ 1 MHz (bi-directional)
  - Hardware Address Input Pins
  - Four programmable all/sub-call addresses
  - Software Reset feature through the I2C-bus
- PWM Generator
  - 256-step individual PWM (97 kHz)
  - 256-step Global PWM 190 Hz dimming and 41 ms to 10.73 S blinking
- Active LOW Output Enable (OE) input
- Packages offered: TSSOP, HVQFN, LQFP
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 200V MM
- Low standby current



Device	# Channel	Package
PCA9624	8-channel	TSSOP24, SO16, HVQFN24
PCA9622	16-channel	TSSOP32
PCA9626	24-channel	LQFP48

# PCA9624/2/6 Voltage Switch LED Controller Block Diagram



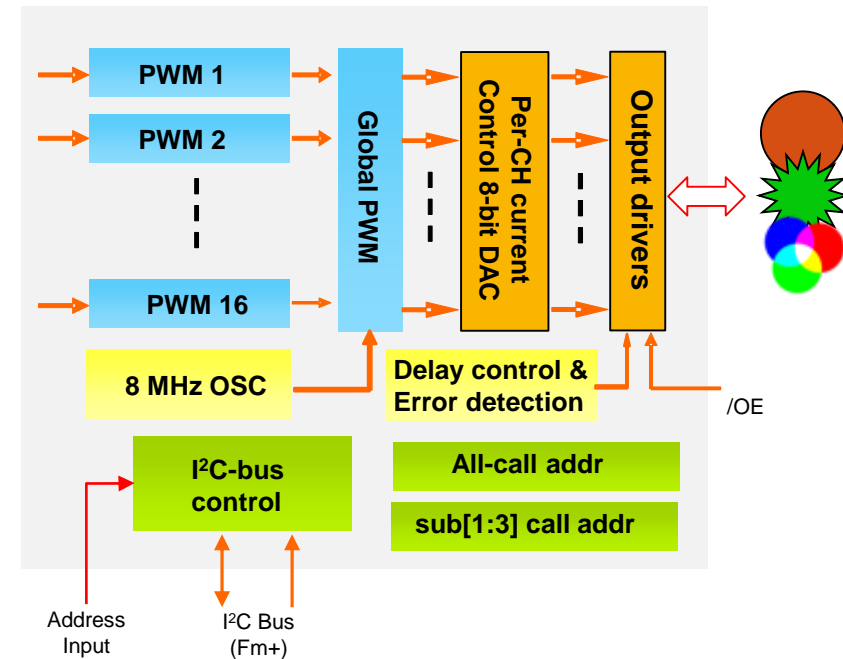


# PCA995x – Constant Current LED Dimming, Blinking and Color Mixing

Current source LED Controllers with individual & global PWMs and current setting, 57 mA/40 V

## Features

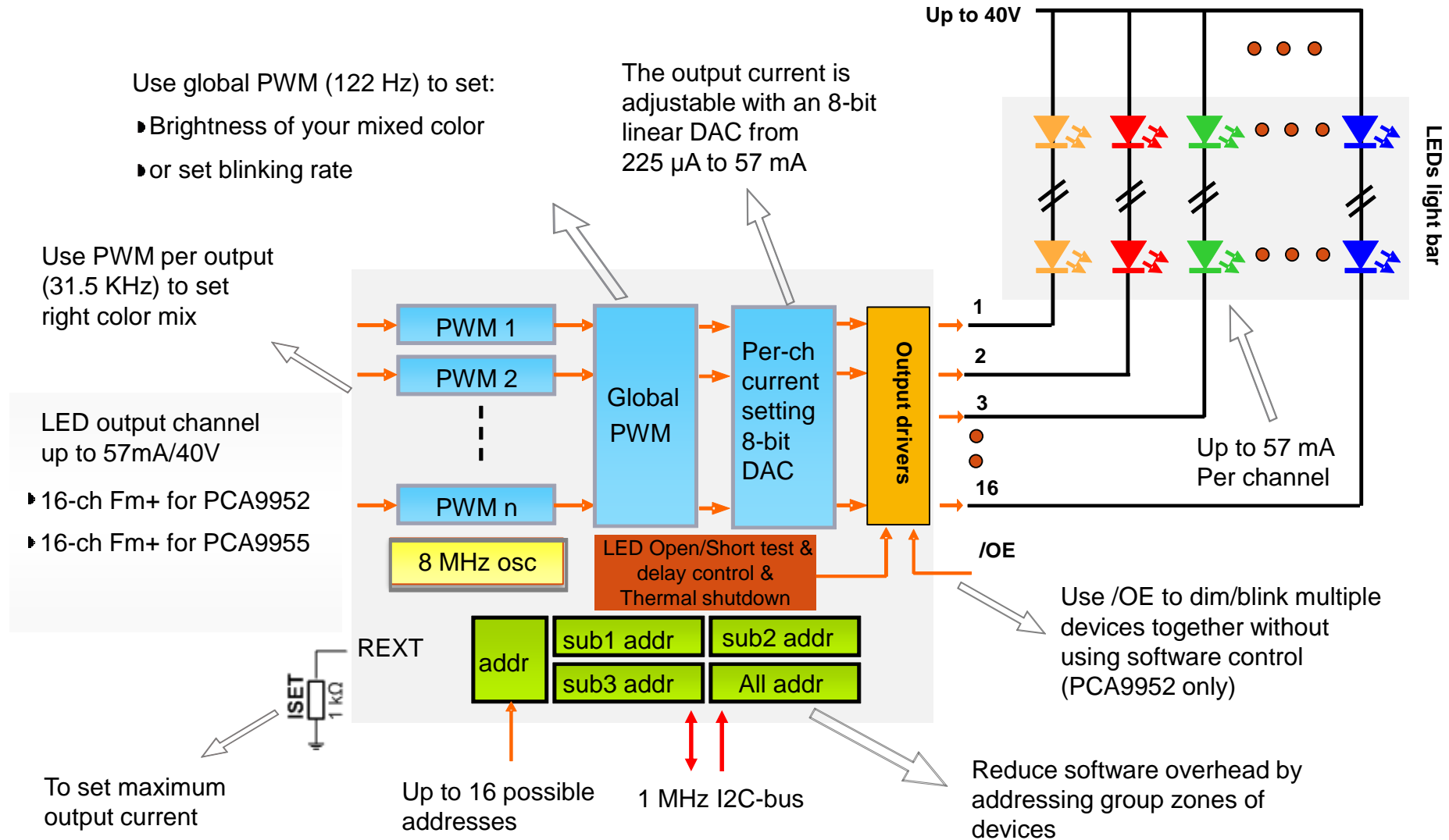
- Device supply voltage 3.0 V to 5.5 V
- Output
  - Open drain up to 57 mA/40 V
  - Error detection for LED open or short
  - Output delay offset
- Digital Interface
  - I2C-bus with software reset control, Fm+ 1 MHz (bi-directional)
  - Hardware Address Input Pins with four all/sub-call addresses
  - Output enable input pin (PCA9952 only)
- PWM Generator
  - 256-step individual PWM (31.25 kHz)
  - 256-step Global PWM 122 Hz dimming and 67 ms to 16.8 S blinking
- Per channel output current setting with 8-bit DAC
- Output current accuracy
  - $\pm 6\%$  between channels;  $\pm 8\%$  between devices
- Packages offered: HTSSOP
- Over temperature protection and thermal shutdown
- -40°C to +85°C operating temperature range
- ESD exceeds 2 kV HBM, 500V CDM
- Low standby current



Device	# Channel	Package
PCA9952 <sup>[1]</sup>	16-channel	HTSSOP28
PCA9955 <sup>[2]</sup>	16-channel	HTSSOP28

Both devices are AEC-Q100 compliant  
 [1] Pin 5 is used for Output Enable (/OE)  
 [2] Pin 5 is used for Address 3 (A3)

# PCA9952/5 Constant Current LED Controller Block Diagram



# PCA9955B: Constant Current LED Dimming, Blinking and Color Mixing

Current source LED Controllers with individual & global PWMs and current setting, 57 mA/20 V

## Features

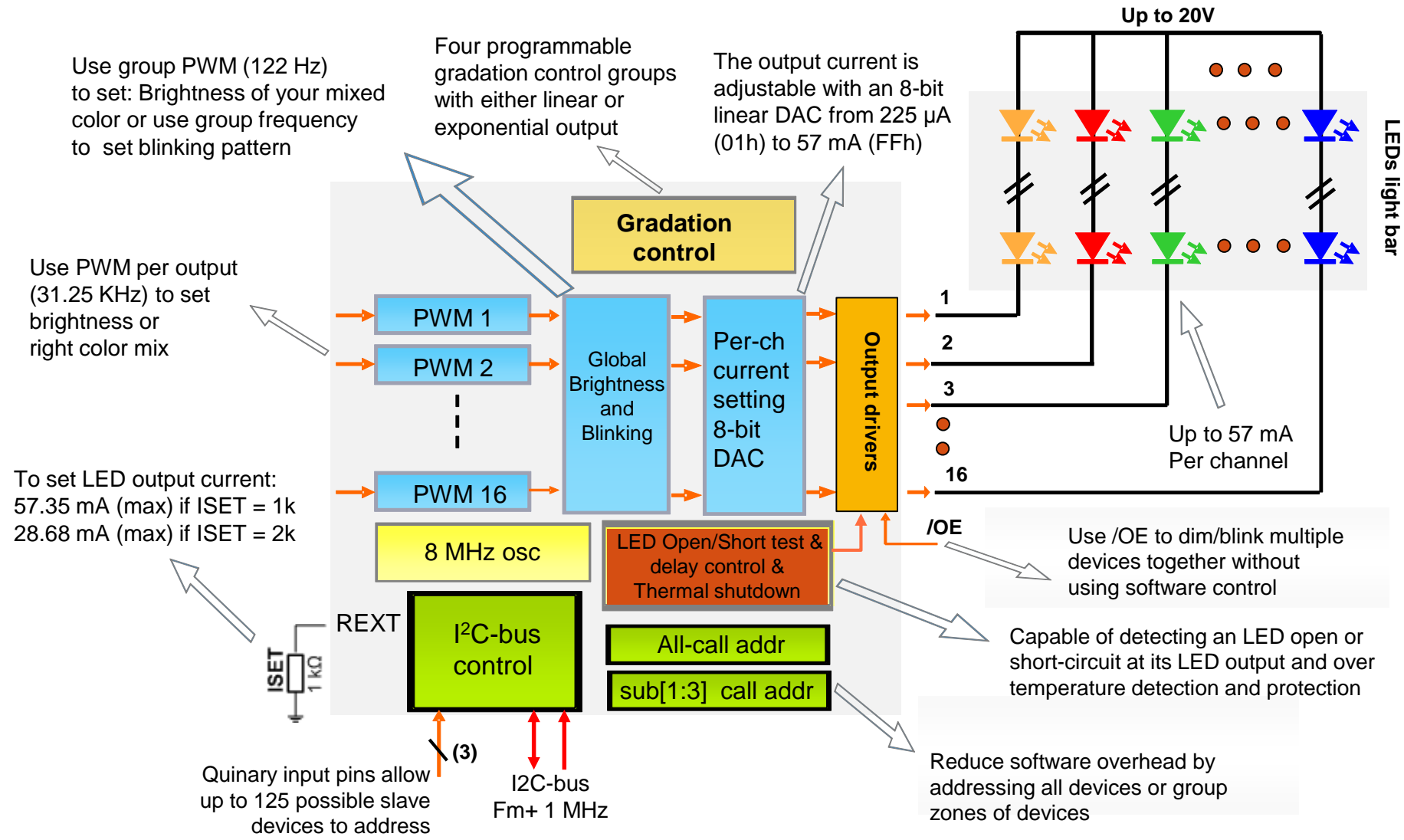
- Device supply voltage 3.0 V to 5.5 V
- Gradation control for all channels to program fade in or out, breathing functions in single shot or continuous mode
- Output
  - Open drain up to 57 mA/20 V
  - Error detection in real time for LED open or short
  - Programmable output delay to deduce EMI and surge current
- Digital Interface
  - I2C-bus with software reset control, Fm+ 1 MHz (bi-directional)
  - Three Quinary (five states) address input pins up to 125 devices within same bus with four all/sub-call addresses
  - Output enable input pin to allow external hardware PWM control for all LED output channels and multiple devices
- PWM Generator
  - 256-step individual PWM (31.25 kHz)
  - 256-step Global PWM 122 Hz dimming and 67 ms to 16.8 S blinking
- Per channel output current setting with 8-bit DAC
- Output current accuracy
  - $\pm 4\%$  between channels;  $\pm 6\%$  between devices
- Package offered: HTSSOP28 thermal package to enhanced thermal performance
- Over temperature protection and thermal shutdown
- $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  operating temperature range
- ESD exceeds 4 kV HBM, 1000V CDM
- Low power SLEEP mode

Device	# Channel	Package
PCA9955B <sup>[1]</sup>	16-channel	HTSSOP28

PCA9955B is AEC-Q100 compliant



# PCA9955B: Constant Current LED Controller Block Diagram



# PCA9956B – Constant Current LED Dimming, Blinking and Color Mixing

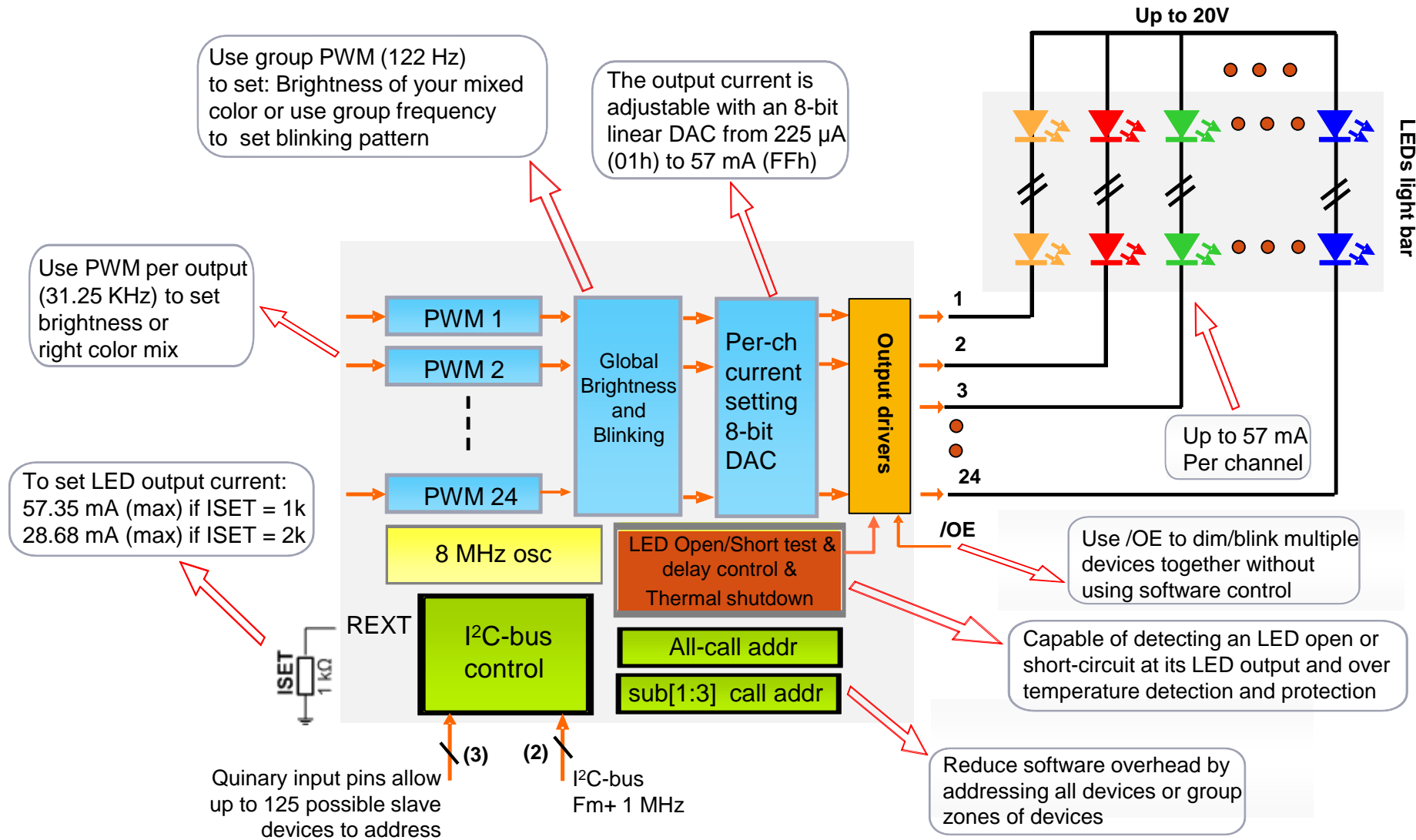
24-channel Fm+ I2C-bus 57 mA/20 V constant current LED controller

## Features

- Device supply voltage 3.0 V to 5.5 V
- Output
  - Open drain up to 57 mA/20 V
  - Error detection in real time for LED open or short
  - Programmable output delay to deduce EMI and surge current
- Digital Interface
  - I2C-bus with software reset control, Fm+ 1 MHz (bi-directional)
  - Three Quinary (five states) address input pins up to 125 devices within same bus with four all/sub-call addresses
  - Output enable input pin to allow external hardware PWM control for all LED output channels and multiple devices
- PWM Generator
  - 256-step individual PWM (31.25 kHz)
  - 256-step Global PWM 122 Hz dimming and 67 ms to 16.8 S blinking
- Per channel output current setting with 8-bit DAC
- Output current accuracy
  - $\pm 4\%$  between channels;  $\pm 6\%$  between devices
- Package offered: HTSSOP38 thermal package to enhanced thermal performance
- Over temperature protection and thermal shutdown
- $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  operating temperature range
- ESD exceeds 3 kV HBM, 1000V CDM
- Low power SLEEP mode

Device	# Channel	Package
PCA9956B	24-channel	HTSSOP38

# PCA9956B Constant Current LED Controller Block Diagram



# PCA9745B: Constant Current LED Dimming, Blinking, Color Mixing

16-channel SPI Serial Bus 57 mA/20 V Constant Current LED Controller

## Features

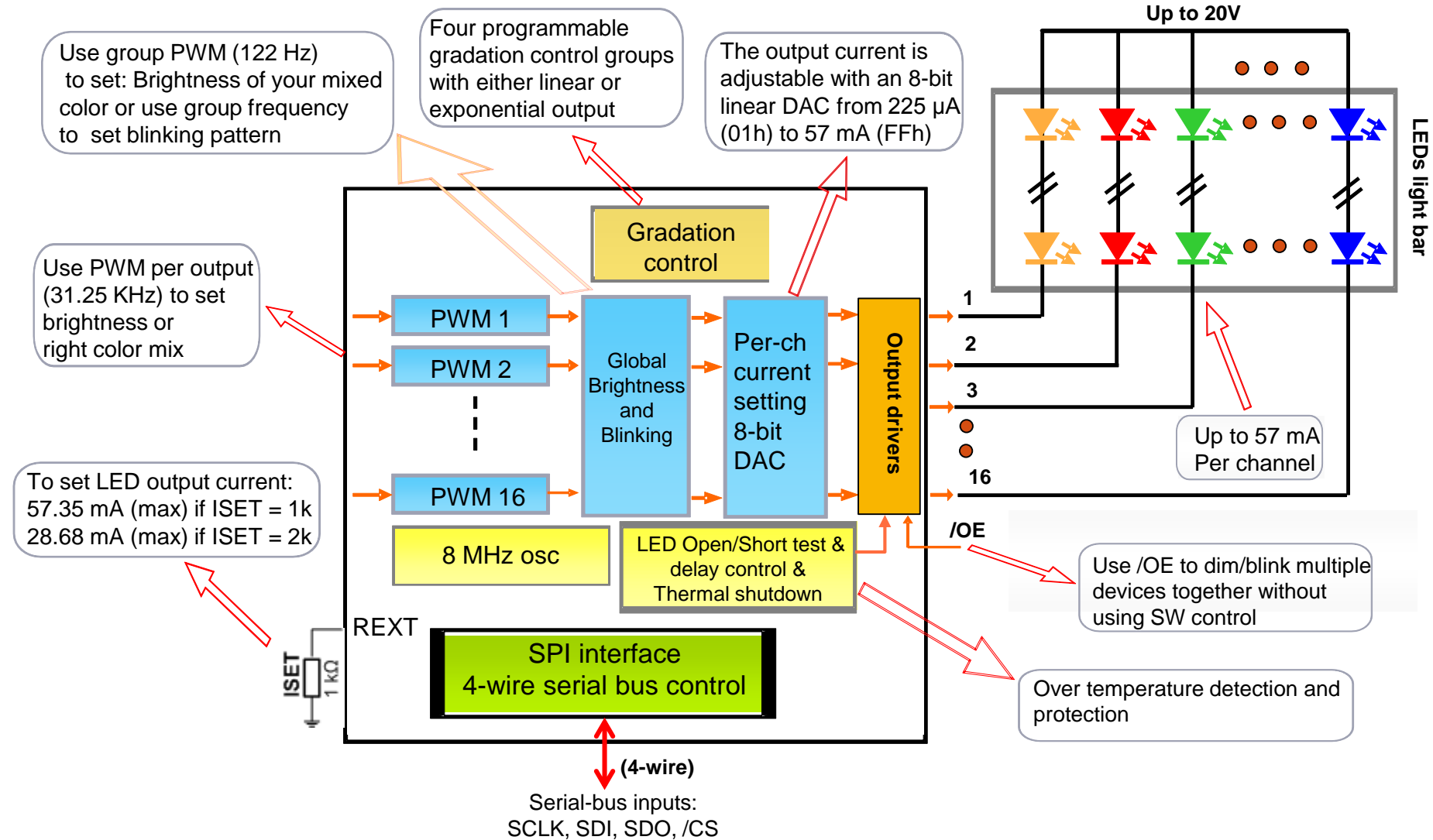
- Device supply voltage 3.0 V to 5.5 V
- Gradation control for all channels to program fade in or out, breathing functions in single shot or continuous mode
- Output
  - Open drain up to 57 mA/20 V
  - Error detection in real time for LED open or short
  - Programmable output delay to deduce EMI and surge current
- Digital Interface
  - 4-wire SPI-compatible serial-bus interface up to 25 MHz data clock rate
  - Output enable input pin to allow external hardware PWM control for all LED output channels and multiple devices
- PWM Generator
  - 256-step individual PWM (31.25 kHz)
  - 256-step Global PWM 122 Hz dimming and 67 ms to 16.8 S blinking
- Per channel output current setting with 8-bit DAC
- Output current accuracy
  - $\pm 4\%$  between channels;  $\pm 6\%$  between devices
- Package offered: HTSSOP28 thermal package to enhanced thermal performance
- Over temperature protection and thermal shutdown
- $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  operating temperature range
- ESD exceeds 4 kV HBM, 1000V CDM
- Low power SLEEP mode

Device	# Channel	Package
PCA9745B <sup>[1]</sup>	16-channel	HTSSOP28

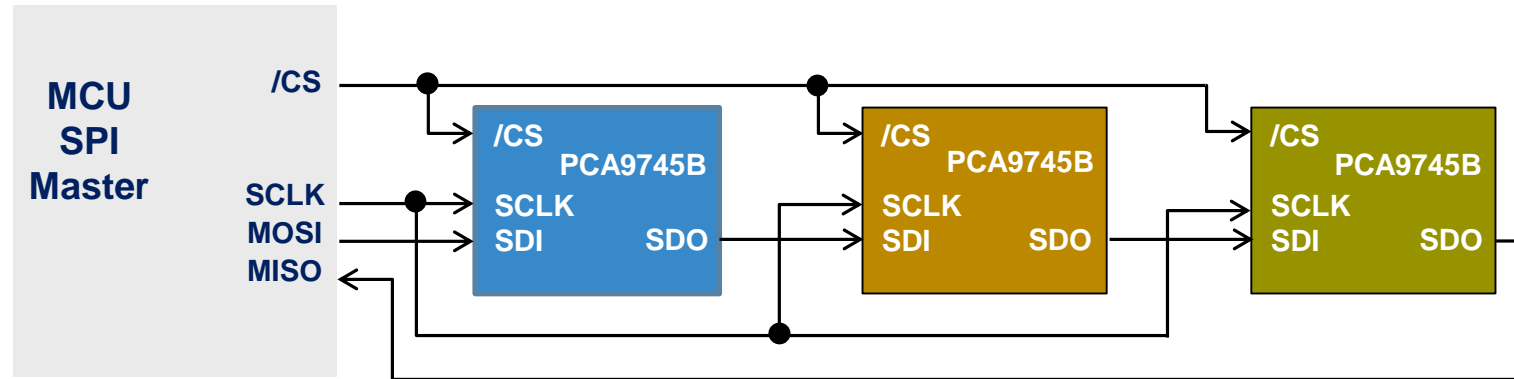
**PCA9745B is AEC-Q100 compliant**



# PCA9745B SPI Daisy-chain LED Controller Block Diagram



# PCA9745B SPI Daisy-chain Connection With Three Devices



SPI Data Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MSB	Register Address					LSB	R / W	MSB	Data						LSB

- SPI Master send 16-bit (clocks with register address and data) x 3 (number of slaves) to access all slave devices at the same time
- Only one byte data can be read/write from/to all slave devices
- No slave address required

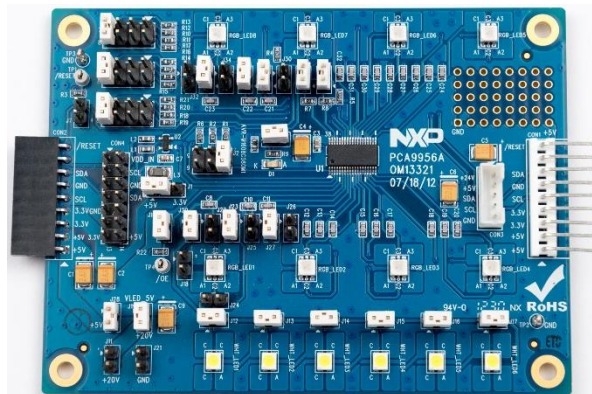
# LED Demo Boards Description

- PCA9532 16-channel Fm I2C-bus dimmer LED driver demo board (OM13528)
- PCA9633 4-channel Fm+ I2C-bus LED driver demo board (OM6282 w/o Micro)
- PCA9634 8-channel Fm+ I2C-bus LED driver demo board (OM13327)
- PCA9635 16-channel Fm+ I2C-bus LED driver demo board (OM13333)
- PCA9685 16-channel, 12-bit PWM Fm+ I2C-bus LED driver demo board (OM13332)
- PCA9952 16-channel Fm+ I2C-bus 57 mA constant current LED driver demo board (OM13329)
- PCA9955 16-channel Fm+ I2C-bus 57 mA constant current LED driver demo board (OM13330)
- PCA9956B 24-channel Fm+ I2C-bus 57 mA constant current LED driver demo board (OM13321)
- PCA9955B 16-channel Fm+ I2C-bus 57 mA constant current LED driver demo board (OM13483)

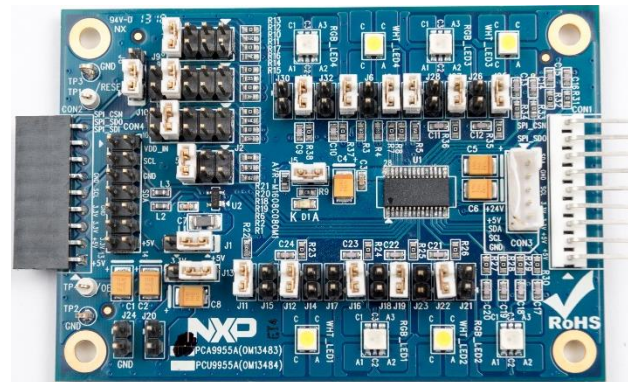


**PCA9532 Demo Board (OM13528)**

**Note: All demo boards are available on eDemoboard store**



**PCA9956B Demo Board (OM13321)**



**PCA9955B Demo Board (OM13483)**



**PCA9635 Demo Board (OM13333)**



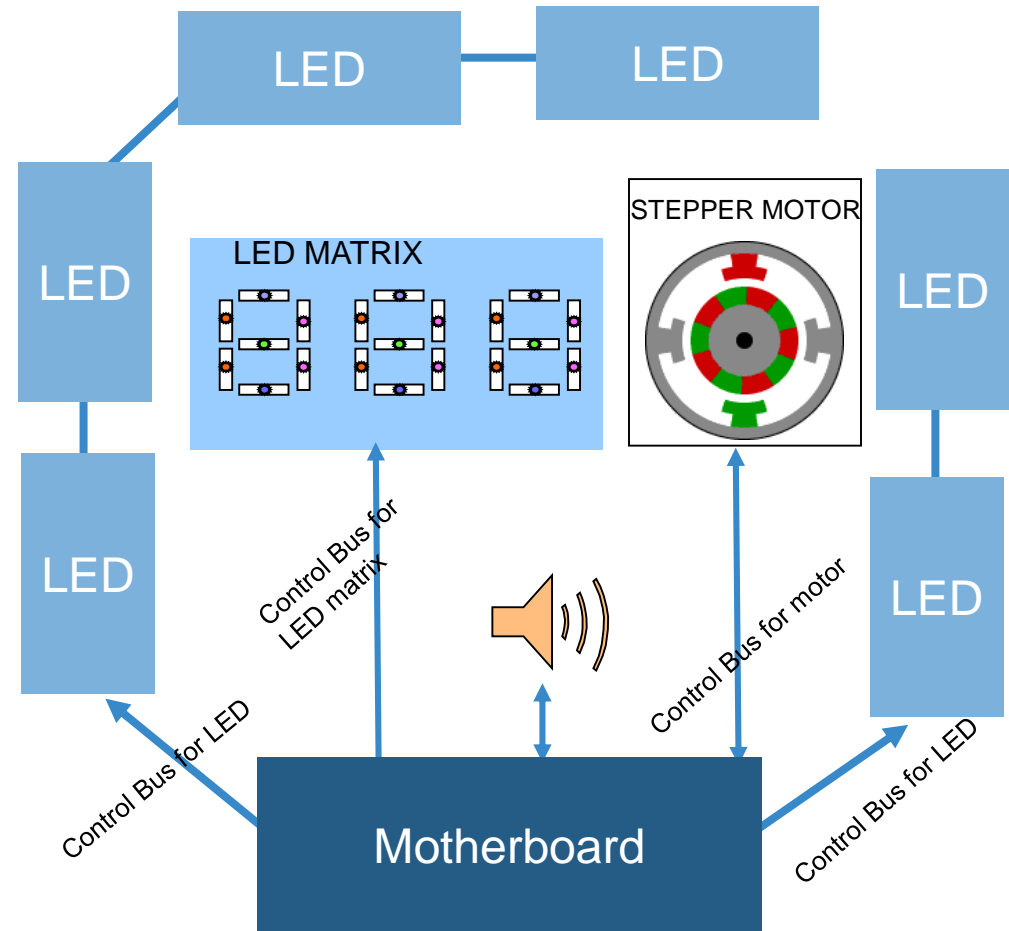
# LED APPLICATIONS



# LED Applications for Pachinko Machine

## New Amusement System

- 2-wire I2C-bus, easy to route and add additional/new devices
- I2C-bus is the ideal control bus for this application (multi-channel and multi-drop devices)
- Off load microcontroller, no burden to host processor with minimal I2C-bus traffic
- Part type: PCA9622, PCA9626





# LED Applications for Backlighting

**Application:** Backlight for Car Audio

**Part Type:** PCA9624PW


**Description:** 8-ch LED controller  
(40V/100mA)



**Application:** Backlight for Head-  
phones

**Part Type:** PCA9633CP2

**Description:** 4-ch LED controller  
(5V/25mA)



**Razer Banshee**  
StarCraft® II Gaming Headset

- ▶ Extended Comfort Circumaural Design
- ▶ True-to-Life Gaming Audio
- ▶ Detachable Microphone Boom
- ▶ APM Lighting System
- ▶ Volume & Mic Control
- ▶ Seven-foot, Lightweight, Non-tangle Cord

**\$119.99**

Not available at the Razer Store.  
[Click here to register your interest.](#)

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# LED Applications for Automotive

## Application:

- Instrument Cluster, Tell-Tale Light,
- Infotainment Backlighting, Interior Lighting

## Part Type:

- PCA9955/PCA9955B/PCA9745B-Q900

## Description:

- 16-ch LED controller (20V/57mA)
- AEC-Q100 compliant





# CONCLUSION AND Q&A

# Success Stories

- Mouse and keyboard backlight
- Car radio backlight
- Pachinko gaming
- Instrumentation cluster
- White goods
- Computing/servers
- Mobile devices



Delonghi EDG455T  
With LED display



# Call to Action

For more Information about LED driver and the entire NXP I2C portfolio, go to [www.nxp.com/i2c](http://www.nxp.com/i2c)



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