



# PCA9955A

## 16-channel Fm+ I<sup>2</sup>C-bus 57 mA/20 V constant current LED driver

Rev. 3 — 14 October 2014

Product data sheet

### 1. General description

The PCA9955A is an I<sup>2</sup>C-bus controlled 16-channel constant current LED driver optimized for dimming and blinking 57 mA Red/Green/Blue/Amber (RGBA) LEDs in amusement products. Each LED output has its own 8-bit resolution (256 steps) fixed frequency individual PWM controller that operates at 31.25 kHz with a duty cycle that is adjustable from 0 % to 100 % to allow the LED to be set to a specific brightness value. An additional 8-bit resolution (256 steps) group PWM controller has both a fixed frequency of 122 Hz and an adjustable frequency between 15 Hz to once every 16.8 seconds with a duty cycle that is adjustable from 0 % to 99.6 % that is used to either dim or blink all LEDs with the same value.

Each LED output can be off, on (no PWM control), set at its individual PWM controller value or at both individual and group PWM controller values. The PCA9955A operates with a supply voltage range of 3 V to 5.5 V and the constant current sink LED outputs allow up to 20 V for the LED supply. The output peak current is adjustable with an 8-bit linear DAC from 225  $\mu$ A to 57 mA.

Gradation control for all current sources is achieved via the I<sup>2</sup>C-bus serial interface and allows user to ramp current automatically without MCU intervention. 8-bit DACs are available to adjust brightness levels for each LED current source. There are four selectable gradation control groups and each group has independently four registers to control ramp-up and ramp-down rate, step time, hold ON/OFF time and final hold ON output current. Two gradation operation modes are available for each group, one is single shot mode (output pattern once) and the other is continuous mode (output pattern repeat). Each channel can be set to either gradation mode or normal mode and assigned to any one of these four gradation control groups.

This device has built-in open, short load and overtemperature detection circuitry. The error information from the corresponding register can be read via the I<sup>2</sup>C-bus. Additionally, a thermal shutdown feature protects the device when internal junction temperature exceeds the limit allowed for the process.

The PCA9955A device has a Fast-mode Plus (Fm+) I<sup>2</sup>C-bus interface. Fm+ devices offer higher frequency (up to 1 MHz) or more densely populated bus operation (up to 4000 pF).

The active LOW output enable input pin ( $\overline{\text{OE}}$ ) blinks all the LED outputs and can be used to externally PWM the outputs, which is useful when multiple devices need to be dimmed or blinked together without using software control.

Software programmable LED Group and three Sub Call I<sup>2</sup>C-bus addresses allow all or defined groups of PCA9955A devices to respond to a common I<sup>2</sup>C-bus address, allowing for example, all red LEDs to be turned on or off at the same time or marquee chasing effect, thus minimizing I<sup>2</sup>C-bus commands. On power-up, PCA9955A has a unique



Sub Call address to identify it as a 16-channel LED driver. This unique address allows mixing of devices with different channel widths. Three hardware address pins on PCA9955A allow up to 125 devices on the same bus.

The Software Reset (SWRST) function allows the master to perform a reset of the PCA9955A through the I<sup>2</sup>C-bus, identical to the Power-On Reset (POR) that initializes the registers to their default state causing the output current switches to be OFF (LED off). This allows an easy and quick way to reconfigure all device registers to the same condition.

## 2. Features and benefits

- 16 LED drivers. Each output programmable at:
  - ◆ Off
  - ◆ On
  - ◆ Programmable LED brightness
  - ◆ Programmable group dimming/blinking mixed with individual LED brightness
  - ◆ Programmable LED output delay to reduce EMI and surge currents
- Gradation control for all channels
  - ◆ Each channel can assign to one of four gradation control groups
  - ◆ Programmable gradation time and rate for ramp-up and/or ramp-down operations
  - ◆ Programmable step time (6-bit) from 0.5 ms (minimum) to 512 ms (maximum)
  - ◆ Programmable hold-on time after ramp-up and hold-off time after ramp-down (3-bit) from 0 s to 6 s
  - ◆ Programmable final ramp-up and hold-on current
  - ◆ Programmable brightness current output adjustment, either linear or exponential curve
- 16 constant current output channels can sink up to 57 mA, tolerate up to 20 V when OFF
- Output current adjusted through an external resistor (REXT input)
- Output current accuracy
  - ◆ ±4 % between output channels
  - ◆ ±6 % between PCA9955A devices
- Open/short load/overtemperature detection mode to detect individual LED errors
- 1 MHz Fast-mode Plus compatible I<sup>2</sup>C-bus interface with 30 mA high drive capability on SDA output for driving high capacitive buses
- 256-step (8-bit) linear programmable brightness per LED output varying from fully off (default) to maximum brightness fully ON using a 31.25 kHz PWM signal
- 256-step group brightness control allows general dimming (using a 122 Hz PWM signal) from fully off to maximum brightness (default)
- 256-step group blinking with frequency programmable from 15 Hz to 16.8 s and duty cycle from 0 % to 99.6 %
- Output state change programmable on the Acknowledge or the STOP condition to update outputs byte-by-byte or all at the same time (default to 'Change on STOP').
- Active LOW Output Enable ( $\overline{\text{OE}}$ ) input pin allows for hardware blinking and dimming of the LEDs

- Three quinary hardware address pins allow 125 PCA9955A devices to be connected to the same I<sup>2</sup>C-bus and to be individually programmed
- 4 software programmable I<sup>2</sup>C-bus addresses (one LED Group Call address and three LED Sub Call addresses) allow groups of devices to be addressed at the same time in any combination (for example, one register used for 'All Call' so that all the PCA9955As on the I<sup>2</sup>C-bus can be addressed at the same time and the second register used for three different addresses so that  $\frac{1}{3}$  of all devices on the bus can be addressed at the same time in a group). Software enable and disable for each programmable I<sup>2</sup>C-bus address.
- Unique power-up default Sub Call address allows mixing of devices with different channel widths
- Software Reset feature (SWRST Call) allows the device to be reset through the I<sup>2</sup>C-bus
- 8 MHz internal oscillator requires no external components
- Internal power-on reset
- Noise filter on SDA/SCL inputs
- No glitch on LEDn outputs on power-up
- Low standby current
- Operating power supply voltage ( $V_{DD}$ ) range of 3 V to 5.5 V
- 5.5 V tolerant inputs on non-LED pins
- -40 °C to +85 °C operation
- ESD protection exceeds 4000 V HBM per JESD22-A114
- Latch-up testing is done to JEDEC Standard JESD78 which exceeds 100 mA
- Packages offered: HTSSOP28

### 3. Applications

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- Amusement products
- RGB or RGBA LED drivers
- LED status information
- LED displays
- LCD backlights
- Keypad backlights for cellular phones or handheld devices
- Fade-in and fade-out for breathlight control
- Automotive lighting (PCA9955ATW/Q900)

## 4. Ordering information

Table 1. Ordering information

| Type number                    | Topside mark | Package  |  |           |
|--------------------------------|--------------|----------|--|-----------|
|                                |              | Name     | Description  | Version   |
| PCA9955ATW                     | PCA9955ATW   | HTSSOP28 | plastic thermal enhanced thin shrink small outline package; 28 leads; body width 4.4 mm; lead pitch 0.65 mm; exposed die pad | SOT1172-3 |
| PCA9955ATW/Q900 <sup>[1]</sup> | PCA9955ATW   | HTSSOP28 | plastic thermal enhanced thin shrink small outline package; 28 leads; body width 4.4 mm; lead pitch 0.65 mm; exposed die pad | SOT1172-3 |

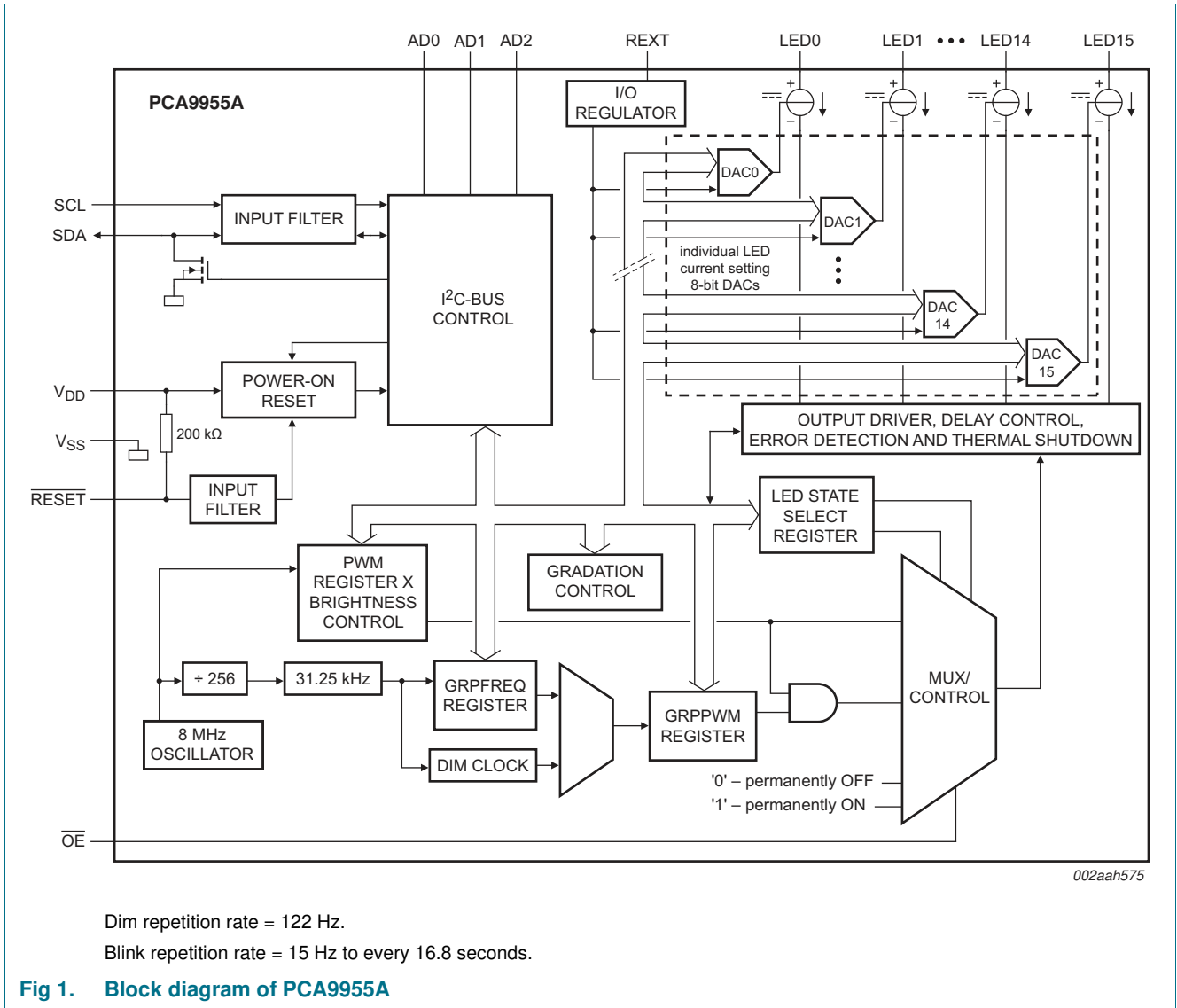
[1] PCA9955ATW/Q900 is AEC-Q100 compliant.

### 4.1 Ordering options

Table 2. Ordering options

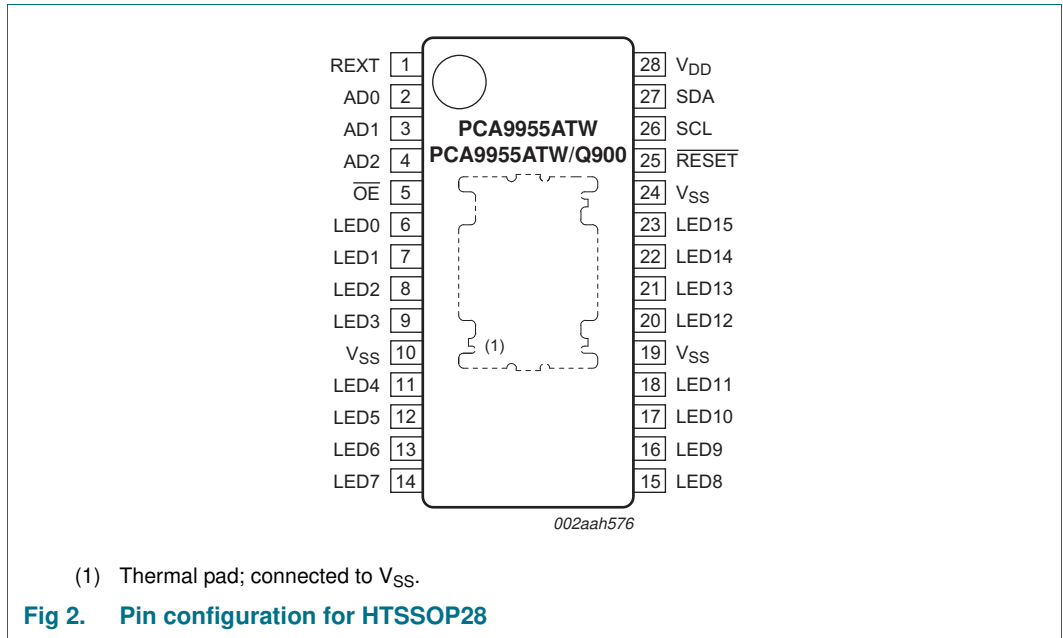
| Type number     | Orderable part number | Package  | Packing method                       | Minimum order quantity | Temperature                         |
|-----------------|-----------------------|----------|--------------------------------------|------------------------|-------------------------------------|
| PCA9955ATW      | PCA9955ATWJ           | HTSSOP28 | Reel 13" Q1/T1<br>*Standard mark SMD | 2500                   | T <sub>amb</sub> = -40 °C to +85 °C |
| PCA9955ATW/Q900 | PCA9955ATW/Q900J      | HTSSOP28 | Reel 13" Q1/T1<br>*Standard mark SMD | 2500                   | T <sub>amb</sub> = -40 °C to +85 °C |

5. Block diagram



## 6. Pinning information

### 6.1 Pinning



## 6.2 Pin description

Table 3. Pin description

| Symbol                    | Pin                            | Type         | Description                                    |
|---------------------------|--------------------------------|--------------|--|
| REXT                      | 1                              | I            | current set resistor input; resistor to ground |
| AD0                       | 2                              | I            | address input 0                                |
| AD1                       | 3                              | I            | address input 1                                |
| AD2                       | 4                              | I            | address input 2                                |
| $\overline{\text{OE}}$    | 5                              | I            | active LOW output enable for LEDs              |
| LED0                      | 6                              | O            | LED driver 0                                   |
| LED1                      | 7                              | O            | LED driver 1                                   |
| LED2                      | 8                              | O            | LED driver 2                                   |
| LED3                      | 9                              | O            | LED driver 3                                   |
| LED4                      | 11                             | O            | LED driver 4                                   |
| LED5                      | 12                             | O            | LED driver 5                                   |
| LED6                      | 13                             | O            | LED driver 6                                   |
| LED7                      | 14                             | O            | LED driver 7                                   |
| LED8                      | 15                             | O            | LED driver 8                                   |
| LED9                      | 16                             | O            | LED driver 9                                   |
| LED10                     | 17                             | O            | LED driver 10                                  |
| LED11                     | 18                             | O            | LED driver 11                                  |
| LED12                     | 20                             | O            | LED driver 12                                  |
| LED13                     | 21                             | O            | LED driver 13                                  |
| LED14                     | 22                             | O            | LED driver 14                                  |
| LED15                     | 23                             | O            | LED driver 15                                  |
| $\overline{\text{RESET}}$ | 25                             | I            | active LOW reset input                         |
| SCL                       | 26                             | I            | serial clock line                              |
| SDA                       | 27                             | I/O          | serial data line                               |
| V <sub>SS</sub>           | 10, 19, 24 <a href="#">[1]</a> | ground       | supply ground                                  |
| V <sub>DD</sub>           | 28                             | power supply | supply voltage                                 |

- [1] HTSSOP28 package supply ground is connected to both V<sub>SS</sub> pins and exposed center pad. V<sub>SS</sub> pins must be connected to supply ground for proper device operation. For enhanced thermal, electrical, and board level performance, the exposed pad must be soldered to the board using a corresponding thermal pad on the board and for proper heat conduction through the board, thermal vias must be incorporated in the printed-circuit board in the thermal pad region.

## 7. Functional description

Refer to [Figure 1 “Block diagram of PCA9955A”](#).

### 7.1 Device addresses

Following a START condition, the bus master must output the address of the slave it is accessing.

For PCA9955A there are a maximum of 125 possible programmable addresses using the three quinary hardware address pins.

#### 7.1.1 Regular I<sup>2</sup>C-bus slave address

The I<sup>2</sup>C-bus slave address of the PCA9955A is shown in [Figure 3](#). The 7-bit slave address is determined by the quinary input pads AD0, AD1 and AD2. Each pad can have one of five states (GND, pull-up, floating, pull-down, and V<sub>DD</sub>) based on how the input pad is connected on the board. At power-up or hardware/software reset, the quinary input pads are sampled and set the slave address of the device internally. To conserve power, once the slave address is determined, the quinary input pads are turned off and will not be sampled until the next time the device is power cycled. [Table 4](#) lists the five possible connections for the quinary input pads along with the external resistor values that must be used.

**Table 4. Quinary input pad connection**

| Pad connection (pins AD2, AD1, AD0) <sup>[1]</sup> | Mnemonic        | External resistor (kΩ) |      |
|--|-----------------|------------------------|------|
|  |                 | Min.                   | Max. |
| tie to ground                                      | GND             | 0                      | 17.9 |
| resistor pull-down to ground                       | PD              | 34.8                   | 270  |
| open (floating)                                    | FLT             | 503                    | ∞    |
| resistor pull-up to V <sub>DD</sub>                | PU              | 31.7                   | 340  |
| tie to V <sub>DD</sub>                             | V <sub>DD</sub> | 0                      | 22.1 |

[1] These AD[2:0] inputs must be stable before the supply V<sub>DD</sub> to the chip.

[Table 5](#) lists all 125 possible slave addresses of the device based on all combinations of the five states connected to three address input pins AD0, AD1 and AD2.

**Table 5. I<sup>2</sup>C-bus slave address**

| Hardware selectable input pins |     |                 | I <sup>2</sup> C-bus slave address for PCA9955A |             |                        |                   |
|--------------------------------|-----|-----------------|---|-------------|------------------------|-------------------|
| AD2                            | AD1 | AD0             | Decimal   | Hexadecimal | Binary (A[6:0])        | Address (R/W = 0) |
| GND                            | GND | GND             | 1   | 01          | 0000001 <sup>[1]</sup> | 02h               |
| GND                            | GND | PD              | 2   | 02          | 0000010 <sup>[1]</sup> | 04h               |
| GND                            | GND | FLT             | 3   | 03          | 0000011 <sup>[1]</sup> | 06h               |
| GND                            | GND | PU              | 4   | 04          | 0000100 <sup>[1]</sup> | 08h               |
| GND                            | GND | V <sub>DD</sub> | 5   | 05          | 0000101 <sup>[1]</sup> | 0Ah               |
| GND                            | PD  | GND             | 6   | 06          | 0000110 <sup>[1]</sup> | 0Ch               |
| GND                            | PD  | PD              | 7   | 07          | 0000111 <sup>[1]</sup> | 0Eh               |



Table 5. I<sup>2</sup>C-bus slave address ...continued

| Hardware selectable input pins |                 |                 | I <sup>2</sup> C-bus slave address for PCA9955A |             |                 |                   |
|--------------------------------|-----------------|-----------------|---|-------------|-----------------|-------------------|
| AD2                            | AD1             | AD0             | Decimal   | Hexadecimal | Binary (A[6:0]) | Address (R/W = 0) |
| GND                            | PD              | FLT             | 8   | 08          | 0001000         | 10h               |
| GND                            | PD              | PU              | 9   | 09          | 0001001         | 12h               |
| GND                            | PD              | V <sub>DD</sub> | 10  | 0A          | 0001010         | 14h               |
| GND                            | FLT             | GND             | 11  | 0B          | 0001011         | 16h               |
| GND                            | FLT             | PD              | 12  | 0C          | 0001100         | 18h               |
| GND                            | FLT             | FLT             | 13  | 0D          | 0001101         | 1Ah               |
| GND                            | FLT             | PU              | 14  | 0E          | 0001110         | 1Ch               |
| GND                            | FLT             | V <sub>DD</sub> | 15  | 0F          | 0001111         | 1Eh               |
| GND                            | PU              | GND             | 16  | 10          | 0010000         | 20h               |
| GND                            | PU              | PD              | 17  | 11          | 0010001         | 22h               |
| GND                            | PU              | FLT             | 18  | 12          | 0010010         | 24h               |
| GND                            | PU              | PU              | 19  | 13          | 0010011         | 26h               |
| GND                            | PU              | V <sub>DD</sub> | 20  | 14          | 0010100         | 28h               |
| GND                            | V <sub>DD</sub> | GND             | 21  | 15          | 0010101         | 2Ah               |
| GND                            | V <sub>DD</sub> | PD              | 22  | 16          | 0010110         | 2Ch               |
| GND                            | V <sub>DD</sub> | FLT             | 23  | 17          | 0010111         | 2Eh               |
| GND                            | V <sub>DD</sub> | PU              | 24  | 18          | 0011000         | 30h               |
| GND                            | V <sub>DD</sub> | V <sub>DD</sub> | 25  | 19          | 0011001         | 32h               |
| PD                             | GND             | GND             | 26  | 1A          | 0011010         | 34h               |
| PD                             | GND             | PD              | 27  | 1B          | 0011011         | 36h               |
| PD                             | GND             | FLT             | 28  | 1C          | 0011100         | 38h               |
| PD                             | GND             | PU              | 29  | 1D          | 0011101         | 3Ah               |
| PD                             | GND             | V <sub>DD</sub> | 30  | 1E          | 0011110         | 3Ch               |
| PD                             | PD              | GND             | 31  | 1F          | 0011111         | 3Eh               |
| PD                             | PD              | PD              | 32  | 20          | 0100000         | 40h               |
| PD                             | PD              | FLT             | 33  | 21          | 0100001         | 42h               |
| PD                             | PD              | PU              | 34  | 22          | 0100010         | 44h               |
| PD                             | PD              | V <sub>DD</sub> | 35  | 23          | 0100011         | 46h               |
| PD                             | FLT             | GND             | 36  | 24          | 0100100         | 48h               |
| PD                             | FLT             | PD              | 37  | 25          | 0100101         | 4Ah               |
| PD                             | FLT             | FLT             | 38  | 26          | 0100110         | 4Ch               |
| PD                             | FLT             | PU              | 39  | 27          | 0100111         | 4Eh               |
| PD                             | FLT             | V <sub>DD</sub> | 40  | 28          | 0101000         | 50h               |
| PD                             | PU              | GND             | 41  | 29          | 0101001         | 52h               |
| PD                             | PU              | PD              | 42  | 2A          | 0101010         | 54h               |
| PD                             | PU              | FLT             | 43  | 2B          | 0101011         | 56h               |
| PD                             | PU              | PU              | 44  | 2C          | 0101100         | 58h               |
| PD                             | PU              | V <sub>DD</sub> | 45  | 2D          | 0101101         | 5Ah               |
| PD                             | V <sub>DD</sub> | GND             | 46  | 2E          | 0101110         | 5Ch               |
| PD                             | V <sub>DD</sub> | PD              | 47  | 2F          | 0101111         | 5Eh               |

Table 5. I<sup>2</sup>C-bus slave address ...continued

| Hardware selectable input pins |                 |                 | I <sup>2</sup> C-bus slave address for PCA9955A |             |                 |                   |
|--------------------------------|-----------------|-----------------|---|-------------|-----------------|-------------------|
| AD2                            | AD1             | AD0             | Decimal   | Hexadecimal | Binary (A[6:0]) | Address (R/W = 0) |
| PD                             | V <sub>DD</sub> | FLT             | 48  | 30          | 0110000         | 60h               |
| PD                             | V <sub>DD</sub> | PU              | 49  | 31          | 0110001         | 62h               |
| PD                             | V <sub>DD</sub> | V <sub>DD</sub> | 50  | 32          | 0110010         | 64h               |
| FLT                            | GND             | GND             | 51  | 33          | 0110011         | 66h               |
| FLT                            | GND             | PD              | 52  | 34          | 0110100         | 68h               |
| FLT                            | GND             | FLT             | 53  | 35          | 0110101         | 6Ah               |
| FLT                            | GND             | PU              | 54  | 36          | 0110110         | 6Ch               |
| FLT                            | GND             | V <sub>DD</sub> | 55  | 37          | 0110111         | 6Eh               |
| FLT                            | PD              | GND             | 56  | 38          | 0111000         | 70h               |
| FLT                            | PD              | PD              | 57  | 39          | 0111001         | 72h               |
| FLT                            | PD              | FLT             | 58  | 3A          | 0111010         | 74h               |
| FLT                            | PD              | PU              | 59  | 3B          | 0111011         | 76h               |
| FLT                            | PD              | V <sub>DD</sub> | 60  | 3C          | 0111100         | 78h               |
| FLT                            | FLT             | GND             | 61  | 3D          | 0111101         | 7Ah               |
| FLT                            | FLT             | PD              | 62  | 3E          | 0111110         | 7Ch               |
| FLT                            | FLT             | FLT             | 63  | 3F          | 0111111         | 7Eh               |
| FLT                            | FLT             | PU              | 64  | 40          | 1000000         | 80h               |
| FLT                            | FLT             | V <sub>DD</sub> | 65  | 41          | 1000001         | 82h               |
| FLT                            | PU              | GND             | 66  | 42          | 1000010         | 84h               |
| FLT                            | PU              | PD              | 67  | 43          | 1000011         | 86h               |
| FLT                            | PU              | FLT             | 68  | 44          | 1000100         | 88h               |
| FLT                            | PU              | PU              | 69  | 45          | 1000101         | 8Ah               |
| FLT                            | PU              | V <sub>DD</sub> | 70  | 46          | 1000110         | 8Ch               |
| FLT                            | V <sub>DD</sub> | GND             | 71  | 47          | 1000111         | 8Eh               |
| FLT                            | V <sub>DD</sub> | PD              | 72  | 48          | 1001000         | 90h               |
| FLT                            | V <sub>DD</sub> | FLT             | 73  | 49          | 1001001         | 92h               |
| FLT                            | V <sub>DD</sub> | PU              | 74  | 4A          | 1001010         | 94h               |
| FLT                            | V <sub>DD</sub> | V <sub>DD</sub> | 75  | 4B          | 1001011         | 96h               |
| PU                             | GND             | GND             | 76  | 4C          | 1001100         | 98h               |
| PU                             | GND             | PD              | 77  | 4D          | 1001101         | 9Ah               |
| PU                             | GND             | FLT             | 78  | 4E          | 1001110         | 9Ch               |
| PU                             | GND             | PU              | 79  | 4F          | 1001111         | 9Eh               |
| PU                             | GND             | V <sub>DD</sub> | 80  | 50          | 1010000         | A0h               |
| PU                             | PD              | GND             | 81  | 51          | 1010001         | A2h               |
| PU                             | PD              | PD              | 82  | 52          | 1010010         | A4h               |
| PU                             | PD              | FLT             | 83  | 53          | 1010011         | A6h               |
| PU                             | PD              | PU              | 84  | 54          | 1010100         | A8h               |
| PU                             | PD              | V <sub>DD</sub> | 85  | 55          | 1010101         | AAh               |
| PU                             | FLT             | GND             | 86  | 56          | 1010110         | ACh               |
| PU                             | FLT             | PD              | 87  | 57          | 1010111         | A Eh              |

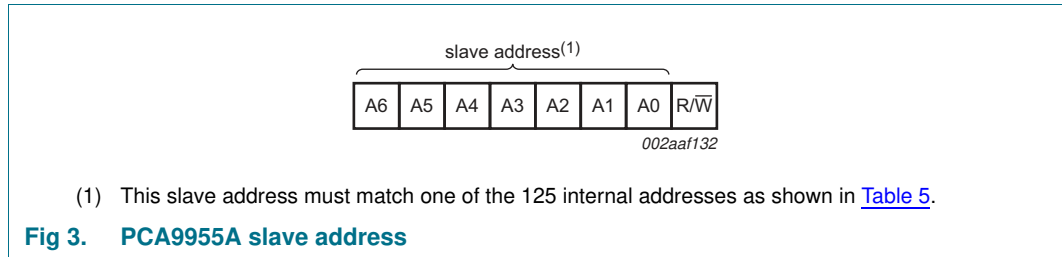
Table 5. I<sup>2</sup>C-bus slave address ...continued

| Hardware selectable input pins |                 |                 | I <sup>2</sup> C-bus slave address for PCA9955A |             |                        |                   |
|--------------------------------|-----------------|-----------------|---|-------------|------------------------|-------------------|
| AD2                            | AD1             | AD0             | Decimal   | Hexadecimal | Binary (A[6:0])        | Address (R/W = 0) |
| PU                             | FLT             | FLT             | 88  | 58          | 1011000                | B0h               |
| PU                             | FLT             | PU              | 89  | 59          | 1011001                | B2h               |
| PU                             | FLT             | V <sub>DD</sub> | 90  | 5A          | 1011010                | B4h               |
| PU                             | PU              | GND             | 91  | 5B          | 1011011                | B6h               |
| PU                             | PU              | PD              | 92  | 5C          | 1011100                | B8h               |
| PU                             | PU              | FLT             | 93  | 5D          | 1011101                | BAh               |
| PU                             | PU              | PU              | 94  | 5E          | 1011110                | BCh               |
| PU                             | PU              | V <sub>DD</sub> | 95  | 5F          | 1011111                | BEh               |
| PU                             | V <sub>DD</sub> | GND             | 96  | 60          | 1100000                | C0h               |
| PU                             | V <sub>DD</sub> | PD              | 97  | 61          | 1100001                | C2h               |
| PU                             | V <sub>DD</sub> | FLT             | 98  | 62          | 1100010                | C4h               |
| PU                             | V <sub>DD</sub> | PU              | 99  | 63          | 1100011                | C6h               |
| PU                             | V <sub>DD</sub> | V <sub>DD</sub> | 100   | 64          | 1100100                | C8h               |
| V <sub>DD</sub>                | GND             | GND             | 101   | 65          | 1100101                | CAh               |
| V <sub>DD</sub>                | GND             | PD              | 102   | 66          | 1100110                | CCh               |
| V <sub>DD</sub>                | GND             | FLT             | 103   | 67          | 1100111                | CEh               |
| V <sub>DD</sub>                | GND             | PU              | 104   | 68          | 1101000                | D0h               |
| V <sub>DD</sub>                | GND             | V <sub>DD</sub> | 105   | 69          | 1101001                | D2h               |
| V <sub>DD</sub>                | PD              | GND             | 106   | 6A          | 1101010                | D4h               |
| V <sub>DD</sub>                | PD              | PD              | 107   | 6B          | 1101011                | D6h               |
| V <sub>DD</sub>                | PD              | FLT             | 108   | 6C          | 1101100                | D8h               |
| V <sub>DD</sub>                | PD              | PU              | 109   | 6D          | 1101101                | DAh               |
| V <sub>DD</sub>                | PD              | V <sub>DD</sub> | 110   | 6E          | 1101110                | DCh               |
| V <sub>DD</sub>                | FLT             | GND             | 111   | 6F          | 1101111                | DEh               |
| V <sub>DD</sub>                | FLT             | PD              | 112   | 70          | 1110000                | E0h               |
| V <sub>DD</sub>                | FLT             | FLT             | 113   | 71          | 1110001                | E2h               |
| V <sub>DD</sub>                | FLT             | PU              | 114   | 72          | 1110010                | E4h               |
| V <sub>DD</sub>                | FLT             | V <sub>DD</sub> | 115   | 73          | 1110011                | E6h               |
| V <sub>DD</sub>                | PU              | GND             | 116   | 74          | 1110100                | E8h               |
| V <sub>DD</sub>                | PU              | PD              | 117   | 75          | 1110101                | EAh               |
| V <sub>DD</sub>                | PU              | FLT             | 118   | 76          | 1110110                | ECh               |
| V <sub>DD</sub>                | PU              | PU              | 119   | 77          | 1110111                | EEh               |
| V <sub>DD</sub>                | PU              | V <sub>DD</sub> | 120   | 78          | 1111000 <sup>[1]</sup> | F0h               |
| V <sub>DD</sub>                | V <sub>DD</sub> | GND             | 121   | 79          | 1111001 <sup>[1]</sup> | F2h               |
| V <sub>DD</sub>                | V <sub>DD</sub> | PD              | 122   | 7A          | 1111010 <sup>[1]</sup> | F4h               |
| V <sub>DD</sub>                | V <sub>DD</sub> | FLT             | 123   | 7B          | 1111011 <sup>[1]</sup> | F6h               |
| V <sub>DD</sub>                | V <sub>DD</sub> | PU              | 124   | 7C          | 1111100 <sup>[1]</sup> | F8h               |
| V <sub>DD</sub>                | V <sub>DD</sub> | V <sub>DD</sub> | 125   | 7D          | 1111101 <sup>[1]</sup> | FAh               |

[1] See 'Remark' below.

**Remark:** Reserved I<sup>2</sup>C-bus addresses must be used with caution since they can interfere with:

- ‘reserved for future use’ I<sup>2</sup>C-bus addresses (0000 011, 1111 1XX)
- slave devices that use the 10-bit addressing scheme (1111 0XX)
- slave devices that are designed to respond to the General Call address (0000 000)
- High-speed mode (Hs-mode) master code (0000 1XX)



The last bit of the address byte defines the operation to be performed. When set to logic 1 a read is selected, while a logic 0 selects a write operation.

### 7.1.2 LED All Call I<sup>2</sup>C-bus address

- Default power-up value (ALLCALLADR register): E0h or 1110 000X
- Programmable through I<sup>2</sup>C-bus (volatile programming)
- At power-up, LED All Call I<sup>2</sup>C-bus address is enabled. PCA9955A sends an ACK when E0h (R/W = 0) or E1h (R/W = 1) is sent by the master.

See [Section 7.3.11 “ALLCALLADR, LED All Call I<sup>2</sup>C-bus address”](#) for more detail.

**Remark:** The default LED All Call I<sup>2</sup>C-bus address (E0h or 1110 000X) must not be used as a regular I<sup>2</sup>C-bus slave address since this address is enabled at power-up. All of the PCA9955As on the I<sup>2</sup>C-bus acknowledge the address if sent by the I<sup>2</sup>C-bus master.

### 7.1.3 LED Sub Call I<sup>2</sup>C-bus addresses

- 3 different I<sup>2</sup>C-bus addresses can be used
- Default power-up values:
  - SUBADR1 register: ECh or 1110 110X
  - SUBADR2 register: ECh or 1110 110X
  - SUBADR3 register: ECh or 1110 110X
- Programmable through I<sup>2</sup>C-bus (volatile programming)
- At power-up, SUBADR1 is enabled while SUBADR2 and SUBADR3 I<sup>2</sup>C-bus addresses are disabled.

**Remark:** At power-up SUBADR1 identifies this device as a 16-channel driver.

See [Section 7.3.10 “LED Sub Call I<sup>2</sup>C-bus addresses for PCA9955A”](#) for more detail.

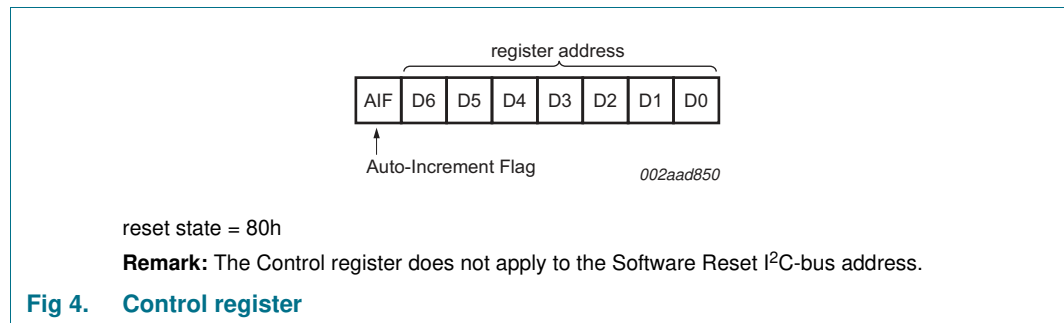
**Remark:** The default LED Sub Call I<sup>2</sup>C-bus addresses may be used as regular I<sup>2</sup>C-bus slave addresses as long as they are disabled.

### 7.2 Control register

Following the successful acknowledgement of the slave address, LED All Call address or LED Sub Call address, the bus master sends a byte to the PCA9955A, which is stored in the Control register.

The lowest 7 bits are used as a pointer to determine which register is accessed (D[6:0]). The highest bit is used as Auto-Increment Flag (AIF).

This bit along with the MODE1 register bit 5 and bit 6 provide the Auto-Increment feature.



When the Auto-Increment Flag is set (AIF = logic 1), the seven low-order bits of the Control register are automatically incremented after a read or write. This allows the user to program the registers sequentially. Four different types of Auto-Increment are possible, depending on AI1 and AI0 values of MODE1 register.

**Table 6. Auto-Increment options**

| AIF | AI1 <sup>[1]</sup> | AI0 <sup>[1]</sup> | Function   |
|-----|--------------------|--------------------|--|
| 0   | 0                  | 0                  | no Auto-Increment  |
| 1   | 0                  | 0                  | Auto-Increment for registers (00h to 43h). D[6:0] roll over to 00h after the last register 43h is accessed.  |
| 1   | 0                  | 1                  | Auto-Increment for individual brightness registers only (08h to 17h). D[6:0] roll over to 08h after the last register (17h) is accessed.                         |
| 1   | 1                  | 0                  | Auto-Increment for MODE1 to IREF15 control registers (00h to 27h). D[6:0] roll over to 00h after the last register (27h) is accessed.                            |
| 1   | 1                  | 1                  | Auto-Increment for global control registers and individual brightness registers (06h to 17h). D[6:0] roll over to 06h after the last register (17h) is accessed. |

[1] AI1 and AI0 come from MODE1 register.

**Remark:** Other combinations not shown in [Table 6](#) (AIF + AI[1:0] = 001b, 010b and 011b) are reserved and must not be used for proper device operation.

AIF + AI[1:0] = 000b is used when the same register must be accessed several times during a single I<sup>2</sup>C-bus communication, for example, changes the brightness of a single LED. Data is overwritten each time the register is accessed during a write operation.

AIF + AI[1:0] = 100b is used when all the registers must be sequentially accessed, for example, power-up programming.

AIF + AI[1:0] = 101b is used when the 16 LED drivers must be individually programmed with different values during the same I<sup>2</sup>C-bus communication, for example, changing color setting to another color setting.

AIF + AI[1:0] = 110b is used when MODE1 to IREF15 registers must be programmed with different settings during the same I<sup>2</sup>C-bus communication.

AIF + AI[1:0] = 111b is used when the 16 LED drivers must be individually programmed with different values in addition to global programming.

Only the 7 least significant bits D[6:0] are affected by the AIF, AI1 and AI0 bits.

When the Control register is written, the register entry point determined by D[6:0] is the first register that will be addressed (read or write operation), and can be anywhere between 00h and 49h (as defined in Table 7). When AIF = 1, the Auto-Increment Flag is set and the rollover value at which the register increment stops and goes to the next one is determined by AIF, AI1 and AI0. See Table 6 for rollover values. For example, if MODE1 register bit AI1 = 0 and AI0 = 1 and if the Control register = 1001 0000, then the register addressing sequence is (in hexadecimal):

10 → 11 → ... → 17 → 08 → 09 → ... → 17 → 08 → 09 → ... as long as the master keeps sending or reading data.

If MODE1 register bit AI1 = 0 and AI0 = 1 and if the Control register = 1010 0010, then the register addressing sequence is (in hexadecimal):

22 → 23 → ... → 43 → 00 → 01 → ... → 17 → 08 → 09 → ... as long as the master keeps sending or reading data.

If MODE1 register bit AI1 = 0 and AI0 = 1 and if the Control register = 1000 0101, then the register addressing sequence is (in hexadecimal):

05 → 06 → ... → 17 → 08 → 09 → ... → 17 → 08 → 09 → ... as long as the master keeps sending or reading data.

**Remark:** Writing to registers marked 'not used' returns NACK.

### 7.3 Register definitions

Table 7. Register summary

| Register number (hex) | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name    | Type       | Function                 |
|-----------------------|----|----|----|----|----|----|----|---------|------------|--------------------------|
| 00h                   | 0  | 0  | 0  | 0  | 0  | 0  | 0  | MODE1   | read/write | Mode register 1          |
| 01h                   | 0  | 0  | 0  | 0  | 0  | 0  | 1  | MODE2   | read/write | Mode register 2          |
| 02h                   | 0  | 0  | 0  | 0  | 0  | 1  | 0  | LEDOUT0 | read/write | LED output state 0       |
| 03h                   | 0  | 0  | 0  | 0  | 0  | 1  | 1  | LEDOUT1 | read/write | LED output state 1       |
| 04h                   | 0  | 0  | 0  | 0  | 1  | 0  | 0  | LEDOUT2 | read/write | LED output state 2       |
| 05h                   | 0  | 0  | 0  | 0  | 1  | 0  | 1  | LEDOUT3 | read/write | LED output state 3       |
| 06h                   | 0  | 0  | 0  | 0  | 1  | 1  | 0  | GRPPWM  | read/write | group duty cycle control |
| 07h                   | 0  | 0  | 0  | 0  | 1  | 1  | 1  | GRPFREQ | read/write | group frequency          |
| 08h                   | 0  | 0  | 0  | 1  | 0  | 0  | 0  | PWM0    | read/write | brightness control LED0  |
| 09h                   | 0  | 0  | 0  | 1  | 0  | 0  | 1  | PWM1    | read/write | brightness control LED1  |
| 0Ah                   | 0  | 0  | 0  | 1  | 0  | 1  | 0  | PWM2    | read/write | brightness control LED2  |
| 0Bh                   | 0  | 0  | 0  | 1  | 0  | 1  | 1  | PWM3    | read/write | brightness control LED3  |
| 0Ch                   | 0  | 0  | 0  | 1  | 1  | 0  | 0  | PWM4    | read/write | brightness control LED4  |
| 0Dh                   | 0  | 0  | 0  | 1  | 1  | 0  | 1  | PWM5    | read/write | brightness control LED5  |
| 0Eh                   | 0  | 0  | 0  | 1  | 1  | 1  | 0  | PWM6    | read/write | brightness control LED6  |

Table 7. Register summary ...continued

| Register number (hex) | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name           | Type       | Function                                 |
|-----------------------|----|----|----|----|----|----|----|----------------|------------|--|
| 0Fh                   | 0  | 0  | 0  | 1  | 1  | 1  | 1  | PWM7           | read/write | brightness control LED7                  |
| 10h                   | 0  | 0  | 1  | 0  | 0  | 0  | 0  | PWM8           | read/write | brightness control LED8                  |
| 11h                   | 0  | 0  | 1  | 0  | 0  | 0  | 1  | PWM9           | read/write | brightness control LED9                  |
| 12h                   | 0  | 0  | 1  | 0  | 0  | 1  | 0  | PWM10          | read/write | brightness control LED10                 |
| 13h                   | 0  | 0  | 1  | 0  | 0  | 1  | 1  | PWM11          | read/write | brightness control LED11                 |
| 14h                   | 0  | 0  | 1  | 0  | 1  | 0  | 0  | PWM12          | read/write | brightness control LED12                 |
| 15h                   | 0  | 0  | 1  | 0  | 1  | 0  | 1  | PWM13          | read/write | brightness control LED13                 |
| 16h                   | 0  | 0  | 1  | 0  | 1  | 1  | 0  | PWM14          | read/write | brightness control LED14                 |
| 17h                   | 0  | 0  | 1  | 0  | 1  | 1  | 1  | PWM15          | read/write | brightness control LED15                 |
| 18h                   | 0  | 0  | 1  | 1  | 0  | 0  | 0  | IREF0          | read/write | output gain control register 0           |
| 19h                   | 0  | 0  | 1  | 1  | 0  | 0  | 1  | IREF1          | read/write | output gain control register 1           |
| 1Ah                   | 0  | 0  | 1  | 1  | 0  | 1  | 0  | IREF2          | read/write | output gain control register 2           |
| 1Bh                   | 0  | 0  | 1  | 1  | 0  | 1  | 1  | IREF3          | read/write | output gain control register 3           |
| 1Ch                   | 0  | 0  | 1  | 1  | 1  | 0  | 0  | IREF4          | read/write | output gain control register 4           |
| 1Dh                   | 0  | 0  | 1  | 1  | 1  | 0  | 1  | IREF5          | read/write | output gain control register 5           |
| 1Eh                   | 0  | 0  | 1  | 1  | 1  | 1  | 0  | IREF6          | read/write | output gain control register 6           |
| 1Fh                   | 0  | 0  | 1  | 1  | 1  | 1  | 1  | IREF7          | read/write | output gain control register 7           |
| 20h                   | 0  | 1  | 0  | 0  | 0  | 0  | 0  | IREF8          | read/write | output gain control register 8           |
| 21h                   | 0  | 1  | 0  | 0  | 0  | 0  | 1  | IREF9          | read/write | output gain control register 9           |
| 22h                   | 0  | 1  | 0  | 0  | 0  | 1  | 0  | IREF10         | read/write | output gain control register 10          |
| 23h                   | 0  | 1  | 0  | 0  | 0  | 1  | 1  | IREF11         | read/write | output gain control register 11          |
| 24h                   | 0  | 1  | 0  | 0  | 1  | 0  | 0  | IREF12         | read/write | output gain control register 12          |
| 25h                   | 0  | 1  | 0  | 0  | 1  | 0  | 1  | IREF13         | read/write | output gain control register 13          |
| 26h                   | 0  | 1  | 0  | 0  | 1  | 1  | 0  | IREF14         | read/write | output gain control register 14          |
| 27h                   | 0  | 1  | 0  | 0  | 1  | 1  | 1  | IREF15         | read/write | output gain control register 15          |
| 28h                   | 0  | 1  | 0  | 1  | 0  | 0  | 0  | RAMP_RATE_GRP0 | read/write | ramp enable and rate control for group 0 |
| 29h                   | 0  | 1  | 0  | 1  | 0  | 0  | 1  | STEP_TIME_GRP0 | read/write | step time control for group 0            |
| 2Ah                   | 0  | 1  | 0  | 1  | 0  | 1  | 0  | HOLD_CNTL_GRP0 | read/write | hold ON/OFF time control for group 0     |
| 2Bh                   | 0  | 1  | 0  | 1  | 0  | 1  | 1  | IREF_GRP0      | read/write | output gain control for group 0          |
| 2Ch                   | 0  | 1  | 0  | 1  | 1  | 0  | 0  | RAMP_RATE_GRP1 | read/write | ramp enable and rate control for group 1 |
| 2Dh                   | 0  | 1  | 0  | 1  | 1  | 0  | 1  | STEP_TIME_GRP1 | read/write | step time control for group 1            |
| 2Eh                   | 0  | 1  | 0  | 1  | 1  | 1  | 0  | HOLD_CNTL_GRP1 | read/write | hold ON/OFF time control for group 1     |
| 2Fh                   | 0  | 1  | 0  | 1  | 1  | 1  | 1  | IREF_GRP1      | read/write | output gain control for group 1          |
| 30h                   | 0  | 1  | 1  | 0  | 0  | 0  | 0  | RAMP_RATE_GRP2 | read/write | ramp enable and rate control for group 2 |
| 31h                   | 0  | 1  | 1  | 0  | 0  | 0  | 1  | STEP_TIME_GRP2 | read/write | step time control for group 2            |
| 32h                   | 0  | 1  | 1  | 0  | 0  | 1  | 0  | HOLD_CNTL_GRP2 | read/write | hold ON/OFF time control for group 2     |

Table 7. Register summary ...continued

| Register number (hex) | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name           | Type       | Function   |
|-----------------------|----|----|----|----|----|----|----|----------------|------------|--|
| 33h                   | 0  | 1  | 1  | 0  | 0  | 1  | 1  | IREF_GRP2      | read/write | output gain control for group 2                            |
| 34h                   | 0  | 1  | 1  | 0  | 1  | 0  | 0  | RAMP_RATE_GRP3 | read/write | ramp enable and rate control for group 3                   |
| 35h                   | 0  | 1  | 1  | 0  | 1  | 0  | 1  | STEP_TIME_GRP3 | read/write | step time control for group 3                              |
| 36h                   | 0  | 1  | 1  | 0  | 1  | 1  | 0  | HOLD_CNTL_GRP3 | read/write | hold ON/OFF time control for group 3                       |
| 37h                   | 0  | 1  | 1  | 0  | 1  | 1  | 1  | IREF_GRP3      | read/write | output gain control for group 3                            |
| 38h                   | 0  | 1  | 1  | 1  | 0  | 0  | 0  | GRAD_MODE_SEL0 | read/write | gradation mode select register for channel 7 to channel 0  |
| 39h                   | 0  | 1  | 1  | 1  | 0  | 0  | 1  | GRAD_MODE_SEL1 | read/write | gradation mode select register for channel 15 to channel 8 |
| 3Ah                   | 0  | 1  | 1  | 1  | 0  | 1  | 0  | GRAD_GRP_SEL0  | read/write | gradation group select for channel 3 to channel 0          |
| 3Bh                   | 0  | 1  | 1  | 1  | 0  | 1  | 1  | GRAD_GRP_SEL1  | read/write | gradation group select for channel 7 to channel 4          |
| 3Ch                   | 0  | 1  | 1  | 1  | 1  | 0  | 0  | GRAD_GRP_SEL2  | read/write | gradation group select for channel 11 to channel 8         |
| 3Dh                   | 0  | 1  | 1  | 1  | 1  | 0  | 1  | GRAD_GRP_SEL3  | read/write | gradation group select for channel 15 to channel 12        |
| 3Eh                   | 0  | 1  | 1  | 1  | 1  | 1  | 0  | GRAD_CNTL      | read/write | gradation control register for all four groups             |
| 3Fh                   | 0  | 1  | 1  | 1  | 1  | 1  | 1  | OFFSET         | read/write | Offset/delay on LEDn outputs                               |
| 40h                   | 1  | 0  | 0  | 0  | 0  | 0  | 0  | SUBADR1        | read/write | I <sup>2</sup> C-bus subaddress 1                          |
| 41h                   | 1  | 0  | 0  | 0  | 0  | 0  | 1  | SUBADR2        | read/write | I <sup>2</sup> C-bus subaddress 2                          |
| 42h                   | 1  | 0  | 0  | 0  | 0  | 1  | 0  | SUBADR3        | read/write | I <sup>2</sup> C-bus subaddress 3                          |
| 43h                   | 1  | 0  | 0  | 0  | 0  | 1  | 1  | ALLCALLADR     | read/write | All Call I <sup>2</sup> C-bus address                      |
| 44h                   | 1  | 0  | 0  | 0  | 1  | 0  | 0  | PWMALL         | write only | brightness control for all LEDn                            |
| 45h                   | 1  | 0  | 0  | 0  | 1  | 0  | 1  | IREFALL        | write only | output gain control for all registers IREF0 to IREF15      |
| 46h                   | 1  | 0  | 0  | 0  | 1  | 1  | 0  | EFLAG0         | read only  | output error flag 0  |
| 47h                   | 1  | 0  | 0  | 0  | 1  | 1  | 1  | EFLAG1         | read only  | output error flag 1  |
| 48h                   | 1  | 0  | 0  | 1  | 0  | 0  | 0  | EFLAG2         | read only  | output error flag 2  |
| 49h                   | 1  | 0  | 0  | 1  | 0  | 0  | 1  | EFLAG3         | read only  | output error flag 3  |
| 4Ah to 7Fh            | -  | -  | -  | -  | -  | -  | -  | reserved       | read only  | not used <sup>[1]</sup>                                    |

[1] Reserved registers should not be written to and will always read back as zeros.



### 7.3.1 MODE1 — Mode register 1

**Table 8. MODE1 - Mode register 1 (address 00h) bit description**

Legend: \* default value.

| Bit | Symbol  | Access    | Value | Description  |
|-----|---------|-----------|-------|--|
| 7   | AIF     | read only | 0     | Register Auto-Increment disabled.  |
|     |         |           | 1*    | Register Auto-Increment enabled.   |
| 6   | AI1     | R/W       | 0*    | Auto-Increment bit 1 = 0. Auto-increment range as defined in <a href="#">Table 6</a> . |
|     |         |           | 1     | Auto-Increment bit 1 = 1. Auto-increment range as defined in <a href="#">Table 6</a> . |
| 5   | AI0     | R/W       | 0*    | Auto-Increment bit 0 = 0. Auto-increment range as defined in <a href="#">Table 6</a> . |
|     |         |           | 1     | Auto-Increment bit 0 = 1. Auto-increment range as defined in <a href="#">Table 6</a> . |
| 4   | SLEEP   | R/W       | 0*    | Normal mode <sup>[1]</sup> .   |
|     |         |           | 1     | Low power mode. Oscillator off <sup>[2]</sup> .  |
| 3   | SUB1    | R/W       | 0     | PCA9955A does not respond to I <sup>2</sup> C-bus subaddress 1.                        |
|     |         |           | 1*    | PCA9955A responds to I <sup>2</sup> C-bus subaddress 1.                                |
| 2   | SUB2    | R/W       | 0*    | PCA9955A does not respond to I <sup>2</sup> C-bus subaddress 2.                        |
|     |         |           | 1     | PCA9955A responds to I <sup>2</sup> C-bus subaddress 2.                                |
| 1   | SUB3    | R/W       | 0*    | PCA9955A does not respond to I <sup>2</sup> C-bus subaddress 3.                        |
|     |         |           | 1     | PCA9955A responds to I <sup>2</sup> C-bus subaddress 3.                                |
| 0   | ALLCALL | R/W       | 0     | PCA9955A does not respond to LED All Call I <sup>2</sup> C-bus address.                |
|     |         |           | 1*    | PCA9955A responds to LED All Call I <sup>2</sup> C-bus address.                        |

[1] It takes 500  $\mu$ s max. for the oscillator to be up and running once SLEEP bit has been set to logic 0. Timings on LEDn outputs are not guaranteed if PWMx, GRPPWM or GRPFREQ registers are accessed within the 500  $\mu$ s window.

[2] No blinking, dimming or gradation control is possible when the oscillator is off.

7.3.2 MODE2 — Mode register 2

Table 9. MODE2 - Mode register 2 (address 01h) bit description

Legend: \* default value.

| Bit | Symbol   | Access     | Value | Description   |
|-----|----------|------------|-------|---|
| 7   | OVERTEMP | read only  | 0*    | O.K.  |
|     |          |            | 1     | overtemperature condition   |
| 6   | ERROR    | read only  | 0*    | no error at LED outputs   |
|     |          |            | 1     | any open or short-circuit detected in error flag registers (EFLAGn)   |
| 5   | DMBLNK   | R/W        | 0*    | group control = dimming   |
|     |          |            | 1     | group control = blinking  |
| 4   | CLRERR   | write only | 0*    | self clear after write '1'  |
|     |          |            | 1     | Write '1' to clear all error status bits in EFLAGn register and ERROR (bit 6). The EFLAGn and ERROR bit sets to '1' if open or short-circuit is detected again. |
| 3   | OCH      | R/W        | 0*    | outputs change on STOP condition  |
|     |          |            | 1     | outputs change on ACK   |
| 2   | EXP_EN   | R/W        | 0*    | linear adjustment for gradation control   |
|     |          |            | 1     | exponential adjustment for gradation control  |
| 1   | -        | read only  | 0*    | reserved  |
| 0   | -        | read only  | 1*    | reserved  |

Brightness adjustment for gradation control is either linear or exponential by setting the EXP\_EN bit as shown in Figure 5. When EXP\_EN = 0, linear adjustment scale is used. When EXP\_EN = 1, exponential scale is used.

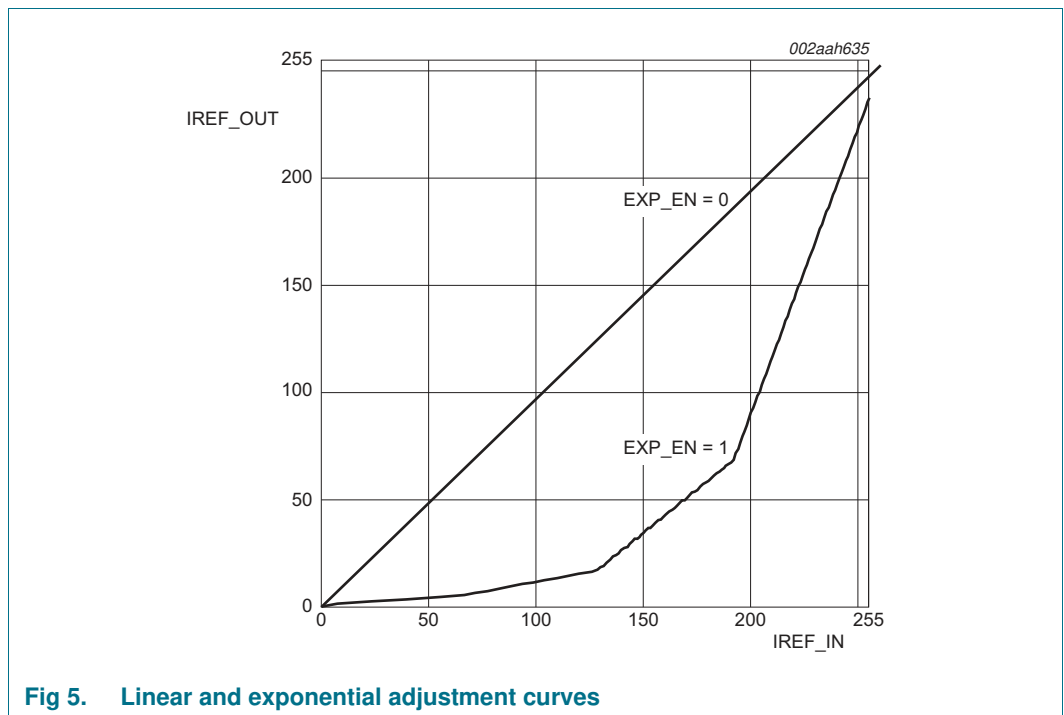


Fig 5. Linear and exponential adjustment curves

### 7.3.3 LEDOUT0 to LEDOUT3, LED driver output state

**Table 10. LEDOUT0 to LEDOUT3 - LED driver output state registers (address 02h to 05h) bit description**

Legend: \* default value.

| Address | Register | Bit | Symbol | Access | Value | Description                |
|---------|----------|-----|--------|--------|-------|----------------------------|
| 02h     | LEDOUT0  | 7:6 | LDR3   | R/W    | 10*   | LED3 output state control  |
|         |          | 5:4 | LDR2   | R/W    | 10*   | LED2 output state control  |
|         |          | 3:2 | LDR1   | R/W    | 10*   | LED1 output state control  |
|         |          | 1:0 | LDR0   | R/W    | 10*   | LED0 output state control  |
| 03h     | LEDOUT1  | 7:6 | LDR7   | R/W    | 10*   | LED7 output state control  |
|         |          | 5:4 | LDR6   | R/W    | 10*   | LED6 output state control  |
|         |          | 3:2 | LDR5   | R/W    | 10*   | LED5 output state control  |
|         |          | 1:0 | LDR4   | R/W    | 10*   | LED4 output state control  |
| 04h     | LEDOUT2  | 7:6 | LDR11  | R/W    | 10*   | LED11 output state control |
|         |          | 5:4 | LDR10  | R/W    | 10*   | LED10 output state control |
|         |          | 3:2 | LDR9   | R/W    | 10*   | LED9 output state control  |
|         |          | 1:0 | LDR8   | R/W    | 10*   | LED8 output state control  |
| 05h     | LEDOUT3  | 7:6 | LDR15  | R/W    | 10*   | LED15 output state control |
|         |          | 5:4 | LDR14  | R/W    | 10*   | LED14 output state control |
|         |          | 3:2 | LDR13  | R/W    | 10*   | LED13 output state control |
|         |          | 1:0 | LDR12  | R/W    | 10*   | LED12 output state control |

**LDRx = 00** — LED driver x is off (x = 0 to 15).

**LDRx = 01** — LED driver x is fully on (individual brightness and group dimming/blinking not controlled). The  $\overline{OE}$  pin can be used as external dimming/blinking control in this state.

**LDRx = 10** — LED driver x individual brightness can be controlled through its PWMx register (default power-up state) or PWMALL register for all LEDn outputs.

**LDRx = 11** — LED driver x individual brightness and group dimming/blinking can be controlled through its PWMx register and the GRPPWM registers.

### 7.3.4 GRPPWM, group duty cycle control

**Table 11. GRPPWM - Group brightness control register (address 06h) bit description**

Legend: \* default value

| Address | Register | Bit | Symbol   | Access | Value      | Description     |
|---------|----------|-----|----------|--------|------------|-----------------|
| 06h     | GRPPWM   | 7:0 | GDC[7:0] | R/W    | 1111 1111* | GRPPWM register |

When DMBLNK bit (MODE2 register) is programmed with logic 0, a 122 Hz fixed frequency signal is superimposed with the 31.25 kHz individual brightness control signal. GRPPWM is then used as a global brightness control allowing the LED outputs to be dimmed with the same value. The value in GRPFREQ is then a 'Don't care'.

General brightness for the 16 outputs is controlled through 255 linear steps from 00h (0 % duty cycle = LED output off) to FFh (99.6 % duty cycle = maximum brightness). Applicable to LED outputs programmed with LDRx = 11 (LEDOUT0 to LEDOUT3 registers).

When DMBLNK bit is programmed with logic 1, GRPPWM and GRPFREQ registers define a global blinking pattern, where GRPFREQ contains the blinking period (from 67 ms to 16.8 s) and GRPPWM the duty cycle (ON/OFF ratio in %).

$$duty\ cycle = \frac{GDC[7:0]}{256} \tag{1}$$

### 7.3.5 GRPFREQ, group frequency

**Table 12. GRPFREQ - Group frequency register (address 07h) bit description**

Legend: \* default value.

| Address | Register | Bit | Symbol    | Access | Value      | Description      |
|---------|----------|-----|-----------|--------|------------|------------------|
| 07h     | GRPFREQ  | 7:0 | GFRQ[7:0] | R/W    | 0000 0000* | GRPFREQ register |

GRPFREQ is used to program the global blinking period when DMBLNK bit (MODE2 register) is equal to 1. Value in this register is a ‘Don’t care’ when DMBLNK = 0. Applicable to LED outputs programmed with LDRx = 11 (LEDOUT0 to LEDOUT3 registers).

Blinking period is controlled through 256 linear steps from 00h (67 ms, frequency 15 Hz) to FFh (16.8 s).

$$global\ blinking\ period = \frac{GFRQ[7:0] + 1}{15.26} (s) \tag{2}$$

### 7.3.6 PWM0 to PWM15, individual brightness control

**Table 13. PWM0 to PWM15 - PWM registers 0 to 15 (address 08h to 17h) bit description**

Legend: \* default value.

| Address | Register | Bit | Symbol     | Access | Value      | Description                 |
|---------|----------|-----|------------|--------|------------|-----------------------------|
| 08h     | PWM0     | 7:0 | IDC0[7:0]  | R/W    | 0000 0000* | PWM0 Individual Duty Cycle  |
| 09h     | PWM1     | 7:0 | IDC1[7:0]  | R/W    | 0000 0000* | PWM1 Individual Duty Cycle  |
| 0Ah     | PWM2     | 7:0 | IDC2[7:0]  | R/W    | 0000 0000* | PWM2 Individual Duty Cycle  |
| 0Bh     | PWM3     | 7:0 | IDC3[7:0]  | R/W    | 0000 0000* | PWM3 Individual Duty Cycle  |
| 0Ch     | PWM4     | 7:0 | IDC4[7:0]  | R/W    | 0000 0000* | PWM4 Individual Duty Cycle  |
| 0Dh     | PWM5     | 7:0 | IDC5[7:0]  | R/W    | 0000 0000* | PWM5 Individual Duty Cycle  |
| 0Eh     | PWM6     | 7:0 | IDC6[7:0]  | R/W    | 0000 0000* | PWM6 Individual Duty Cycle  |
| 0Fh     | PWM7     | 7:0 | IDC7[7:0]  | R/W    | 0000 0000* | PWM7 Individual Duty Cycle  |
| 10h     | PWM8     | 7:0 | IDC8[7:0]  | R/W    | 0000 0000* | PWM8 Individual Duty Cycle  |
| 11h     | PWM9     | 7:0 | IDC9[7:0]  | R/W    | 0000 0000* | PWM9 Individual Duty Cycle  |
| 12h     | PWM10    | 7:0 | IDC10[7:0] | R/W    | 0000 0000* | PWM10 Individual Duty Cycle |
| 13h     | PWM11    | 7:0 | IDC11[7:0] | R/W    | 0000 0000* | PWM11 Individual Duty Cycle |
| 14h     | PWM12    | 7:0 | IDC12[7:0] | R/W    | 0000 0000* | PWM12 Individual Duty Cycle |
| 15h     | PWM13    | 7:0 | IDC13[7:0] | R/W    | 0000 0000* | PWM13 Individual Duty Cycle |
| 16h     | PWM14    | 7:0 | IDC14[7:0] | R/W    | 0000 0000* | PWM14 Individual Duty Cycle |
| 17h     | PWM15    | 7:0 | IDC15[7:0] | R/W    | 0000 0000* | PWM15 Individual Duty Cycle |

A 31.25 kHz fixed frequency signal is used for each output. Duty cycle is controlled through 255 linear steps from 00h (0 % duty cycle = LED output off) to FEh (99.2 % duty cycle = LED output at maximum brightness) and FFh (100 % duty cycle = LED output completed ON). Applicable to LED outputs programmed with LDRx = 10 or 11 (LEDOUT0 to LEDOUT3 registers).

$$duty\ cycle = \frac{IDC_x[7:0]}{256} \tag{3}$$

**Remark:** The first lower end 8 steps of PWM and the last (higher end) steps of PWM will not have effective brightness control of LEDs due to edge rate control of LED output pins.

### 7.3.7 IREF0 to IREF15, LED output current value registers

These registers reflect the gain settings for output current for LED0 to LED15.

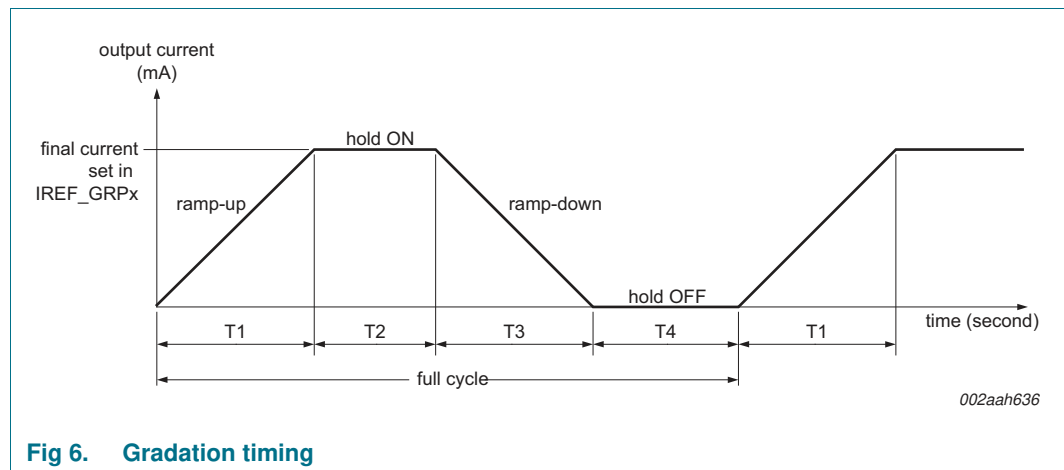
**Table 14. IREF0 to IREF15 - LED output gain control registers (address 18h to 27h) bit description**

Legend: \* default value.

| Address | Register | Bit | Access | Value | Description                  |
|---------|----------|-----|--------|-------|------------------------------|
| 18h     | IREF0    | 7:0 | R/W    | 00h*  | LED0 output current setting  |
| 19h     | IREF1    | 7:0 | R/W    | 00h*  | LED1 output current setting  |
| 1Ah     | IREF2    | 7:0 | R/W    | 00h*  | LED2 output current setting  |
| 1Bh     | IREF3    | 7:0 | R/W    | 00h*  | LED3 output current setting  |
| 1Ch     | IREF4    | 7:0 | R/W    | 00h*  | LED4 output current setting  |
| 1Dh     | IREF5    | 7:0 | R/W    | 00h*  | LED5 output current setting  |
| 1Eh     | IREF6    | 7:0 | R/W    | 00h*  | LED6 output current setting  |
| 1Fh     | IREF7    | 7:0 | R/W    | 00h*  | LED7 output current setting  |
| 20h     | IREF8    | 7:0 | R/W    | 00h*  | LED8 output current setting  |
| 21h     | IREF9    | 7:0 | R/W    | 00h*  | LED9 output current setting  |
| 22h     | IREF10   | 7:0 | R/W    | 00h*  | LED10 output current setting |
| 23h     | IREF11   | 7:0 | R/W    | 00h*  | LED11 output current setting |
| 24h     | IREF12   | 7:0 | R/W    | 00h*  | LED12 output current setting |
| 25h     | IREF13   | 7:0 | R/W    | 00h*  | LED13 output current setting |
| 26h     | IREF14   | 7:0 | R/W    | 00h*  | LED14 output current setting |
| 27h     | IREF15   | 7:0 | R/W    | 00h*  | LED15 output current setting |

### 7.3.8 Gradation control

Gradation control is designed to use four independent groups of registers to program the full cycle of the gradation timing to implement on each selected channel. Each group has four registers to define the ramp rate, step time, hold ON/OFF time, and final hold ON current, as shown in [Figure 6](#).



**Fig 6. Gradation timing**

- The ‘final’ and ‘hold ON’ current is defined in IREF\_GRPx register value × (225 μA if REXT = 1 kΩ, or 112.5 μA if REXT = 2 kΩ).
- Ramp rate value and enable/disable ramp operation is defined in RAMP\_RATE\_GRPx register.
- Total number of ramp steps (or level changes) is calculated as ‘IREF\_GRPx value’ ÷ ‘ramp rate value in RAMP\_RATE\_GRPx’. Rounds a number up to the next integer if the total number is not an integer.
- Time for each step is calculated as ‘cycle time’ × ‘multiple factor’ bits in STEP\_TIME\_GRPx register. Minimum time for one step is 0.5 ms (0.5 ms × 1) and maximum time is 512 ms (8 ms × 64).
- The ramp-up or ramp-down time (T1 or T3) is calculated as ‘(total steps + 1) × ‘step time’.
- Hold ON or OFF time (T2 or T4) is defined in HOLD\_CNTL\_GRPx register in the range of 0/0.25/0.5/0.75/1/2/4/6 seconds.
- Gradation start or stop with single shot mode (one full cycle only) or continuous mode (repeat full cycle) is defined in the GRAD\_CNTL register for all groups.
- Each channel can be assigned to one of these four groups in the GRAD\_GRP\_SELx register.
- Each channel can set either normal mode or gradation mode operation in the GRAD\_MODE\_SELx register.

To enable the gradation operation, the following steps are required:

1. Program all gradation control registers except the gradation start bit in GRAD\_CNTL register.
2. Program either LDRx = 01 (LED fully ON mode) only, or LDRx = 10 or 11 (PWM control mode) with individual brightness control PWMx register for duty cycle.

3. Program output current value IREFx register to non-zero, which will enable LED output.
4. Set the gradation start bit in GRAD\_CNTL register for enabling gradation operation.

**7.3.8.1 RAMP\_RATE\_GRP0 to RAMP\_RATE\_GRP3, ramp rate control registers**

**Table 15. RAMP\_RATE\_GRP[0:3] - Ramp enable and rate control registers (address 28h, 2Ch, 30h, 34h) for each group bit description**

Legend: \* default value.

| Address | Register       | Bit | Access | Value | Description  |
|---------|----------------|-----|--------|-------|--|
| 28h     | RAMP_RATE_GRP0 | 7   | R/W    | 0*    | Ramp-up disable  |
| 2Ch     | RAMP_RATE_GRP1 |     |        | 1     | Ramp-up enable   |
| 30h     | RAMP_RATE_GRP2 | 6   | R/W    | 0*    | Ramp-down disable  |
| 34h     | RAMP_RATE_GRP3 |     |        | 1     | Ramp-down enable   |
|         |                | 5:0 | R/W    | 0x00* | Ramp rate value per step is defined from 1 (00h) to 64 (3Fh) <sup>[1][2]</sup> |

[1] Total number of ramp steps is defined as 'IREF\_GRP[7:0] ÷ 'ramp\_rate[5:0]'. (Round up to next integer if it is not an integer number.)

[2] Per step current increment or decrement is calculated by the (ramp\_rate × I<sub>ref</sub>), where the I<sub>ref</sub> reference current is 112.5 μA (REXT = 2 kΩ) or 225 μA (REXT = 1 kΩ).

**7.3.8.2 STEP\_TIME\_GRP0 to STEP\_TIME\_GRP3, step time control registers**

**Table 16. STEP\_TIME\_GRP[0:3] - Step time control registers (address 29h, 2Dh, 31h, 35h) for each group bit description**

Legend: \* default value.

| Address | Register       | Bit | Access    | Value | Description  |
|---------|----------------|-----|-----------|-------|--|
| 29h     | STEP_TIME_GRP0 | 7   | read only | 0*    | reserved   |
| 2Dh     | STEP_TIME_GRP1 | 6   | R/W       | 0*    | Cycle time is set to 0.5 ms  |
| 31h     | STEP_TIME_GRP2 |     |           | 1     | Cycle time is set to 8 ms  |
| 35h     | STEP_TIME_GRP3 | 5:0 | R/W       | 0x00* | Multiple factor per step, the multiple factor is defined from 1 (00h) to 64 (3Fh) <sup>[1]</sup> |

[1] Step time = cycle time (0.5 ms or 8 ms) × multiple factor (1 ~ 64); minimum step time is 0.5 ms and maximum step time is 512 ms.

7.3.8.3 HOLD\_CNTL\_GRP0 to HOLD\_CNTL\_GRP3, hold ON and OFF control registers

Table 17. HOLD\_CNTL\_GRP[0:3] - Hold ON and OFF enable and time control registers (address 2Ah, 2Eh, 32h, 36h) for each group bit description

Legend: \* default value.

| Address | Register       | Bit | Access | Value | Description   |
|---------|----------------|-----|--------|-------|---|
| 2Ah     | HOLD_CNTL_GRP0 | 7   | R/W    | 0*    | Hold ON disable   |
| 2Eh     | HOLD_CNTL_GRP1 |     |        | 1     | Hold ON enable  |
| 32h     | HOLD_CNTL_GRP2 | 6   | R/W    | 0*    | Hold OFF disable  |
| 36h     | HOLD_CNTL_GRP3 |     |        | 1     | Hold OFF enable   |
|         |                | 5:3 | R/W    | 000*  | Hold ON time select: <a href="#">[1]</a><br>000: 0 s<br>001: 0.25 s<br>010: 0.5 s<br>011: 0.75 s<br>100: 1 s<br>101: 2 s<br>110: 4 s<br>111: 6 s  |
|         |                | 2:0 | R/W    | 000*  | Hold OFF time select: <a href="#">[1]</a><br>000: 0 s<br>001: 0.25 s<br>010: 0.5 s<br>011: 0.75 s<br>100: 1 s<br>101: 2 s<br>110: 4 s<br>111: 6 s |

[1] Hold ON or OFF minimum time is 0 s and maximum time is 6 s.

7.3.8.4 IREF\_GRP0 to IREF\_GRP3, output gain control

Table 18. IREF\_GRP[0:3] - Final and hold ON output gain setting registers (address 2Bh, 2Fh, 33h, 37h) for each group bit description

Legend: \* default value.

| Address | Register  | Bit | Access | Value | Description   |
|---------|-----------|-----|--------|-------|---|
| 2Bh     | IREF_GRP0 | 7:0 | R/W    | 00h*  | Final ramp-up and hold ON output current gain setting <a href="#">[1]</a> |
| 2Fh     | IREF_GRP1 |     |        |       |   |
| 33h     | IREF_GRP2 |     |        |       |   |
| 37h     | IREF_GRP3 |     |        |       |   |

[1] Output current = I<sub>ref</sub> × IREF\_GRPx[7:0], where I<sub>ref</sub> is reference current. I<sub>ref</sub> = 112.5 μA if REXT = 2 kΩ, or I<sub>ref</sub> = 225 μA if REXT = 1 kΩ



7.3.8.5 GRAD\_MODE\_SEL0 to GRAD\_MODE\_SEL1, Gradation mode select registers

Table 19. GRAD\_MODE\_SEL[0:1] - Gradation mode select register for channel 15 to channel 0 (address 38h, 39h) bit description

Legend: \* default value.

| Address | Register       | Bit | Access | Value | Description <sup>[1][2]</sup>                        |
|---------|----------------|-----|--------|-------|--|
| 38h     | GRAD_MODE_SEL0 | 7:0 | R/W    | 00*   | Normal operation mode for channel 7 to channel 0     |
|         |                |     |        | FFh   | Gradation operation mode for channel 7 to channel 0  |
| 39h     | GRAD_MODE_SEL1 | 7:0 | R/W    | 00*   | Normal operation mode for channel 15 to channel 8    |
|         |                |     |        | FFh   | Gradation operation mode for channel 15 to channel 8 |

- [1] Each bit represents one channel that can set either 0 for normal mode (use IREFx to set individual LED output current), or 1 for gradation mode (use IREF\_GRPx to set group LEDs output current).
- [2] In gradation mode, it only affects the source of the IREF current level and does not affect the PWMx operation or LEDOUTx registers' function. It is possible to use the gradation feature, individual PWMx and group PWM simultaneously.

7.3.8.6 GRAD\_GRP\_SEL0 to GRAD\_GRP\_SEL3, Gradation group select registers

Table 20. GRAD\_GRP\_SEL[0:3] - Gradation group select register for channel 15 to channel 0 (address 3Ah, 3Bh, 3Ch, 3Dh) bit description

Legend: \* default value.

| Address | Register      | Bit | Access | Value | Description <sup>[1]</sup>              |
|---------|---------------|-----|--------|-------|---|
| 3Ah     | GRAD_GRP_SEL0 | 7:6 | R/W    | 00*   | Gradation group select for LED3 output  |
|         |               | 5:4 | R/W    | 00*   | Gradation group select for LED2 output  |
|         |               | 3:2 | R/W    | 00*   | Gradation group select for LED1 output  |
|         |               | 1:0 | R/W    | 00*   | Gradation group select for LED0 output  |
| 3Bh     | GRAD_GRP_SEL1 | 7:6 | R/W    | 01*   | Gradation group select for LED7 output  |
|         |               | 5:4 | R/W    | 01*   | Gradation group select for LED6 output  |
|         |               | 3:2 | R/W    | 01*   | Gradation group select for LED5 output  |
|         |               | 1:0 | R/W    | 01*   | Gradation group select for LED4 output  |
| 3Ch     | GRAD_GRP_SEL2 | 7:6 | R/W    | 10*   | Gradation group select for LED11 output |
|         |               | 5:4 | R/W    | 10*   | Gradation group select for LED10 output |
|         |               | 3:2 | R/W    | 10*   | Gradation group select for LED9 output  |
|         |               | 1:0 | R/W    | 10*   | Gradation group select for LED8 output  |
| 3Dh     | GRAD_GRP_SEL3 | 7:6 | R/W    | 11*   | Gradation group select for LED15 output |
|         |               | 5:4 | R/W    | 11*   | Gradation group select for LED14 output |
|         |               | 3:2 | R/W    | 11*   | Gradation group select for LED13 output |
|         |               | 1:0 | R/W    | 11*   | Gradation group select for LED12 output |

- [1] LED[3:0] outputs default assigned to group 0; LED[7:4] outputs default assigned to group 1; LED[11:8] outputs default assigned to group 2; LED[15:12] outputs default assigned to group 3.

## 7.3.8.7 GRAD\_CNTL, Gradation control register

Table 21. GRAD\_CNTL - Gradation control register for group 3 to group 0 (address 3Eh)  
bit description

Legend: \* default value.

| Address | Register  | Bit | Access | Value | Description                                       |
|---------|-----------|-----|--------|-------|---|
| 3Eh     | GRAD_CNTL | 7   | R/W    | 0*    | Gradation stop or done for group 3 <sup>[1]</sup> |
|         |           |     |        | 1     | Gradation start for group 3 <sup>[2]</sup>        |
|         |           | 6   | R/W    | 0*    | Single shot operation for group 3                 |
|         |           |     |        | 1     | Continuous operation for group 3                  |
|         |           | 5   | R/W    | 0*    | Gradation stop or done for group 2 <sup>[1]</sup> |
|         |           |     |        | 1     | Gradation start for group 2 <sup>[2]</sup>        |
|         |           | 4   | R/W    | 0*    | Single shot operation for group 2                 |
|         |           |     |        | 1     | Continuous operation for group 2                  |
|         |           | 3   | R/W    | 0*    | Gradation stop or done for group 1 <sup>[1]</sup> |
|         |           |     |        | 1     | Gradation start for group 1 <sup>[2]</sup>        |
|         |           | 2   | R/W    | 0*    | Single shot operation for group 1                 |
|         |           |     |        | 1     | Continuous operation for group 1                  |
|         |           | 1   | R/W    | 0*    | Gradation stop or done for group 0 <sup>[1]</sup> |
|         |           |     |        | 1     | Gradation start for group 0 <sup>[2]</sup>        |
|         |           | 0   | R/W    | 0*    | Single shot operation for group 0                 |
|         |           |     |        | 1     | Continuous operation for group 0                  |

[1] When the gradation operation is forced to stop, the output current stops immediately and is frozen at the last output level.

[2] This bit will be self-cleared when single mode is completed, and writing 0 to this bit will force to stop the gradation operation when single mode is not completed or continuous mode is running.

7.3.8.8 Ramp control — equation and calculation example

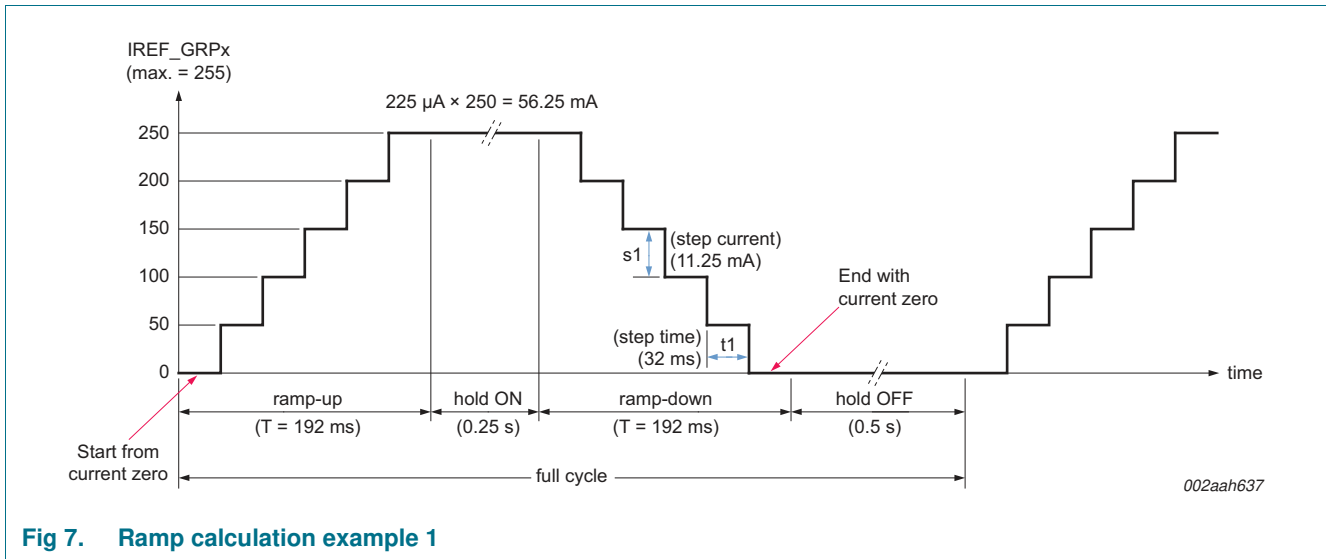


Fig 7. Ramp calculation example 1

- t1 (step time) = cycle time × multiple factor, where:
  - Cycle time = 0.5 ms (fast ramp) or 8 ms (slow ramp) in STEP\_TIME\_GRPx[6]
  - Multiple factor = 6-bit, from 1 (00h) to 64 (3Fh) counts in STEP\_TIME\_GRPx[5:0]
- s1 (step current) = ramp\_rate × I<sub>ref</sub>, where:
  - ramp\_rate = 6-bit, from 1 (00h) to 64 (3Fh) counts in RAMP\_RATE\_GRPx[5:0]
  - I<sub>ref</sub> = reference current either 112.5 μA if REXT = 2 kΩ, or 225 μA if REXT = 1 kΩ
- S (total steps) = (IREF\_GRPx / ramp\_rate), where:
  - IREF\_GRPx = output current gain setting, 8-bit, up to 255 counts
  - ramp\_rate = 6-bit, up to 64 counts in RAMP\_RATE\_GRPx[5:0]
  - If it is not an integer, then round up to next integer number.
- T (ramp time) = (S (total steps) + 1) × t1 (step time)
  - Ramp-up time starts from zero current and ends at the maximum current
  - Ramp-down time starts from the maximum current and ends at the zero current

Calculation example 1 (Figure 7):

- Assumption:
  - I<sub>ref</sub> = 225 μA if REXT = 1 kΩ
  - Output hold ON current = 225 μA × 250 = 56.25 mA (IREF\_GRPx[7:0] = FAh)
  - Cycle time = 0.5 ms (STEP\_TIME\_GRPx[6] = 0)
  - Multiple factor = 64 (STEP\_TIME\_GRPx[5:0] = 3Fh)
  - Ramp rate = 50 (RAMP\_RATE\_GRPx[5:0] = 31h)
  - Hold ON = 0.25 s (HOLD\_CNTL\_GRPx[5:3] = 001)
  - Hold OFF = 0.5 s (HOLD\_CNTL\_GRPx[2:0] = 010)
- t1 (step time) = cycle time (0.5 ms) × multiple (64) = 32 ms
- Step current = ramp\_rate × I<sub>ref</sub> = 50 × 225 μA = 11.25 mA

- $S$  (total steps) =  $(I_{REF\_GRP_x} \div \text{ramp\_rate}) = (250 \div 50) = 5$  steps
- $T$  (ramp time) =  $(S + 1) \times t_1 = 6 \times 32 \text{ ms} = 192 \text{ ms}$

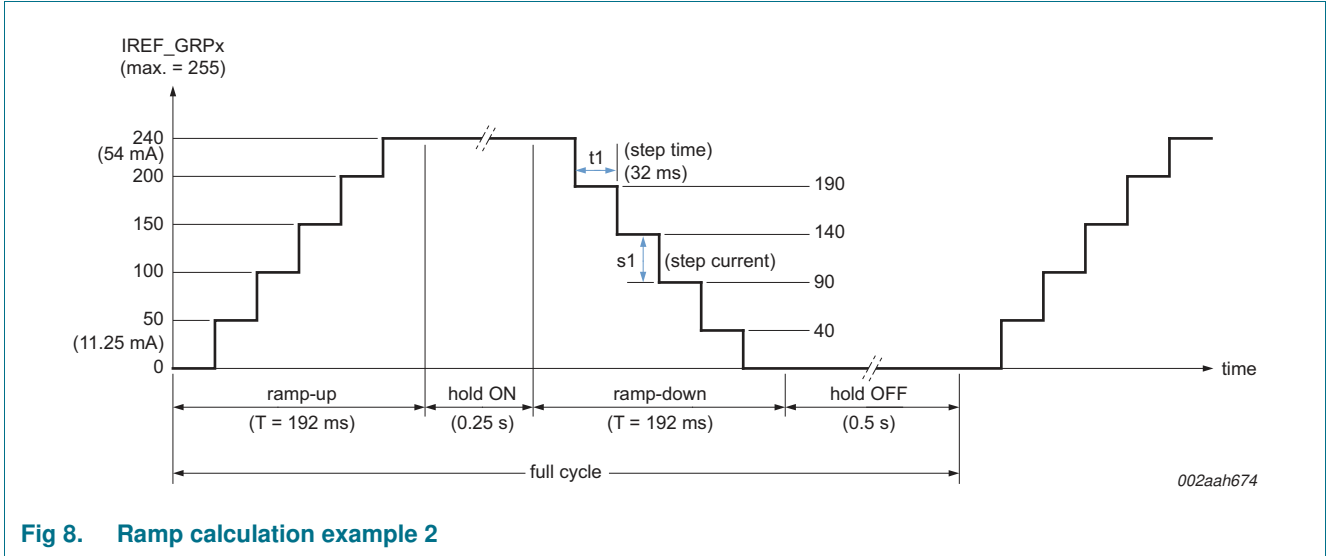
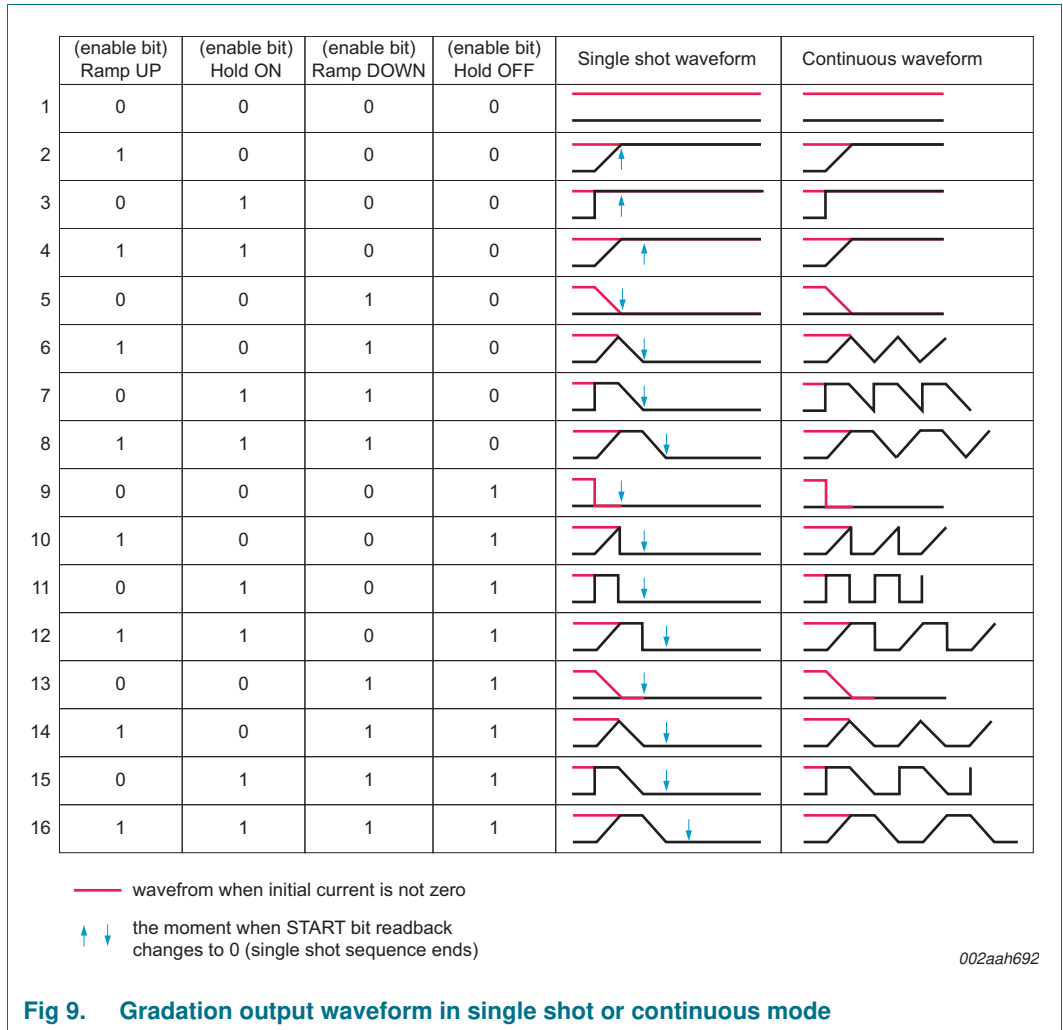


Fig 8. Ramp calculation example 2

**Calculation example 2:**

- Assumption:
  - $I_{ref} = 225 \mu\text{A}$  if  $R_{EXT} = 1 \text{ k}\Omega$
  - Output hold ON current =  $225 \mu\text{A} \times 240 = 54 \text{ mA}$  ( $I_{REF\_GRP_x}[7:0] = F0h$ )
  - Cycle time =  $0.5 \text{ ms}$  ( $STEP\_TIME\_GRP_x[6] = 0$ )
  - Multiple factor =  $64$  ( $STEP\_TIME\_GRP_x[5:0] = 3Fh$ )
  - Ramp rate =  $50$  ( $RAMP\_RATE\_GRP_x[5:0] = 31h$ )
  - Hold ON =  $0.25 \text{ s}$  ( $HOLD\_CNTL\_GRP_x[5:3] = 001$ )
  - Hold OFF =  $0.5 \text{ s}$  ( $HOLD\_CNTL\_GRP_x[2:0] = 010$ )
- $t_1$  (step time) = cycle time ( $0.5 \text{ ms}$ )  $\times$  multiple ( $64$ ) =  $32 \text{ ms}$
- Step current = ramp\_rate  $\times I_{ref} = 50 \times 225 \mu\text{A} = 11.25 \text{ mA}$  (except the last one)
- $S$  (total steps) =  $I_{REF\_GRP_x} \div \text{ramp\_rate} = 240 \div 50 = 4.8$  steps (round up to next integer) =  $5$  steps
- $T$  (ramp time) =  $(S + 1) \times t_1 = 6 \times 32 \text{ ms} = 192 \text{ ms}$



7.3.9 OFFSET — LEDn output delay offset register

Table 22. OFFSET - LEDn output delay offset register (address 3Fh) bit description

Legend: \* default value.

| Address | Register | Bit | Access    | Value | Description                     |
|---------|----------|-----|-----------|-------|---------------------------------|
| 3Fh     | OFFSET   | 7:4 | read only | 0000* | not used                        |
|         |          | 3:0 | R/W       | 1000* | LEDn output delay offset factor |

The PCA9955A can be programmed to have turn-on delay between LED outputs. This helps to reduce peak current for the V<sub>DD</sub> supply and reduces EMI.

The order in which the LED outputs are enabled will always be the same (channel 0 will enable first and channel 15 will enable last).

OFFSET control register bits [3:0] determine the delay used between the turn-on times as follows:

- 0000 = no delay between outputs (all on, all off at the same time)
- 0001 = delay of 1 clock cycle (125 ns) between successive outputs
- 0010 = delay of 2 clock cycles (250 ns) between successive outputs
- 0011 = delay of 3 clock cycles (375 ns) between successive outputs
- :
- 1111 = delay of 15 clock cycles (1.875 μs) between successive outputs

**Example:** If the value in the OFFSET register is 1000 the corresponding delay = 8 × 125 ns = 1 μs delay between successive outputs.

- channel 0 turns on at time 0 μs
- channel 1 turns on at time 1 μs
- channel 2 turns on at time 2 μs
- channel 3 turns on at time 3 μs
- channel 4 turns on at time 4 μs
- channel 5 turns on at time 5 μs
- channel 6 turns on at time 6 μs
- channel 7 turns on at time 7 μs
- channel 8 turns on at time 8 μs
- channel 9 turns on at time 9 μs
- channel 10 turns on at time 10 μs
- channel 11 turns on at time 11 μs
- channel 12 turns on at time 12 μs
- channel 13 turns on at time 13 μs
- channel 14 turns on at time 14 μs
- channel 15 turns on at time 15 μs

7.3.10 LED Sub Call I<sup>2</sup>C-bus addresses for PCA9955A

Table 23. SUBADR1 to SUBADR3 - I<sup>2</sup>C-bus subaddress registers 1 to 3 (address 40h to 42h) bit description

Legend: \* default value.

| Address | Register | Bit | Symbol  | Access | Value     | Description                       |
|---------|----------|-----|---------|--------|-----------|-----------------------------------|
| 40h     | SUBADR1  | 7:1 | A1[7:1] | R/W    | 1110 110* | I <sup>2</sup> C-bus subaddress 1 |
|         |          | 0   | A1[0]   | R only | 0*        | reserved                          |
| 41h     | SUBADR2  | 7:1 | A2[7:1] | R/W    | 1110 110* | I <sup>2</sup> C-bus subaddress 2 |
|         |          | 0   | A2[0]   | R only | 0*        | reserved                          |
| 42h     | SUBADR3  | 7:1 | A3[7:1] | R/W    | 1110 110* | I <sup>2</sup> C-bus subaddress 3 |
|         |          | 0   | A3[0]   | R only | 0*        | reserved                          |

Default power-up values are ECh, ECh, ECh. At power-up, SUBADR1 is enabled while SUBADR2 and SUBADR3 are disabled. The power-up default bit subaddress of ECh indicates that this device is a 16-channel LED driver.

All three subaddresses are programmable. Once subaddresses have been programmed to their right values, SUBx bits need to be set to logic 1 in order to have the device acknowledging these addresses (MODE1 register) (0). When SUBx is set to logic 1, the corresponding I<sup>2</sup>C-bus subaddress can be used during either an I<sup>2</sup>C-bus read or write sequence.

7.3.11 ALLCALLADR, LED All Call I<sup>2</sup>C-bus address

Table 24. ALLCALLADR - LED All Call I<sup>2</sup>C-bus address register (address 43h) bit description

Legend: \* default value.

| Address | Register   | Bit | Symbol  | Access | Value     | Description                                   |
|---------|------------|-----|---------|--------|-----------|---|
| 43h     | ALLCALLADR | 7:1 | AC[7:1] | R/W    | 1110 000* | ALLCALL I <sup>2</sup> C-bus address register |
|         |            | 0   | AC[0]   | R only | 0*        | reserved                                      |

The LED All Call I<sup>2</sup>C-bus address allows all the PCA9955As on the bus to be programmed at the same time (ALLCALL bit in register MODE1 must be equal to logic 1 [power-up default state]). This address is programmable through the I<sup>2</sup>C-bus and can be used during either an I<sup>2</sup>C-bus read or write sequence. The register address can also be programmed as a Sub Call.

Only the 7 MSBs representing the All Call I<sup>2</sup>C-bus address are valid. The LSB in ALLCALLADR register is a read-only bit (0).

If ALLCALL bit = 0 in MODE1 register, the device does not acknowledge the address programmed in register ALLCALLADR.

**7.3.12 PWMALL — brightness control for all LEDn outputs**

When programmed, the value in this register will be used for PWM duty cycle for all the LEDn outputs and will be reflected in PWM0 through PWM15 registers.

**Table 25. PWMALL - brightness control for all LEDn outputs register (address 44h) bit description**

Legend: \* default value.

| Address | Register | Bit | Access     | Value      | Description                     |
|---------|----------|-----|------------|------------|---------------------------------|
| 44h     | PWMALL   | 7:0 | write only | 0000 0000* | duty cycle for all LEDn outputs |

**Remark:** Write to any of the PWM0 to PWM15 registers will overwrite the value in corresponding PWMn register programmed by PWMALL.

**7.3.13 IREFALL register: output current value for all LED outputs**

The output current setting for all outputs is held in this register. When this register is written to or updated, all LED outputs will be set to a current corresponding to this register value.

Writes to IREF0 to IREF15 will overwrite the output current settings.

**Table 26. IREFALL - Output gain control for all LED outputs (address 45h) bit description**

Legend: \* default value.

| Address | Register | Bit | Access     | Value | Description                               |
|---------|----------|-----|------------|-------|---|
| 45h     | IREFALL  | 7:0 | write only | 00h*  | Current gain setting for all LED outputs. |

**7.3.14 LED driver constant current outputs**

In LED display applications, PCA9955A provides nearly no current variations from channel to channel and from device to device. The maximum current skew between channels is less than ±4 % and less than ±6 % between devices.

**7.3.14.1 Adjusting output current**

The PCA9955A scales up the reference current ( $I_{ref}$ ) set by the external resistor ( $R_{ext}$ ) to sink the output current ( $I_O$ ) at each output port. The maximum output current for the outputs can be set using  $R_{ext}$ . In addition, the constant value for current drive at each of the outputs is independently programmable using command registers IREF0 to IREF15. Alternatively, programming the IREFALL register allows all outputs to be set at one current value determined by the value in IREFALL register.

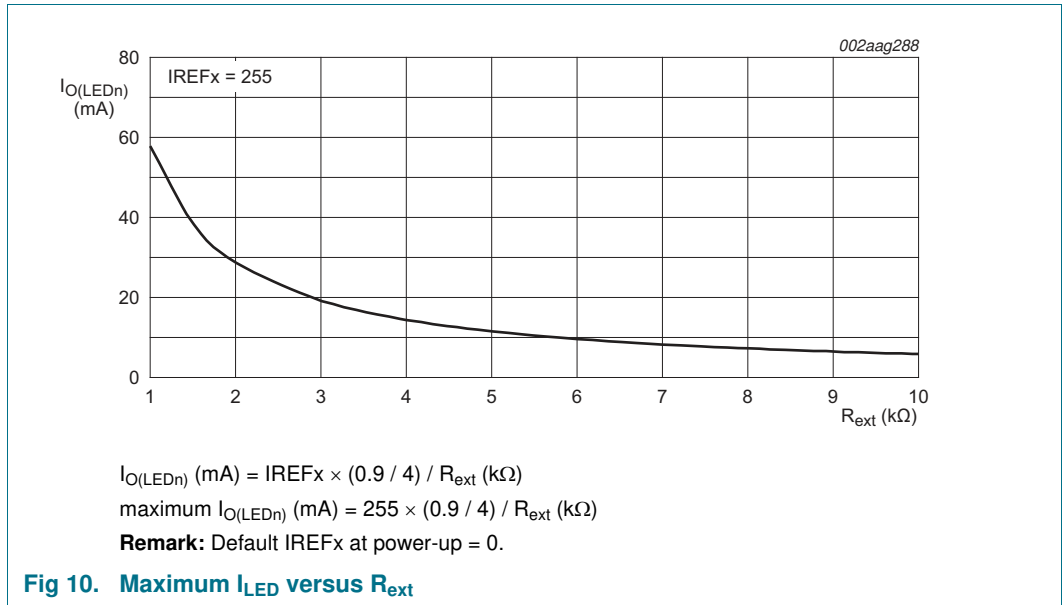
[Equation 4](#) and [Equation 5](#) can be used to calculate the minimum and maximum constant current values that can be programmed for the outputs for a chosen  $R_{ext}$ .

$$I_{O\_LED\_MIN} = \frac{900\text{ mV}}{R_{ext}} \times \frac{1}{4} \text{ (minimum constant current)} \tag{4}$$

$$I_{O\_LED\_MAX} = (255 \times I_{O\_LED\_MIN}) = \left( \frac{900\text{ mV}}{R_{ext}} \times \frac{255}{4} \right) \tag{5}$$

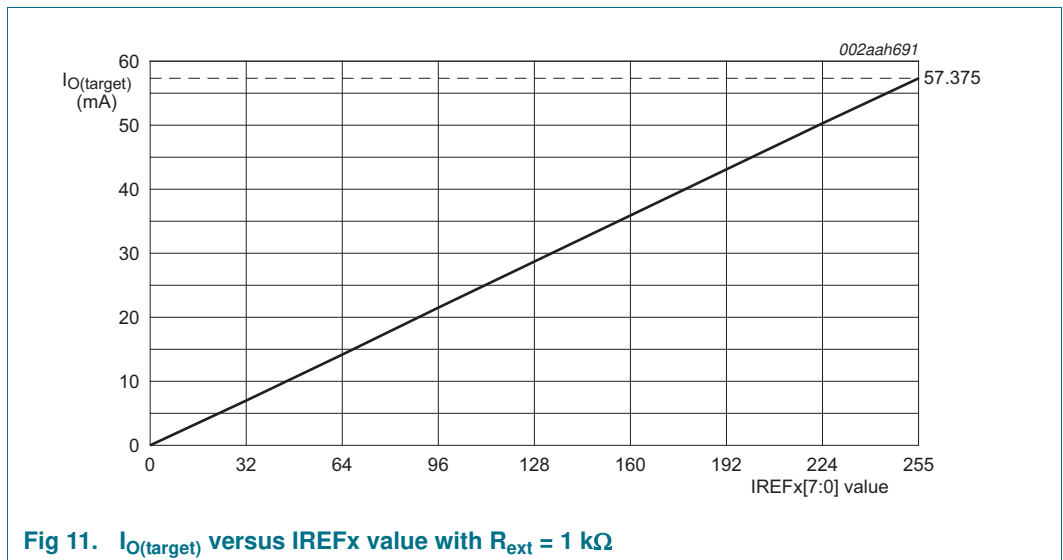
For a given IREFx setting,  $I_{O\_LED} = IREFx \times \frac{900\text{ mV}}{R_{ext}} \times \frac{1}{4}$ .





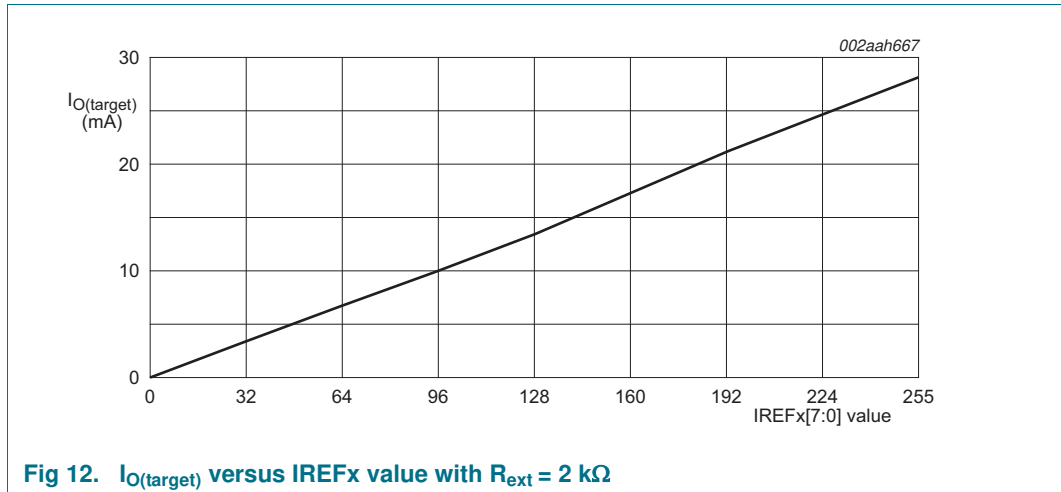
**Example 1:** If  $R_{ext} = 1 \text{ k}\Omega$ ,  $I_{O\_LED\_MIN} = 225 \text{ }\mu\text{A}$ ,  $I_{O\_LED\_MAX} = 57.375 \text{ mA}$  (as shown in [Figure 11](#)).

So each channel can be programmed with its individual IREFx in 256 steps and in 225  $\mu\text{A}$  increments to a maximum output current of 57.375 mA independently.



**Example 2:** If  $R_{ext} = 2\text{ k}\Omega$ ,  $I_{O\_LED\_MIN} = 112.5\ \mu\text{A}$ ,  $I_{O\_LED\_MAX} = 28.687\text{ mA}$  (as shown in [Figure 12](#)).

So each channel can be programmed with its individual IREFx in 256 steps and in  $112.5\ \mu\text{A}$  increments to a maximum output channel of 28.687 mA independently.



**Fig 12.**  $I_{O(target)}$  versus IREFx value with  $R_{ext} = 2\text{ k}\Omega$

7.3.15 LED error detection

The PCA9955A is capable of detecting an LED open or a short condition at its open-drain LED outputs. Users will recognize these faults by reading the status of a pair of error bits (ERRx) in error flag registers (EFLAGn) for each channel. Both LDRx value in LEDOUTx registers and IREFx value must be set to '00' for those unused LED output channels. If the output is selected to be fully on, individual dim, or individual and group dim, that channel will be tested.

The user can poll the ERROR status bit (bit 6 in MODE2 register) to check if there is a fault condition in any of the 16 channels. The EFLAGn registers can then be read to determine which channels are at fault and the type of fault in those channels. The error status reported by the EFLAGn register is real time information that will get self cleared once the error is fixed and write '1' to CLRERR bit (bit 4 in MODE2 register).

**Remark:** When LED outputs programmed with LDRx = 10 or 11 in LEDOUT[3:0] registers, checks for open and short-circuit will not occur if the PWM value in PWM0 to PWM15 registers is less than 8 or 255 (100 % duty cycle).

Table 27. EFLAG0 to EFLAG3 - Error flag registers (address 46h to 49h) bit description

Legend: \* default value.

| Address | Register | Bit | Symbol | Access | Value | Description                   |
|---------|----------|-----|--------|--------|-------|-------------------------------|
| 46h     | EFLAG0   | 7:6 | ERR3   | R only | 00*   | Error status for LED3 output  |
|         |          | 5:4 | ERR2   | R only | 00*   | Error status for LED2 output  |
|         |          | 3:2 | ERR1   | R only | 00*   | Error status for LED1 output  |
|         |          | 1:0 | ERR0   | R only | 00*   | Error status for LED0 output  |
| 47h     | EFLAG1   | 7:6 | ERR7   | R only | 00*   | Error status for LED7 output  |
|         |          | 5:4 | ERR6   | R only | 00*   | Error status for LED6 output  |
|         |          | 3:2 | ERR5   | R only | 00*   | Error status for LED5 output  |
|         |          | 1:0 | ERR4   | R only | 00*   | Error status for LED4 output  |
| 48h     | EFLAG2   | 7:6 | ERR11  | R only | 00*   | Error status for LED11 output |
|         |          | 5:4 | ERR10  | R only | 00*   | Error status for LED10 output |
|         |          | 3:2 | ERR9   | R only | 00*   | Error status for LED9 output  |
|         |          | 1:0 | ERR8   | R only | 00*   | Error status for LED8 output  |
| 49h     | EFLAG3   | 7:6 | ERR15  | R only | 00*   | Error status for LED15 output |
|         |          | 5:4 | ERR14  | R only | 00*   | Error status for LED14 output |
|         |          | 3:2 | ERR13  | R only | 00*   | Error status for LED13 output |
|         |          | 1:0 | ERR12  | R only | 00*   | Error status for LED12 output |

Table 28. ERRx bit description

| LED error detection status | ERRx  |       | Description                          |
|----------------------------|-------|-------|--------------------------------------|
|                            | Bit 1 | Bit 0 |                                      |
| No error                   | 0     | 0     | In normal operation and no error     |
| Short-circuit              | 0     | 1     | Detected LED short-circuit condition |
| Open-circuit               | 1     | 0     | Detected LED open-circuit condition  |
| DNE (Do Not Exist)         | 1     | 1     | This condition does not exist        |

7.3.15.1 Open-circuit detection principle

The PCA9955A LED open-circuit detection compares the effective current level  $I_O$  with the open load detection threshold current  $I_{th(det)}$ . If  $I_O$  is below the threshold  $I_{th(det)}$ , the PCA9955A detects an open load condition. This error status can be read out as an error flag through the EFLAGn registers. For open-circuit error detection of an output channel, that channel must be ON.

Table 29. Open-circuit detection

| State of output port | Condition of output current | Error status code                       | Description            |
|----------------------|-----------------------------|---|------------------------|
| OFF                  | $I_O = 0 \text{ mA}$        | 0                                       | detection not possible |
| ON                   | $I_O < I_{th(det)}$ [1]     | 1                                       | open-circuit           |
|                      | $I_O \geq I_{th(det)}$ [1]  | this channel open error status bit is 0 | normal                 |

[1]  $I_{th(det)} = 0.5 \times I_{O(target)}$  (typical). This threshold may be different for each I/O and only depends on IREFx and R<sub>ext</sub>.

7.3.15.2 Short-circuit detection principle

The LED short-circuit detection compares the effective output voltage level ( $V_O$ ) with the shorted-load detection threshold voltages  $V_{th(trig)}$ . If  $V_O$  is above the  $V_{th(trig)}$  threshold, the PCA9955A detects a shorted-load condition. If  $V_O$  is below the  $V_{th(trig)}$  threshold, no error is detected and error bit is set to '0'. This error status can be read out as an error flag through the EFLAGn registers. For short-circuit error detection of an output channel, that channel must be ON.

Table 30. Short-circuit detection

| State of output port | Condition of output voltage | Error status code                        | Description            |
|----------------------|-----------------------------|--|------------------------|
| OFF                  | -                           | 0  | detection not possible |
| ON                   | $V_O \geq V_{th(trig)}$ [1] | 1  | short-circuit          |
|                      | $V_O < V_{th(trig)}$ [1]    | this channel short error status bit is 0 | normal                 |

[1]  $V_{th} \approx 2.85 \text{ V}$ .

**Remark:** The error status distinguishes between an LED short condition and an LED open condition. Upon detecting an LED short or open, the corresponding LED outputs should be turned OFF to prevent heat dissipation for a short in the chip. Although an open event will not be harmful, the outputs should be turned OFF for both occasions to repair the LED string.

7.3.16 Overtemperature protection

If the PCA9955A chip temperature exceeds its limit ( $T_{th(otp)}$  rising, see Table 33), all output channels will be disabled until the temperature drops below its limit minus a small hysteresis ( $T_{th(otp)}$  hysteresis, see Table 33). When an overtemperature situation is encountered, the OVERTEMP flag (bit 7) is set in the MODE2 register. Once the die temperature reduces below the  $T_{th(otp)}$  rising -  $T_{th(otp)}$  hysteresis, the chip will return to the same condition it was prior to the overtemperature event and the OVERTEMP flag will be cleared.

## 7.4 Active LOW output enable input

The active LOW output enable ( $\overline{OE}$ ) pin on PCA9955A allows to enable or disable all the LED outputs at the same time.

- When a LOW level is applied to  $\overline{OE}$  pin, all the LED outputs are enabled.
- When a HIGH level is applied to  $\overline{OE}$  pin, all the LED outputs are high-impedance.

The  $\overline{OE}$  pin can be used as a synchronization signal to switch on/off several PCA9955A devices at the same time when LED drive output state is set fully ON (LDRx = 01 in LEDOUTx register) in these devices. This requires an external clock reference that provides blinking period and the duty cycle.

The  $\overline{OE}$  pin can also be used as an external dimming control signal. The frequency of the external clock must be high enough not to be seen by the human eye, and the duty cycle value determines the brightness of the LEDs.

**Remark:** Do not use  $\overline{OE}$  as an external blinking control signal when internal global blinking is selected (DMBLNK = 1, MODE2 register) since it will result in an undefined blinking pattern. Do not use  $\overline{OE}$  as an external dimming control signal when internal global dimming is selected (DMBLNK = 0, MODE2 register) since it will result in an undefined dimming pattern.

## 7.5 Power-on reset

When power is applied to  $V_{DD}$ , an internal power-on reset holds the PCA9955A in a reset condition until  $V_{DD}$  has reached  $V_{POR}$ . At this point, the reset condition is released and the PCA9955A registers and I<sup>2</sup>C-bus state machine are initialized to their default states (all zeroes) causing all the channels to be deselected. Thereafter,  $V_{DD}$  must be pulled lower than 1 V and stay LOW for longer than 20  $\mu$ s. The device will reset itself, and allow 2 ms for the device to fully wake up.

**Remark:** In order to guarantee a proper Power-On Reset operation for device, the rising rate of  $V_{DD}$  must be less than 3 ms per 1 V or less than 10 ms from 0 V to 3.3 V. Also,  $V_{DD}$  must return to 0 V for a minimum of 10 ms before rising again while  $V_{DD}$  power is re-cycling.

## 7.6 Hardware reset recovery

When a reset of PCA9955A is activated using an active LOW input on the  $\overline{RESET}$  pin, a reset pulse width of 2.5  $\mu$ s minimum is required. The maximum wait time after  $\overline{RESET}$  pin is released is 1.5 ms.

### 7.7 Software reset

The Software Reset Call (SWRST Call) allows all the devices in the I<sup>2</sup>C-bus to be reset to the power-up state value through a specific formatted I<sup>2</sup>C-bus command. To be performed correctly, it implies that the I<sup>2</sup>C-bus is functional and that there is no device hanging the bus.

The maximum wait time after software reset is 1 ms.

The SWRST Call function is defined as the following:

1. A START command is sent by the I<sup>2</sup>C-bus master.
2. The reserved General Call address '0000 000' with the R/W bit set to '0' (write) is sent by the I<sup>2</sup>C-bus master.
3. The PCA9955A device(s) acknowledge(s) after seeing the General Call address '0000 0000' (00h) only. If the R/W bit is set to '1' (read), no acknowledge is returned to the I<sup>2</sup>C-bus master.
4. Once the General Call address has been sent and acknowledged, the master sends 1 byte with 1 specific value (SWRST data byte 1):
  - a. Byte 1 = 06h: the PCA9955A acknowledges this value only. If byte 1 is not equal to 06h, the PCA9955A does not acknowledge it.

If more than 1 byte of data is sent, the PCA9955A does not acknowledge any more.

5. Once the correct byte (SWRST data byte 1) has been sent and correctly acknowledged, the master sends a STOP condition to end the SWRST function: the PCA9955A then resets to the default value (power-up value) and is ready to be addressed again within the specified bus free time (t<sub>BUF</sub>).

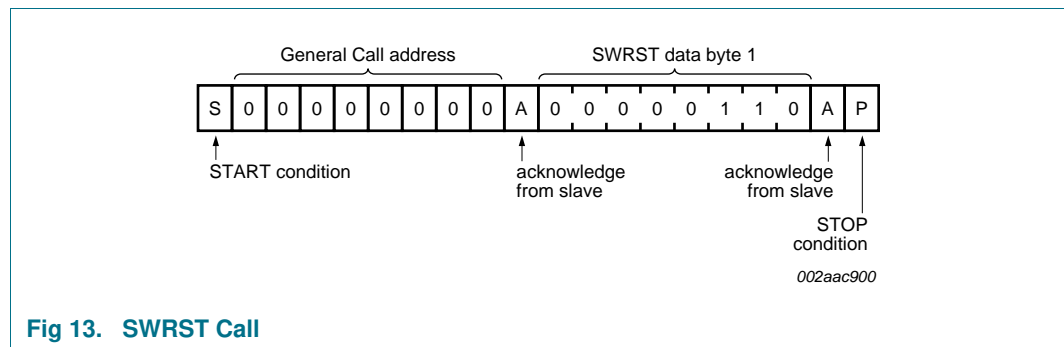


Fig 13. SWRST Call

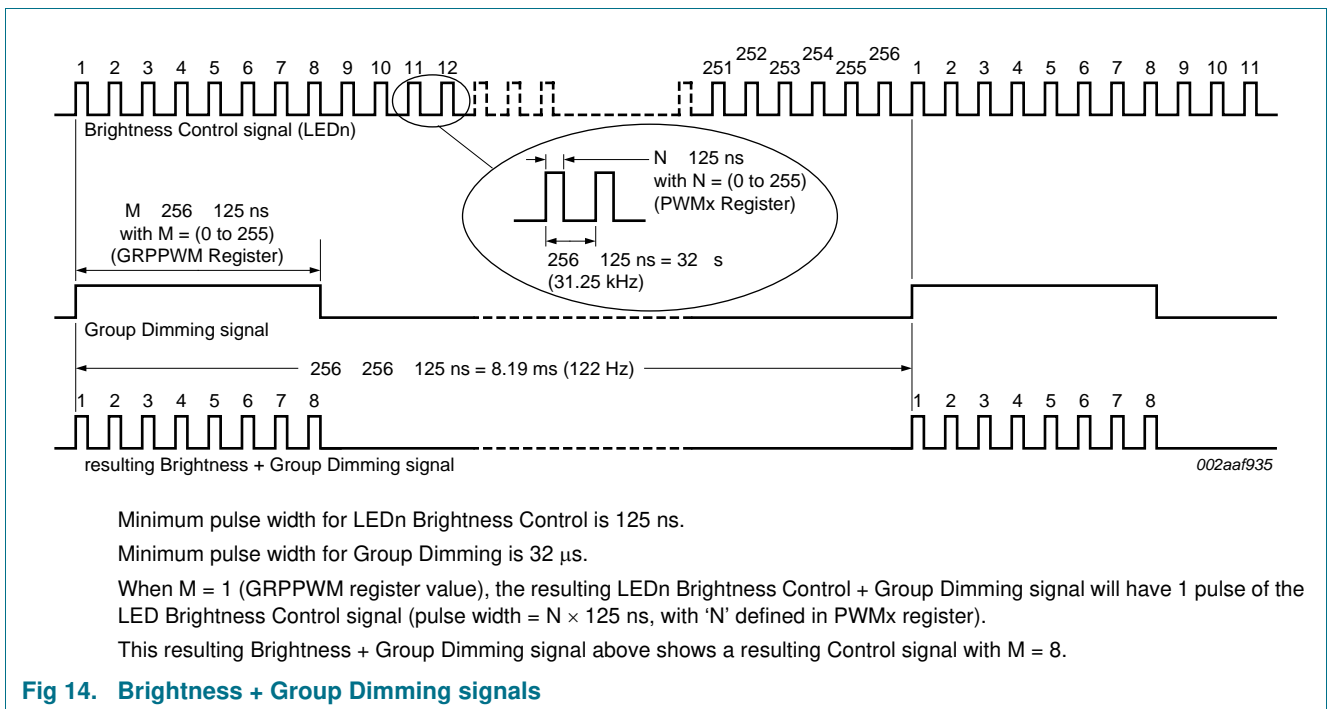
The I<sup>2</sup>C-bus master must interpret a non-acknowledge from the PCA9955A (at any time) as a 'SWRST Call Abort'. The PCA9955A does not initiate a reset of its registers. This happens only when the format of the SWRST Call sequence is not correct.

**7.8 Individual brightness control with group dimming/blinking**

A 31.25 kHz fixed frequency signal with programmable duty cycle (8 bits, 256 steps) is used to control individually the brightness for each LED.

On top of this signal, one of the following signals can be superimposed (this signal can be applied to the 16 LED outputs LED0 to LED15).

- A lower 122 Hz fixed frequency signal with programmable duty cycle (8 bits, 256 steps) is used to provide a global brightness control.
- A programmable frequency signal from 15 Hz to every 16.8 seconds (8 bits, 256 steps) with programmable duty cycle (8 bits, 256 steps) is used to provide a global blinking control.



**Fig 14. Brightness + Group Dimming signals**

## 8. Characteristics of the I<sup>2</sup>C-bus

The I<sup>2</sup>C-bus is for 2-way, 2-line communication between different ICs or modules. The two lines are a serial data line (SDA) and a serial clock line (SCL). Both lines must be connected to a positive supply via a pull-up resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

### 8.1 Bit transfer

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the HIGH period of the clock pulse as changes in the data line at this time will be interpreted as control signals (see [Figure 15](#)).

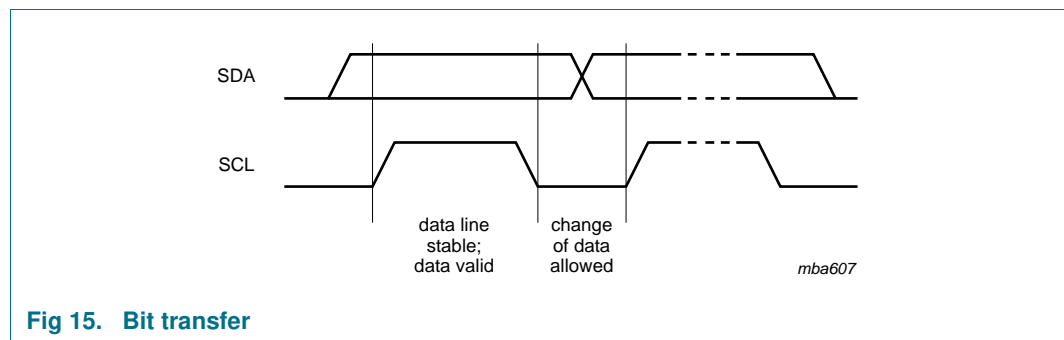


Fig 15. Bit transfer

#### 8.1.1 START and STOP conditions

Both data and clock lines remain HIGH when the bus is not busy. A HIGH-to-LOW transition of the data line while the clock is HIGH is defined as the START condition (S). A LOW-to-HIGH transition of the data line while the clock is HIGH is defined as the STOP condition (P) (see [Figure 16](#)).

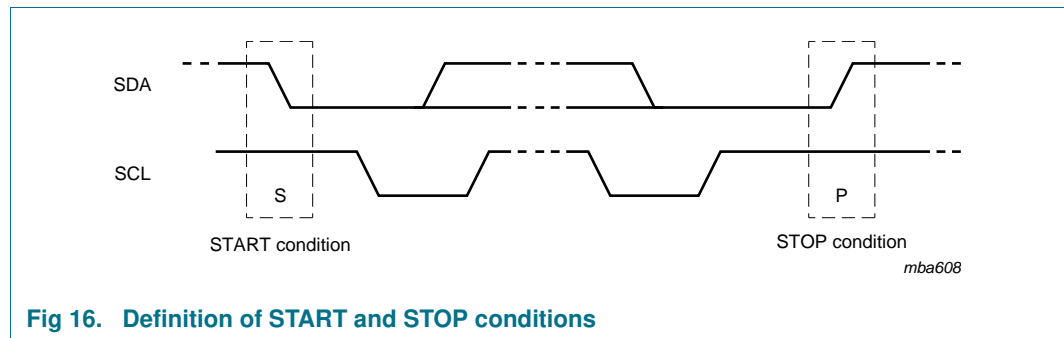


Fig 16. Definition of START and STOP conditions

### 8.2 System configuration

A device generating a message is a 'transmitter'; a device receiving is the 'receiver'. The device that controls the message is the 'master' and the devices which are controlled by the master are the 'slaves' (see [Figure 17](#)).



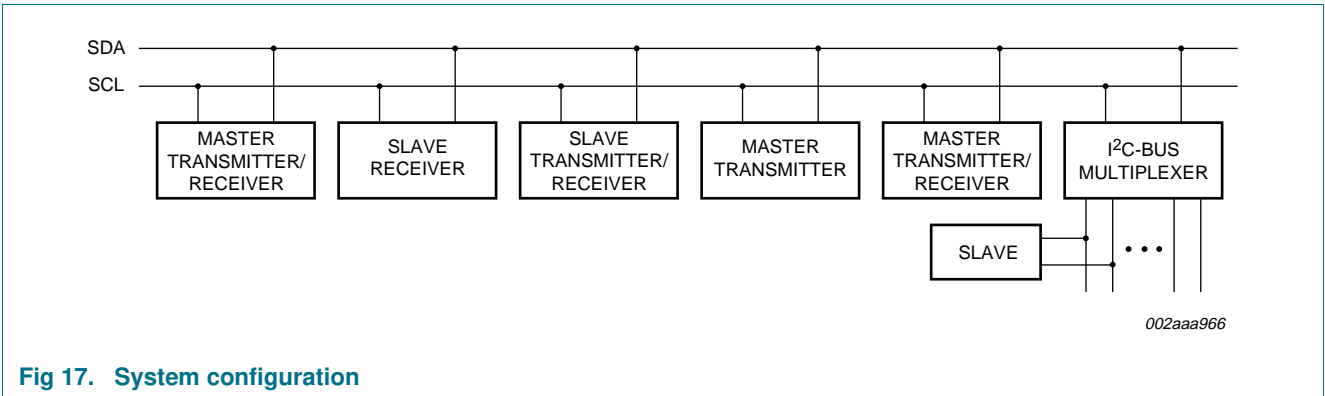


Fig 17. System configuration

### 8.3 Acknowledge

The number of data bytes transferred between the START and the STOP conditions from transmitter to receiver is not limited. Each byte of eight bits is followed by one acknowledge bit. The acknowledge bit is a HIGH level put on the bus by the transmitter, whereas the master generates an extra acknowledge related clock pulse.

A slave receiver which is addressed must generate an acknowledge after the reception of each byte. Also a master must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter. The device that acknowledges has to pull down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the HIGH period of the acknowledge related clock pulse; set-up time and hold time must be taken into account.

A master receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte that has been clocked out of the slave. In this event, the transmitter must leave the data line HIGH to enable the master to generate a STOP condition.

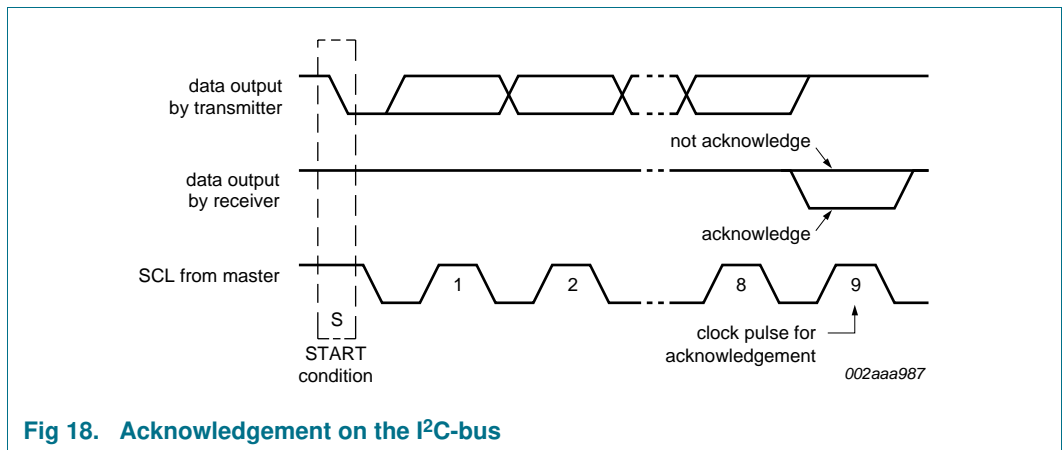
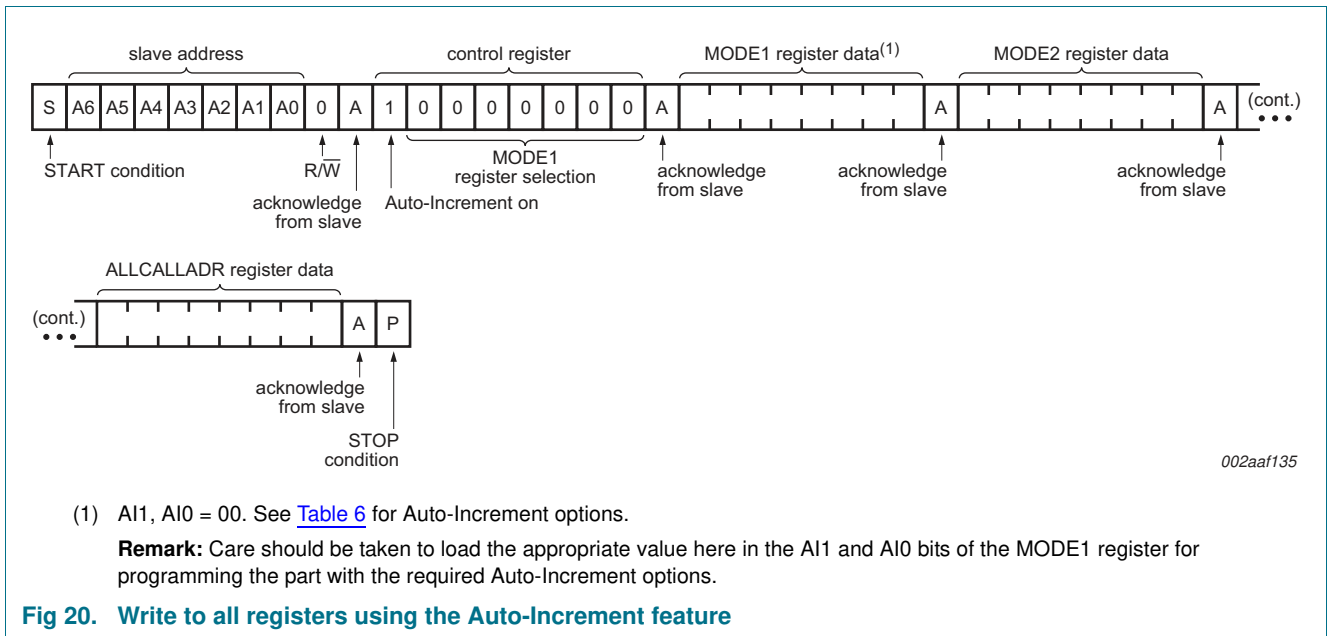
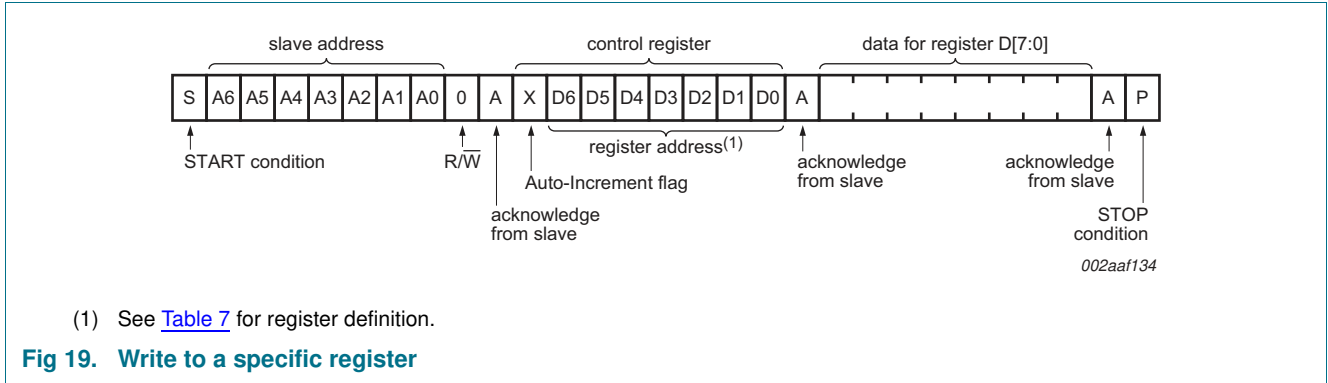
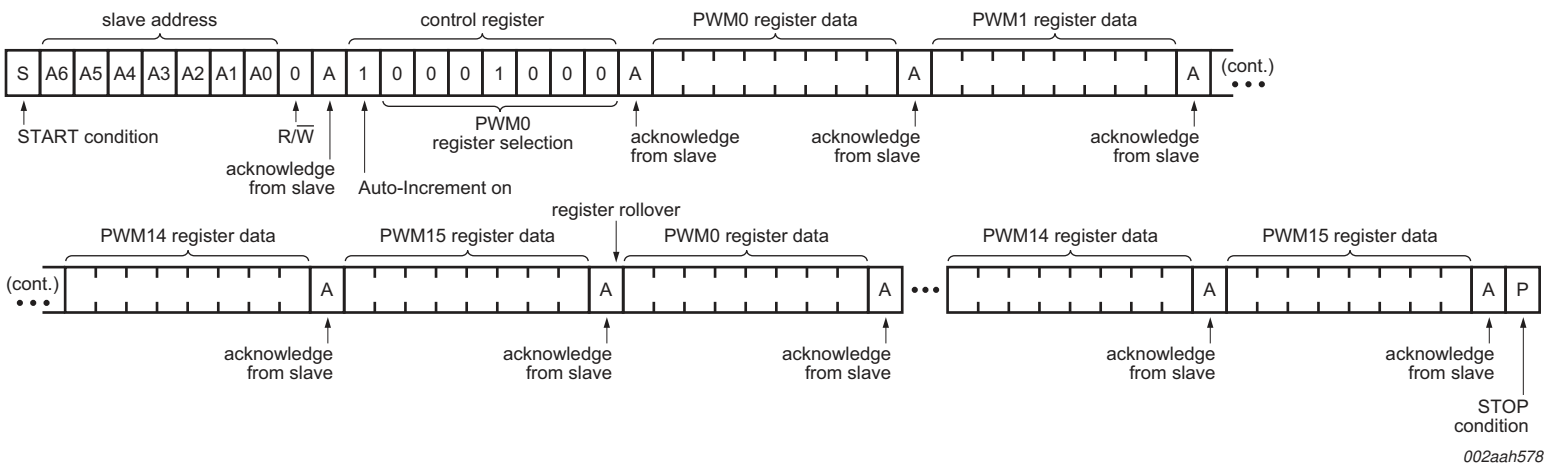


Fig 18. Acknowledgement on the I<sup>2</sup>C-bus

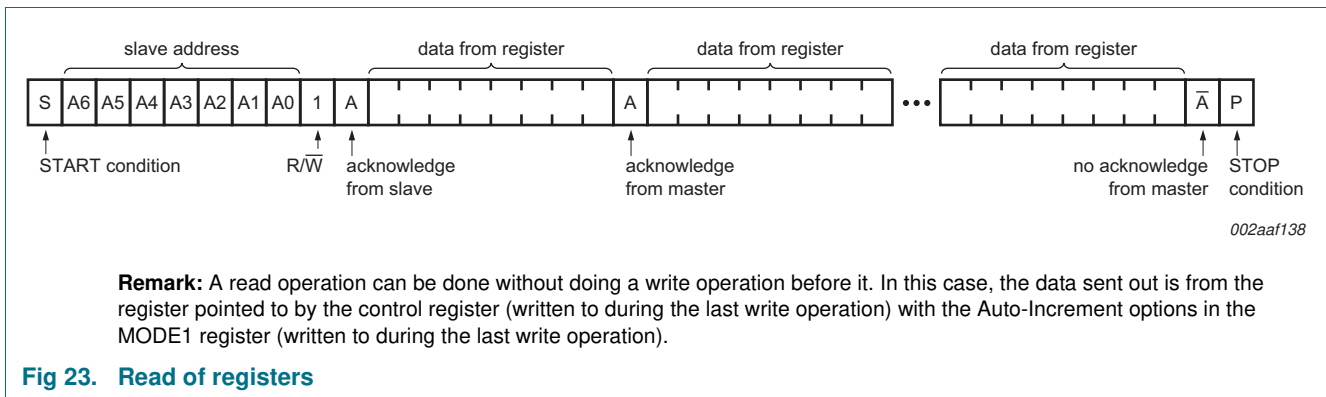
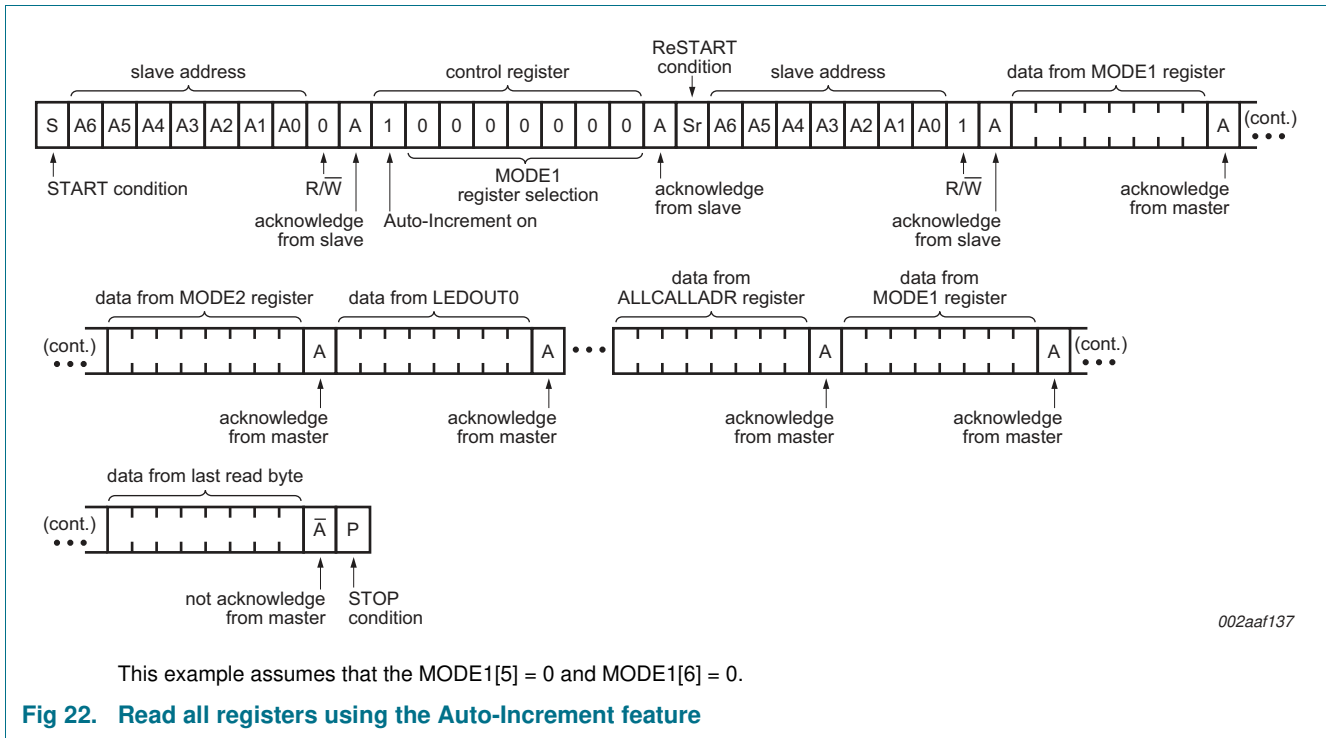
### 9. Bus transactions

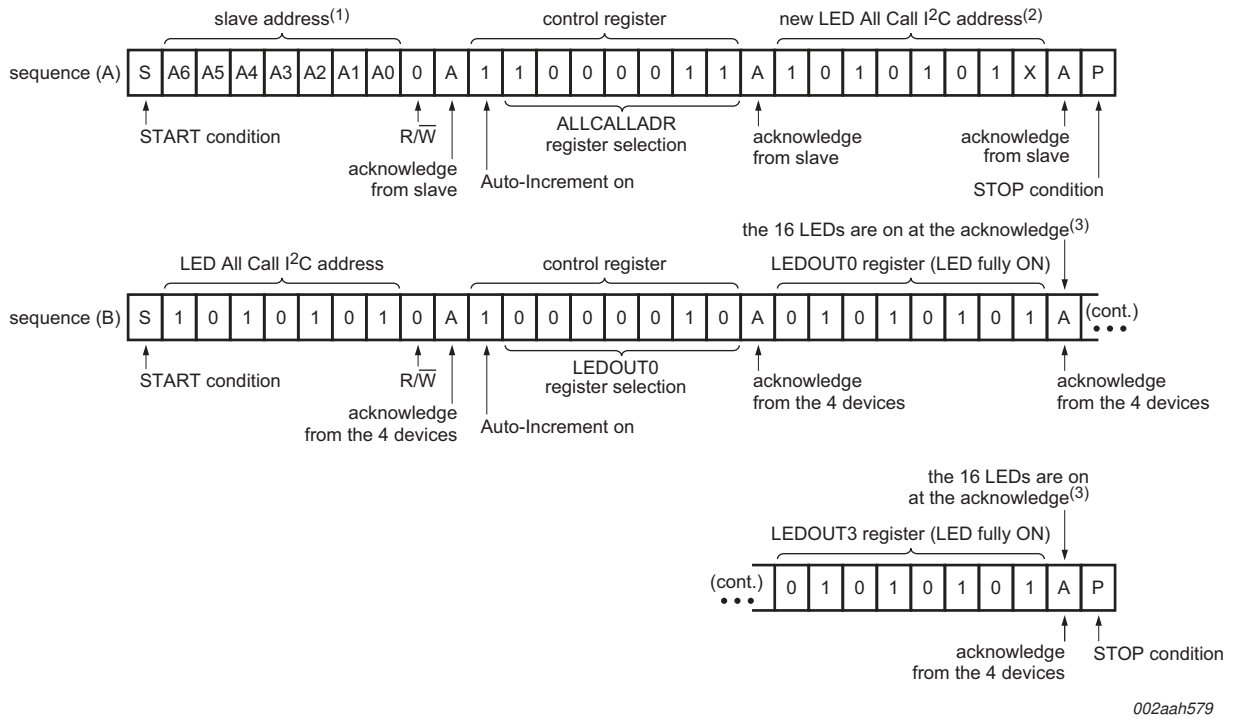




This example assumes that AIF + AI[1:0] = 101b.

**Fig 21. Multiple writes to Individual Brightness registers only using the Auto-Increment feature**

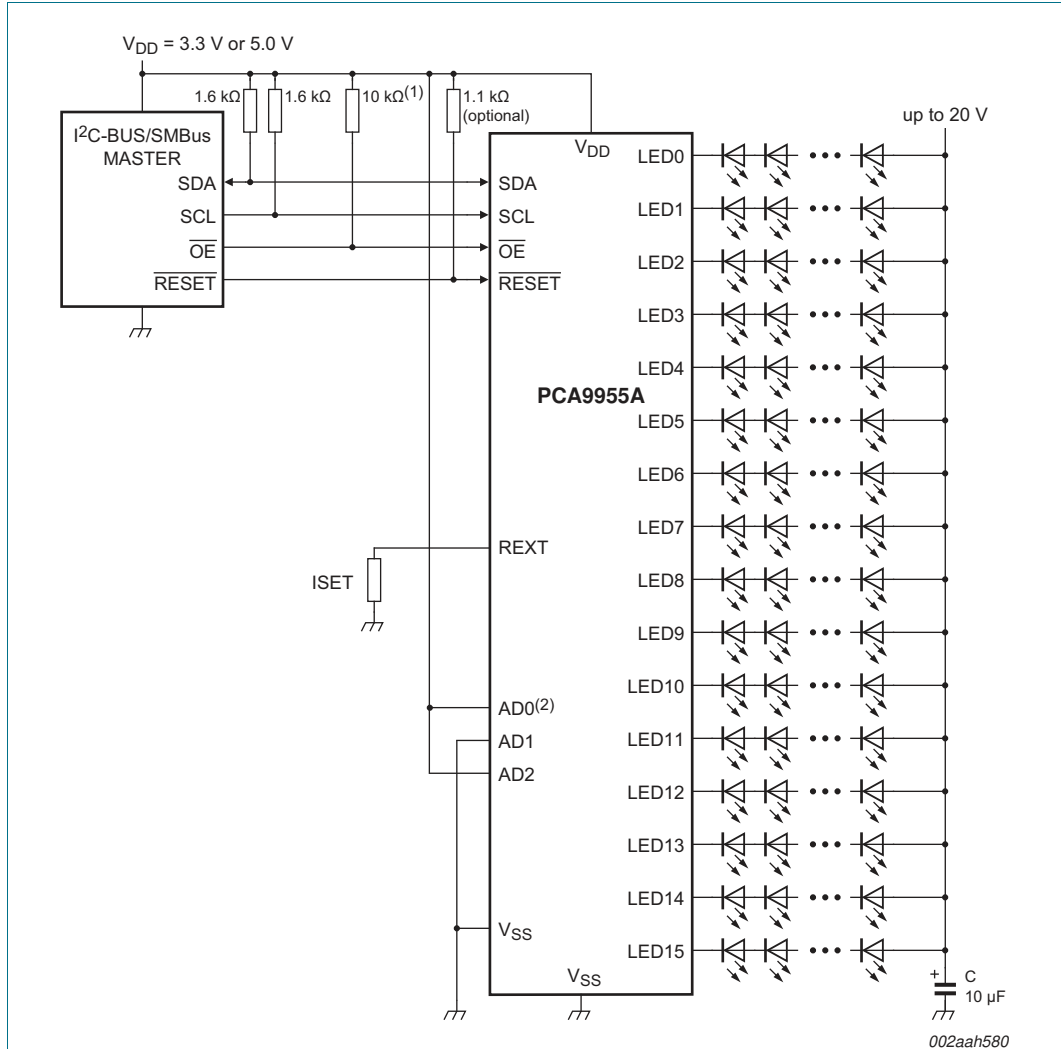




- (1) In this example, several PCA9955As are used and the same sequence (A) (above) is sent to each of them.
- (2) ALLCALL bit in MODE1 register is previously set to 1 for this example.
- (3) OCH bit in MODE2 register is previously set to 1 for this example.

**Fig 24. LED All Call I<sup>2</sup>C-bus address programming and LED All Call sequence example**

### 10. Application design-in information



- (1)  $\overline{OE}$  requires pull-up resistor if control signal from the master is open-drain.
- (2) I<sup>2</sup>C-bus address = 1101001 when AD0, AD2 tied to V<sub>DD</sub> and AD1 tied to V<sub>SS</sub> (see [Table 5](#)).

**Fig 25. Typical application**

#### 10.1 Thermal considerations

Since the PCA9955A device integrates 16 linear current sources, thermal considerations should be taken into account to prevent overheating, which can cause the device to go into thermal shutdown.

Perhaps the major contributor for device's overheating is the LED forward voltage mismatch. This is because it can cause significant voltage differences between the LED strings of the same type (for example, 2 V to 3 V), which ultimately translates into higher power dissipation in the device. The voltage drop across the LED channels of the device is given by the difference between the supply voltage and the LED forward voltage of each

LED string. Reducing this to a minimum (for example, 0.8 V) helps to keep the power dissipation down. Therefore LEDs binning is recommended to minimize LED voltage forward variation and reduce power dissipation in the device.

In order to ensure that the device will not go into thermal shutdown when operating under certain application conditions, its junction temperature ( $T_j$ ) should be calculated to ensure that is below the overtemperature threshold limit (130 °C). The  $T_j$  of the device depends on the ambient temperature ( $T_{amb}$ ), device's total power dissipation ( $P_{tot}$ ), and thermal resistance.

The device junction temperature can be calculated by using the following equation:

$$T_j = T_{amb} + R_{th(j-a)} \times P_{tot} \tag{6}$$

where:

- $T_j$  = junction temperature
- $T_{amb}$  = ambient temperature
- $R_{th(j-a)}$  = junction to ambient thermal resistance
- $P_{tot}$  = (device) total power dissipation

An example of this calculation is show below:

**Conditions:**

- $T_{amb} = 50\text{ °C}$
- $R_{th(j-a)} = 39\text{ °C/W}$  (per JEDEC 51 standard for multilayer PCB)
- $I_{LED} = 30\text{ mA / channel}$
- $I_{DD(max)} = 20\text{ mA}$
- $V_{DD} = 5\text{ V}$
- LEDs per channel = 5 LEDs / channel
- LED  $V_{F(typ)} = 3\text{ V}$  per LED (15 V total for 5 LEDs in series)
- LED  $V_F$  mismatch = 0.2 V per LED (1 V total for 5 LEDs in series)
- $V_{reg(drv)} = 0.8\text{ V}$  (This will be present only in the LED string with the highest LED forward voltage.)
- $V_{sup} = LED\ V_{F(typ)} + LED\ V_F\ mismatch + V_{reg(drv)} = 15\text{ V} + 1\text{ V} + 0.8\text{ V} = 16.8\text{ V}$

**$P_{tot}$  calculation:**

- $P_{tot} = IC\_power + LED\ drivers\_power;$
- $IC\_power = (I_{DD} \times V_{DD}) + (SDA\_V_{OL} \times I_{OL})$
- $IC\_power = (0.02\text{ A} \times 5\text{ V}) + (0.4\text{ V} \times 0.03\text{ A}) = 0.112\text{ W}$
- $LED\ drivers\_power = [(16 - 1) \times (I_{LED}) \times (LED\ V_F\ mismatch + V_{reg(drv)})] + (I_{LED} \times V_{reg(drv)})$
- $LED\ drivers\_power = [15 \times 0.03\text{ A} \times (1\text{ V} + 0.8\text{ V})] + (0.03\text{ A} \times 0.8\text{ V}) = 0.834\text{ W}$
- $P_{tot} = 0.112\text{ W} + 0.834\text{ W} = 0.946\text{ W}$

**T<sub>j</sub> calculation:**

$$T_j = T_{amb} + R_{th(j-a)} \times P_{tot}$$

$$T_j = 50 \text{ °C} + (39 \text{ °C/W} \times 0.946 \text{ W}) = 86.894 \text{ °C}$$

This confirms that the junction temperature is below the minimum overtemperature threshold of 130 °C, which ensures the device will not go into thermal shutdown under these conditions.

It is important to mention that the value of the thermal resistance junction-to-ambient ( $R_{th(j-a)}$ ) strongly depends in the PCB design. Therefore, the thermal pad of the device should be attached to a big enough PCB copper area to ensure proper thermal dissipation (similar to JEDEC 51 standard). Several thermal vias in the PCB thermal pad should be used as well to increase the effectiveness of the heat dissipation (for example, 15 thermal vias). The thermal vias should be distributed evenly in the PCB thermal pad.

Finally, it is important to point out that this calculation should be taken as a reference only and therefore evaluations should still be performed under the application environment and conditions to confirm proper system operation.

## 11. Limiting values

**Table 31. Limiting values**

*In accordance with the Absolute Maximum Rating System (IEC 60134).*

| Symbol                | Parameter                      | Conditions               | Min                   | Max  | Unit |
|-----------------------|--------------------------------|--------------------------|-----------------------|------|------|
| V <sub>DD</sub>       | supply voltage                 |                          | -0.5                  | +6.0 | V    |
| V <sub>I/O</sub>      | voltage on an input/output pin |                          | V <sub>SS</sub> - 0.5 | 5.5  | V    |
| V <sub>drv(LED)</sub> | LED driver voltage             |                          | V <sub>SS</sub> - 0.5 | 20   | V    |
| I <sub>O(LEDn)</sub>  | output current on pin LEDn     |                          | -                     | 65   | mA   |
| I <sub>SS</sub>       | ground supply current          |                          | -                     | 1.0  | A    |
| P <sub>tot</sub>      | total power dissipation        | T <sub>amb</sub> = 25 °C | -                     | 2.56 | W    |
|                       |                                | T <sub>amb</sub> = 85 °C | -                     | 1.03 | W    |
| T <sub>stg</sub>      | storage temperature            |                          | -65                   | +150 | °C   |
| T <sub>amb</sub>      | ambient temperature            | operating                | -40                   | +85  | °C   |
| T <sub>j</sub>        | junction temperature           |                          | -40                   | +125 | °C   |

## 12. Thermal characteristics

**Table 32. Thermal characteristics**

| Symbol               | Parameter                                   | Conditions | Typ    | Unit |
|----------------------|---|------------|--------|------|
| R <sub>th(j-a)</sub> | thermal resistance from junction to ambient | HTSSOP28   | [1] 39 | °C/W |

[1] Per JEDEC 51 standard for multilayer PCB and Wind Speed (m/s) = 0.



### 13. Static characteristics

**Table 33. Static characteristics**

$V_{DD} = 3\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ °C to }+85\text{ °C}$ ; unless otherwise specified.

| Symbol  | Parameter                              | Conditions   | Min              | Typ <sup>[1]</sup> | Max           | Unit          |
|---|--|--|------------------|--------------------|---------------|---------------|
| <b>Supply</b>                                 |  |  |                  |                    |               |               |
| $V_{DD}$                                      | supply voltage                         |  | 3                | -                  | 5.5           | V             |
| $I_{DD}$                                      | supply current                         | on pin $V_{DD}$ ; operating mode;<br>$f_{SCL} = 1\text{ MHz}$  |                  |                    |               |               |
|   |  | $R_{ext} = 2\text{ k}\Omega$ ; LED[15:0] = off;<br>IREF <sub>x</sub> = 00h   | -                | 11                 | 12            | mA            |
|   |  | $R_{ext} = 1\text{ k}\Omega$ ; LED[15:0] = off;<br>IREF <sub>x</sub> = 00h   | -                | 13                 | 14            | mA            |
|   |  | $R_{ext} = 2\text{ k}\Omega$ ; LED[15:0] = on;<br>IREF <sub>x</sub> = FFh  | -                | 15                 | 19            | mA            |
|   |  | $R_{ext} = 1\text{ k}\Omega$ ; LED[15:0] = on;<br>IREF <sub>x</sub> = FFh  | -                | 17                 | 21            | mA            |
| $I_{stb}$                                     | standby current                        | on pin $V_{DD}$ ; no load; $f_{SCL} = 0\text{ Hz}$ ;<br>MODE1[4] = 1; $V_I = V_{DD}$   |                  |                    |               |               |
|   |  | $V_{DD} = 3.3\text{ V}$  | -                | 170                | 600           | $\mu\text{A}$ |
|   |  | $V_{DD} = 5.5\text{ V}$  | -                | 170                | 700           | $\mu\text{A}$ |
| $V_{POR}$                                     | power-on reset voltage                 | no load; $V_I = V_{DD}$ or $V_{SS}$  | -                | 2                  | -             | V             |
| $V_{PDR}$                                     | power-down reset voltage               | no load; $V_I = V_{DD}$ or $V_{SS}$  | <sup>[2]</sup> - | 1                  | -             | V             |
| <b>Input SCL; input/output SDA</b>            |  |  |                  |                    |               |               |
| $V_{IL}$                                      | LOW-level input voltage                |  | -0.5             | -                  | +0.3 $V_{DD}$ | V             |
| $V_{IH}$                                      | HIGH-level input voltage               |  | 0.7 $V_{DD}$     | -                  | 5.5           | V             |
| $I_{OL}$                                      | LOW-level output current               | $V_{OL} = 0.4\text{ V}$ ; $V_{DD} = 3\text{ V}$  | 20               | -                  | -             | mA            |
|   |  | $V_{OL} = 0.4\text{ V}$ ; $V_{DD} = 5\text{ V}$  | 30               | -                  | -             | mA            |
| $I_L$   | leakage current                        | $V_I = V_{DD}$ or $V_{SS}$   | -1               | -                  | +1            | $\mu\text{A}$ |
| $C_i$   | input capacitance                      | $V_I = V_{SS}$   | -                | 6                  | 10            | pF            |
| <b>Current controlled outputs (LED[15:0])</b> |  |  |                  |                    |               |               |
| $I_{O(LEDn)}$                                 | output current on pin LED <sub>n</sub> | $V_O = 0.8\text{ V}$ ; IREF <sub>x</sub> = 80h; $R_{ext} = 1\text{ k}\Omega$   | 25               | -                  | 30            | mA            |
|   |  | $V_O = 0.8\text{ V}$ ; IREF <sub>x</sub> = FFh; $R_{ext} = 1\text{ k}\Omega$   | 50               | -                  | 60            | mA            |
| $\Delta I_O$                                  | output current variation               | $V_{DD} = 3.0\text{ V}$ ; $T_{amb} = 25\text{ °C}$ ; $V_O = 0.8\text{ V}$ ;<br>IREF <sub>x</sub> = 80h; $R_{ext} = 1\text{ k}\Omega$ ; guaranteed<br>by design |                  |                    |               |               |
|   |  | between bits (different ICs, same<br>channel) <sup>[3]</sup>   | -                | -                  | ±6            | %             |
|   |  | between bits (2 channels, same IC) <sup>[4]</sup>  | -                | -                  | ±4            | %             |
| $V_{reg(drv)}$                                | driver regulation voltage              | minimum regulation voltage;<br>IREF <sub>x</sub> = FFh; $R_{ext} = 1\text{ k}\Omega$   | 0.8              | 1                  | 20            | V             |
| $I_{L(off)}$                                  | off-state leakage current              | $V_O = 20\text{ V}$  | -                | -                  | 1             | $\mu\text{A}$ |
| $V_{trip}$                                    | trip voltage                           | short LED protection; Error flag will trip<br>during verification test if $V_O \geq V_{trip}$ ;<br>$R_{ext} = 1\text{ k}\Omega$                                | 2.7              | 2.85               | -             | V             |

**Table 33. Static characteristics ...continued**

$V_{DD} = 3\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C to }+85\text{ }^{\circ}\text{C}$ ; unless otherwise specified.

| Symbol                              | Parameter  | Conditions              | Min          | Typ <sup>[1]</sup> | Max           | Unit               |
|-------------------------------------|--|-------------------------|--------------|--------------------|---------------|--------------------|
| <b>OE input, RESET input</b>        |  |                         |              |                    |               |                    |
| $V_{IL}$                            | LOW-level input voltage                          |                         | -0.5         | -                  | +0.3 $V_{DD}$ | V                  |
| $V_{IH}$                            | HIGH-level input voltage                         |                         | 0.7 $V_{DD}$ | -                  | 5.5           | V                  |
| $I_{LI}$                            | input leakage current                            |                         | -1           | -                  | +1            | $\mu\text{A}$      |
| $C_i$                               | input capacitance                                |                         | -            | 3.7                | 5             | pF                 |
| <b>Address inputs AD2, AD1, AD0</b> |  |                         |              |                    |               |                    |
| $V_i$                               | input voltage                                    | voltage on an input pin | -0.5         | -                  | 5.5           | V                  |
| $I_{LI}$                            | input leakage current                            |                         | -1           | -                  | +1            | $\mu\text{A}$      |
| $C_i$                               | input capacitance                                |                         | -            | 3.7                | 5             | pF                 |
| <b>Overtemperature protection</b>   |  |                         |              |                    |               |                    |
| $T_{th(otp)}$                       | overtemperature protection threshold temperature | rising                  | 130          | -                  | 150           | $^{\circ}\text{C}$ |
|                                     |  | hysteresis              | 15           | -                  | 30            | $^{\circ}\text{C}$ |

[1] Typical limits at  $V_{DD} = 3.3\text{ V}$ ,  $T_{amb} = 25\text{ }^{\circ}\text{C}$ .

[2]  $V_{DD}$  must be lowered to 1 V in order to reset part.

[3] Part-to-part mismatch is calculated:

$$\Delta\% = \left( \frac{\left( \frac{I_{O(LED0)} + I_{O(LED1)} + \dots + I_{O(LED14)} + I_{O(LED15)}}{16} - \text{ideal output current} \right)}{\text{ideal output current}} \right) \times 100$$

where 'ideal output current' = 28.68 mA ( $R_{ext} = 1\text{ k}\Omega$ ,  $I_{REFx} = 80\text{h}$ ).

[4] Channel-to-channel mismatch is calculated:

$$\Delta\% = \left( \frac{I_{O(LEDn)} \text{ (where } n = 0 \text{ to } 15)}{\left( \frac{I_{O(LED0)} + I_{O(LED1)} + \dots + I_{O(LED14)} + I_{O(LED15)}}{16} \right)} - 1 \right) \times 100$$

## 14. Dynamic characteristics

Table 34. Dynamic characteristics

| Symbol              | Parameter   | Conditions | Standard-mode I <sup>2</sup> C-bus |      | Fast-mode I <sup>2</sup> C-bus |     | Fast-mode Plus I <sup>2</sup> C-bus |      | Unit |
|---------------------|---|------------|------------------------------------|------|--------------------------------|-----|-------------------------------------|------|------|
|                     |   |            | Min                                | Max  | Min                            | Max | Min                                 | Max  |      |
| f <sub>SCL</sub>    | SCL clock frequency   |            | 0                                  | 100  | 0                              | 400 | 0                                   | 1000 | kHz  |
| t <sub>BUF</sub>    | bus free time between a STOP and START condition                  |            | 4.7                                | -    | 1.3                            | -   | 0.5                                 | -    | μs   |
| t <sub>HD,STA</sub> | hold time (repeated) START condition                              |            | 4.0                                | -    | 0.6                            | -   | 0.26                                | -    | μs   |
| t <sub>SU,STA</sub> | set-up time for a repeated START condition                        |            | 4.7                                | -    | 0.6                            | -   | 0.26                                | -    | μs   |
| t <sub>SU,STO</sub> | set-up time for STOP condition                                    |            | 4.0                                | -    | 0.6                            | -   | 0.26                                | -    | μs   |
| t <sub>HD,DAT</sub> | data hold time  |            | 0                                  | -    | 0                              | -   | 0                                   | -    | ns   |
| t <sub>VD,ACK</sub> | data valid acknowledge time                                       | [1]        | 0.3                                | 3.45 | 0.1                            | 0.9 | 0.05                                | 0.45 | μs   |
| t <sub>VD,DAT</sub> | data valid time   | [2]        | 0.3                                | 3.45 | 0.1                            | 0.9 | 0.05                                | 0.45 | μs   |
| t <sub>SU,DAT</sub> | data set-up time  |            | 250                                | -    | 100                            | -   | 50                                  | -    | ns   |
| t <sub>LOW</sub>    | LOW period of the SCL clock                                       |            | 4.7                                | -    | 1.3                            | -   | 0.5                                 | -    | μs   |
| t <sub>HIGH</sub>   | HIGH period of the SCL clock                                      |            | 4.0                                | -    | 0.6                            | -   | 0.26                                | -    | μs   |
| t <sub>f</sub>      | fall time of both SDA and SCL signals                             | [3][4]     | -                                  | 300  | 20 + 0.1C <sub>b</sub> [5]     | 300 | -                                   | 120  | ns   |
| t <sub>r</sub>      | rise time of both SDA and SCL signals                             |            | -                                  | 1000 | 20 + 0.1C <sub>b</sub> [5]     | 300 | -                                   | 120  | ns   |
| t <sub>SP</sub>     | pulse width of spikes that must be suppressed by the input filter | [6]        | -                                  | 50   | -                              | 50  | -                                   | 50   | ns   |
| t <sub>w(rst)</sub> | reset pulse width   |            | 2.5                                | -    | 2.5                            | -   | 2.5                                 | -    | μs   |

[1] t<sub>VD,ACK</sub> = time for Acknowledgement signal from SCL LOW to SDA (out) LOW.

[2] t<sub>VD,DAT</sub> = minimum time for SDA data out to be valid following SCL LOW.

[3] A master device must internally provide a hold time of at least 300 ns for the SDA signal (refer to the V<sub>IL</sub> of the SCL signal) in order to bridge the undefined region of SCL's falling edge.

[4] The maximum t<sub>f</sub> for the SDA and SCL bus lines is specified at 300 ns. The maximum fall time (t<sub>f</sub>) for the SDA output stage is specified at 250 ns. This allows series protection resistors to be connected between the SDA and the SCL pins and the SDA/SCL bus lines without exceeding the maximum specified t<sub>f</sub>.

[5] C<sub>b</sub> = total capacitance of one bus line in pF.

[6] Input filters on the SDA and SCL inputs suppress noise spikes less than 50 ns.

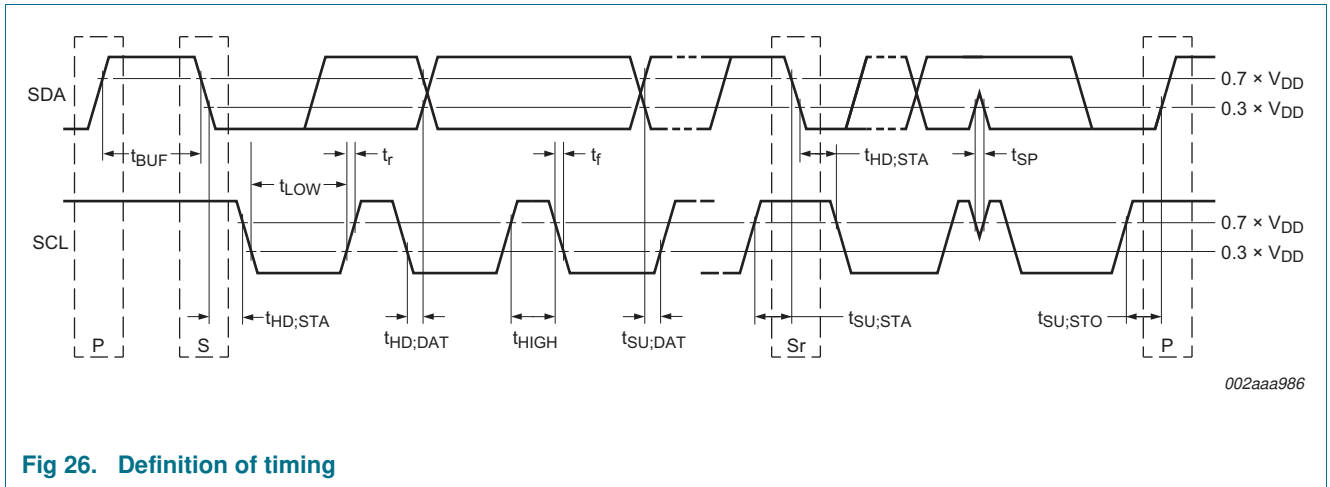


Fig 26. Definition of timing

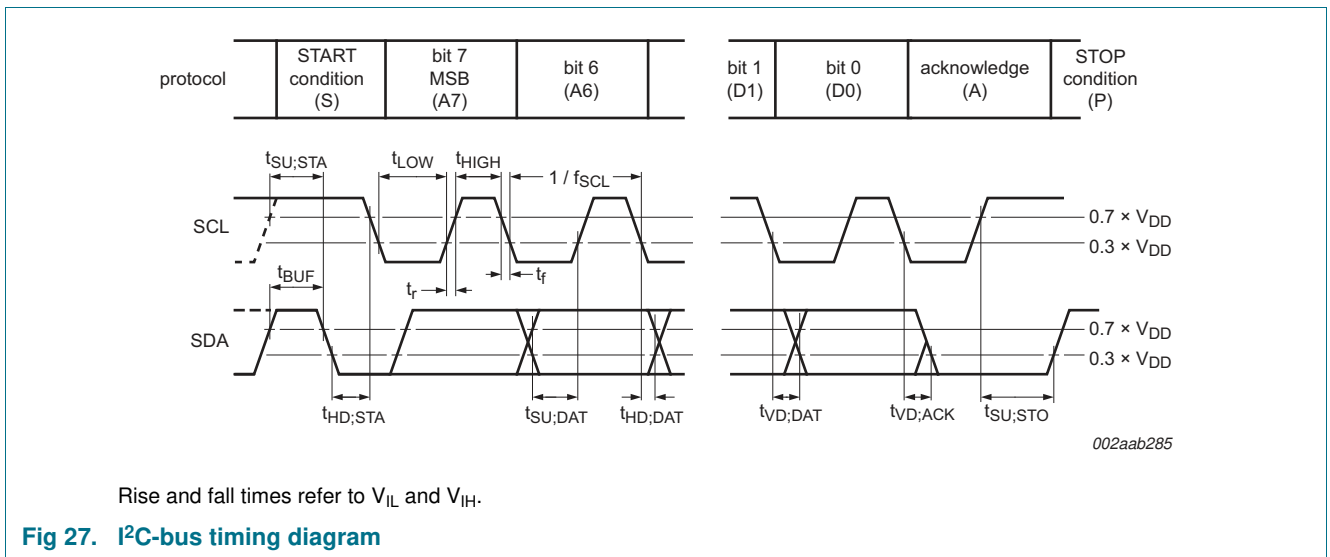


Fig 27. I<sup>2</sup>C-bus timing diagram

## 15. Test information

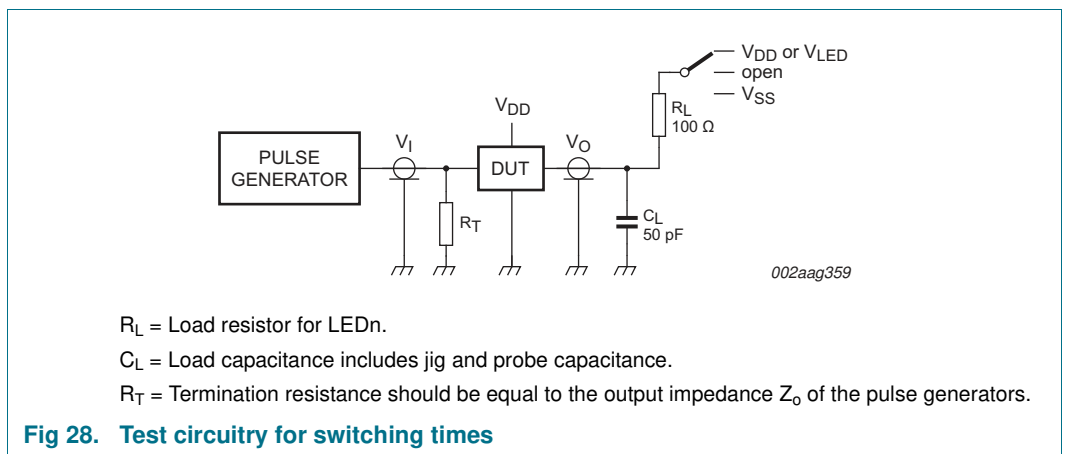


Fig 28. Test circuitry for switching times

16. Package outline

HTSSOP28: plastic thermal enhanced thin shrink small outline package; 28 leads; body width 4.4 mm; lead pitch 0.65 mm; exposed die pad

SOT1172-3

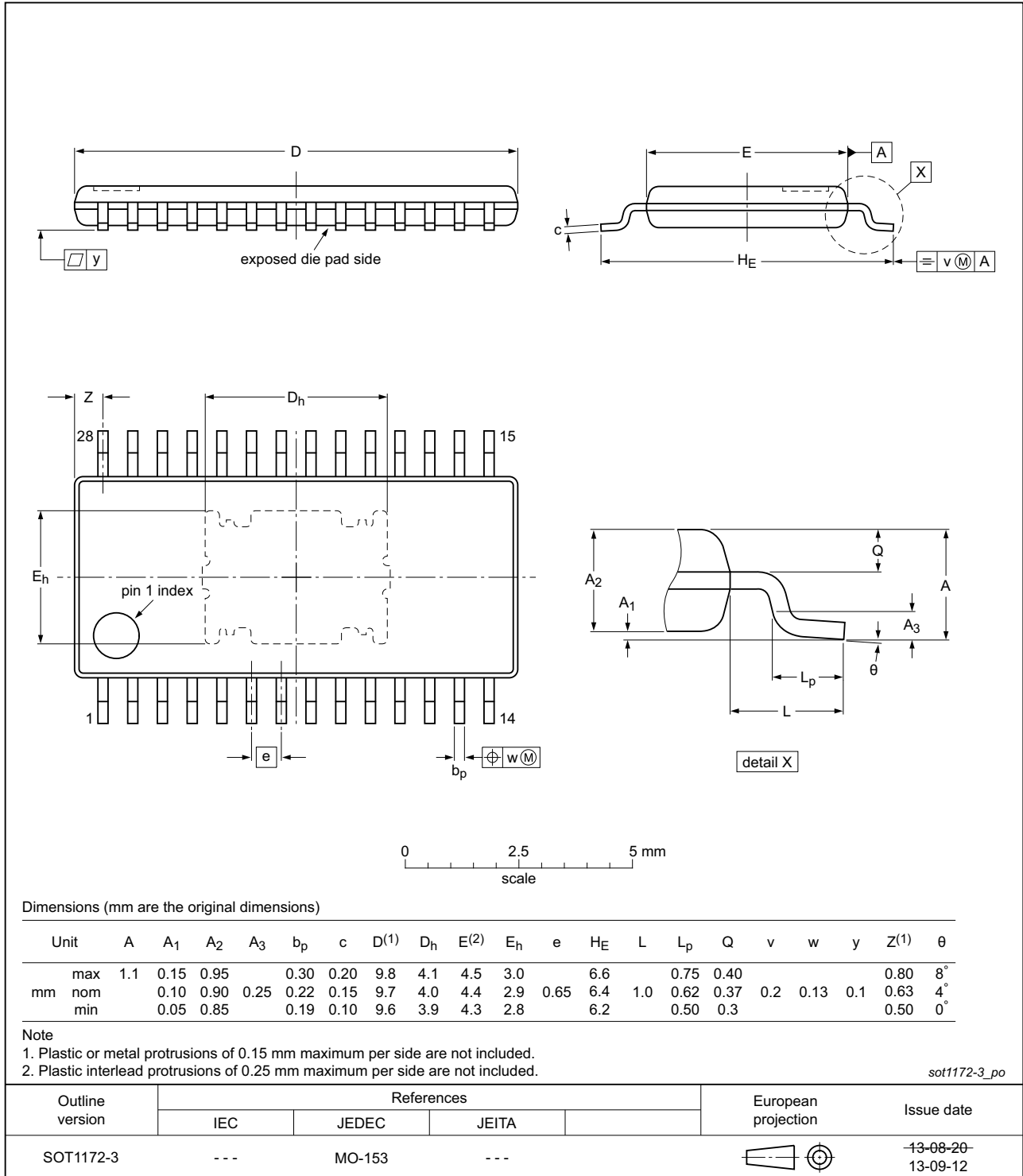


Fig 29. Package outline SOT1172-3 (HTSSOP28)

## 17. Handling information

All input and output pins are protected against ElectroStatic Discharge (ESD) under normal handling. When handling ensure that the appropriate precautions are taken as described in *JESD625-A* or equivalent standards.

## 18. Soldering of SMD packages

This text provides a very brief insight into a complex technology. A more in-depth account of soldering ICs can be found in Application Note *AN10365 "Surface mount reflow soldering description"*.

### 18.1 Introduction to soldering

Soldering is one of the most common methods through which packages are attached to Printed Circuit Boards (PCBs), to form electrical circuits. The soldered joint provides both the mechanical and the electrical connection. There is no single soldering method that is ideal for all IC packages. Wave soldering is often preferred when through-hole and Surface Mount Devices (SMDs) are mixed on one printed wiring board; however, it is not suitable for fine pitch SMDs. Reflow soldering is ideal for the small pitches and high densities that come with increased miniaturization.

### 18.2 Wave and reflow soldering

Wave soldering is a joining technology in which the joints are made by solder coming from a standing wave of liquid solder. The wave soldering process is suitable for the following:

- Through-hole components
- Leaded or leadless SMDs, which are glued to the surface of the printed circuit board

Not all SMDs can be wave soldered. Packages with solder balls, and some leadless packages which have solder lands underneath the body, cannot be wave soldered. Also, leaded SMDs with leads having a pitch smaller than ~0.6 mm cannot be wave soldered, due to an increased probability of bridging.

The reflow soldering process involves applying solder paste to a board, followed by component placement and exposure to a temperature profile. Leaded packages, packages with solder balls, and leadless packages are all reflow solderable.

Key characteristics in both wave and reflow soldering are:

- Board specifications, including the board finish, solder masks and vias
- Package footprints, including solder thieves and orientation
- The moisture sensitivity level of the packages
- Package placement
- Inspection and repair
- Lead-free soldering versus SnPb soldering

### 18.3 Wave soldering

Key characteristics in wave soldering are:

- Process issues, such as application of adhesive and flux, clinching of leads, board transport, the solder wave parameters, and the time during which components are exposed to the wave
- Solder bath specifications, including temperature and impurities

### 18.4 Reflow soldering

Key characteristics in reflow soldering are:

- Lead-free versus SnPb soldering; note that a lead-free reflow process usually leads to higher minimum peak temperatures (see [Figure 30](#)) than a SnPb process, thus reducing the process window
- Solder paste printing issues including smearing, release, and adjusting the process window for a mix of large and small components on one board
- Reflow temperature profile; this profile includes preheat, reflow (in which the board is heated to the peak temperature) and cooling down. It is imperative that the peak temperature is high enough for the solder to make reliable solder joints (a solder paste characteristic). In addition, the peak temperature must be low enough that the packages and/or boards are not damaged. The peak temperature of the package depends on package thickness and volume and is classified in accordance with [Table 35](#) and [36](#)

**Table 35. SnPb eutectic process (from J-STD-020D)**

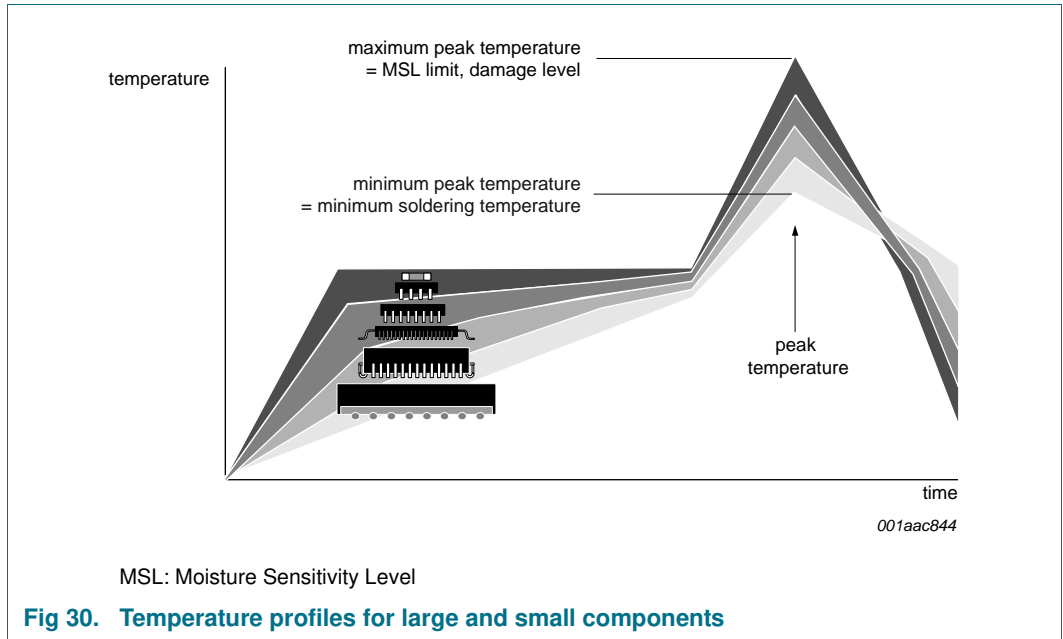
| Package thickness (mm) | Package reflow temperature (°C) |       |
|------------------------|---------------------------------|-------|
|                        | Volume (mm <sup>3</sup> )       |       |
|                        | < 350                           | ≥ 350 |
| < 2.5                  | 235                             | 220   |
| ≥ 2.5                  | 220                             | 220   |

**Table 36. Lead-free process (from J-STD-020D)**

| Package thickness (mm) | Package reflow temperature (°C) |             |        |
|------------------------|---------------------------------|-------------|--------|
|                        | Volume (mm <sup>3</sup> )       |             |        |
|                        | < 350                           | 350 to 2000 | > 2000 |
| < 1.6                  | 260                             | 260         | 260    |
| 1.6 to 2.5             | 260                             | 250         | 245    |
| > 2.5                  | 250                             | 245         | 245    |

Moisture sensitivity precautions, as indicated on the packing, must be respected at all times.

Studies have shown that small packages reach higher temperatures during reflow soldering, see [Figure 30](#).



For further information on temperature profiles, refer to Application Note AN10365 “Surface mount reflow soldering description”.



19. Soldering: PCB footprints

Footprint information for reflow soldering of HTSSOP28 package

SOT1172-3

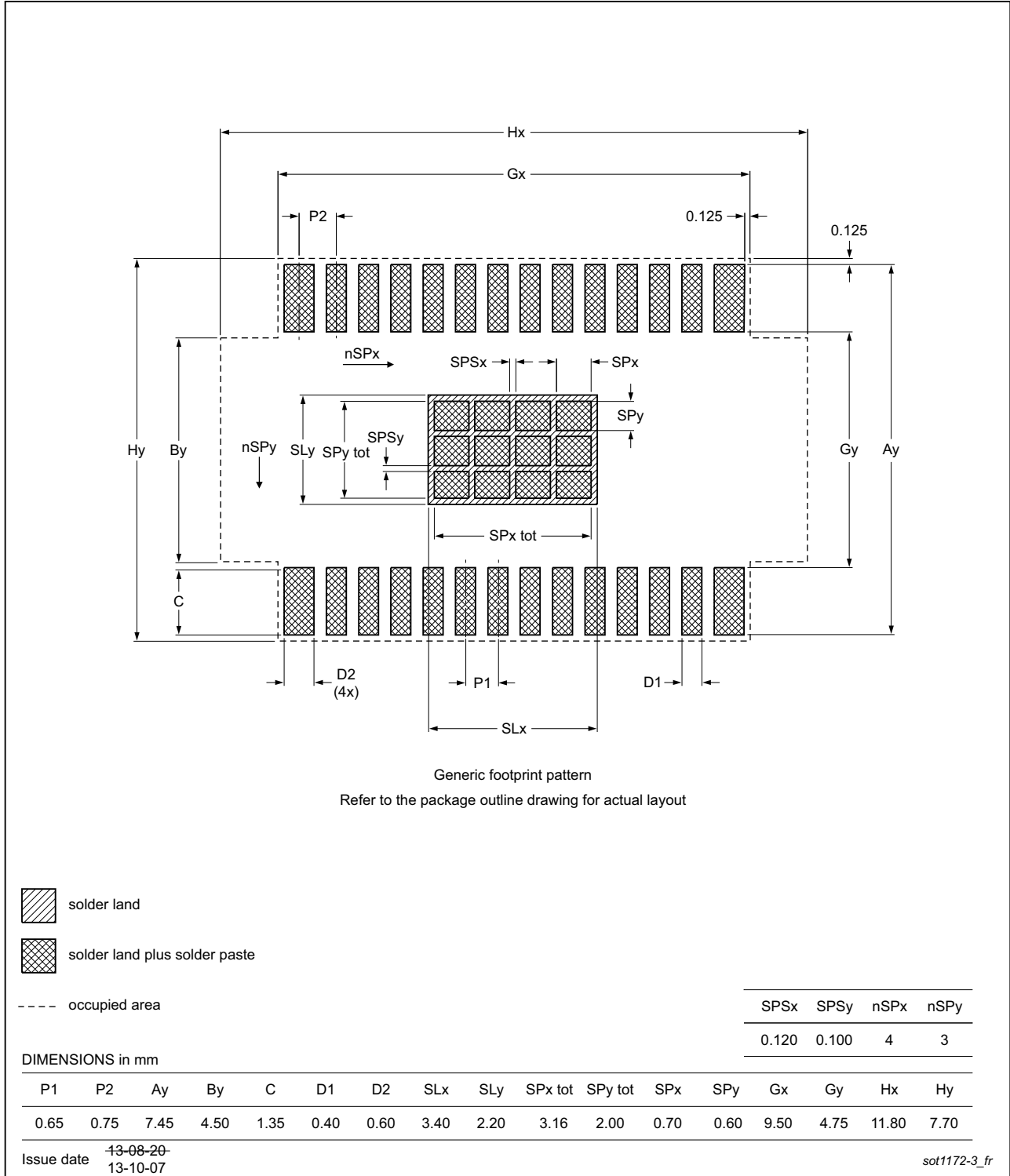


Fig 31. PCB footprint for SOT1172-3 (HTSSOP28); reflow soldering

## 20. Abbreviations

Table 37. Abbreviations

| Acronym              | Description                                |
|----------------------|--|
| ACK                  | Acknowledge                                |
| CDM                  | Charged-Device Model                       |
| DAC                  | Digital-to-Analog Converter                |
| DUT                  | Device Under Test                          |
| ESD                  | ElectroStatic Discharge                    |
| FET                  | Field-Effect Transistor                    |
| HBM                  | Human Body Model                           |
| I <sup>2</sup> C-bus | Inter-Integrated Circuit bus               |
| LED                  | Light Emitting Diode                       |
| LSB                  | Least Significant Bit                      |
| MCU                  | MicroController Unit                       |
| MSB                  | Most Significant Bit                       |
| NMOS                 | Negative-channel Metal-Oxide Semiconductor |
| PCB                  | Printed-Circuit Board                      |
| PMOS                 | Positive-channel Metal-Oxide Semiconductor |
| PWM                  | Pulse Width Modulation                     |
| RGB                  | Red/Green/Blue                             |
| RGBA                 | Red/Green/Blue/Amber                       |
| SMBus                | System Management Bus                      |

## 21. Revision history

Table 38. Revision history

| Document ID    | Release date  | Data sheet status      | Change notice | Supersedes   |
|----------------|---|------------------------|---------------|--------------|
| PCA9955A v.3   | 20141014  | Product data sheet     | -             | PCA9955A v.2 |
| Modifications: | <ul style="list-style-type: none"> <li><a href="#">Section 7.5 "Power-on reset"</a>: added remark.</li> </ul> |                        |               |              |
| PCA9955A v.2   | 20140403  | Product data sheet     | -             | PCA9955A v.1 |
| PCA9955A v.1   | 20140203  | Preliminary data sheet | -             | -            |

## 22. Legal information

### 22.1 Data sheet status

| Document status <sup>[1][2]</sup> | Product status <sup>[3]</sup> | Definition  |
|-----------------------------------|-------------------------------|---|
| Objective [short] data sheet      | Development                   | This document contains data from the objective specification for product development. |
| Preliminary [short] data sheet    | Qualification                 | This document contains data from the preliminary specification.                       |
| Product [short] data sheet        | Production                    | This document contains the product specification.                                     |

[1] Please consult the most recently issued document before initiating or completing a design.

[2] The term 'short data sheet' is explained in section "Definitions".

[3] The product status of device(s) described in this document may have changed since this document was published and may differ in case of multiple devices. The latest product status information is available on the Internet at URL <http://www.nxp.com>.

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