



**THE DATASHEET OF  
PCA9685BS,118**





# PCA9685

16-channel, 12-bit PWM Fm+ I<sup>2</sup>C-bus LED controller

Rev. 4 — 16 April 2015

Product data sheet

## 1. General description

The PCA9685 is an I<sup>2</sup>C-bus controlled 16-channel LED controller optimized for Red/Green/Blue/Amber (RGBA) color backlighting applications. Each LED output has its own 12-bit resolution (4096 steps) fixed frequency individual PWM controller that operates at a programmable frequency from a typical of 24 Hz to 1526 Hz with a duty cycle that is adjustable from 0 % to 100 % to allow the LED to be set to a specific brightness value. All outputs are set to the same PWM frequency.

Each LED output can be off or on (no PWM control), or set at its individual PWM controller value. The LED output driver is programmed to be either open-drain with a 25 mA current sink capability at 5 V or totem pole with a 25 mA sink, 10 mA source capability at 5 V. The PCA9685 operates with a supply voltage range of 2.3 V to 5.5 V and the inputs and outputs are 5.5 V tolerant. LEDs can be directly connected to the LED output (up to 25 mA, 5.5 V) or controlled with external drivers and a minimum amount of discrete components for larger current or higher voltage LEDs.

The PCA9685 is in the new Fast-mode Plus (Fm+) family. Fm+ devices offer higher frequency (up to 1 MHz) and more densely populated bus operation (up to 4000 pF).

Although the PCA9635 and PCA9685 have many similar features, the PCA9685 has some unique features that make it more suitable for applications such as LCD or LED backlighting and Ambientlight:

- The PCA9685 allows staggered LED output on and off times to minimize current surges. The on and off time delay is independently programmable for each of the 16 channels. This feature is not available in PCA9635.
- The PCA9685 has 4096 steps (12-bit PWM) of individual LED brightness control. The PCA9635 has only 256 steps (8-bit PWM).
- When multiple LED controllers are incorporated in a system, the PWM pulse widths between multiple devices may differ if PCA9635s are used. The PCA9685 has a programmable prescaler to adjust the PWM pulse widths of multiple devices.
- The PCA9685 has an external clock input pin that will accept user-supplied clock (50 MHz max.) in place of the internal 25 MHz oscillator. This feature allows synchronization of multiple devices. The PCA9635 does not have external clock input feature.
- Like the PCA9635, PCA9685 also has a built-in oscillator for the PWM control. However, the frequency used for PWM control in the PCA9685 is adjustable from about 24 Hz to 1526 Hz as compared to the typical 97.6 kHz frequency of the PCA9635. This allows the use of PCA9685 with external power supply controllers. All bits are set at the same frequency.
- The Power-On Reset (POR) default state of LEDn output pins is LOW in the case of PCA9685. It is HIGH for PCA9635.



The active LOW Output Enable input pin ( $\overline{OE}$ ) allows asynchronous control of the LED outputs and can be used to set all the outputs to a defined I<sup>2</sup>C-bus programmable logic state. The  $\overline{OE}$  can also be used to externally 'pulse width modulate' the outputs, which is useful when multiple devices need to be dimmed or blinked together using software control.

Software programmable LED All Call and three Sub Call I<sup>2</sup>C-bus addresses allow all or defined groups of PCA9685 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. Six hardware address pins allow up to 62 devices on the same bus.

The Software Reset (SWRST) General Call allows the master to perform a reset of the PCA9685 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 outputs to be set LOW. This allows an easy and quick way to reconfigure all device registers to the same condition via software.

## 2. Features and benefits

- 16 LED drivers. Each output programmable at:
  - ◆ Off
  - ◆ On
  - ◆ Programmable LED brightness
  - ◆ Programmable LED turn-on time to help reduce EMI
- 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
- 4096-step (12-bit) linear programmable brightness per LED output varying from fully off (default) to maximum brightness
- LED output frequency (all LEDs) typically varies from 24 Hz to 1526 Hz (Default of 1Eh in PRE\_SCALE register results in a 200 Hz refresh rate with oscillator clock of 25 MHz.)
- Sixteen totem pole outputs (sink 25 mA and source 10 mA at 5 V) with software programmable open-drain LED outputs selection (default at totem pole). No input function.
- Output state change programmable on the Acknowledge or the STOP Command to update outputs byte-by-byte or all at the same time (default to 'Change on STOP').
- Active LOW Output Enable ( $\overline{OE}$ ) input pin. LEDn outputs programmable to logic 1, logic 0 (default at power-up) or 'high-impedance' when  $\overline{OE}$  is HIGH.
- 6 hardware address pins allow 62 PCA9685 devices to be connected to the same I<sup>2</sup>C-bus
- Toggling  $\overline{OE}$  allows for hardware LED blinking
- 4 software programmable I<sup>2</sup>C-bus addresses (one LED All 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 PCA9685s 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 these I<sup>2</sup>C-bus address.
- Software Reset feature (SWRST General Call) allows the device to be reset through the I<sup>2</sup>C-bus

- 25 MHz typical internal oscillator requires no external components
- External 50 MHz (max.) clock input
- Internal power-on reset
- Noise filter on SDA/SCL inputs
- Edge rate control on outputs
- No output glitches on power-up
- Supports hot insertion
- Low standby current
- Operating power supply voltage range of 2.3 V to 5.5 V
- 5.5 V tolerant inputs
- -40 °C to +85 °C operation
- ESD protection exceeds 2000 V HBM per JESD22-A114, 200 V MM per JESD22-A115 and 1000 V CDM per JESD22-C101
- Latch-up testing is done to JEDEC Standard JESD78 which exceeds 100 mA
- Packages offered: TSSOP28, HVQFN28

### 3. Applications

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- RGB or RGBA LED drivers
- LED status information
- LED displays
- LCD backlights
- Keypad backlights for cellular phones or handheld devices

## 4. Ordering information

Table 1. Ordering information

| Type number                   | Topside mark | Package |  |          |
|-------------------------------|--------------|---------|--|----------|
|                               |              | Name    | Description  | Version  |
| PCA9685PW                     | PCA9685PW    | TSSOP28 | plastic thin shrink small outline package; 28 leads; body width 4.4 mm                             | SOT361-1 |
| PCA9685PW/Q900 <sup>[1]</sup> | PCA9685PW    | TSSOP28 | plastic thin shrink small outline package; 28 leads; body width 4.4 mm                             | SOT361-1 |
| PCA9685BS                     | P9685        | HVQFN28 | plastic thermal enhanced very thin quad flat package; no leads; 28 terminals; body 6 × 6 × 0.85 mm | SOT788-1 |

[1] PCA9685PW/Q900 is AEC-Q100 compliant. Contact [i2c.support@nxp.com](mailto:i2c.support@nxp.com) for PPAP.

### 4.1 Ordering options

Table 2. Ordering options

| Type number    | Orderable part number | Package | Packing method                          | Minimum order quantity | Temperature                         |
|----------------|-----------------------|---------|---|------------------------|-------------------------------------|
| PCA9685PW      | PCA9685PW,118         | TSSOP28 | REEL 13" Q1/T1<br>*STANDARD MARK<br>SMD | 2500                   | T <sub>amb</sub> = -40 °C to +85 °C |
| PCA9685PW/Q900 | PCA9685PW/Q900,118    | TSSOP28 | REEL 13" Q1/T1<br>*STANDARD MARK<br>SMD | 2500                   | T <sub>amb</sub> = -40 °C to +85 °C |
| PCA9685BS      | PCA9685BS,118         | HVQFN28 | REEL 13" Q1/T1<br>*STANDARD MARK<br>SMD | 4000                   | T <sub>amb</sub> = -40 °C to +85 °C |

### 5. Block diagram

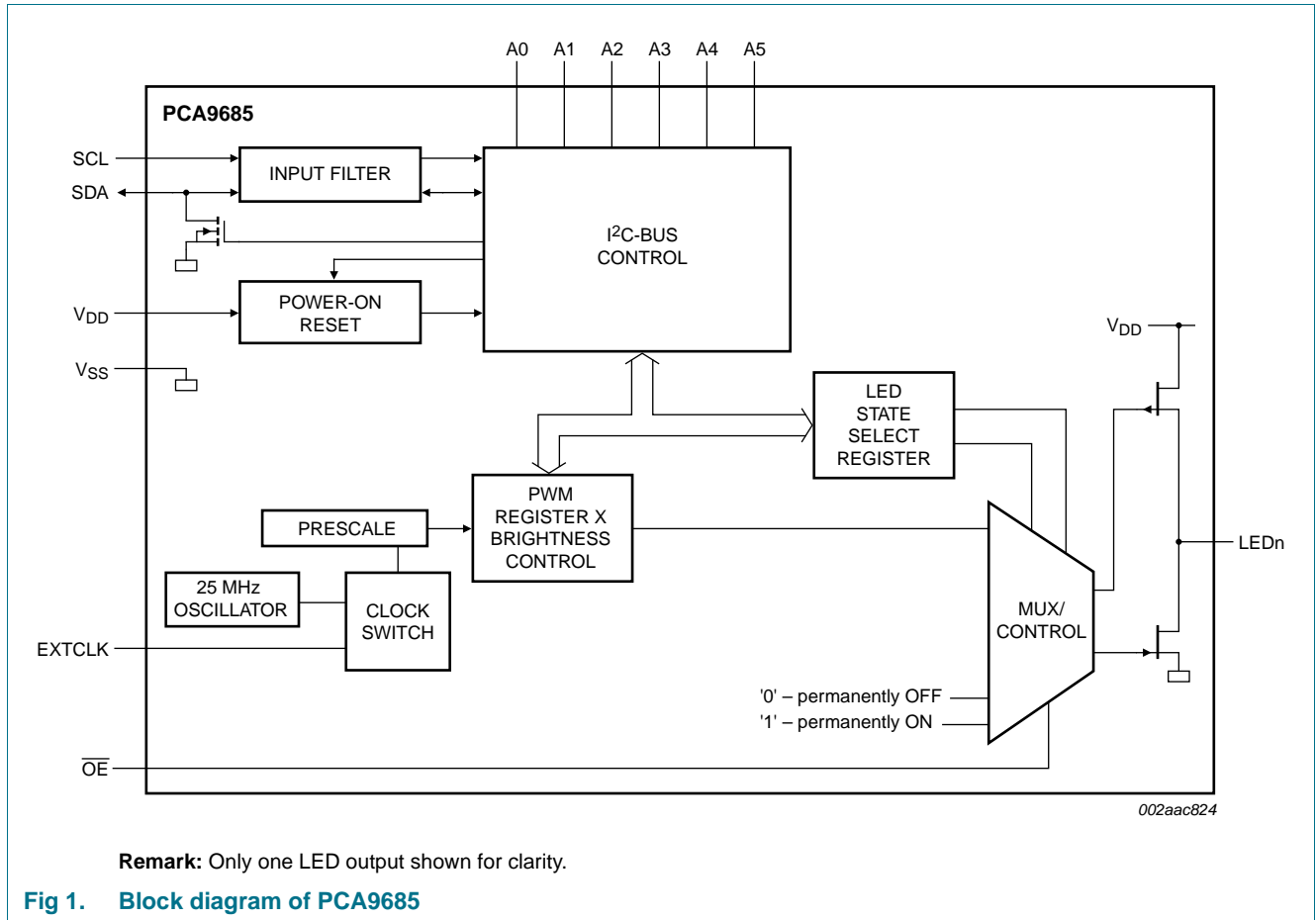


Fig 1. Block diagram of PCA9685

## 6. Pinning information

### 6.1 Pinning

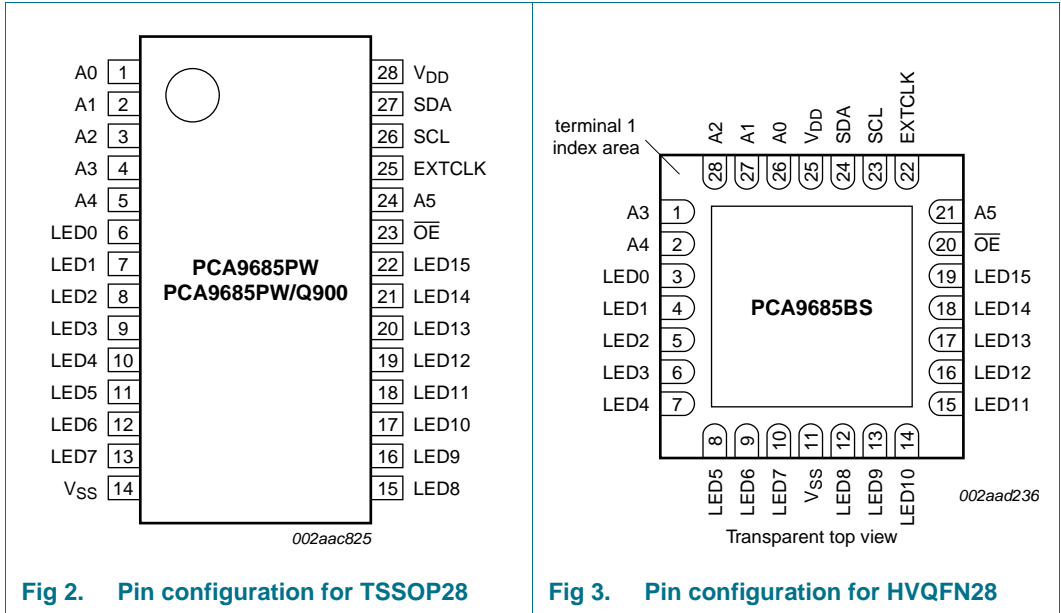


Fig 2. Pin configuration for TSSOP28

Fig 3. Pin configuration for HVQFN28

### 6.2 Pin description

Table 3. Pin description

| Symbol          | Pin     |                   | Type         | Description     |
|-----------------|---------|-------------------|--------------|-----------------|
|                 | TSSOP28 | HVQFN28           |              |                 |
| A0              | 1       | 26                | I            | address input 0 |
| A1              | 2       | 27                | I            | address input 1 |
| A2              | 3       | 28                | I            | address input 2 |
| A3              | 4       | 1                 | I            | address input 3 |
| A4              | 5       | 2                 | I            | address input 4 |
| LED0            | 6       | 3                 | O            | LED driver 0    |
| LED1            | 7       | 4                 | O            | LED driver 1    |
| LED2            | 8       | 5                 | O            | LED driver 2    |
| LED3            | 9       | 6                 | O            | LED driver 3    |
| LED4            | 10      | 7                 | O            | LED driver 4    |
| LED5            | 11      | 8                 | O            | LED driver 5    |
| LED6            | 12      | 9                 | O            | LED driver 6    |
| LED7            | 13      | 10                | O            | LED driver 7    |
| V <sub>SS</sub> | 14      | 11 <sup>[1]</sup> | power supply | supply ground   |
| LED8            | 15      | 12                | O            | LED driver 8    |
| LED9            | 16      | 13                | O            | LED driver 9    |
| LED10           | 17      | 14                | O            | LED driver 10   |
| LED11           | 18      | 15                | O            | LED driver 11   |

Table 3. Pin description ...continued

| Symbol                 | Pin     |         | Type         | Description                         |
|------------------------|---------|---------|--------------|-------------------------------------|
|                        | TSSOP28 | HVQFN28 |              |                                     |
| LED12                  | 19      | 16      | O            | LED driver 12                       |
| LED13                  | 20      | 17      | O            | LED driver 13                       |
| LED14                  | 21      | 18      | O            | LED driver 14                       |
| LED15                  | 22      | 19      | O            | LED driver 15                       |
| $\overline{\text{OE}}$ | 23      | 20      | I            | active LOW output enable            |
| A5                     | 24      | 21      | I            | address input 5                     |
| EXTCLK                 | 25      | 22      | I            | external clock input <sup>[2]</sup> |
| SCL                    | 26      | 23      | I            | serial clock line                   |
| SDA                    | 27      | 24      | I/O          | serial data line                    |
| V <sub>DD</sub>        | 28      | 25      | power supply | supply voltage                      |

[1] HVQFN28 package die supply ground is connected to both V<sub>SS</sub> pin and exposed center pad. V<sub>SS</sub> pin must be connected to supply ground for proper device operation. For enhanced thermal, electrical, and board level performance, the exposed pad needs to be soldered to the board using a corresponding thermal pad on the board and for proper heat conduction through the board, thermal vias need to be incorporated in the PCB in the thermal pad region.

[2] This pin must be grounded when this feature is not used.

## 7. Functional description

Refer to [Figure 1 “Block diagram of PCA9685”](#).

### 7.1 Device addresses

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

There are a maximum of 64 possible programmable addresses using the 6 hardware address pins. Two of these addresses, Software Reset and LED All Call, cannot be used because their default power-up state is ON, leaving a maximum of 62 addresses. Using other reserved addresses, as well as any other subcall address, will reduce the total number of possible addresses even further.

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

The I<sup>2</sup>C-bus slave address of the PCA9685 is shown in [Figure 4](#). To conserve power, no internal pull-up resistors are incorporated on the hardware selectable address pins and they must be pulled HIGH or LOW.

**Remark:** Using reserved I<sup>2</sup>C-bus addresses will interfere with other devices, but only if the devices are on the bus and/or the bus will be open to other I<sup>2</sup>C-bus systems at some later date. In a closed system where the designer controls the address assignment these addresses can be used since the PCA9685 treats them like any other address. The LED All Call, Software Reset and PCA9564 or PCA9665 slave address (if on the bus) can never be used for individual device addresses.

- PCA9685 LED All Call address (1110 000) and Software Reset (0000 0110) which are active on start-up

- PCA9564 (0000 000) or PCA9665 (1110 000) slave address which is active on start-up
- ‘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) which is used as the software reset address
- High-speed mode (Hs-mode) master code (0000 1XX)

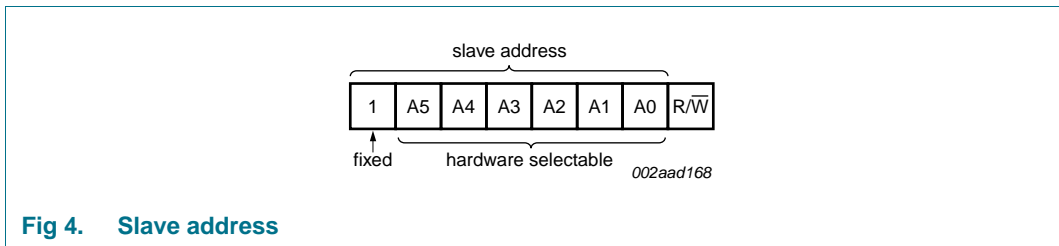


Fig 4. Slave address

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. PCA9685 sends an ACK when E0h (R/W = 0) or E1h (R/W = 1) is sent by the master.

See [Section 7.3.7 “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 the PCA9685s on the I<sup>2</sup>C-bus will 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

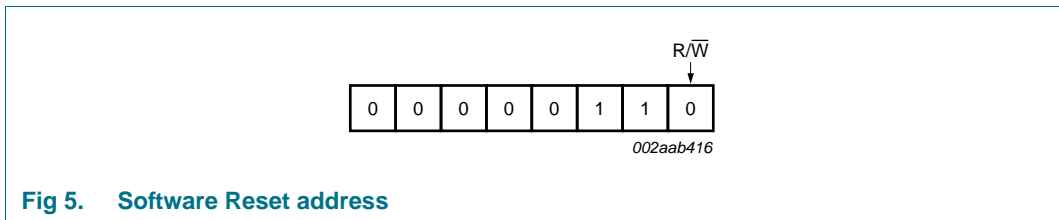
- 3 different I<sup>2</sup>C-bus addresses can be used
- Default power-up values:
  - SUBADR1 register: E2h or 1110 001X
  - SUBADR2 register: E4h or 1110 010X
  - SUBADR3 register: E8h or 1110 100X
- Programmable through I<sup>2</sup>C-bus (volatile programming)
- At power-up, Sub Call I<sup>2</sup>C-bus addresses are disabled. PCA9685 does not send an ACK when E2h (R/W = 0) or E3h (R/W = 1), E4h (R/W = 0) or E5h (R/W = 1), or E8h (R/W = 0) or E9h (R/W = 1) is sent by the master.

See [Section 7.3.6 “SUBADR1 to SUBADR3, I<sup>2</sup>C-bus subaddress 1 to 3”](#) 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.

**7.1.4 Software Reset I<sup>2</sup>C-bus address**

The address shown in [Figure 5](#) is used when a reset of the PCA9685 needs to be performed by the master. The Software Reset address (SWRST Call) must be used with  $R/\overline{W} = \text{logic } 0$ . If  $R/\overline{W} = \text{logic } 1$ , the PCA9685 does not acknowledge the SWRST. See [Section 7.6 “Software reset”](#) for more detail.



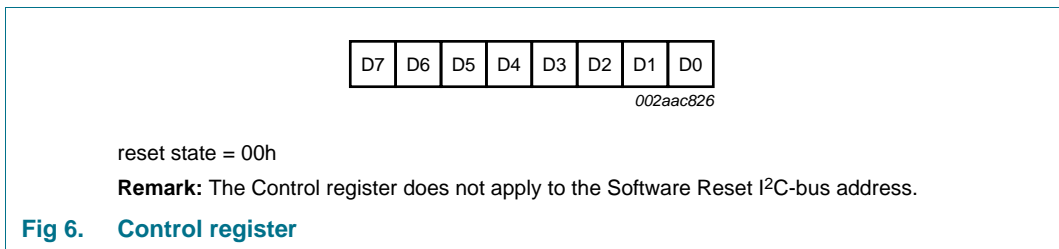
**Fig 5. Software Reset address**

**Remark:** The Software Reset I<sup>2</sup>C-bus address is a reserved address and cannot be used as a regular I<sup>2</sup>C-bus slave address or as an LED All Call or LED Sub Call address.

**7.2 Control register**

Following the successful acknowledgement of the slave address, LED All Call address or LED Sub Call address, the bus master will send a byte to the PCA9685, which will be stored in the Control register.

This register is used as a pointer to determine which register will be accessed.



**Fig 6. Control register**

### 7.3 Register definitions

Table 4. Register summary

| Register# (decimal) | Register# (hex) | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name       | Type       | Function                                  |
|---------------------|-----------------|----|----|----|----|----|----|----|----|------------|------------|---|
| 0                   | 00              | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | MODE1      | read/write | Mode register 1                           |
| 1                   | 01              | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | MODE2      | read/write | Mode register 2                           |
| 2                   | 02              | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | SUBADR1    | read/write | I <sup>2</sup> C-bus subaddress 1         |
| 3                   | 03              | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | SUBADR2    | read/write | I <sup>2</sup> C-bus subaddress 2         |
| 4                   | 04              | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | SUBADR3    | read/write | I <sup>2</sup> C-bus subaddress 3         |
| 5                   | 05              | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | ALLCALLADR | read/write | LED All Call I <sup>2</sup> C-bus address |
| 6                   | 06              | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 0  | LED0_ON_L  | read/write | LED0 output and brightness control byte 0 |
| 7                   | 07              | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 1  | LED0_ON_H  | read/write | LED0 output and brightness control byte 1 |
| 8                   | 08              | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | LED0_OFF_L | read/write | LED0 output and brightness control byte 2 |
| 9                   | 09              | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 1  | LED0_OFF_H | read/write | LED0 output and brightness control byte 3 |
| 10                  | 0A              | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | LED1_ON_L  | read/write | LED1 output and brightness control byte 0 |
| 11                  | 0B              | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 1  | LED1_ON_H  | read/write | LED1 output and brightness control byte 1 |
| 12                  | 0C              | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 0  | LED1_OFF_L | read/write | LED1 output and brightness control byte 2 |
| 13                  | 0D              | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 1  | LED1_OFF_H | read/write | LED1 output and brightness control byte 3 |
| 14                  | 0E              | 0  | 0  | 0  | 0  | 1  | 1  | 1  | 0  | LED2_ON_L  | read/write | LED2 output and brightness control byte 0 |
| 15                  | 0F              | 0  | 0  | 0  | 0  | 1  | 1  | 1  | 1  | LED2_ON_H  | read/write | LED2 output and brightness control byte 1 |
| 16                  | 10              | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | LED2_OFF_L | read/write | LED2 output and brightness control byte 2 |
| 17                  | 11              | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 1  | LED2_OFF_H | read/write | LED2 output and brightness control byte 3 |
| 18                  | 12              | 0  | 0  | 0  | 1  | 0  | 0  | 1  | 0  | LED3_ON_L  | read/write | LED3 output and brightness control byte 0 |
| 19                  | 13              | 0  | 0  | 0  | 1  | 0  | 0  | 1  | 1  | LED3_ON_H  | read/write | LED3 output and brightness control byte 1 |
| 20                  | 14              | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 0  | LED3_OFF_L | read/write | LED3 output and brightness control byte 2 |
| 21                  | 15              | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 1  | LED3_OFF_H | read/write | LED3 output and brightness control byte 3 |

Table 4. Register summary ...continued

| Register#<br>(decimal) | Register#<br>(hex) | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name       | Type       | Function                                  |
|------------------------|--------------------|----|----|----|----|----|----|----|----|------------|------------|---|
| 22                     | 16                 | 0  | 0  | 0  | 1  | 0  | 1  | 1  | 0  | LED4_ON_L  | read/write | LED4 output and brightness control byte 0 |
| 23                     | 17                 | 0  | 0  | 0  | 1  | 0  | 1  | 1  | 1  | LED4_ON_H  | read/write | LED4 output and brightness control byte 1 |
| 24                     | 18                 | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 0  | LED4_OFF_L | read/write | LED4 output and brightness control byte 2 |
| 25                     | 19                 | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 1  | LED4_OFF_H | read/write | LED4 output and brightness control byte 3 |
| 26                     | 1A                 | 0  | 0  | 0  | 1  | 1  | 0  | 1  | 0  | LED5_ON_L  | read/write | LED5 output and brightness control byte 0 |
| 27                     | 1B                 | 0  | 0  | 0  | 1  | 1  | 0  | 1  | 1  | LED5_ON_H  | read/write | LED5 output and brightness control byte 1 |
| 28                     | 1C                 | 0  | 0  | 0  | 1  | 1  | 1  | 0  | 0  | LED5_OFF_L | read/write | LED5 output and brightness control byte 2 |
| 29                     | 1D                 | 0  | 0  | 0  | 1  | 1  | 1  | 0  | 1  | LED5_OFF_H | read/write | LED5 output and brightness control byte 3 |
| 30                     | 1E                 | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 0  | LED6_ON_L  | read/write | LED6 output and brightness control byte 0 |
| 31                     | 1F                 | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | LED6_ON_H  | read/write | LED6 output and brightness control byte 1 |
| 32                     | 20                 | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | LED6_OFF_L | read/write | LED6 output and brightness control byte 2 |
| 33                     | 21                 | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | LED6_OFF_H | read/write | LED6 output and brightness control byte 3 |
| 34                     | 22                 | 0  | 0  | 1  | 0  | 0  | 0  | 1  | 0  | LED7_ON_L  | read/write | LED7 output and brightness control byte 0 |
| 35                     | 23                 | 0  | 0  | 1  | 0  | 0  | 0  | 1  | 1  | LED7_ON_H  | read/write | LED7 output and brightness control byte 1 |
| 36                     | 24                 | 0  | 0  | 1  | 0  | 0  | 1  | 0  | 0  | LED7_OFF_L | read/write | LED7 output and brightness control byte 2 |
| 37                     | 25                 | 0  | 0  | 1  | 0  | 0  | 1  | 0  | 1  | LED7_OFF_H | read/write | LED7 output and brightness control byte 3 |
| 38                     | 26                 | 0  | 0  | 1  | 0  | 0  | 1  | 1  | 0  | LED8_ON_L  | read/write | LED8 output and brightness control byte 0 |
| 39                     | 27                 | 0  | 0  | 1  | 0  | 0  | 1  | 1  | 1  | LED8_ON_H  | read/write | LED8 output and brightness control byte 1 |
| 40                     | 28                 | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | LED8_OFF_L | read/write | LED8 output and brightness control byte 2 |
| 41                     | 29                 | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 1  | LED8_OFF_H | read/write | LED8 output and brightness control byte 3 |

Table 4. Register summary ...continued

| Register# (decimal) | Register# (hex) | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name        | Type       | Function                                   |
|---------------------|-----------------|----|----|----|----|----|----|----|----|-------------|------------|--|
| 42                  | 2A              | 0  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | LED9_ON_L   | read/write | LED9 output and brightness control byte 0  |
| 43                  | 2B              | 0  | 0  | 1  | 0  | 1  | 0  | 1  | 1  | LED9_ON_H   | read/write | LED9 output and brightness control byte 1  |
| 44                  | 2C              | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 0  | LED9_OFF_L  | read/write | LED9 output and brightness control byte 2  |
| 45                  | 2D              | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 1  | LED9_OFF_H  | read/write | LED9 output and brightness control byte 3  |
| 46                  | 2E              | 0  | 0  | 1  | 0  | 1  | 1  | 1  | 0  | LED10_ON_L  | read/write | LED10 output and brightness control byte 0 |
| 47                  | 2F              | 0  | 0  | 1  | 0  | 1  | 1  | 1  | 1  | LED10_ON_H  | read/write | LED10 output and brightness control byte 1 |
| 48                  | 30              | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | LED10_OFF_L | read/write | LED10 output and brightness control byte 2 |
| 49                  | 31              | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 1  | LED10_OFF_H | read/write | LED10 output and brightness control byte 3 |
| 50                  | 32              | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 0  | LED11_ON_L  | read/write | LED11 output and brightness control byte 0 |
| 51                  | 33              | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 1  | LED11_ON_H  | read/write | LED11 output and brightness control byte 1 |
| 52                  | 34              | 0  | 0  | 1  | 1  | 0  | 1  | 0  | 0  | LED11_OFF_L | read/write | LED11 output and brightness control byte 2 |
| 53                  | 35              | 0  | 0  | 1  | 1  | 0  | 1  | 0  | 1  | LED11_OFF_H | read/write | LED11 output and brightness control byte 3 |
| 54                  | 36              | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | LED12_ON_L  | read/write | LED12 output and brightness control byte 0 |
| 55                  | 37              | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | LED12_ON_H  | read/write | LED12 output and brightness control byte 1 |
| 56                  | 38              | 0  | 0  | 1  | 1  | 1  | 0  | 0  | 0  | LED12_OFF_L | read/write | LED12 output and brightness control byte 2 |
| 57                  | 39              | 0  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | LED12_OFF_H | read/write | LED12 output and brightness control byte 3 |
| 58                  | 3A              | 0  | 0  | 1  | 1  | 1  | 0  | 1  | 0  | LED13_ON_L  | read/write | LED13 output and brightness control byte 0 |
| 59                  | 3B              | 0  | 0  | 1  | 1  | 1  | 0  | 1  | 1  | LED13_ON_H  | read/write | LED13 output and brightness control byte 1 |
| 60                  | 3C              | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 0  | LED13_OFF_L | read/write | LED13 output and brightness control byte 2 |
| 61                  | 3D              | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | LED13_OFF_H | read/write | LED13 output and brightness control byte 3 |

Table 4. Register summary ...continued

| Register# (decimal) | Register# (hex)   | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Name                     | Type            | Function   |
|---------------------|---|----|----|----|----|----|----|----|----|--------------------------|-----------------|--|
| 62                  | 3E  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 0  | LED14_ON_L               | read/write      | LED14 output and brightness control byte 0           |
| 63                  | 3F  | 0  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | LED14_ON_H               | read/write      | LED14 output and brightness control byte 1           |
| 64                  | 40  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | LED14_OFF_L              | read/write      | LED14 output and brightness control byte 2           |
| 65                  | 41  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 1  | LED14_OFF_H              | read/write      | LED14 output and brightness control byte 3           |
| 66                  | 42  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 0  | LED15_ON_L               | read/write      | LED15 output and brightness control byte 0           |
| 67                  | 43  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 1  | LED15_ON_H               | read/write      | LED15 output and brightness control byte 1           |
| 68                  | 44  | 0  | 1  | 0  | 0  | 0  | 1  | 0  | 0  | LED15_OFF_L              | read/write      | LED15 output and brightness control byte 2           |
| 69                  | 45  | 0  | 1  | 0  | 0  | 0  | 1  | 0  | 1  | LED15_OFF_H              | read/write      | LED15 output and brightness control byte 3           |
| ...                 | reserved for future use   |    |    |    |    |    |    |    |    |                          |                 |  |
| 250                 | FA  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 0  | ALL_LED_ON_L             | write/read zero | load all the LED <sub>n</sub> _ON registers, byte 0  |
| 251                 | FB  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | ALL_LED_ON_H             | write/read zero | load all the LED <sub>n</sub> _ON registers, byte 1  |
| 252                 | FC  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 0  | ALL_LED_OFF_L            | write/read zero | load all the LED <sub>n</sub> _OFF registers, byte 0 |
| 253                 | FD  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | ALL_LED_OFF_H            | write/read zero | load all the LED <sub>n</sub> _OFF registers, byte 1 |
| 254                 | FE  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | PRE_SCALE <sup>[1]</sup> | read/write      | prescaler for PWM output frequency                   |
| 255                 | FF  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | TestMode <sup>[2]</sup>  | read/write      | defines the test mode to be entered                  |
| ...                 | All further addresses are reserved for future use; reserved addresses will not be acknowledged. |    |    |    |    |    |    |    |    |                          |                 |  |

[1] Writes to PRE\_SCALE register are blocked when SLEEP bit is logic 0 (MODE 1).

[2] Reserved. Writes to this register may cause unpredictable results.

**Remark:** Auto Increment past register 69 will point to MODE1 register (register 0). Auto Increment also works from register 250 to register 254, then rolls over to register 0.

### 7.3.1 Mode register 1, MODE1

**Table 5. MODE1 - Mode register 1 (address 00h) bit description**

Legend: \* default value.

| Bit | Symbol  | Access | Value | Description  |
|-----|---------|--------|-------|--|
| 7   | RESTART | R      |       | Shows state of RESTART logic. See <a href="#">Section 7.3.1.1</a> for detail.  |
|     |         |        | W     | User writes logic 1 to this bit to clear it to logic 0. A user write of logic 0 will have no effect. See <a href="#">Section 7.3.1.1</a> for detail.   |
|     |         |        | 0*    | Restart disabled.  |
|     |         |        | 1     | Restart enabled.   |
| 6   | EXTCLK  | R/W    |       | To use the EXTCLK pin, this bit must be set by the following sequence: <ol style="list-style-type: none"> <li>1. Set the SLEEP bit in MODE1. This turns off the internal oscillator.</li> <li>2. Write logic 1s to both the SLEEP and EXTCLK bits in MODE1. The switch is now made. The external clock can be active during the switch because the SLEEP bit is set.</li> </ol> This bit is a 'sticky bit', that is, it cannot be cleared by writing a logic 0 to it. The EXTCLK bit can <b>only</b> be cleared by a power cycle or software reset.<br>EXTCLK range is DC to 50 MHz. $refresh\_rate = \frac{EXTCLK}{4096 \times (prescale + 1)}$ |
|     |         |        | 0*    | Use internal clock.  |
|     |         |        | 1     | Use EXTCLK pin clock.  |
|     |         |        |       |  |
| 5   | AI      | R/W    | 0*    | Register Auto-Increment disabled <sup>[1]</sup> .  |
|     |         |        | 1     | Register Auto-Increment enabled.   |
| 4   | SLEEP   | R/W    | 0     | Normal mode <sup>[2]</sup> .   |
|     |         |        | 1*    | Low power mode. Oscillator off <sup>[3][4]</sup> .   |
| 3   | SUB1    | R/W    | 0*    | PCA9685 does not respond to I <sup>2</sup> C-bus subaddress 1.   |
|     |         |        | 1     | PCA9685 responds to I <sup>2</sup> C-bus subaddress 1.   |
| 2   | SUB2    | R/W    | 0*    | PCA9685 does not respond to I <sup>2</sup> C-bus subaddress 2.   |
|     |         |        | 1     | PCA9685 responds to I <sup>2</sup> C-bus subaddress 2.   |
| 1   | SUB3    | R/W    | 0*    | PCA9685 does not respond to I <sup>2</sup> C-bus subaddress 3.   |
|     |         |        | 1     | PCA9685 responds to I <sup>2</sup> C-bus subaddress 3.   |
| 0   | ALLCALL | R/W    | 0     | PCA9685 does not respond to LED All Call I <sup>2</sup> C-bus address.   |
|     |         |        | 1*    | PCA9685 responds to LED All Call I <sup>2</sup> C-bus address.   |

- [1] When the Auto Increment flag is set, AI = 1, the Control register is automatically incremented after a read or write. This allows the user to program the registers sequentially.
- [2] It takes 500 μs 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 PWM control registers are accessed within the 500 μs window. There is no start-up delay required when using the EXTCLK pin as the PWM clock.
- [3] No PWM control is possible when the oscillator is off.
- [4] When the oscillator is off (Sleep mode) the LEDn outputs cannot be turned on, off or dimmed/blinked.

### 7.3.1.1 Restart mode

If the PCA9685 is operating and the user decides to put the chip to sleep (setting MODE1 bit 4) without stopping any of the PWM channels, the RESTART bit (MODE1 bit 7) will be set to logic 1 at the end of the PWM refresh cycle. The contents of each PWM register are held valid when the clock is off.

To restart all of the previously active PWM channels with a few I<sup>2</sup>C-bus cycles do the following steps:

1. Read MODE1 register.
2. Check that bit 7 (RESTART) is a logic 1. If it is, clear bit 4 (SLEEP). Allow time for oscillator to stabilize (500  $\mu$ s).
3. Write logic 1 to bit 7 of MODE1 register. All PWM channels will restart and the RESTART bit will clear.

**Remark:** The SLEEP bit **must** be logic 0 for at least 500  $\mu$ s, before a logic 1 is written into the RESTART bit.

Other actions that will clear the RESTART bit are:

1. Power cycle.
2. I<sup>2</sup>C Software Reset command.
3. If the MODE2 OCH bit is logic 0, write to any PWM register then issue an I<sup>2</sup>C-bus STOP.
4. If the MODE2 OCH bit is logic 1, write to all four PWM registers in any PWM channel.

Likewise, if the user does an orderly shutdown<sup>1</sup> of all the PWM channels before setting the SLEEP bit, the RESTART bit will be cleared. If this is done the contents of all PWM registers are invalidated and must be reloaded before reuse.

An example of the use of the RESTART bit would be the restoring of a customer's laptop LCD backlight intensity coming out of Standby to the level it was before going into Standby.

1. Two methods can be used to do an orderly shutdown. The fastest is to write a logic 1 to bit 4 in register ALL\_LED\_OFF\_H. The other method is to write logic 1 to bit 4 in each active PWM channel LEDn\_OFF\_H register.

### 7.3.2 Mode register 2, MODE2

**Table 6. MODE2 - Mode register 2 (address 01h) bit description**

Legend: \* default value.

| Bit    | Symbol                    | Access    | Value | Description   |
|--------|---------------------------|-----------|-------|---|
| 7 to 5 | -                         | read only | 000*  | reserved  |
| 4      | INVRT <sup>[1]</sup>      | R/W       | 0*    | Output logic state not inverted. Value to use when external driver used. Applicable when $\overline{OE} = 0$ .  |
|        |                           |           | 1     | Output logic state inverted. Value to use when no external driver used. Applicable when $\overline{OE} = 0$ .   |
| 3      | OCH                       | R/W       | 0*    | Outputs change on STOP command <sup>[2]</sup> .   |
|        |                           |           | 1     | Outputs change on ACK <sup>[3]</sup> .  |
| 2      | OUTDRV <sup>[1]</sup>     | R/W       | 0     | The 16 LEDn outputs are configured with an open-drain structure.  |
|        |                           |           | 1*    | The 16 LEDn outputs are configured with a totem pole structure.   |
| 1 to 0 | OUTNE[1:0] <sup>[4]</sup> | R/W       | 00*   | When $\overline{OE} = 1$ (output drivers not enabled), LEDn = 0.  |
|        |                           |           | 01    | When $\overline{OE} = 1$ (output drivers not enabled):<br>LEDn = 1 when OUTDRV = 1<br>LEDn = high-impedance when OUTDRV = 0 (same as OUTNE[1:0] = 10) |
|        |                           |           | 1X    | When $\overline{OE} = 1$ (output drivers not enabled), LEDn = high-impedance.   |

- [1] See [Section 7.7 “Using the PCA9685 with and without external drivers”](#) for more details. Normal LEDs can be driven directly in either mode. Some newer LEDs include integrated Zener diodes to limit voltage transients, reduce EMI, protect the LEDs and these must be driven only in the open-drain mode to prevent overheating the IC. Power on reset default state of LEDn output pins is LOW.
- [2] Change of the outputs at the STOP command allows synchronizing outputs of more than one PCA9685. Applicable to registers from 06h (LED0\_ON\_L) to 45h (LED15\_OFF\_H) only. 1 or more registers can be written, in any order, before STOP.
- [3] Update on ACK requires **all** 4 PWM channel registers to be loaded before outputs will change on the **last** ACK.
- [4] See [Section 7.4 “Active LOW output enable input”](#) for more details.

### 7.3.3 LED output and PWM control

The turn-on time of each LED driver output and the duty cycle of PWM can be controlled independently using the LEDn\_ON and LEDn\_OFF registers.

There will be two 12-bit registers per LED output. These registers will be programmed by the user. Both registers will hold a value from 0 to 4095. One 12-bit register will hold a value for the ON time and the other 12-bit register will hold the value for the OFF time. The ON and OFF times are compared with the value of a 12-bit counter that will be running continuously from 0000h to 0FFFh (0 to 4095 decimal).

Update on ACK requires all 4 PWM channel registers to be loaded before outputs will change on the last ACK.

The ON time, which is programmable, will be the time the LED output will be asserted and the OFF time, which is also programmable, will be the time when the LED output will be negated. In this way, the phase shift becomes completely programmable. The resolution for the phase shift is  $\frac{1}{4096}$  of the target frequency. [Table 7](#) lists these registers.

The following two examples illustrate how to calculate values to be loaded into these registers.

**Example 1:** (assumes that the LED0 output is used and (delay time) + (PWM duty cycle) ≤ 100 %)

Delay time = 10 %; PWM duty cycle = 20 % (LED on time = 20 %; LED off time = 80 %).

Delay time = 10 % = 409.6 ~ 410 counts = 19Ah.

Since the counter starts at 0 and ends at 4095, we will subtract 1, so delay time = 199h counts.

LED0\_ON\_H = 1h; LED0\_ON\_L = 99h (LED start turn on after this delay count to 409)

LED on time = 20 % = 819.2 ~ 819 counts.

LED off time = 4CCh (decimal 410 + 819 - 1 = 1228)

LED0\_OFF\_H = 4h; LED0\_OFF\_L = CCh (LED start turn off after this count to 1228)

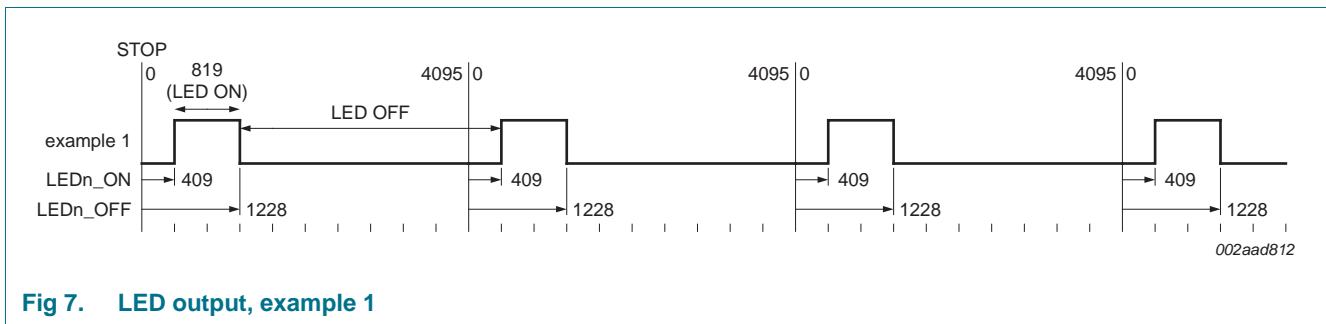


Fig 7. LED output, example 1

**Example 2:** (assumes that the LED4 output is used and (delay time) + (PWM duty cycle) > 100 %)

Delay time = 90 %; PWM duty cycle = 90 % (LED on time = 90 %; LED off time = 10 %).

Delay time = 90 % = 3686.4 ~ 3686 counts - 1 = 3685 = E65h.

LED4\_ON\_H = Eh; LED4\_ON\_L = 65h (LED start turn on after this delay count to 3685)

LED on time = 90 % = 3686 counts.

Since the delay time and LED on period of the duty cycle is greater than 4096 counts, the LEDn\_OFF count will occur in the next frame. Therefore, 4096 is subtracted from the LEDn\_OFF count to get the correct LEDn\_OFF count. See [Figure 9](#), [Figure 10](#) and [Figure 11](#).

LED off time = CCBh (decimal 3685 + 3686 = 7372 - 4096 = 3275)

LED4\_OFF\_H = Ch; LED4\_OFF\_L = CBh (LED start turn off after this count to 3275)

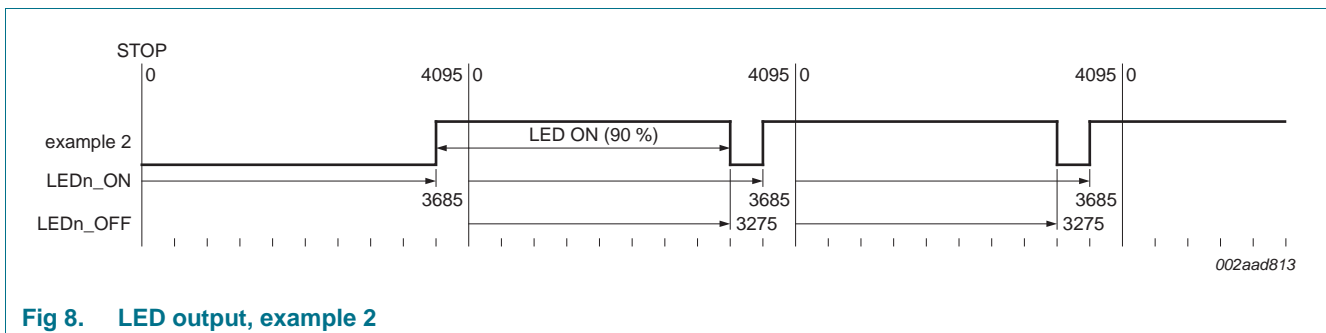


Fig 8. LED output, example 2

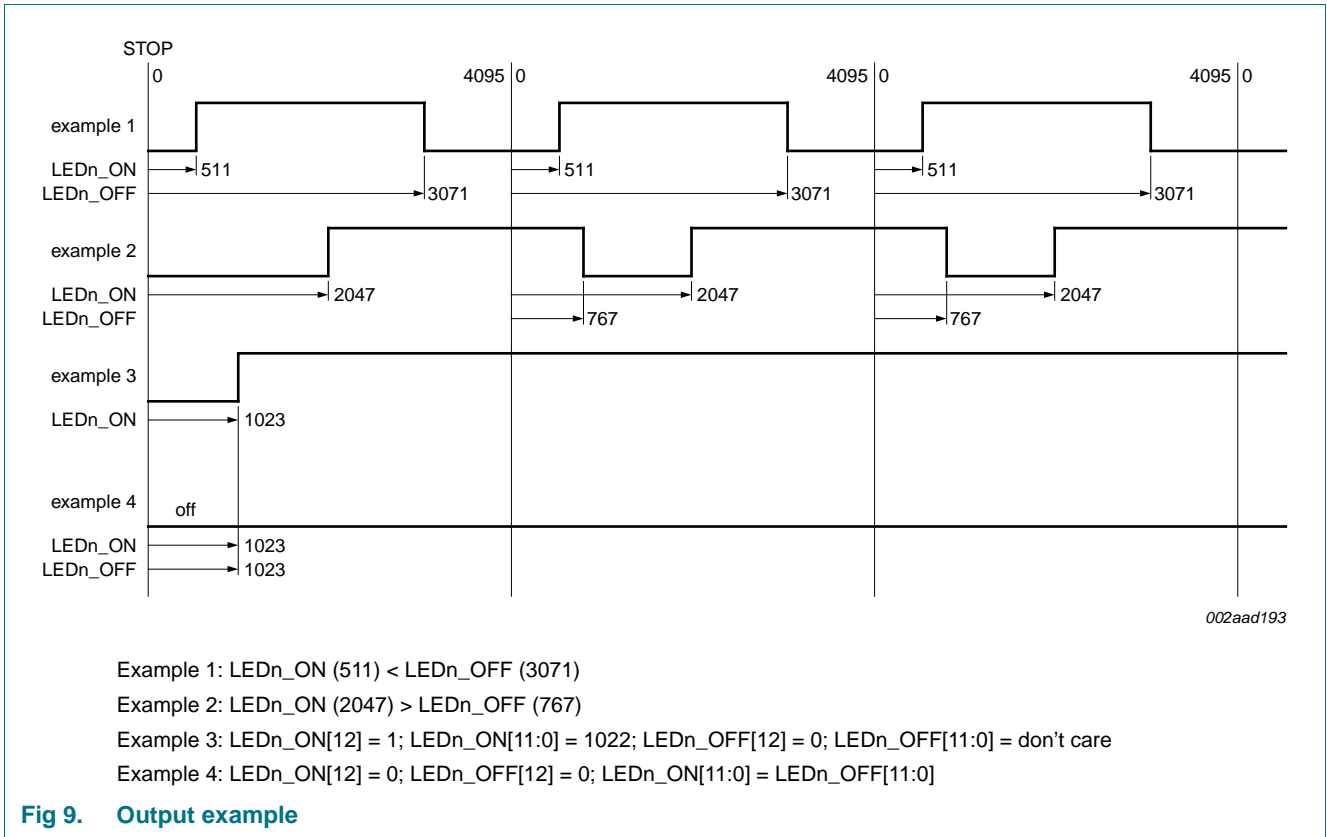
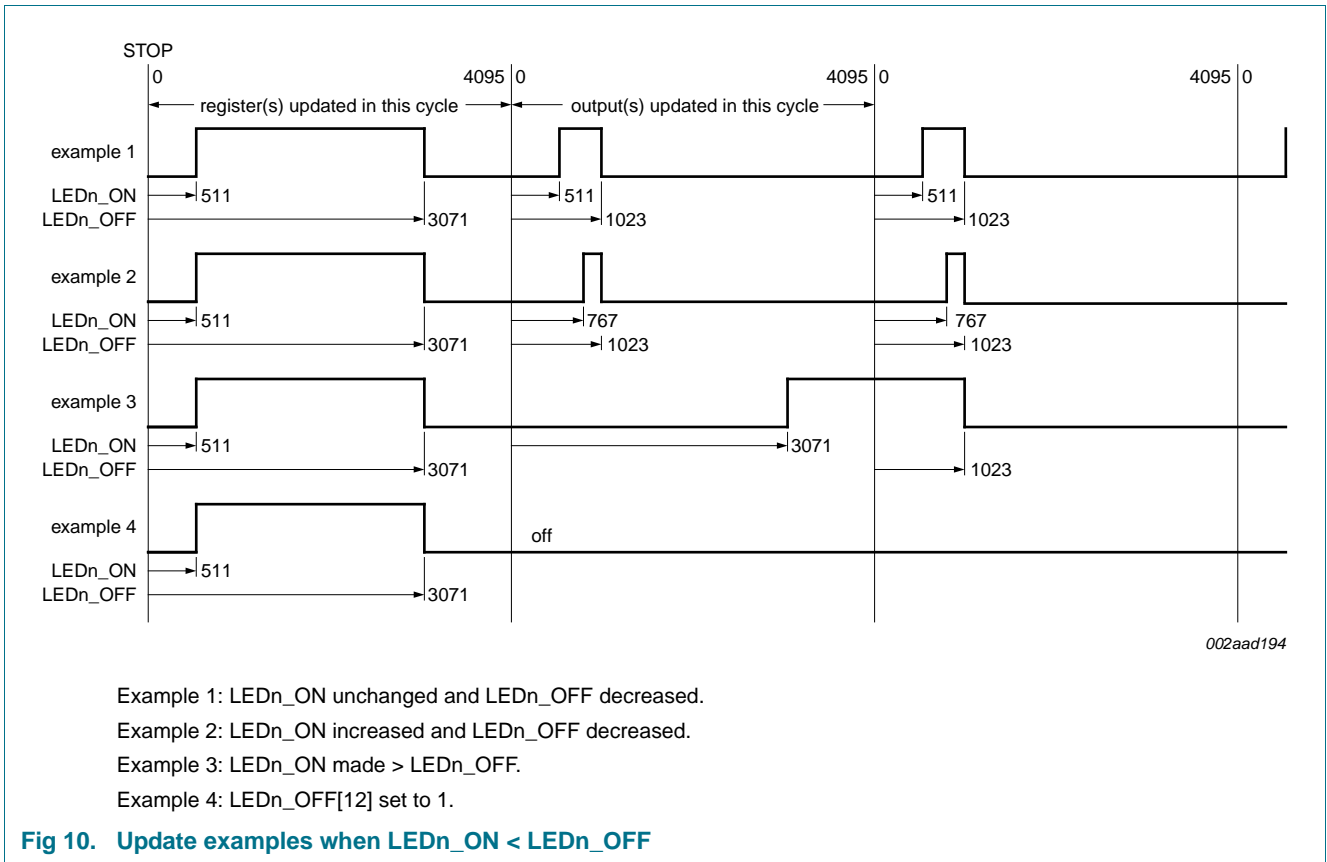
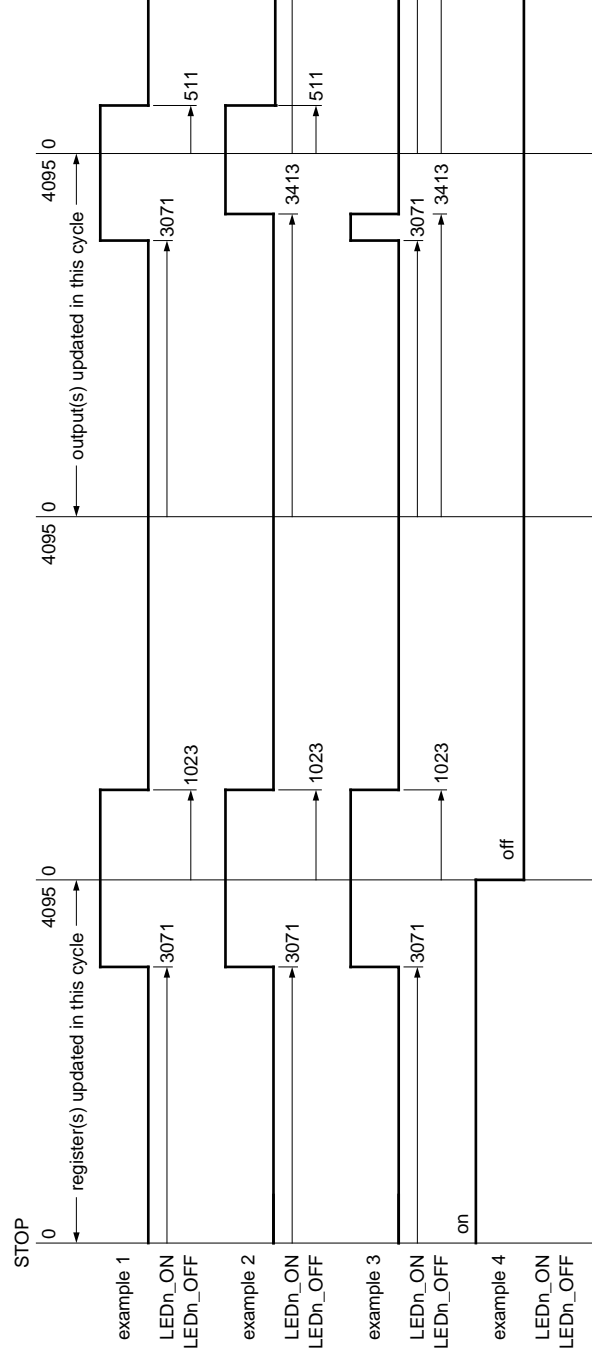


Fig 9. Output example





- Example 1: LEDn\_ON unchanged and LEDn\_OFF decreased, but delay still > LEDn\_OFF
- Example 2: LEDn\_ON changed and LEDn\_OFF changed, but delay still > LEDn\_OFF
- Example 3: LEDn\_ON unchanged and LEDn\_OFF increased where LEDn\_ON < LEDn\_OFF
- Example 4: LEDn\_ON[12] = 1 and LEDn\_OFF[12] changed from 0 to 1

**Fig 11. Update examples when LEDn\_ON > LEDn\_OFF**

**Table 7. LED\_ON, LED\_OFF control registers (address 06h to 45h) bit description**

Legend: \* default value.

| Address | Register   | Bit | Symbol          | Access | Value      | Description                     |
|---------|------------|-----|-----------------|--------|------------|---------------------------------|
| 06h     | LED0_ON_L  | 7:0 | LED0_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED0, 8 LSBs  |
| 07h     | LED0_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED0_ON_H[4]    | R/W    | 0*         | LED0 full ON                    |
|         |            | 3:0 | LED0_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED0, 4 MSBs  |
| 08h     | LED0_OFF_L | 7:0 | LED0_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED0, 8 LSBs |
| 09h     | LED0_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED0_OFF_H[4]   | R/W    | 1*         | LED0 full OFF                   |
|         |            | 3:0 | LED0_OFF_H[3:0] | R/W    | 0000*      |                                 |
| 0Ah     | LED1_ON_L  | 7:0 | LED1_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED1, 8 LSBs  |
| 0Bh     | LED1_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED1_ON_H[4]    | R/W    | 0*         | LED1 full ON                    |
|         |            | 3:0 | LED1_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED1, 4 MSBs  |
| 0Ch     | LED1_OFF_L | 7:0 | LED1_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED1, 8 LSBs |
| 0Dh     | LED1_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED1_OFF_H[4]   | R/W    | 1*         | LED1 full OFF                   |
|         |            | 3:0 | LED1_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED1, 4 MSBs |
| 0Eh     | LED2_ON_L  | 7:0 | LED2_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED2, 8 LSBs  |
| 0Fh     | LED2_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED2_ON_H[4]    | R/W    | 0*         | LED2 full ON                    |
|         |            | 3:0 | LED2_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED2, 4 MSBs  |
| 10h     | LED2_OFF_L | 7:0 | LED2_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED2, 8 LSBs |
| 11h     | LED2_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED2_OFF_H[4]   | R/W    | 1*         | LED2 full OFF                   |
|         |            | 3:0 | LED2_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED2, 4 MSBs |
| 12h     | LED3_ON_L  | 7:0 | LED3_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED3, 8 LSBs  |
| 13h     | LED3_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED3_ON_H[4]    | R/W    | 0*         | LED3 full ON                    |
|         |            | 3:0 | LED3_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED3, 4 MSBs  |
| 14h     | LED3_OFF_L | 7:0 | LED3_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED3, 8 LSBs |
| 15h     | LED3_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED3_OFF_H[4]   | R/W    | 1*         | LED3 full OFF                   |
|         |            | 3:0 | LED3_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED3, 4 MSBs |
| 16h     | LED4_ON_L  | 7:0 | LED4_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED4, 8 LSBs  |
| 17h     | LED4_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED4_ON_H[4]    | R/W    | 0*         | LED4 full ON                    |
|         |            | 3:0 | LED4_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED4, 4 MSBs  |

Table 7. LED\_ON, LED\_OFF control registers (address 06h to 45h) bit description ...continued

Legend: \* default value.

| Address | Register   | Bit | Symbol          | Access | Value      | Description                     |
|---------|------------|-----|-----------------|--------|------------|---------------------------------|
| 18h     | LED4_OFF_L | 7:0 | LED4_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED4, 8 LSBs |
| 19h     | LED4_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED4_OFF_H[4]   | R/W    | 1*         | LED4 full OFF                   |
|         |            | 3:0 | LED4_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED4, 4 MSBs |
| 1Ah     | LED5_ON_L  | 7:0 | LED5_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED5, 8 LSBs  |
| 1Bh     | LED5_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED5_ON_H[4]    | R/W    | 0*         | LED5 full ON                    |
|         |            | 3:0 | LED5_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED5, 4 MSBs  |
| 1Ch     | LED5_OFF_L | 7:0 | LED5_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED5, 8 LSBs |
| 1Dh     | LED5_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED5_OFF_H[4]   | R/W    | 1*         | LED5 full OFF                   |
|         |            | 3:0 | LED5_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED5, 4 MSBs |
| 1Eh     | LED6_ON_L  | 7:0 | LED6_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED6, 8 LSBs  |
| 1Fh     | LED6_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED6_ON_H[4]    | R/W    | 0*         | LED6 full ON                    |
|         |            | 3:0 | LED6_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED6, 4 MSBs  |
| 20h     | LED6_OFF_L | 7:0 | LED6_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED6, 8 LSBs |
| 21h     | LED6_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED6_OFF_H[4]   | R/W    | 1*         | LED6 full OFF                   |
|         |            | 3:0 | LED6_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED6, 4 MSBs |
| 22h     | LED7_ON_L  | 7:0 | LED7_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED7, 8 LSBs  |
| 23h     | LED7_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED7_ON_H[4]    | R/W    | 0*         | LED7 full ON                    |
|         |            | 3:0 | LED7_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED7, 4 MSBs  |
| 24h     | LED7_OFF_L | 7:0 | LED7_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED7, 8 LSBs |
| 25h     | LED7_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED7_OFF_H[4]   | R/W    | 1*         | LED7 full OFF                   |
|         |            | 3:0 | LED7_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED7, 4 MSBs |
| 26h     | LED8_ON_L  | 7:0 | LED8_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED8, 8 LSBs  |
| 27h     | LED8_ON_H  | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED8_ON_H[4]    | R/W    | 0*         | LED8 full ON                    |
|         |            | 3:0 | LED8_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED8, 4 MSBs  |
| 28h     | LED8_OFF_L | 7:0 | LED8_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED8, 8 LSBs |
| 29h     | LED8_OFF_H | 7:5 | reserved        | R      | 000*       | non-writable                    |
|         |            | 4   | LED8_OFF_H[4]   | R/W    | 1*         | LED8 full OFF                   |
|         |            | 3:0 | LED8_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED8, 4 MSBs |

Table 7. LED\_ON, LED\_OFF control registers (address 06h to 45h) bit description ...continued

Legend: \* default value.

| Address | Register    | Bit | Symbol           | Access | Value      | Description                      |
|---------|-------------|-----|------------------|--------|------------|----------------------------------|
| 2Ah     | LED9_ON_L   | 7:0 | LED9_ON_L[7:0]   | R/W    | 0000 0000* | LEDn_ON count for LED9, 8 LSBs   |
| 2Bh     | LED9_ON_H   | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED9_ON_H[4]     | R/W    | 0*         | LED9 full ON                     |
|         |             | 3:0 | LED9_ON_H[3:0]   | R/W    | 0000*      | LEDn_ON count for LED9, 4 MSBs   |
| 2Ch     | LED9_OFF_L  | 7:0 | LED9_OFF_L[7:0]  | R/W    | 0000 0000* | LEDn_OFF count for LED9, 8 LSBs  |
| 2Dh     | LED9_OFF_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED9_OFF_H[4]    | R/W    | 1*         | LED9 full OFF                    |
|         |             | 3:0 | LED9_OFF_H[3:0]  | R/W    | 0000*      | LEDn_OFF count for LED9, 4 MSBs  |
| 2Eh     | LED10_ON_L  | 7:0 | LED10_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED10, 8 LSBs  |
| 2Fh     | LED10_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED10_ON_H[4]    | R/W    | 0*         | LED10 full ON                    |
|         |             | 3:0 | LED10_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED10, 4 MSBs  |
| 30h     | LED10_OFF_L | 7:0 | LED10_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED10, 8 LSBs |
| 31h     | LED10_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED10_OFF_H[4]   | R/W    | 1*         | LED10 full OFF                   |
|         |             | 3:0 | LED10_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED10, 4 MSBs |
| 32h     | LED11_ON_L  | 7:0 | LED11_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED11, 8 LSBs  |
| 33h     | LED11_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED11_ON_H[4]    | R/W    | 0*         | LED11 full ON                    |
|         |             | 3:0 | LED11_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED11, 4 MSBs  |
| 34h     | LED11_OFF_L | 7:0 | LED11_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED11, 8 LSBs |
| 35h     | LED11_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED11_OFF_H[4]   | R/W    | 1*         | LED11 full OFF                   |
|         |             | 3:0 | LED11_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED11, 4 MSBs |
| 36h     | LED12_ON_L  | 7:0 | LED12_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED12, 8 LSBs  |
| 37h     | LED12_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED12_ON_H[4]    | R/W    | 0*         | LED12 full ON                    |
|         |             | 3:0 | LED12_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED12, 4 MSBs  |
| 38h     | LED12_OFF_L | 7:0 | LED12_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED12, 8 LSBs |
| 39h     | LED12_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED12_OFF_H[4]   | R/W    | 1*         | LED12 full OFF                   |
|         |             | 3:0 | LED12_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED12, 4 MSBs |
| 3Ah     | LED13_ON_L  | 7:0 | LED13_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED13, 8 LSBs  |
| 3Bh     | LED13_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED13_ON_H[4]    | R/W    | 0*         | LED13 full ON                    |
|         |             | 3:0 | LED13_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED13, 4 MSBs  |

**Table 7. LED\_ON, LED\_OFF control registers (address 06h to 45h) bit description ...continued**

Legend: \* default value.

| Address | Register    | Bit | Symbol           | Access | Value      | Description                      |
|---------|-------------|-----|------------------|--------|------------|----------------------------------|
| 3Ch     | LED13_OFF_L | 7:0 | LED13_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED13, 8 LSBs |
| 3Dh     | LED13_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED13_OFF_H[4]   | R/W    | 1*         | LED13 full OFF                   |
|         |             | 3:0 | LED13_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED13, 4 MSBs |
| 3Eh     | LED14_ON_L  | 7:0 | LED14_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED14, 8 LSBs  |
| 3Fh     | LED14_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED14_ON_H[4]    | R/W    | 0*         | LED14 full ON                    |
|         |             | 3:0 | LED14_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED14, 4 MSBs  |
| 40h     | LED14_OFF_L | 7:0 | LED14_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED14, 8 LSBs |
| 41h     | LED14_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED14_OFF_H[4]   | R/W    | 1*         | LED14 full OFF                   |
|         |             | 3:0 | LED14_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED14, 4 MSBs |
| 42h     | LED15_ON_L  | 7:0 | LED15_ON_L[7:0]  | R/W    | 0000 0000* | LEDn_ON count for LED15, 8 LSBs  |
| 43h     | LED15_ON_H  | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED15_ON_H[4]    | R/W    | 0*         | LED15 full ON                    |
|         |             | 3:0 | LED15_ON_H[3:0]  | R/W    | 0000*      | LEDn_ON count for LED15, 4 MSBs  |
| 44h     | LED15_OFF_L | 7:0 | LED15_OFF_L[7:0] | R/W    | 0000 0000* | LEDn_OFF count for LED15, 8 LSBs |
| 45h     | LED15_OFF_H | 7:5 | reserved         | R      | 000*       | non-writable                     |
|         |             | 4   | LED15_OFF_H[4]   | R/W    | 1*         | LED15 full OFF                   |
|         |             | 3:0 | LED15_OFF_H[3:0] | R/W    | 0000*      | LEDn_OFF count for LED15, 4 MSBs |

The LEDn\_ON\_H output control bit 4, when set to logic 1, causes the output to be always ON. The turning ON of the LED is delayed by the amount in the LEDn\_ON registers. LEDn\_OFF[11:0] are ignored. When this bit = 0, then the LEDn\_ON and LEDn\_OFF registers are used according to their normal definition.

The LEDn\_OFF\_H output control bit 4, when set to logic 1, causes the output to be always OFF. In this case the values in the LEDn\_ON registers are ignored.

**Remark:** When all LED outputs are configured as 'always OFF', the prescale counter and all associated PWM cycle timing logic are disabled. If LEDn\_ON\_H[4] and LEDn\_OFF\_H[4] are set at the same time, the LEDn\_OFF\_H[4] function takes precedence.

**7.3.4 ALL\_LED\_ON and ALL\_LED\_OFF control**

The ALL\_LED\_ON and ALL\_LED\_OFF registers allow just four I<sup>2</sup>C-bus write sequences to fill all the ON and OFF registers with the same patterns.

**Table 8. ALL\_LED\_ON and ALL\_LED\_OFF control registers (address FAh to FEh) bit description**

Legend: \* default value.

| Address | Register      | Bit | Symbol             | Access | Value      | Description   |
|---------|---------------|-----|--------------------|--------|------------|---|
| FAh     | ALL_LED_ON_L  | 7:0 | ALL_LED_ON_L[7:0]  | W only | 0000 0000* | LEDn_ON count for ALL_LED, 8 MSBs                                 |
| FBh     | ALL_LED_ON_H  | 7:5 | reserved           | R      | 000*       | non-writable  |
|         |               | 4   | ALL_LED_ON_H[4]    | W only | 1*         | ALL_LED full ON   |
|         |               | 3:0 | ALL_LED_ON_H[3:0]  | W only | 0000*      | LEDn_ON count for ALL_LED, 4 MSBs                                 |
| FCh     | ALL_LED_OFF_L | 7:0 | ALL_LED_OFF_L[7:0] | W only | 0000 0000* | LEDn_OFF count for ALL_LED, 8 MSBs                                |
| FDh     | ALL_LED_OFF_H | 7:5 | reserved           | R      | 000*       | non-writable  |
|         |               | 4   | ALL_LED_OFF_H[4]   | W only | 1*         | ALL_LED full OFF  |
|         |               | 3:0 | ALL_LED_OFF_H[3:0] | W only | 0000*      | LEDn_OFF count for ALL_LED, 4 MSBs                                |
| FEh     | PRE_SCALE     | 7:0 | PRE_SCALE[7:0]     | R/W    | 0001 1110* | prescaler to program the PWM output frequency (default is 200 Hz) |

The LEDn\_ON and LEDn\_OFF counts can vary from 0 to 4095. The LEDn\_ON and LEDn\_OFF count registers should never be programmed with the same values.

Because the loading of the LEDn\_ON and LEDn\_OFF registers is via the I<sup>2</sup>C-bus, and asynchronous to the internal oscillator, we want to ensure that we do not see any visual artifacts of changing the ON and OFF values. This is achieved by updating the changes at the end of the LOW cycle.

**7.3.5 PWM frequency PRE\_SCALE**

The hardware forces a minimum value that can be loaded into the PRE\_SCALE register at '3'. The PRE\_SCALE register defines the frequency at which the outputs modulate. The prescale value is determined with the formula shown in [Equation 1](#):

$$prescale\ value = round\left(\frac{osc\_clock}{4096 \times update\_rate}\right) - 1 \tag{1}$$

where the update rate is the output modulation frequency required. For example, for an output default frequency of 200 Hz with an oscillator clock frequency of 25 MHz:

$$prescale\ value = round\left(\frac{25\ MHz}{4096 \times 200}\right) - 1 = 30\ (0x1Eh) \tag{2}$$

The maximum PWM frequency is 1526 Hz if the PRE\_SCALE register is set "0x03h".

The minimum PWM frequency is 24 Hz if the PRE\_SCALE register is set "0xFFh".

The PRE\_SCALE register can only be set when the SLEEP bit of MODE1 register is set to logic 1.

7.3.6 SUBADR1 to SUBADR3, I<sup>2</sup>C-bus subaddress 1 to 3

Table 9. SUBADR1 to SUBADR3 - I<sup>2</sup>C-bus subaddress registers 0 to 3 (address 02h to 04h) bit description

Legend: \* default value.

| Address | Register | Bit | Symbol  | Access | Value     | Description                       |
|---------|----------|-----|---------|--------|-----------|-----------------------------------|
| 02h     | SUBADR1  | 7:1 | A1[7:1] | R/W    | 1110 001* | I <sup>2</sup> C-bus subaddress 1 |
|         |          | 0   | A1[0]   | R only | 0*        | reserved                          |
| 03h     | SUBADR2  | 7:1 | A2[7:1] | R/W    | 1110 010* | I <sup>2</sup> C-bus subaddress 2 |
|         |          | 0   | A2[0]   | R only | 0*        | reserved                          |
| 04h     | SUBADR3  | 7:1 | A3[7:1] | R/W    | 1110 100* | I <sup>2</sup> C-bus subaddress 3 |
|         |          | 0   | A3[0]   | R only | 0*        | reserved                          |

Subaddresses are programmable through the I<sup>2</sup>C-bus. Default power-up values are E2h, E4h, E8h, and the device(s) will not acknowledge these addresses right after power-up (the corresponding SUBx bit in MODE1 register is equal to 0).

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).

Only the 7 MSBs representing the I<sup>2</sup>C-bus subaddress are valid. The LSB in SUBADR<sub>x</sub> register is a read-only bit (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.

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

Table 10. ALLCALLADR - LED All Call I<sup>2</sup>C-bus address register (address 05h) bit description

Legend: \* default value.

| Address | Register   | Bit | Symbol  | Access | Value     | Description                                   |
|---------|------------|-----|---------|--------|-----------|---|
| 05h     | 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 PCA9685s in the bus to be programmed at the same time (ALLCALL bit in register MODE1 must be equal to 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, the device does not acknowledge the address programmed in register ALLCALLADR.

## 7.4 Active LOW output enable input

The active LOW output enable ( $\overline{OE}$ ) pin, 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 and follow the output state defined in the LEDn\_ON and LEDn\_OFF registers with the polarity defined by INVRT bit (MODE2 register).
- When a HIGH level is applied to  $\overline{OE}$  pin, all the LED outputs are programmed to the value that is defined by OUTNE[1:0] in the MODE2 register.

**Table 11. LED outputs when  $\overline{OE} = 1$**

| OUTNE1 | OUTNE0 | LED outputs                                   |
|--------|--------|---|
| 0      | 0      | 0   |
| 0      | 1      | 1 if OUTDRV = 1, high-impedance if OUTDRV = 0 |
| 1      | 0      | high-impedance                                |
| 1      | 1      | high-impedance                                |

The  $\overline{OE}$  pin can be used as a synchronization signal to switch on/off several PCA9685 devices at the same time. 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.

## 7.5 Power-on reset

When power is applied to  $V_{DD}$ , an internal power-on reset holds the PCA9685 in a reset condition until  $V_{DD}$  has reached  $V_{POR}$ . At this point, the reset condition is released and the PCA9685 registers and I<sup>2</sup>C-bus state machine are initialized to their default states. Thereafter,  $V_{DD}$  must be lowered below 0.2 V to reset the device.

**7.6 Software reset**

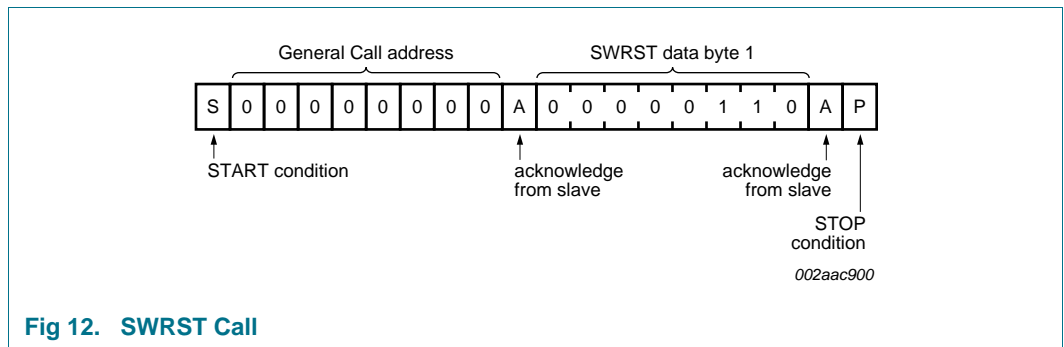
The Software Reset Call (SWRST Call) allows all the devices in the I<sup>2</sup>C-bus to be reset to the power-up state value through a specific formatted I<sup>2</sup>C-bus command. To be performed correctly, it implies that the I<sup>2</sup>C-bus is functional and that there is no device hanging the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

The 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 SWRST I<sup>2</sup>C-bus 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 PCA9685 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 PCA9685 acknowledges this value only. If byte 1 is not equal to 06h, the PCA9685 does not acknowledge it.

If more than 1 byte of data is sent, the PCA9685 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 command to end the SWRST Call: the PCA9685 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 12. SWRST Call**

The I<sup>2</sup>C-bus master must interpret a non-acknowledge from the PCA9685 (at any time) as a 'SWRST Call Abort'. The PCA9685 does not initiate a reset of its registers. This happens only when the format of the SWRST Call sequence is not correct.

7.7 Using the PCA9685 with and without external drivers

The PCA9685 LED output drivers are 5.5 V only tolerant and can sink up to 25 mA at 5 V.

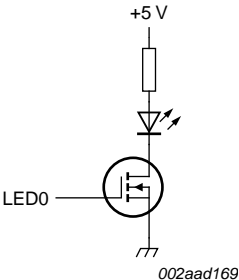
If the device needs to drive LEDs to a higher voltage and/or higher current, use of an external driver is required.

- INVRT bit (MODE2 register) can be used to keep the LED PWM control firmware the same independently of the type of external driver. This bit allows LED output polarity inversion/non-inversion only when  $\overline{OE} = 0$ .
- OUTDRV bit (MODE2 register) allows minimizing the amount of external components required to control the external driver (N-type or P-type device).

Table 12. Use of INVRT and OUTDRV based on connection to the LEDn outputs when  $\overline{OE} = 0$ <sup>[1]</sup>

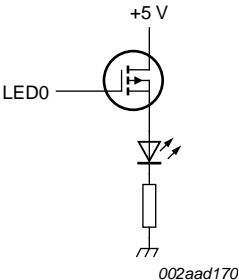
| INVRT | OUTDRV | Direct connection to LEDn                                 |                                       | External N-type driver                                    |                             | External P-type driver                                    |                             |
|-------|--------|---|---------------------------------------|---|-----------------------------|---|-----------------------------|
|       |        | Firmware  | External pull-up resistor             | Firmware  | External pull-up resistor   | Firmware  | External pull-up resistor   |
| 0     | 0      | formulas and LED output state values inverted             | LED current limiting R <sup>[2]</sup> | formulas and LED output state values inverted             | required                    | formulas and LED output state values apply                | required                    |
| 0     | 1      | formulas and LED output state values inverted             | LED current limiting R <sup>[2]</sup> | formulas and LED output state values apply <sup>[3]</sup> | not required <sup>[3]</sup> | formulas and LED output state values inverted             | not required                |
| 1     | 0      | formulas and LED output state values apply <sup>[2]</sup> | LED current limiting R                | formulas and LED output state values apply                | required                    | formulas and LED output state values inverted             | required                    |
| 1     | 1      | formulas and LED output state values apply <sup>[2]</sup> | LED current limiting R                | formulas and LED output state values inverted             | not required                | formulas and LED output state values apply <sup>[4]</sup> | not required <sup>[4]</sup> |

- [1] When  $\overline{OE} = 1$ , LED output state is controlled only by OUTNE[1:0] bits (MODE2 register).
- [2] Correct configuration when LEDs directly connected to the LEDn outputs (connection to V<sub>DD</sub> through current limiting resistor).
- [3] Optimum configuration when external N-type (NPN, NMOS) driver used.
- [4] Optimum configuration when external P-type (PNP, PMOS) driver used.



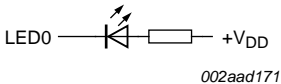
INVRT = 0  
OUTDRV = 1

**Fig 13. External N-type driver**



INVRT = 1  
OUTDRV = 1

**Fig 14. External P-type driver**



INVRT = 1  
OUTDRV = 0

**Fig 15. Direct LED connection**

## 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 16](#)).

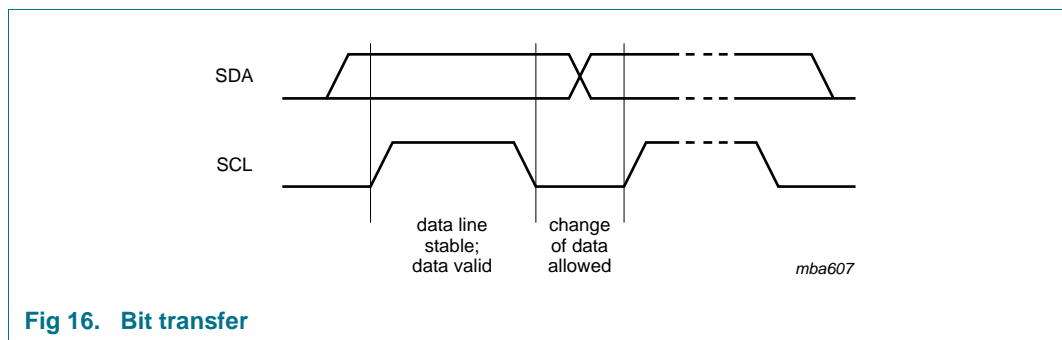


Fig 16. Bit transfer

#### 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 17](#)).

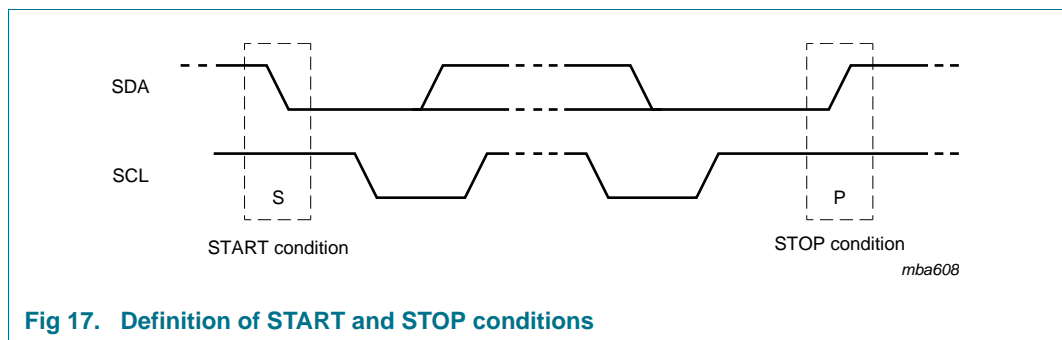


Fig 17. Definition of START and STOP conditions

### 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 18](#)).

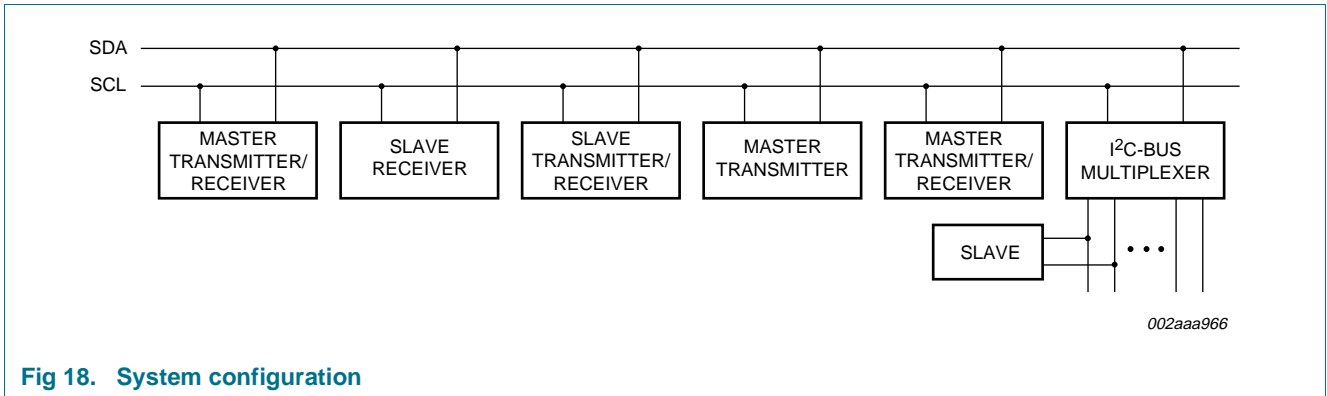


Fig 18. System configuration

### 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.

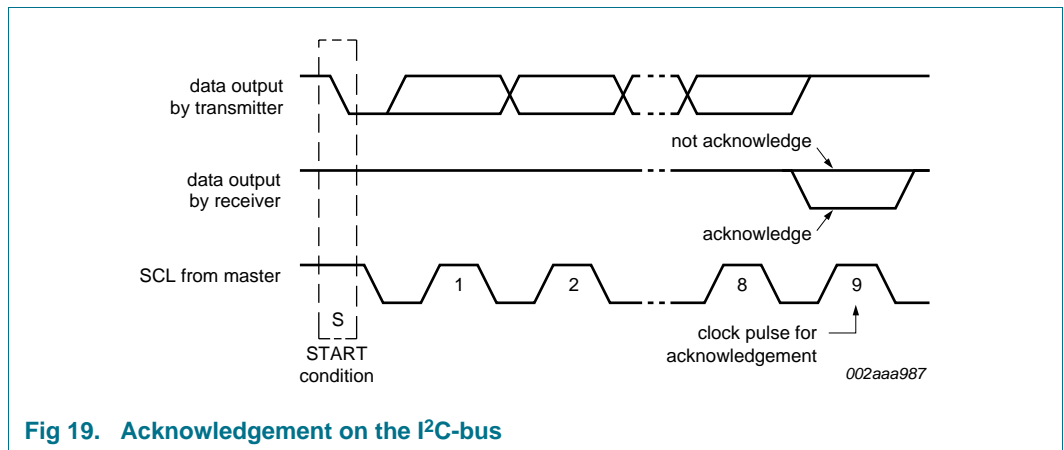
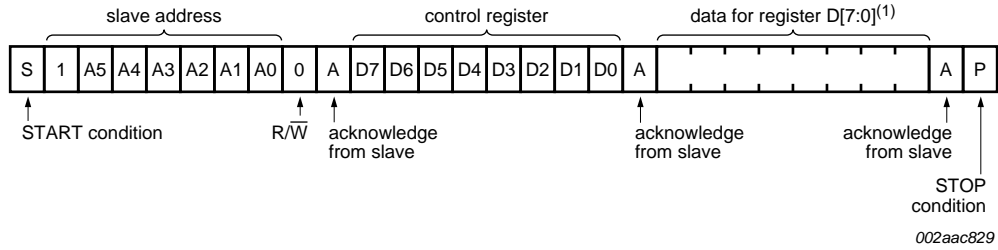


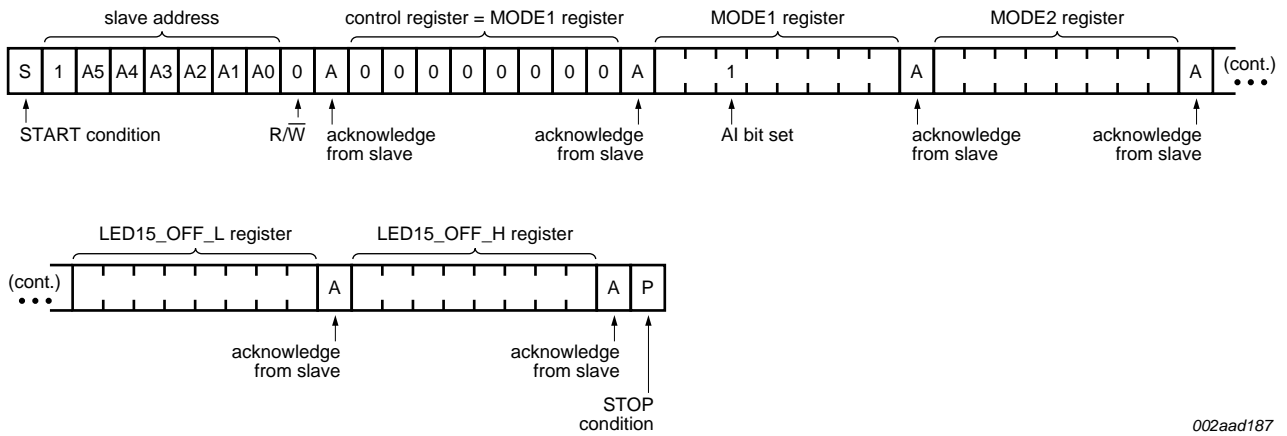
Fig 19. Acknowledgement on the I<sup>2</sup>C-bus

### 9. Bus transactions



(1) See [Table 4](#) for register definition.

**Fig 20. Write to a specific register**



**Fig 21. Write to all registers using the Auto-Increment feature; AI initially clear**

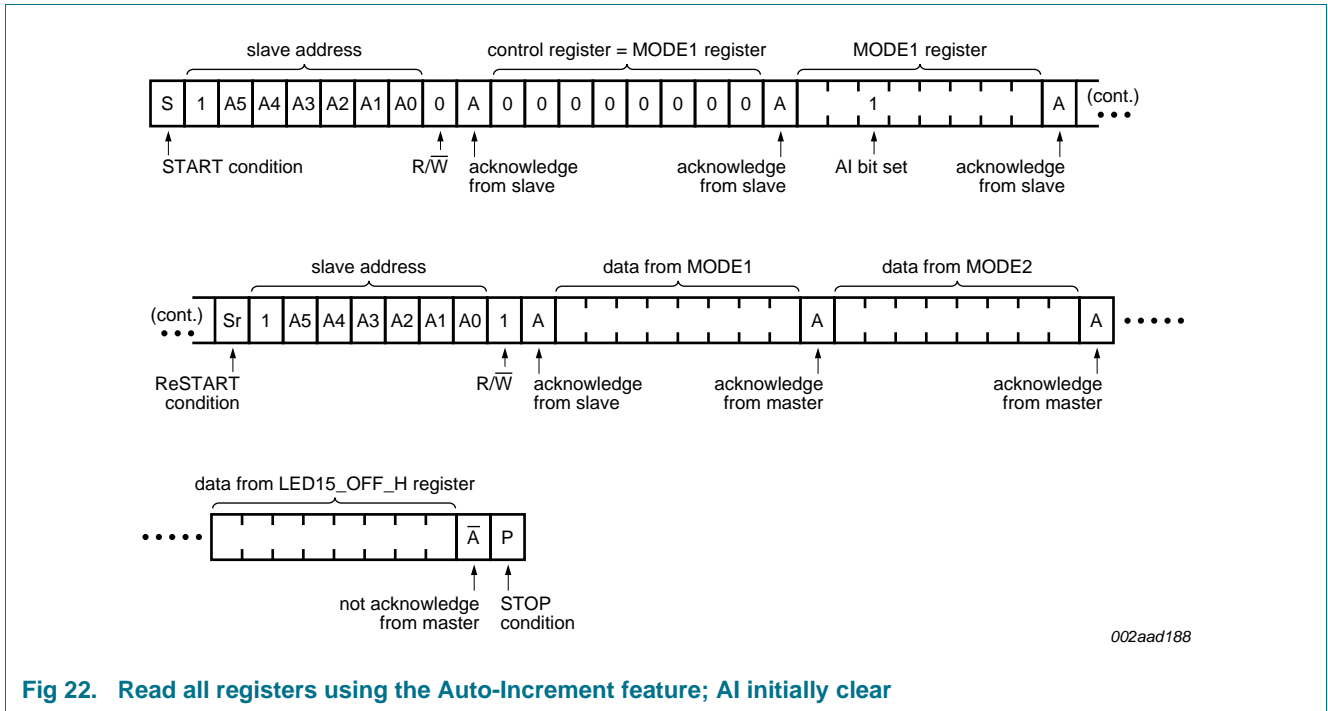


Fig 22. Read all registers using the Auto-Increment feature; AI initially clear

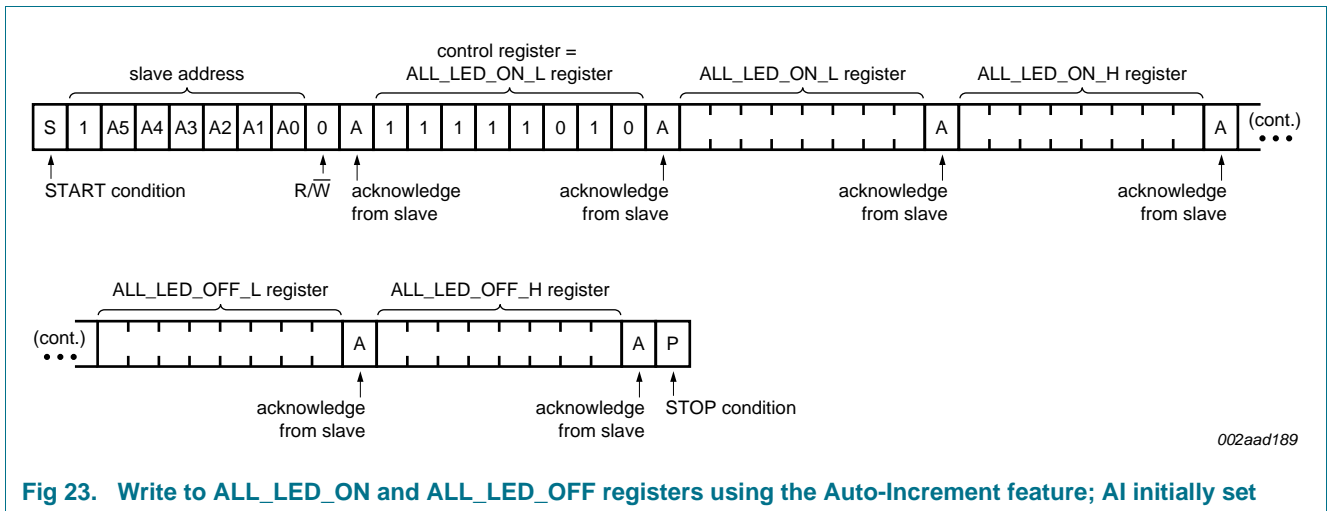


Fig 23. Write to ALL\_LED\_ON and ALL\_LED\_OFF registers using the Auto-Increment feature; AI initially set

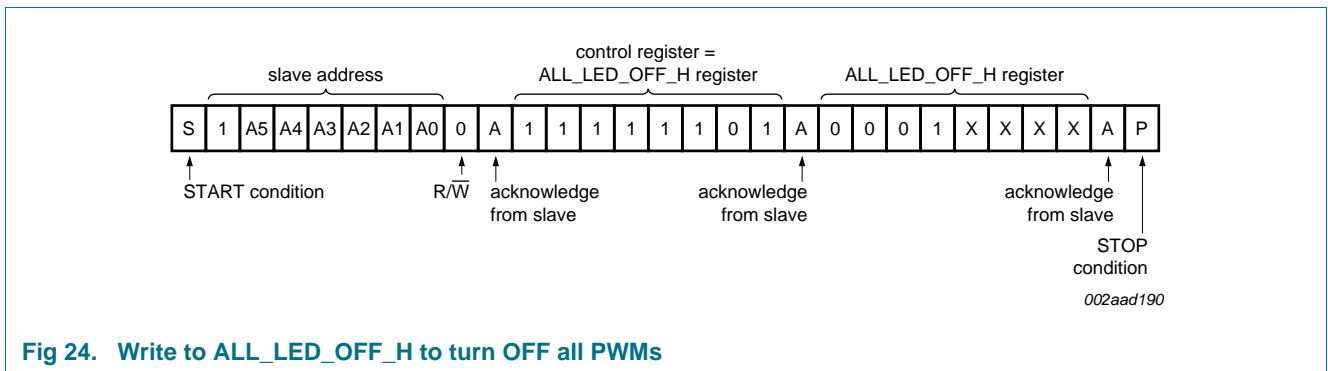
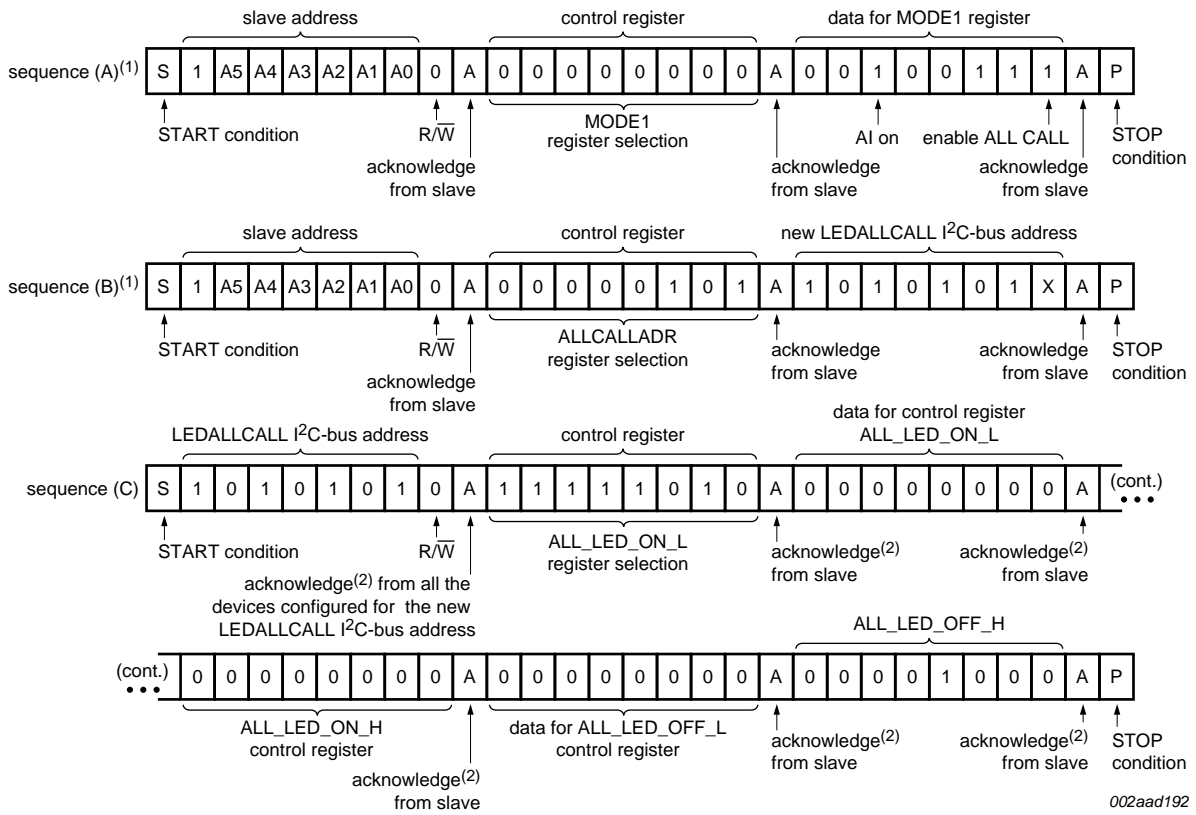


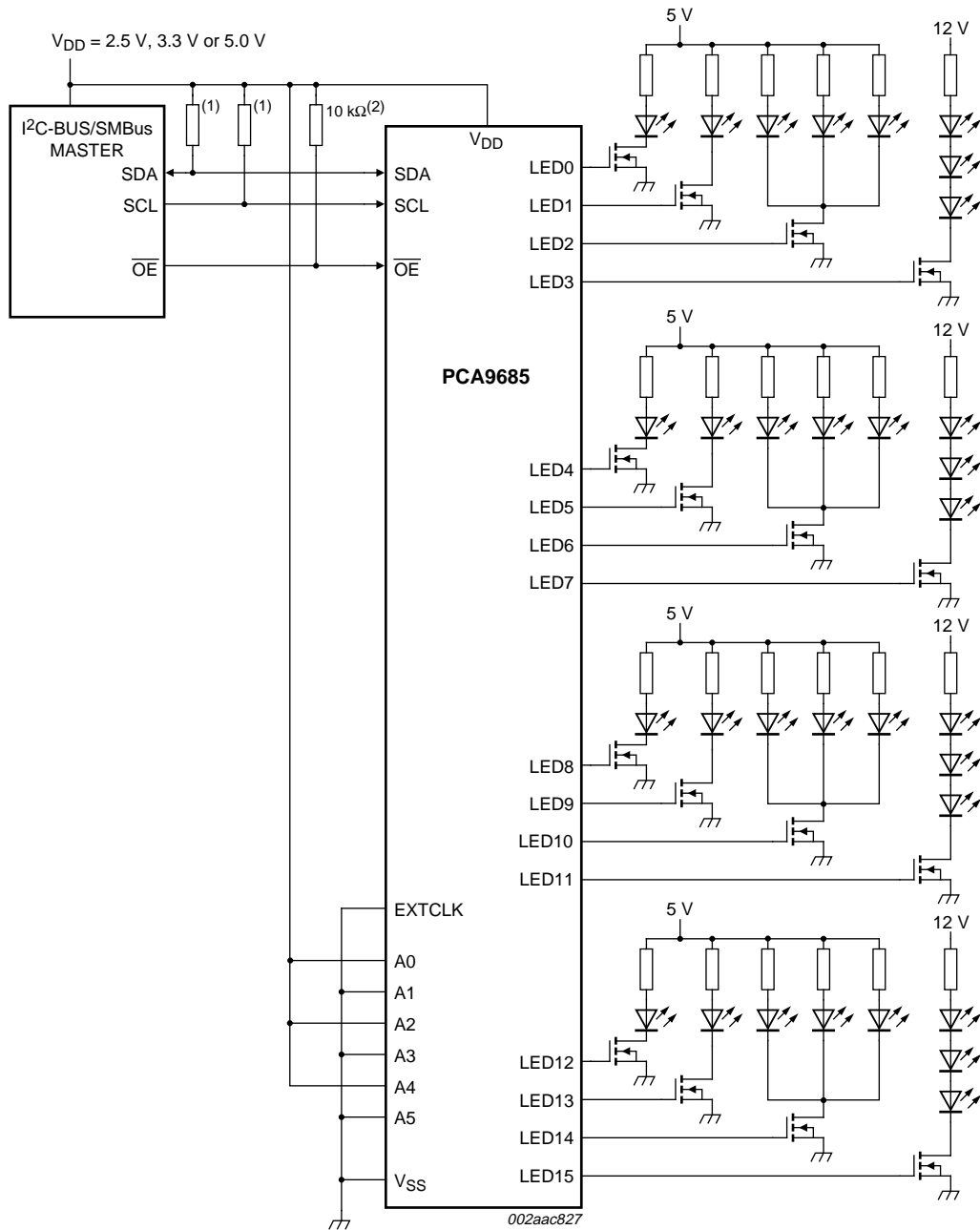
Fig 24. Write to ALL\_LED\_OFF\_H to turn OFF all PWMs



- (1) In this example, several PCA9685s are used and the same sequences (A) and (B) above are sent to each of them.
- (2) Acknowledge from all the slave devices configured for the new LED All Call I<sup>2</sup>C-bus address in sequence (B).

Fig 25. LED All Call I<sup>2</sup>C-bus address programming and LED All Call sequence example

### 10. Application design-in information



I<sup>2</sup>C-bus address = 1010 101x.

All 16 of the LEDn outputs configurable as either open-drain or totem pole. Mixing of configuration is not possible.

**Remark:** Set INVRT = 0, OUTDRV = 1, OUTNE = 01 (MODE2 register bits)

- (1) Resistor value should be chosen by referencing section 7 of UM10204, "I<sup>2</sup>C-bus specification and user manual".
- (2) OE requires pull-up resistor if control signal from the master is open-drain.

Fig 26. Typical application

**Question 1:** What kind of edge rate control is there on the outputs?

- The typical edge rates depend on the output configuration, supply voltage, and the applied load. The outputs can be configured as either open-drain NMOS or totem pole outputs. If the customer is using the part to directly drive LEDs, they should be using it in an open-drain NMOS, if they are concerned about the maximum  $I_{SS}$  and ground bounce. The edge rate control was designed primarily to slow down the turn-on of the output device; it turns off rather quickly (~1.5 ns). In simulation, the typical turn-on time for the open-drain NMOS was ~14 ns ( $V_{DD} = 3.6$  V;  $C_L = 50$  pF;  $R_{PU} = 500$   $\Omega$ ).

**Question 2:** Is ground bounce possible?

- Ground bounce is a possibility, especially if all 16 outputs are changed at full current (25 mA each). There is a fair amount of decoupling capacitance on chip (~50 pF), which is intended to suppress some of the ground bounce. The customer will need to determine if additional decoupling capacitance externally placed as close as physically possible to the device is required.

**Question 3:** Can I really sink 400 mA through the single ground pin on the package and will this cause any ground bounce problem due to the PWM of the LEDs?

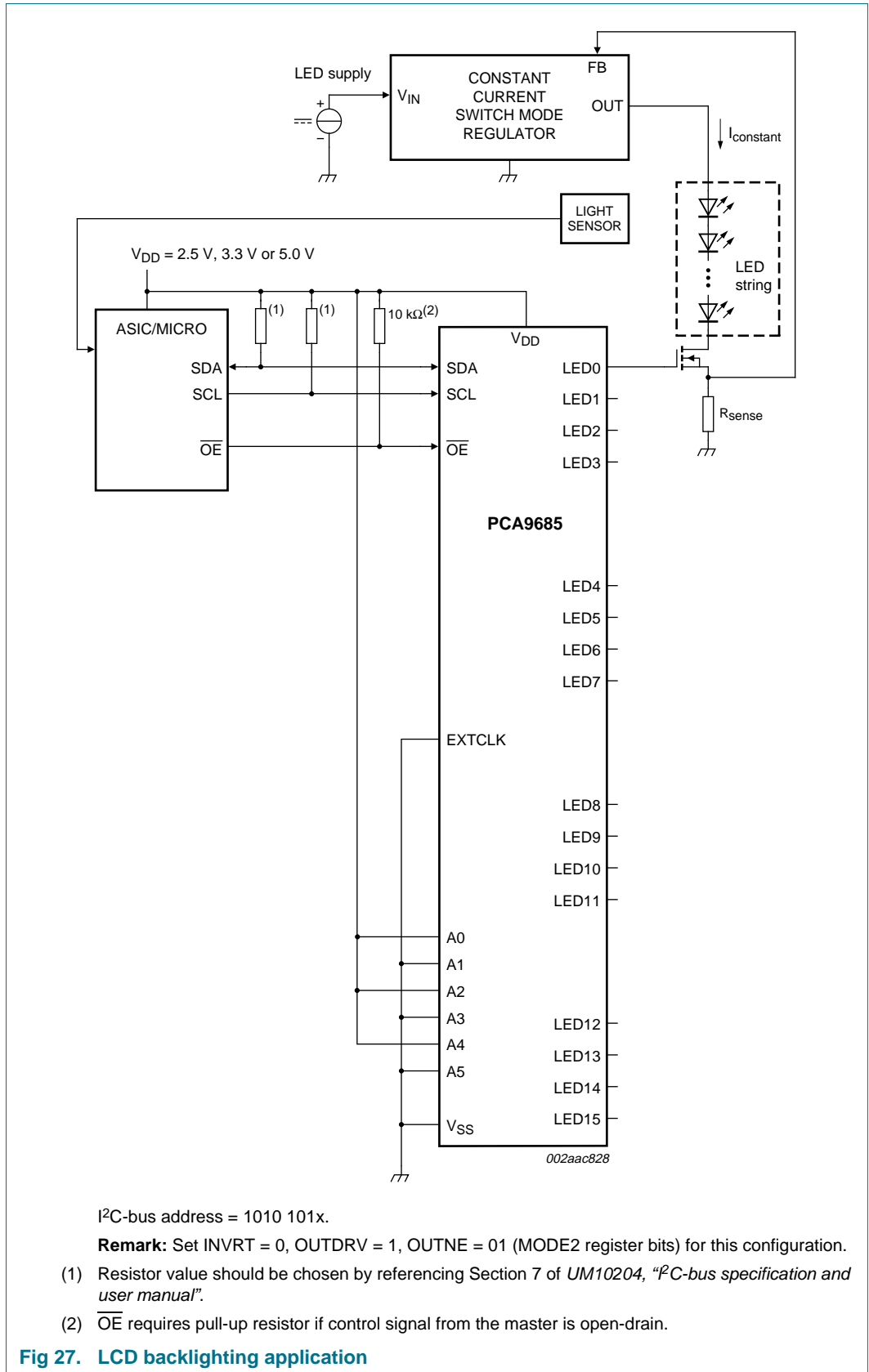
- Yes, you can sink 400 mA through a single ground pin on the **package**. Although the package only has one ground pin, there are two ground pads on the die itself connected to this one pin. Although some ground bounce is likely, it will not disrupt the operation of the part and would be reduced by the external decoupling capacitance.

**Question 4:** I can't turn the LEDs on or off, but their registers are set properly. Why?

- Check the MODE1 register SLEEP (bit 4) setting. The bit needs to be 0 in order to enable the clocking. If both clock sources (internal osc and EXTCLK) are turned OFF (bit 4 = 1), the LEDs cannot be dimmed or blinked.

**Question 5:** I'm using LEDs with integrated Zener diodes and the IC is getting very hot. Why?

- The IC outputs can be set to either open-drain or push-pull and default to push-pull outputs. In this application with the Zener diodes, they need to be set to open-drain since in the push-pull architecture there is a low resistance path to GND through the Zener and this is causing the IC to overheat.



## 11. Limiting values

**Table 13. 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    |
| I <sub>O(LEDn)</sub> | output current on pin LEDn     |            | -                     | 25   | mA   |
| I <sub>SS</sub>      | ground supply current          |            | -                     | 400  | mA   |
| P <sub>tot</sub>     | total power dissipation        |            | -                     | 400  | mW   |
| T <sub>stg</sub>     | storage temperature            |            | -65                   | +150 | °C   |
| T <sub>amb</sub>     | ambient temperature            | operating  | -40                   | +85  | °C   |

## 12. Static characteristics

**Table 14. Static characteristics**

V<sub>DD</sub> = 2.3 V to 5.5 V; V<sub>SS</sub> = 0 V; T<sub>amb</sub> = -40 °C to +85 °C; unless otherwise specified.

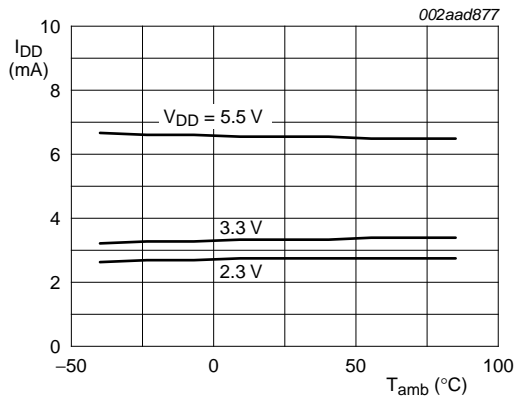
| Symbol                             | Parameter                      | Conditions  | Min                | Typ  | Max                 | Unit |
|------------------------------------|--------------------------------|---|--------------------|------|---------------------|------|
| <b>Supply</b>                      |                                |   |                    |      |                     |      |
| V <sub>DD</sub>                    | supply voltage                 |   | 2.3                | -    | 5.5                 | V    |
| I <sub>DD</sub>                    | supply current                 | operating mode; no load;<br>f <sub>SCL</sub> = 1 MHz; V <sub>DD</sub> = 2.3 V to 5.5 V                                      | -                  | 6    | 10                  | mA   |
| I <sub>stb</sub>                   | standby current                | no load; f <sub>SCL</sub> = 0 Hz; V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub> ;<br>V <sub>DD</sub> = 2.3 V to 5.5 V | -                  | 2.2  | 15.5                | μA   |
| V <sub>POR</sub>                   | power-on reset voltage         | no load; V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub> <a href="#">[1]</a>  | -                  | 1.70 | 2.0                 | V    |
| <b>Input SCL; input/output SDA</b> |                                |   |                    |      |                     |      |
| V <sub>IL</sub>                    | LOW-level input voltage        |   | -0.5               | -    | +0.3V <sub>DD</sub> | V    |
| V <sub>IH</sub>                    | HIGH-level input voltage       |   | 0.7V <sub>DD</sub> | -    | 5.5                 | V    |
| I <sub>OL</sub>                    | LOW-level output current       | V <sub>OL</sub> = 0.4 V; V <sub>DD</sub> = 2.3 V  | 20                 | 28   | -                   | mA   |
|                                    |                                | V <sub>OL</sub> = 0.4 V; V <sub>DD</sub> = 5.0 V  | 30                 | 40   | -                   | mA   |
| I <sub>L</sub>                     | leakage current                | V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub>   | -1                 | -    | +1                  | μA   |
| C <sub>i</sub>                     | input capacitance              | V <sub>I</sub> = V <sub>SS</sub>  | -                  | 6    | 10                  | pF   |
| <b>LED driver outputs</b>          |                                |   |                    |      |                     |      |
| I <sub>OL</sub>                    | LOW-level output current       | V <sub>OL</sub> = 0.5 V; V <sub>DD</sub> = 2.3 V to 4.5 V <a href="#">[2]</a>   | 12                 | 25   | -                   | mA   |
| I <sub>OL(tot)</sub>               | total LOW-level output current | V <sub>OL</sub> = 0.5 V; V <sub>DD</sub> = 4.5 V <a href="#">[2]</a>  | -                  | -    | 400                 | mA   |
| I <sub>OH</sub>                    | HIGH-level output current      | open-drain; V <sub>OH</sub> = V <sub>DD</sub>   | -10                | -    | +10                 | μA   |
| V <sub>OH</sub>                    | HIGH-level output voltage      | I <sub>OH</sub> = -10 mA; V <sub>DD</sub> = 2.3 V   | 1.6                | -    | -                   | V    |
|                                    |                                | I <sub>OH</sub> = -10 mA; V <sub>DD</sub> = 3.0 V   | 2.3                | -    | -                   | V    |
|                                    |                                | I <sub>OH</sub> = -10 mA; V <sub>DD</sub> = 4.5 V   | 4.0                | -    | -                   | V    |
| I <sub>OZ</sub>                    | OFF-state output current       | 3-state; V <sub>OH</sub> = V <sub>DD</sub> or V <sub>SS</sub>   | -10                | -    | +10                 | μA   |
| C <sub>o</sub>                     | output capacitance             |   | -                  | 5    | 8                   | pF   |

**Table 14. Static characteristics ...continued**

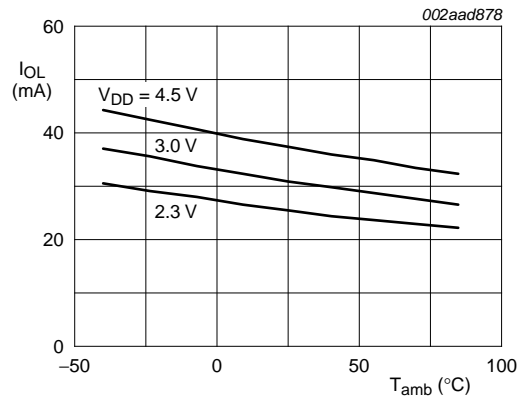
$V_{DD} = 2.3\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C to }+85\text{ }^{\circ}\text{C}$ ; unless otherwise specified.

| Symbol                                  | Parameter                | Conditions | Min          | Typ | Max           | Unit          |
|---|--------------------------|------------|--------------|-----|---------------|---------------|
| <b>Address inputs; OE input; EXTCLK</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   | 5             | pF            |

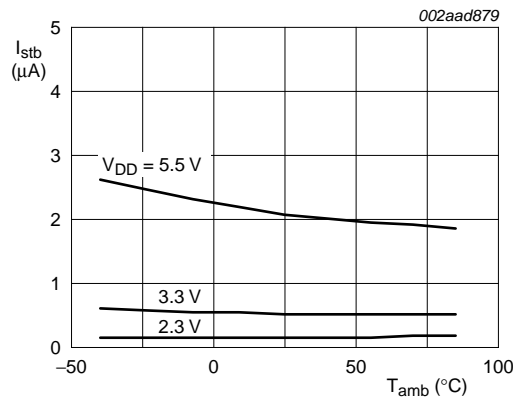
- [1]  $V_{DD}$  must be lowered to 0.2 V in order to reset part.
- [2] Each bit must be limited to a maximum of 25 mA and the total package limited to 400 mA due to internal busing limits.



**Fig 28.  $I_{DD}$  typical values with OSC on and  $f_{SCL} = 1\text{ MHz}$  versus temperature**



**Fig 29.  $I_{OL}$  typical drive (LEDn outputs) versus temperature**



**Fig 30. Standby supply current versus temperature**

## 13. Dynamic characteristics

Table 15. Dynamic characteristics

| Symbol              | Parameter   | Conditions   | Standard-mode I <sup>2</sup> C-bus |      | Fast-mode I <sup>2</sup> C-bus |     |
|---------------------|---|--|------------------------------------|------|--------------------------------|-----|
|                     |   |  | Min                                | Max  | Min                            | Max |
| t <sub>SCL</sub>    | SCL clock frequency   | [1]  | 0                                  | 100  | 0                              | 400 |
| f <sub>EXTCLK</sub> | frequency on pin EXTCLK   |  | DC                                 | 50   | DC                             | 50  |
| t <sub>BUF</sub>    | bus free time between a STOP and START condition                  |  | 4.7                                | -    | 1.3                            | -   |
| t <sub>HD;STA</sub> | hold time (repeated) START condition                              |  | 4.0                                | -    | 0.6                            | -   |
| t <sub>SU;STA</sub> | set-up time for a repeated START condition                        |  | 4.7                                | -    | 0.6                            | -   |
| t <sub>SU;STO</sub> | set-up time for STOP condition                                    |  | 4.0                                | -    | 0.6                            | -   |
| t <sub>HD;DAT</sub> | data hold time  |  | 0                                  | -    | 0                              | -   |
| t <sub>VD;ACK</sub> | data valid acknowledge time                                       | [2]  | 0.3                                | 3.45 | 0.1                            | 0.9 |
| t <sub>VD;DAT</sub> | data valid time   | [3]  | 0.3                                | 3.45 | 0.1                            | 0.9 |
| t <sub>SU;DAT</sub> | data set-up time  |  | 250                                | -    | 100                            | -   |
| t <sub>LOW</sub>    | LOW period of the SCL clock                                       |  | 4.7                                | -    | 1.3                            | -   |
| t <sub>HIGH</sub>   | HIGH period of the SCL clock                                      |  | 4.0                                | -    | 0.6                            | -   |
| t <sub>f</sub>      | fall time of both SDA and SCL signals                             | [4][5]   | -                                  | 300  | 20 + 0.1C <sub>b</sub> [6]     | 300 |
| t <sub>r</sub>      | rise time of both SDA and SCL signals                             |  | -                                  | 1000 | 20 + 0.1C <sub>b</sub> [6]     | 300 |
| t <sub>SP</sub>     | pulse width of spikes that must be suppressed by the input filter | [7]  | -                                  | 50   | -                              | 50  |
| t <sub>PLZ</sub>    | LOW to OFF-state propagation delay                                | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 10 or 11<br>in MODE2 register | -                                  | 40   | -                              | 40  |
| t <sub>PZL</sub>    | OFF-state to LOW propagation delay                                | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 10 or 11<br>in MODE2 register | -                                  | 60   | -                              | 60  |
| t <sub>PHZ</sub>    | HIGH to OFF-state propagation delay                               | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 10 or 11<br>in MODE2 register | -                                  | 60   | -                              | 60  |

Table 15. Dynamic characteristics ...continued

| Symbol           | Parameter                           | Conditions   | Standard-mode I <sup>2</sup> C-bus |     | Fast-mode I <sup>2</sup> C-bus |     |
|------------------|-------------------------------------|--|------------------------------------|-----|--------------------------------|-----|
|                  |                                     |  | Min                                | Max | Min                            | Max |
| t <sub>PZH</sub> | OFF-state to HIGH propagation delay | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 10 or 11<br>in MODE2 register | -                                  | 40  | -                              | 40  |
| t <sub>PLH</sub> | LOW to HIGH propagation delay       | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 01<br>in MODE2 register       | -                                  | 40  | -                              | 40  |
| t <sub>PHL</sub> | HIGH to LOW propagation delay       | $\overline{OE}$ to LEDn;<br>OUTNE[1:0] = 00<br>in MODE2 register       | -                                  | 60  | -                              | 60  |

[1] Minimum SCL clock frequency is limited by the bus time-out feature, which resets the serial bus interface if either SDA or SCL is held LOW for Disable bus time-out feature for DC operation.

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

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

[4] 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 t<sub>SCL</sub>'s falling edge.

[5] The maximum t<sub>r</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. The maximum rise time (t<sub>r</sub>) for the SCL output stage is specified at 250 ns. 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>r</sub> and t<sub>f</sub>.

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

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

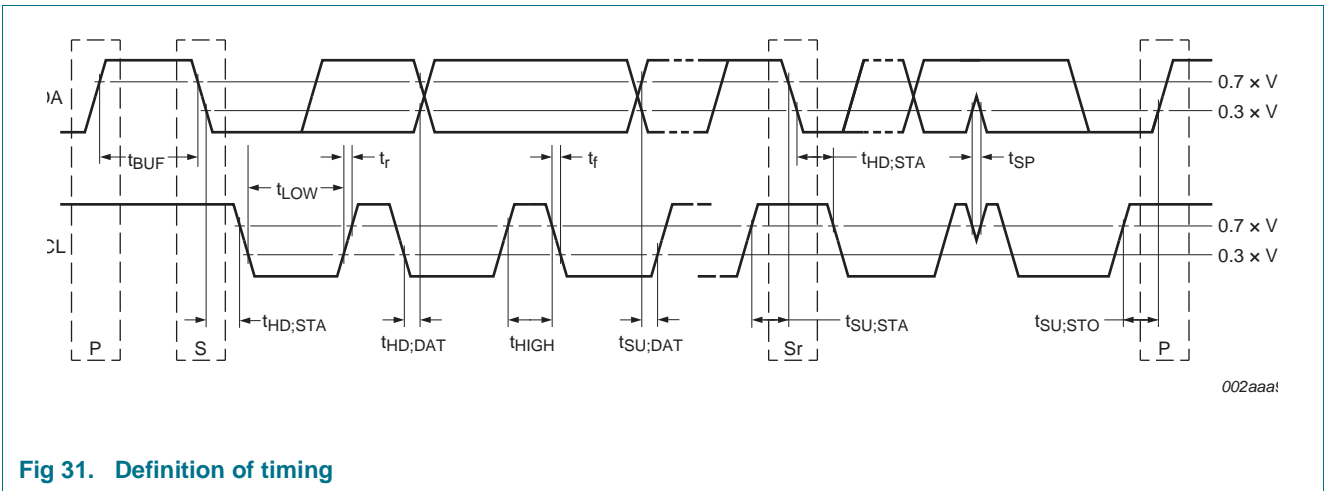


Fig 31. Definition of timing

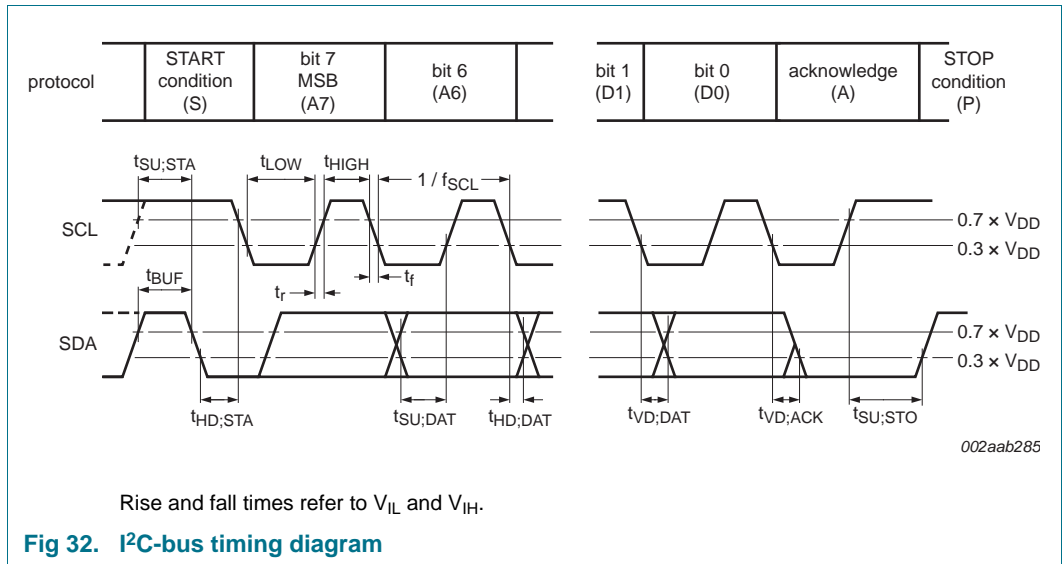


Fig 32. I<sup>2</sup>C-bus timing diagram

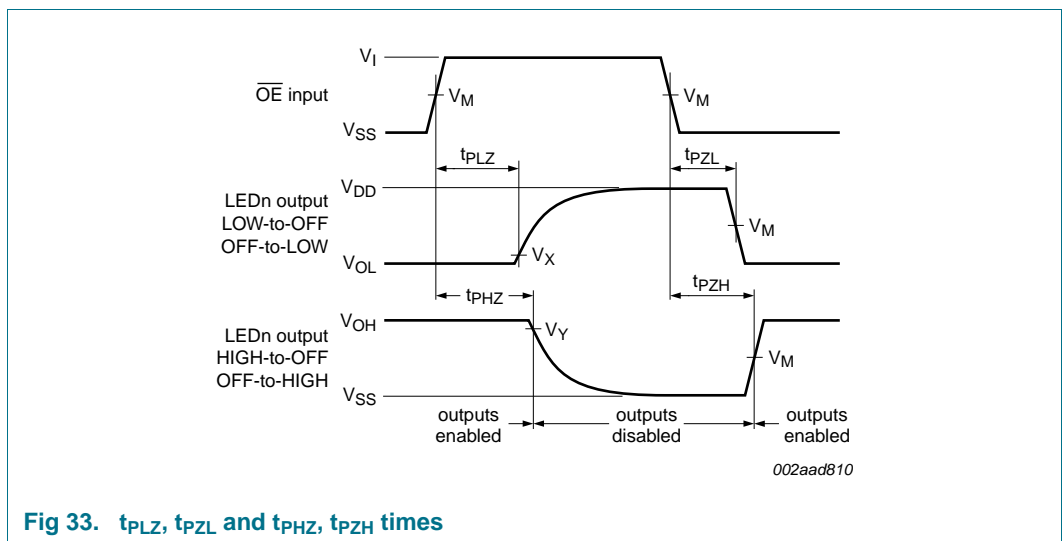
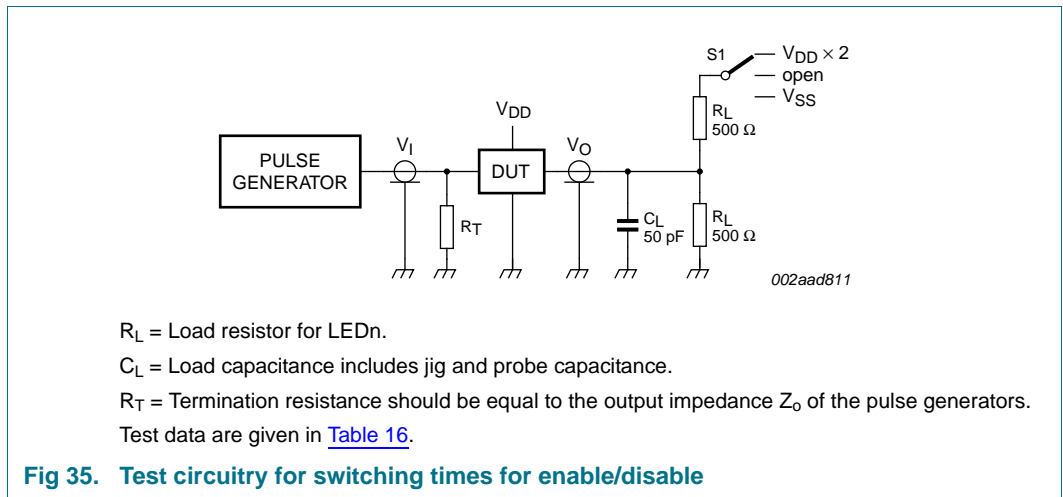
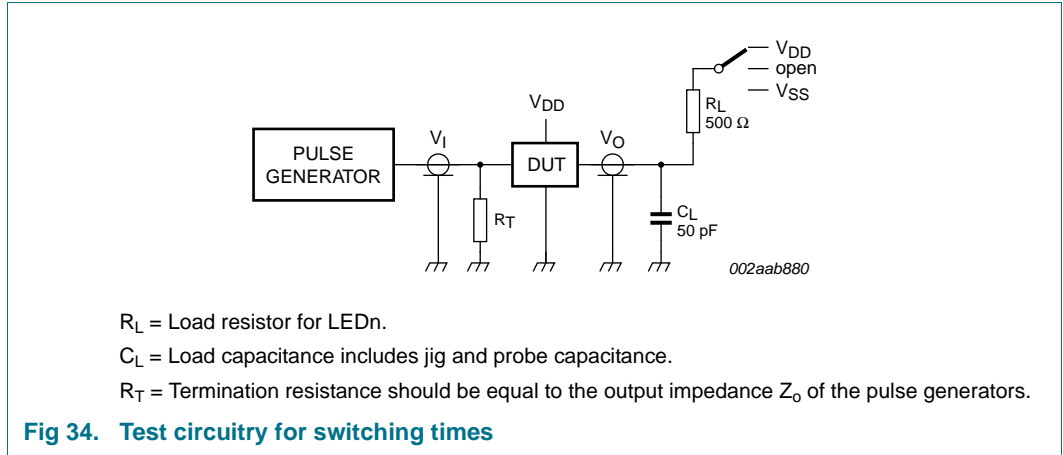


Fig 33.  $t_{PLZ}$ ,  $t_{PZL}$  and  $t_{PHZ}$ ,  $t_{PZH}$  times

14. Test information



**Table 16. Test data for enable/disable switching times**

| Test               | Load  |       | Switch            |
|--------------------|-------|-------|-------------------|
|                    | $C_L$ | $R_L$ |                   |
| $t_{PD}$           | 50 pF | 500 Ω | open              |
| $t_{PLZ}, t_{PZL}$ | 50 pF | 500 Ω | $V_{DD} \times 2$ |
| $t_{PHZ}, t_{PZH}$ | 50 pF | 500 Ω | $V_{SS}$          |

15. Package outline

TSSOP28: plastic thin shrink small outline package; 28 leads; body width 4.4 mm

SOT361-1

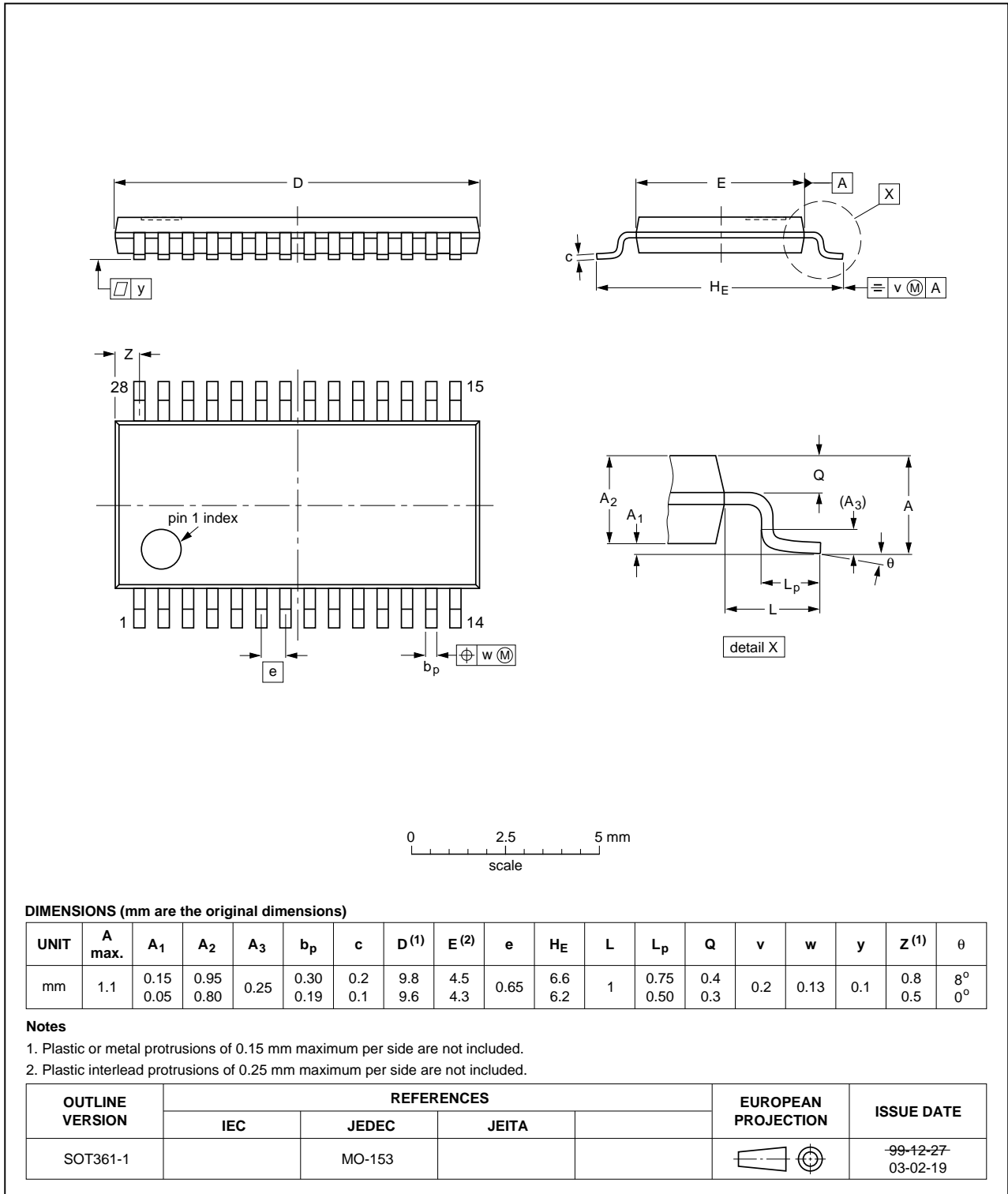


Fig 36. Package outline SOT361-1 (TSSOP28)

HVQFN28: plastic thermal enhanced very thin quad flat package; no leads; 28 terminals; body 6 x 6 x 0.85 mm

SOT788-1

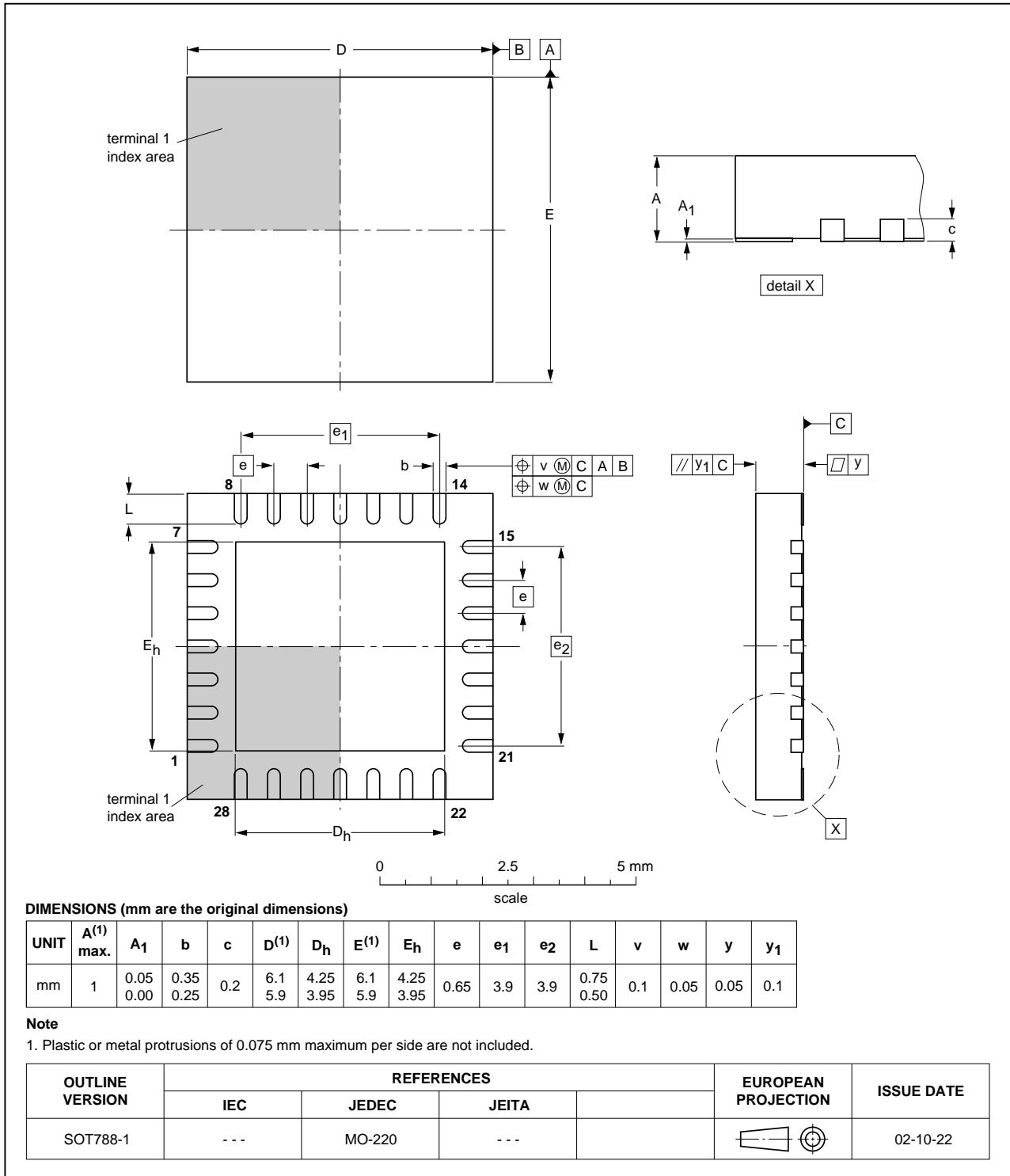


Fig 37. Package outline SOT788-1 (HVQFN28)

## 16. 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.

## 17. 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"*.

### 17.1 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.

### 17.2 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

### 17.3 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

### 17.4 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 38](#)) 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 17](#) and [18](#)

**Table 17. SnPb eutectic process (from J-STD-020D)**

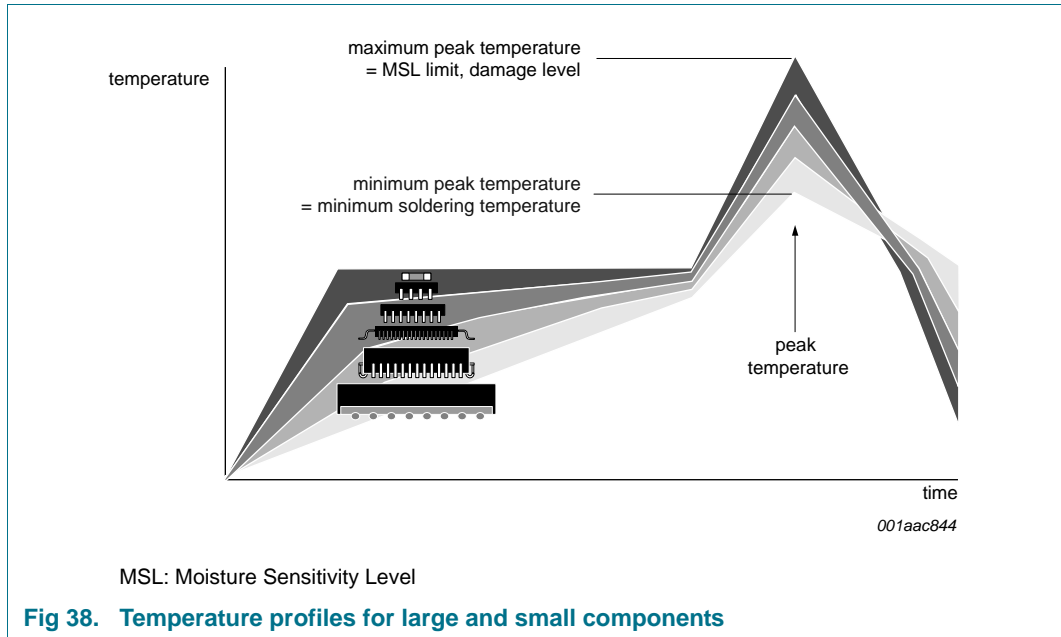
| Package thickness (mm) | Package reflow temperature (°C) |       |
|------------------------|---------------------------------|-------|
|                        | Volume (mm <sup>3</sup> )       |       |
|                        | < 350                           | ≥ 350 |
| < 2.5                 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

**Table 18. 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 38](#).



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

## 18. Abbreviations

**Table 19. Abbreviations**

| Acronym              | Description                                   |
|----------------------|---|
| CDM                  | Charged-Device Model                          |
| DUT                  | Device Under Test                             |
| EMI                  | ElectroMagnetic Interference                  |
| ESD                  | ElectroStatic Discharge                       |
| HBM                  | Human Body Model                              |
| I <sup>2</sup> C-bus | Inter-Integrated Circuit bus                  |
| LCD                  | Liquid Crystal Display                        |
| LED                  | Light Emitting Diode                          |
| LSB                  | Least Significant Bit                         |
| MM                   | Machine Model                                 |
| MSB                  | Most Significant Bit                          |
| NMOS                 | Negative-channel Metal-Oxide Semiconductor    |
| PCB                  | Printed-Circuit Board                         |
| PMOS                 | Positive-channel Metal-Oxide Semiconductor    |
| POR                  | Power-On Reset                                |
| PWM                  | Pulse Width Modulation; Pulse Width Modulator |
| RGB                  | Red/Green/Blue                                |
| RGBA                 | Red/Green/Blue/Amber                          |
| SMBus                | System Management Bus                         |

## 19. Revision history

**Table 20. Revision history**

| Document ID    | Release date  | Data sheet status  | Change notice | Supersedes  |
|----------------|---|--------------------|---------------|-------------|
| PCA9685 v.4    | 20150416  | Product data sheet | -             | PCA9685 v.3 |
| Modifications: | <ul style="list-style-type: none"><li>• Changed programmable frequency to “24 Hz to 1526 Hz” throughout</li><li>• Minor edits to text and figures to provide clarity regarding cycle count throughout</li></ul> |                    |               |             |
| PCA9685 v.3    | 20100902  | Product data sheet | -             | PCA9685 v.2 |
| PCA9685 v.2    | 20090716  | Product data sheet | -             | PCA9685 v.1 |
| PCA9685 v.1    | 20080724  | Product data sheet | -             | -           |

## 20. Legal information

### 20.1 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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## 22. Contents

|           |   |           |           |                                      |           |
|-----------|---|-----------|-----------|--------------------------------------|-----------|
| <b>1</b>  | <b>General description</b> . . . . .                                    | <b>1</b>  | 17.1      | Introduction to soldering. . . . .   | 46        |
| <b>2</b>  | <b>Features and benefits</b> . . . . .                                  | <b>2</b>  | 17.2      | Wave and reflow soldering. . . . .   | 46        |
| <b>3</b>  | <b>Applications</b> . . . . .   | <b>3</b>  | 17.3      | Wave soldering . . . . .             | 46        |
| <b>4</b>  | <b>Ordering information</b> . . . . .                                   | <b>4</b>  | 17.4      | Reflow soldering . . . . .           | 47        |
| 4.1       | Ordering options . . . . .  | 4         | <b>18</b> | <b>Abbreviations</b> . . . . .       | <b>48</b> |
| <b>5</b>  | <b>Block diagram</b> . . . . .  | <b>5</b>  | <b>19</b> | <b>Revision history</b> . . . . .    | <b>49</b> |
| <b>6</b>  | <b>Pinning information</b> . . . . .                                    | <b>6</b>  | <b>20</b> | <b>Legal information</b> . . . . .   | <b>50</b> |
| 6.1       | Pinning . . . . .   | 6         | 20.1      | Data sheet status . . . . .          | 50        |
| 6.2       | Pin description . . . . .   | 6         | 20.2      | Definitions . . . . .                | 50        |
| <b>7</b>  | <b>Functional description</b> . . . . .                                 | <b>7</b>  | 20.3      | Disclaimers . . . . .                | 50        |
| 7.1       | Device addresses . . . . .  | 7         | 20.4      | Trademarks . . . . .                 | 51        |
| 7.1.1     | Regular I <sup>2</sup> C-bus slave address. . . . .                     | 7         | <b>21</b> | <b>Contact information</b> . . . . . | <b>51</b> |
| 7.1.2     | LED All Call I <sup>2</sup> C-bus address . . . . .                     | 8         | <b>22</b> | <b>Contents</b> . . . . .            | <b>52</b> |
| 7.1.3     | LED Sub Call I <sup>2</sup> C-bus addresses . . . . .                   | 8         |           |                                      |           |
| 7.1.4     | Software Reset I <sup>2</sup> C-bus address . . . . .                   | 9         |           |                                      |           |
| 7.2       | Control register . . . . .  | 9         |           |                                      |           |
| 7.3       | Register definitions . . . . .  | 10        |           |                                      |           |
| 7.3.1     | Mode register 1, MODE1 . . . . .  | 14        |           |                                      |           |
| 7.3.1.1   | Restart mode . . . . .  | 15        |           |                                      |           |
| 7.3.2     | Mode register 2, MODE2 . . . . .  | 16        |           |                                      |           |
| 7.3.3     | LED output and PWM control . . . . .                                    | 16        |           |                                      |           |
| 7.3.4     | ALL_LED_ON and ALL_LED_OFF control. . . . .                             | 25        |           |                                      |           |
| 7.3.5     | PWM frequency PRE_SCALE . . . . .                                       | 25        |           |                                      |           |
| 7.3.6     | SUBADR1 to SUBADR3, I <sup>2</sup> C-bus<br>subaddress 1 to 3 . . . . . | 26        |           |                                      |           |
| 7.3.7     | ALLCALLADR, LED All Call I <sup>2</sup> C-bus address. . . . .          | 26        |           |                                      |           |
| 7.4       | Active LOW output enable input . . . . .                                | 27        |           |                                      |           |
| 7.5       | Power-on reset . . . . .  | 27        |           |                                      |           |
| 7.6       | Software reset. . . . .   | 28        |           |                                      |           |
| 7.7       | Using the PCA9685 with and without<br>external drivers. . . . .         | 29        |           |                                      |           |
| <b>8</b>  | <b>Characteristics of the I<sup>2</sup>C-bus</b> . . . . .              | <b>30</b> |           |                                      |           |
| 8.1       | Bit transfer . . . . .  | 30        |           |                                      |           |
| 8.1.1     | START and STOP conditions . . . . .                                     | 30        |           |                                      |           |
| 8.2       | System configuration . . . . .  | 30        |           |                                      |           |
| 8.3       | Acknowledge . . . . .   | 31        |           |                                      |           |
| <b>9</b>  | <b>Bus transactions</b> . . . . .                                       | <b>32</b> |           |                                      |           |
| <b>10</b> | <b>Application design-in information</b> . . . . .                      | <b>35</b> |           |                                      |           |
| <b>11</b> | <b>Limiting values</b> . . . . .  | <b>38</b> |           |                                      |           |
| <b>12</b> | <b>Static characteristics</b> . . . . .                                 | <b>38</b> |           |                                      |           |
| <b>13</b> | <b>Dynamic characteristics</b> . . . . .                                | <b>40</b> |           |                                      |           |
| <b>14</b> | <b>Test information</b> . . . . .                                       | <b>43</b> |           |                                      |           |
| <b>15</b> | <b>Package outline</b> . . . . .  | <b>44</b> |           |                                      |           |
| <b>16</b> | <b>Handling information</b> . . . . .                                   | <b>46</b> |           |                                      |           |
| <b>17</b> | <b>Soldering of SMD packages</b> . . . . .                              | <b>46</b> |           |                                      |           |

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