

# DATA SHEET



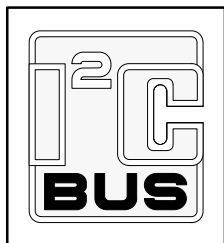
## **PCA9531** 8-bit I<sup>2</sup>C LED dimmer

Product data

2003 Nov 10

8-bit I<sup>2</sup>C LED dimmer

## PCA9531



## FEATURES

- Eight LED drivers (on, off, flashing at a programmable rate)
- Two selectable, fully programmable blink rates (frequency and duty cycle) between 0.625 and 160 Hz (1.6 and 6.25 milliseconds)
- 256 brightness steps
- Input/outputs not used as LED drivers can be used as regular GPIOs
- Internal oscillator requires no external components
- I<sup>2</sup>C interface logic compatible with SMBus
- Internal power-on reset
- Noise filter on SCL/SDA inputs
- Active low reset input
- Eight open drain outputs directly drive LEDs to 25 mA
- Edge rate control on outputs
- No glitch on power-up
- Supports hot insertion
- Low stand-by current
- Operating power supply voltage range of 2.3 V to 5.5 V
- 0 to 400 kHz clock frequency
- ESD protection exceeds 2000 V HBM per JESD22-A114, 150 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
- Package offer: SO16, TSSOP16, HVQFN16

## DESCRIPTION

The PCA9531 is an 8-bit I<sup>2</sup>C & SMBus I/O expander optimized for dimming LEDs in 256 discrete steps for Red/Green/Blue (RGB) color mixing and back light applications.

The PCA9531 contains an internal oscillator with two user programmable blink rates and duty cycles coupled to the output PWM. The LED brightness is controlled by setting the blink rate high enough (> 100 Hz) that the blinking can not be seen and then using the duty cycle to vary the amount of time the LED is on and thus the average current through the LED.

The initial setup sequence programs the two blink rates/duty cycles for each individual PWM. From then on, only one command from the bus master is required to turn individual LEDs ON, OFF, BLINK RATE 1 or BLINK RATE 2. Based on the programmed frequency and duty cycle, BLINK RATE 1 and BLINK RATE 2 will cause the LEDs to appear at a different brightness or blink at periods up to 1.6 second. The open drain outputs directly drive the LEDs with maximum output sink current of 25 mA per bit and 100 mA per package.

To blink LEDs at periods greater than 1.6 second the bus master (MCU, MPU, DSP, chipset, etc.) must send repeated commands to turn the LED on and off as is currently done when using normal I/O Expanders like the Philips PCF8574 or PCA9554. Any bits not used for controlling the LEDs can be used for General Purpose Parallel Input/Output (GPIO) expansion which provides a simple solution when additional I/O is needed for ACPI power switches, sensors, push-buttons, alarm monitoring, fans, etc.

The active low hardware reset pin (RESET) and Power On Reset (POR) initializes the registers to their default state causing the bits to be set high (LED off).

Three hardware address pins on the PCA9531 allow eight devices to operate on the same bus.

## ORDERING INFORMATION

PACKAGES	TEMPERATURE RANGE	ORDER CODE	TOPSIDE MARK	DRAWING NUMBER
16-pin plastic SO	-40 to +85 °C	PCA9531D	PCA9531D	SOT109-1
16-pin plastic TSSOP	-40 to +85 °C	PCA9531PW	PCA9531	SOT403-1
16-pin plastic HVQFN	-40 to +85 °C	PCA9531BS	9531	SOT629-1

Standard packing quantities and other packaging data is available at [www.philipslogic.com/packaging](http://www.philipslogic.com/packaging).

I<sup>2</sup>C is a trademark of Philips Semiconductors Corporation.

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PIN CONFIGURATION — SO, TSSOP

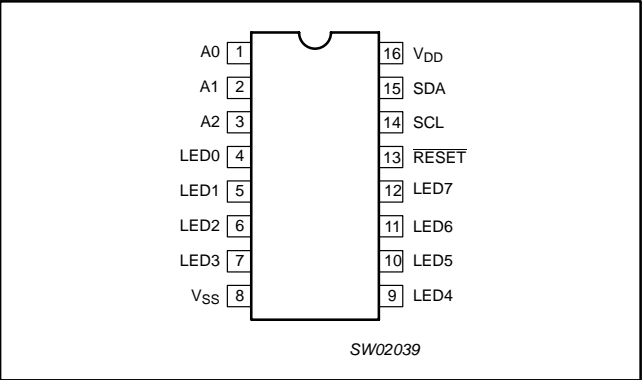


Figure 1. Pin configuration — SO, TSSOP

PIN CONFIGURATION — HVQFN

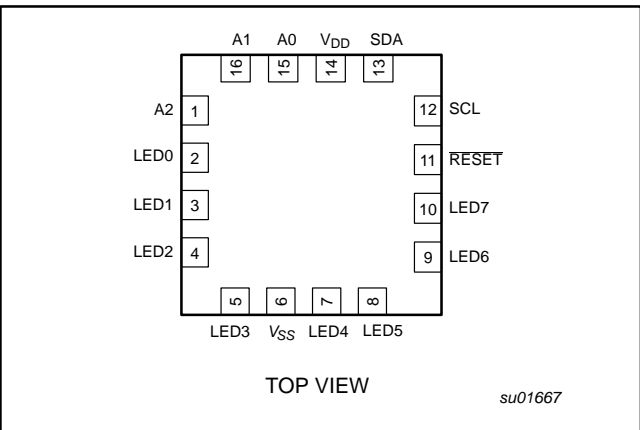


Figure 2. Pin configuration — HVQFN

PIN DESCRIPTION

SO, TSSOP PIN NUMBER	HVQFN PIN NUMBER	SYMBOL	FUNCTION
1	15	A0	Address input 0
2	16	A1	Address input 1
3	1	A2	Address input 2
4, 5, 6, 7	2, 3, 4, 5	LED0-3	LED drivers 0-3
8	6	V <sub>SS</sub>	Supply ground
9, 10, 11, 12	7, 8, 9, 10	LED4-7	LED drivers 4-7
13	11	RESET	Active low reset input
14	12	SCL	Serial clock line
15	13	SDA	Serial data line
16	14	V <sub>DD</sub>	Supply voltage

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BLOCK DIAGRAM

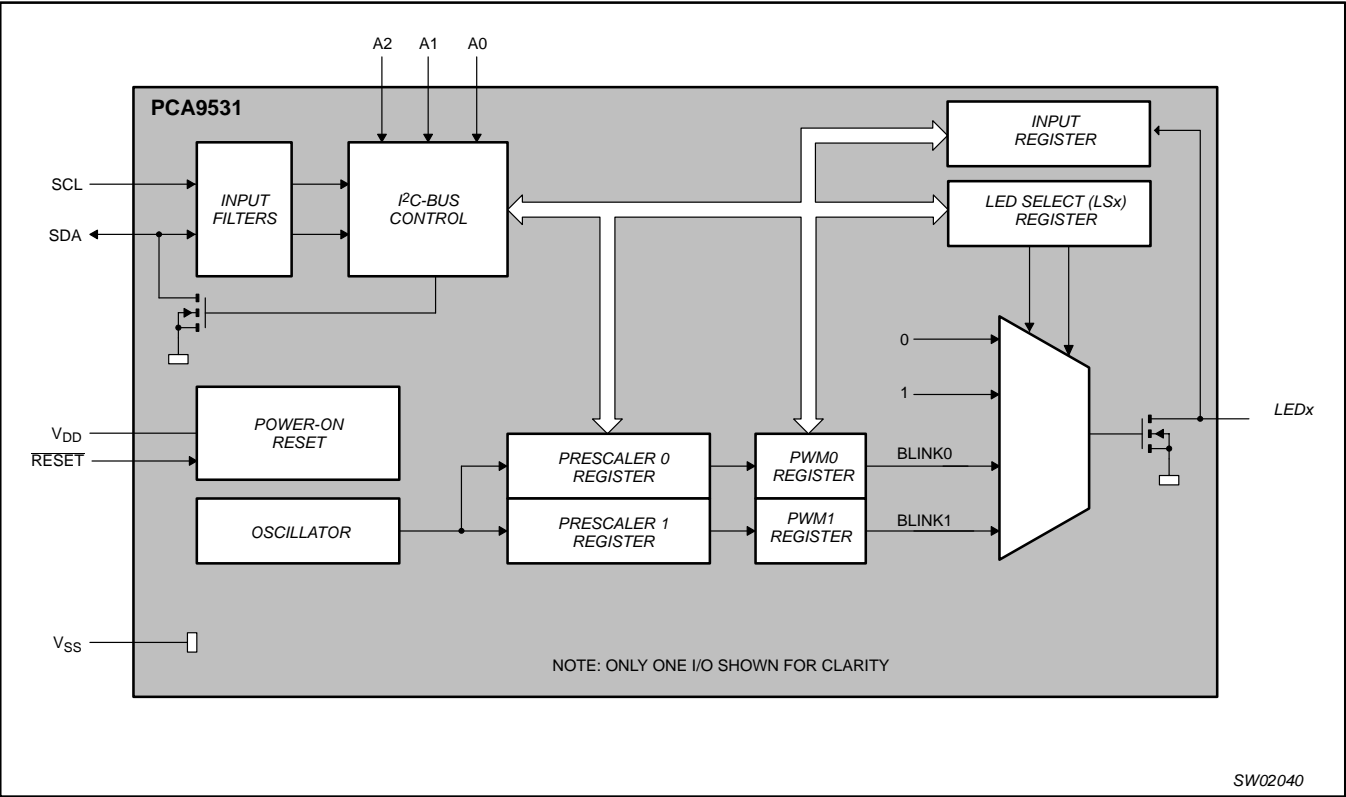


Figure 3. Block diagram

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## PCA9531

## DEVICE ADDRESSING

Following a START condition the bus master must output the address of the slave it is accessing. The address of the PCA9531 is shown in Figure 4. To conserve power, no internal pullup resistors are incorporated on the hardware selectable address pins and they must be pulled HIGH or LOW.

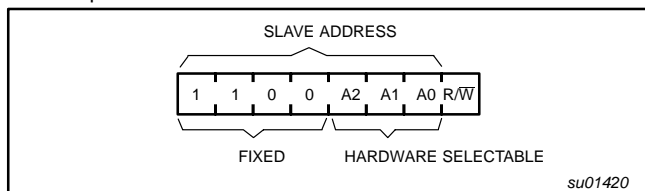


Figure 4. Slave address

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.

## CONTROL REGISTER

Following the successful acknowledgement of the slave address, the bus master will send a byte to the PCA9531 which will be stored in the Control Register.

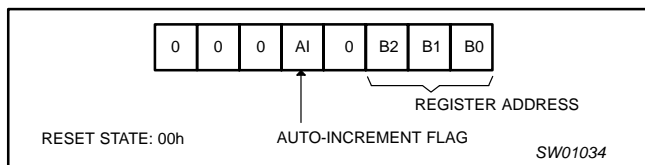


Figure 5. Control register

## CONTROL REGISTER DEFINITION

B2	B1	B0	REGISTER NAME	TYPE	REGISTER FUNCTION
0	0	0	INPUT	READ	INPUT REGISTER
0	0	1	PSC0	READ/ WRITE	FREQUENCY PRESCALER 0
0	1	0	PWM0	READ/ WRITE	PWM REGISTER 0
0	1	1	PSC1	READ/ WRITE	FREQUENCY PRESCALER 1
1	0	0	PWM1	READ/ WRITE	PWM REGISTER 1
1	0	1	LS0	READ/ WRITE	LED0-LED3 SELECTOR
1	1	0	LS1	READ/ WRITE	LED4-LED7 SELECTOR

## REGISTER DESCRIPTION

The lowest 3 bits are used as a pointer to determine which register will be accessed.

If the auto-increment flag is set, the three low order bits of the Control Register are automatically incremented after a read or write. This allows the user to program the registers sequentially. The contents of these bits will rollover to '000' after the last register is accessed.

When auto-increment flag is set (AI = 1) and a read sequence is initiated, the sequence must start by reading a register different from the input register (B2 B1 B0 ≠ 0 0 0).

Only the 3 least significant bits are affected by the AI flag.

Unused bits must be programmed with zeroes.

## INPUT — INPUT REGISTER

bit	7	6	5	4	3	2	1	0
Default	X	X	X	X	X	X	X	X

The INPUT register reflects the state of the device pins. Writes to this register will be acknowledged but will have no effect.

## PSC0 — FREQUENCY PRESCALER 0

bit	7	6	5	4	3	2	1	0
default	0	0	0	0	0	0	0	0

PSC0 is used to program the period of the PWM output.

$$\text{The period of BLINK0} = \frac{(\text{PSC0} + 1)}{152}$$

## PWM0 — PWM REGISTER 0

bit	7	6	5	4	3	2	1	0
default	1	0	0	0	0	0	0	0

The PWM0 register determines the duty cycle of BLINK0. The outputs are LOW (LED on) when the count is less than the value in PWM0 and HIGH (LED off) when it is greater. If PWM0 is programmed with 00h, then the PWM0 output is always HIGH (LED off).

$$\text{The duty cycle of BLINK0 is: } \frac{\text{PWM0}}{256}$$

## PSC1 — FREQUENCY PRESCALER 1

bit	7	6	5	4	3	2	1	0
default	0	0	0	0	0	0	0	0

PSC1 is used to program the period of PWM output.

$$\text{The period of BLINK1} = \frac{(\text{PSC1} + 1)}{152}$$

## PWM1 — PWM REGISTER 1

bit	7	6	5	4	3	2	1	0
default	1	0	0	0	0	0	0	0

The PWM1 register determines the duty cycle of BLINK1. The outputs are LOW (LED on) when the count is less than the value in PWM1 and HIGH (LED off) when it is greater. If PWM1 is programmed with 00h, then the PWM1 output is always HIGH (LED off).

$$\text{The duty cycle of BLINK1 is: } \frac{\text{PWM1}}{256}$$

## LS0 — LED0-3 SELECTOR

	LED 3		LED 2		LED 1		LED 0	
bit	7	6	5	4	3	2	1	0
default	0	0	0	0	0	0	0	0

## LS1 — LED4-7 SELECTOR

	LED 7		LED 6		LED 5		LED 4	
bit	7	6	5	4	3	2	1	0
default	0	0	0	0	0	0	0	0

The LSx LED select registers determine the source of the LED data.

00 = Output is set Hi-Z (LED off - default)

01 = Output is set low (LED on)

10 = Output blinks at PWM0 rate

11 = Output blinks at PWM1 rate

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**POWER-ON RESET**

When power is applied to  $V_{DD}$ , an internal Power On Reset holds the PCA9531 in a reset state until  $V_{DD}$  has reached  $V_{POR}$ . At this point, the reset condition is released and the PCA9531 registers are initialized to their default states, all the outputs in the off state.

**EXTERNAL RESET**

A reset can be accomplished by holding the  $\overline{RESET}$  pin low for a minimum of  $t_{W}$ . The PCA9531 registers and I<sup>2</sup>C state machine will be held in their default state until the  $\overline{RESET}$  input is once again high.

This input requires a pull-up resistor to  $V_{DD}$ .

**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.

**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 6).

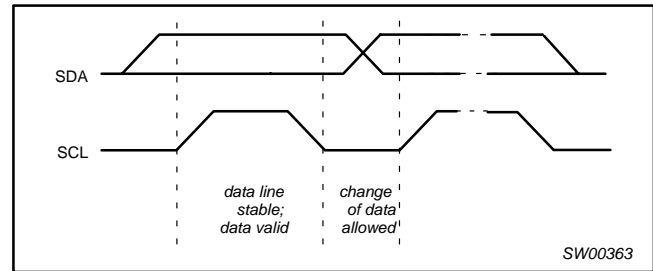


Figure 6. Bit transfer

**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 7).

**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 8).

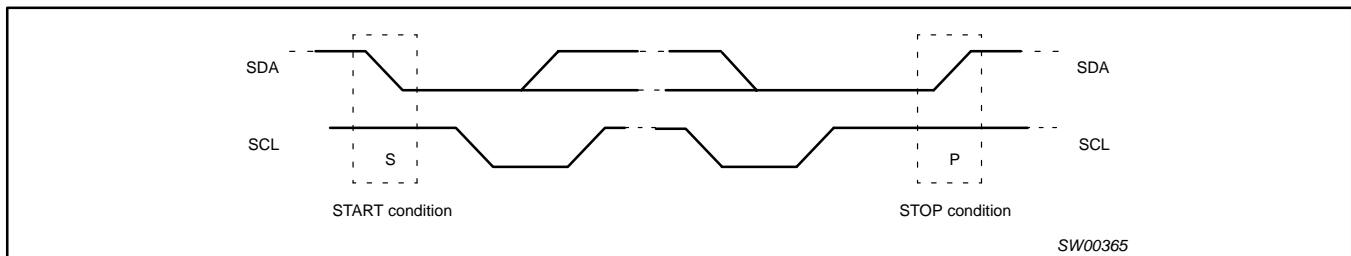


Figure 7. Definition of start and stop conditions

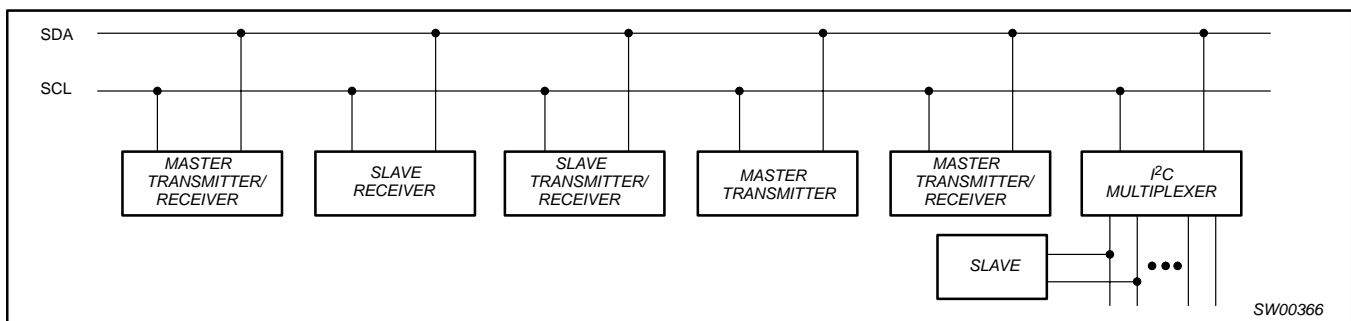


Figure 8. System configuration

8-bit I<sup>2</sup>C LED dimmer

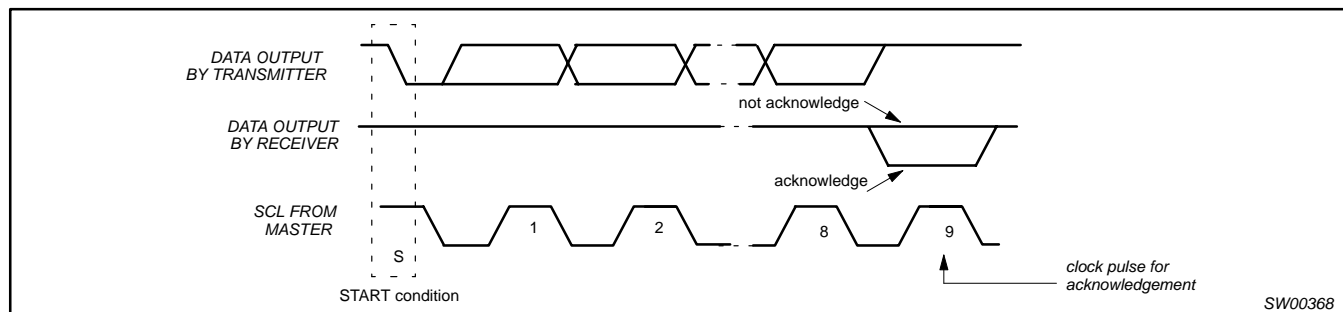
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**Acknowledge**

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 and hold times 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.



**Figure 9. Acknowledgement on the I<sup>2</sup>C-bus**

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Bus transactions

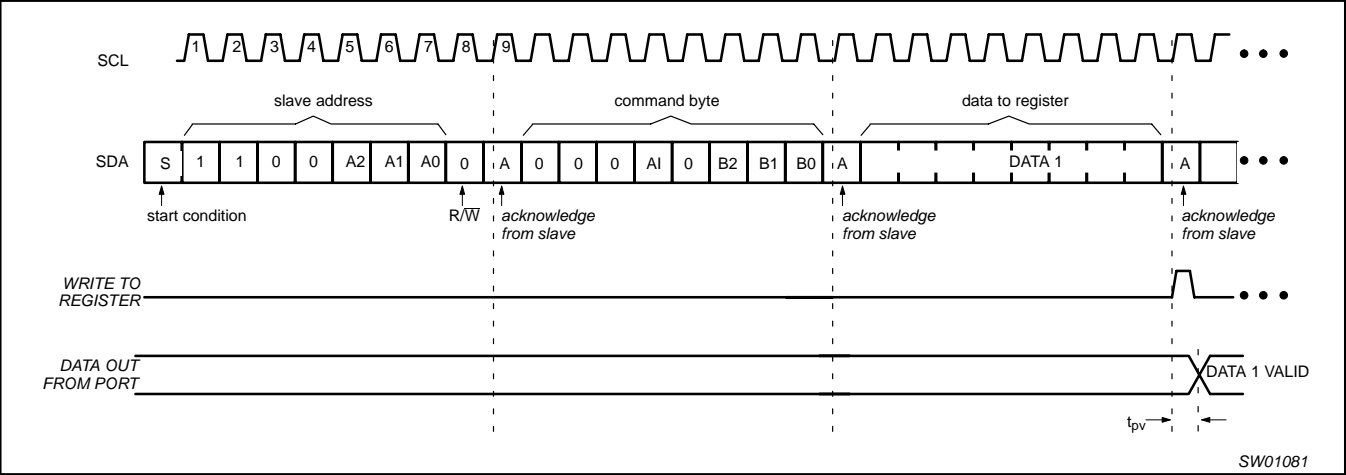


Figure 10. WRITE to register

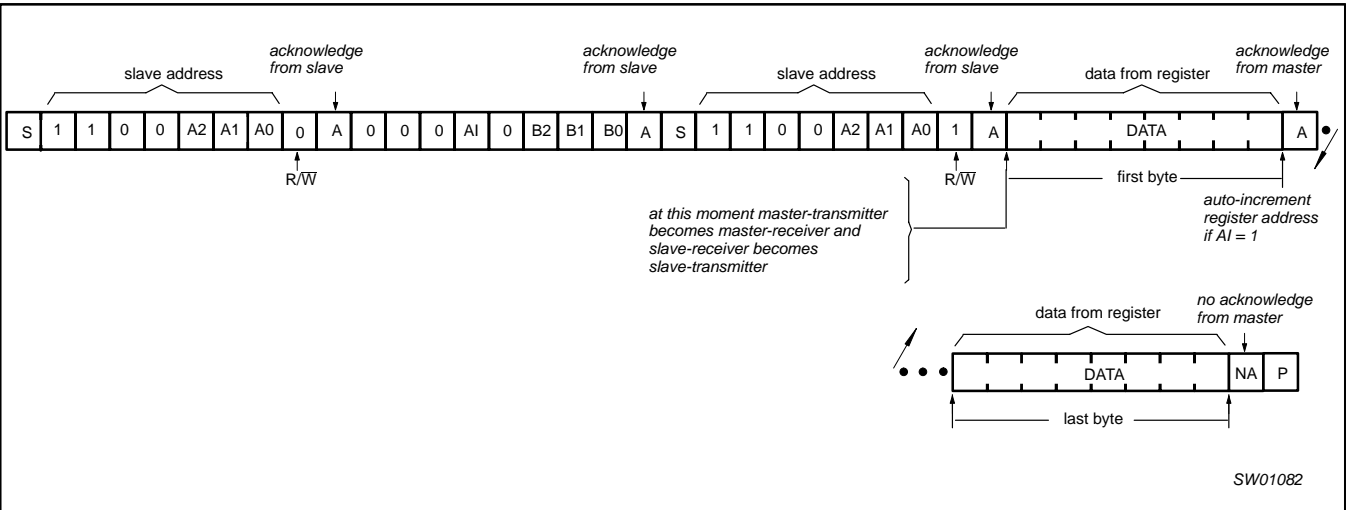
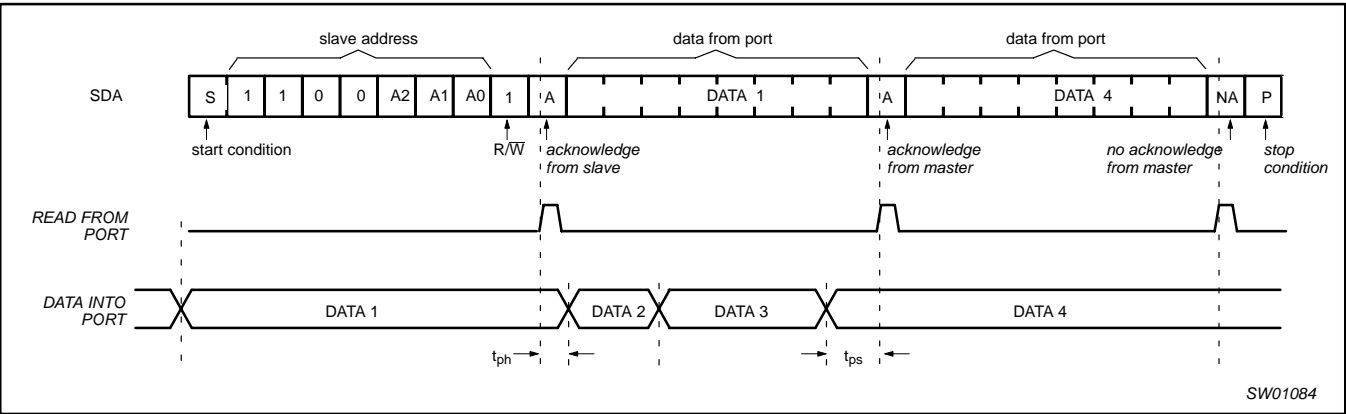


Figure 11. READ from register



NOTES:

1. This figure assumes the command byte has previously been programmed with 00h.

Figure 12. READ input port register



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APPLICATION DATA

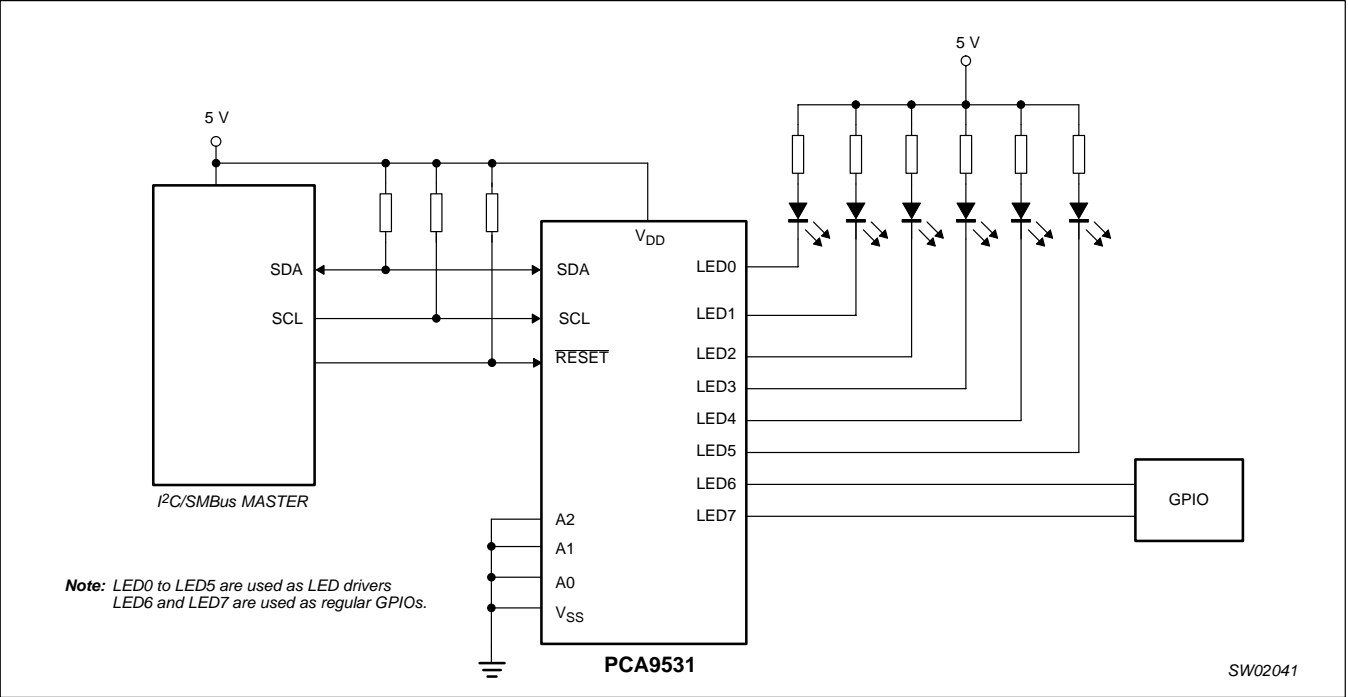


Figure 13. Typical application

Minimizing I<sub>DD</sub> when the I/O is used to control LEDs

When the I/Os are used to control LEDs, they are normally connected to V<sub>DD</sub> through a resistor as shown in Figure 13. Since the LED acts as a diode, when the LED is off the I/O V<sub>IN</sub> is about 1.2 V less than V<sub>DD</sub>. The supply current, I<sub>DD</sub>, increases as V<sub>IN</sub> becomes lower than V<sub>DD</sub> and is specified as ΔI<sub>DD</sub> in the DC characteristics table.

Designs needing to minimize current consumption, such as battery power applications, should consider maintaining the I/O pins greater than or equal to V<sub>DD</sub> when the LED is off. Figure 14 shows a high value resistor in parallel with the LED. Figure 15 shows V<sub>DD</sub> less than the LED supply voltage by at least 1.2 V. Both of these methods maintain the I/O V<sub>IN</sub> at or above V<sub>DD</sub> and prevents additional supply current consumption when the LED is off.

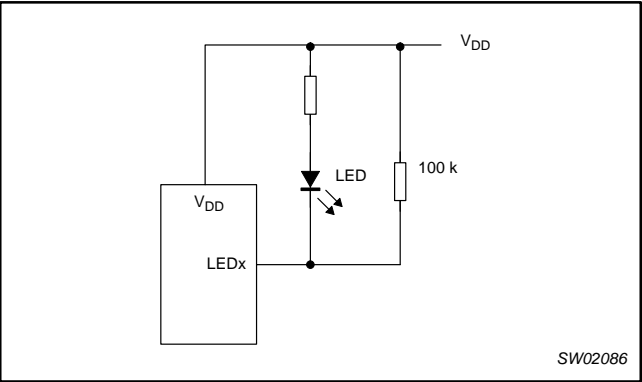


Figure 14. High value resistor in parallel with the LED

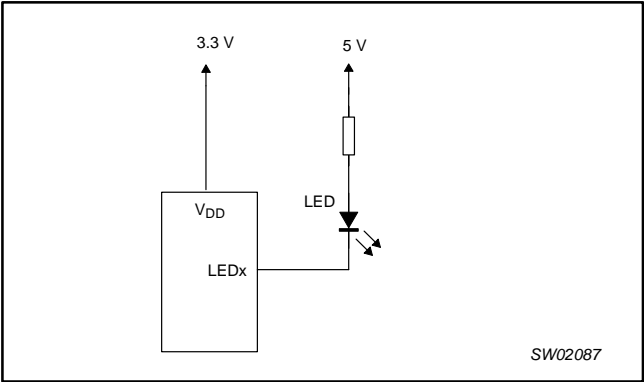


Figure 15. Device supplied by a lower voltage

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## PCA9531

**Programming example**

The following example will show how to set LED0 to LED3 on. It will then set LED4 and LED5 to blink at 1 Hz at a 50% duty cycle. LED6 and LED7 will be set to be dimmed at 25% of their maximum brightness (duty cycle = 25%).

**Table 1.**

	I <sup>2</sup> C-bus
Start	S
PCA9531 address with A0-A2 = low	C0h
PSC0 subaddress + auto-increment	11h
Set prescaler PSC0 to achieve a period of 1 second: $\text{Blink period} = 1 = \frac{\text{PSC0} + 1}{152}$ PSC0 = 151	97h
Set PWM0 duty cycle to 50%: $\frac{\text{PWM0}}{256} = 0.5$ PWM0 = 128	80h
Set prescaler PCS1 to dim at max frequency: Blink period = max PSC1 = 0	00h
Set PWM1 output duty cycle to 25%: $\frac{\text{PWM1}}{256} = 0.25$ PWM1 = 64	40h
Set LED0 to LED3 on	55h
Set LED4 and 5 to PWM0, and LED6 or 7 to PWM1	FAh
Stop	P

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**ABSOLUTE MAXIMUM RATINGS**

In accordance with the Absolute Maximum Rating System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN	MAX	UNIT
V <sub>DD</sub>	Supply voltage		-0.5	6.0	V
V <sub>I/O</sub>	DC voltage on an I/O		V <sub>SS</sub> - 0.5	5.5	V
I <sub>I/O</sub>	DC output current on an I/O		—	+25	mA
I <sub>SS</sub>	Supply current		—	200	mA
P <sub>tot</sub>	Total power dissipation		—	400	mW
T <sub>stg</sub>	Storage temperature range		-65	+150	°C
T <sub>amb</sub>	Operating ambient temperature		-40	+85	°C

**HANDLING**

Inputs and outputs are protected against electrostatic discharge in normal handling. However, to be totally safe, it is desirable to take precautions appropriate to handling MOS devices. Advice can be found in Data Handbook IC24 under "Handling MOS devices".

**DC CHARACTERISTICS**V<sub>DD</sub> = 2.3 to 5.5 V; V<sub>SS</sub> = 0 V; T<sub>amb</sub> = -40 to +85 °C; unless otherwise specified. TYP at 3.3 V and 25 °C.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
<b>Supplies</b>						
V <sub>DD</sub>	Supply voltage		2.3	—	5.5	V
I <sub>DD</sub>	Supply current	Operating mode; V <sub>DD</sub> = 5.5 V; V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub> ; f <sub>SCL</sub> = 100 kHz	—	350	500	μA
I <sub>stb</sub>	Standby current	Standby mode; V <sub>DD</sub> = 5.5 V; V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub> ; f <sub>SCL</sub> = 0 kHz	—	1.9	3.0	μA
ΔI <sub>DD</sub>	Additional standby current	Standby mode; V <sub>DD</sub> = 5.5 V; Every LED I/O at V <sub>IN</sub> = 4.3 V; f <sub>SCL</sub> = 0 kHz	—	—	800	μA
V <sub>POR</sub>	Power-on reset voltage	No load; V <sub>I</sub> = V <sub>DD</sub> or V <sub>SS</sub>	—	1.7	2.2	V
<b>Input SCL; input/output SDA</b>						
V <sub>IL</sub>	LOW level input voltage		-0.5	—	0.3 V <sub>DD</sub>	V
V <sub>IH</sub>	HIGH level input voltage		0.7 V <sub>DD</sub>	—	5.5	V
I <sub>OL</sub>	LOW level output current	V <sub>OL</sub> = 0.4 V	3	6.5	—	mA
I <sub>L</sub>	Leakage current	V <sub>I</sub> = V <sub>DD</sub> = V <sub>SS</sub>	-1	—	+1	μA
C <sub>I</sub>	Input capacitance	V <sub>I</sub> = V <sub>SS</sub>	—	3.7	5	pF
<b>I/Os</b>						
V <sub>IL</sub>	LOW level input voltage		-0.5	—	0.8	V
V <sub>IH</sub>	HIGH level input voltage		2.0	—	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; Note 1	9	—	—	mA
		V <sub>OL</sub> = 0.4 V; V <sub>DD</sub> = 3.0 V; Note 1	12	—	—	mA
		V <sub>OL</sub> = 0.4 V; V <sub>DD</sub> = 5.0 V; Note 1	15	—	—	mA
		V <sub>OL</sub> = 0.7 V; V <sub>DD</sub> = 2.3 V; Note 1	15	—	—	mA
		V <sub>OL</sub> = 0.7 V; V <sub>DD</sub> = 3.0 V; Note 1	20	—	—	mA
		V <sub>OL</sub> = 0.7 V; V <sub>DD</sub> = 5.0 V; Note 1	25	—	—	mA
I <sub>L</sub>	Input leakage current	V <sub>DD</sub> = 3.6 V; V <sub>I</sub> = 0 or V <sub>DD</sub>	-1	—	1	μA
C <sub>IO</sub>	Input/output capacitance		—	2.5	5	pF
<b>Select Inputs A0, A1, A2 / RESET</b>						
V <sub>IL</sub>	LOW level input voltage		-0.5	—	0.8	V
V <sub>IH</sub>	HIGH level input voltage; A0 / RESET		2.0	—	5.5	V
V <sub>IH</sub>	HIGH level input voltage; A1 / A2		2.0	—	V <sub>DD</sub> + 0.5	V
I <sub>LI</sub>	Input leakage current		-1	—	1	μA
C <sub>I</sub>	Input capacitance	V <sub>I</sub> = V <sub>SS</sub>	—	2.3	5	pF

**NOTE:**

1. Each I/O must be externally limited to a maximum of 25 mA and the device must be limited to a maximum current of 100 mA.

8-bit I<sup>2</sup>C LED dimmer

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## AC SPECIFICATIONS

SYMBOL	PARAMETER	STANDARD MODE I <sup>2</sup> C BUS		FAST MODE I <sup>2</sup> C BUS		UNITS
		MIN	MAX	MIN	MAX	
$f_{SCL}$	Operating frequency	0	100	0	400	kHz
$t_{BUF}$	Bus free time between STOP and START conditions	4.7	—	1.3	—	$\mu$ s
$t_{HD;STA}$	Hold time after (repeated) START condition	4.0	—	0.6	—	$\mu$ s
$t_{SU;STA}$	Repeated START condition setup time	4.7	—	0.6	—	$\mu$ s
$t_{SU;STO}$	Setup time for STOP condition	4.0	—	0.6	—	$\mu$ s
$t_{HD;DAT}$	Data in hold time	0	—	0	—	ns
$t_{VD;ACK}$	Valid time for ACK condition <sup>2</sup>	—	600	—	600	ns
$t_{VD;DAT (L)}$	Data out valid time <sup>3</sup>	—	600	—	600	ns
$t_{VD;DAT (H)}$	Data out valid time <sup>3</sup>	—	1500	—	600	ns
$t_{SU;DAT}$	Data setup time	250	—	100	—	ns
$t_{LOW}$	Clock LOW period	4.7	—	1.3	—	$\mu$ s
$t_{HIGH}$	Clock HIGH period	4.0	—	0.6	—	$\mu$ s
$t_F$	Clock/Data fall time	—	300	$20 + 0.1 C_b^1$	300	ns
$t_R$	Clock/Data rise time	—	1000	$20 + 0.1 C_b^1$	300	ns
$t_{SP}$	Pulse width of spikes that must be suppressed by the input filters	—	50	—	50	ns
<b>Port Timing</b>						
$t_{PV}$	Output data valid	—	200	—	200	ns
$t_{PS}$	Input data setup time	100	—	100	—	ns
$t_{PH}$	Input data hold time	1	—	1	—	$\mu$ s
<b>Reset</b>						
$t_W$	Reset pulse width	6	—	6	—	ns
$t_{REC}$	Reset recovery time	0	—	0	—	ns
$t_{RESET}^{4,5}$	Time to reset	400	—	400	—	ns

## NOTES:

- $C_b$  = total capacitance of one bus line in pF.
- $t_{VD;ACK}$  = time for Acknowledgement signal from SCL low to SDA (out) low.
- $t_{VD;DAT}$  = minimum time for SDA data out to be valid following SCL low.
- Resetting the device while actively communicating on the bus may cause glitches or errant STOP conditions.
- Upon reset, the full delay will be the sum of  $t_{RESET}$  and the RC time constant of the SDA bus.

8-bit I<sup>2</sup>C LED dimmer

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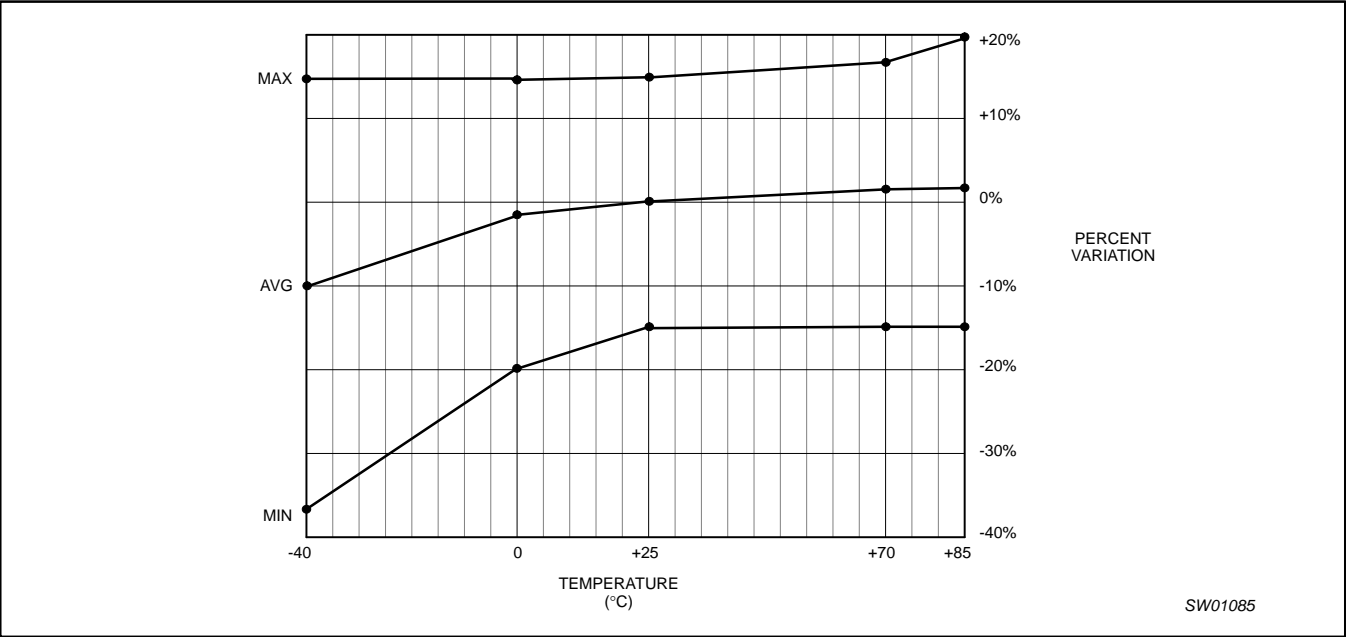


Figure 16. Typical frequency variation over process at  $V_{DD} = 2.3\text{ V to }3.0\text{ V}$

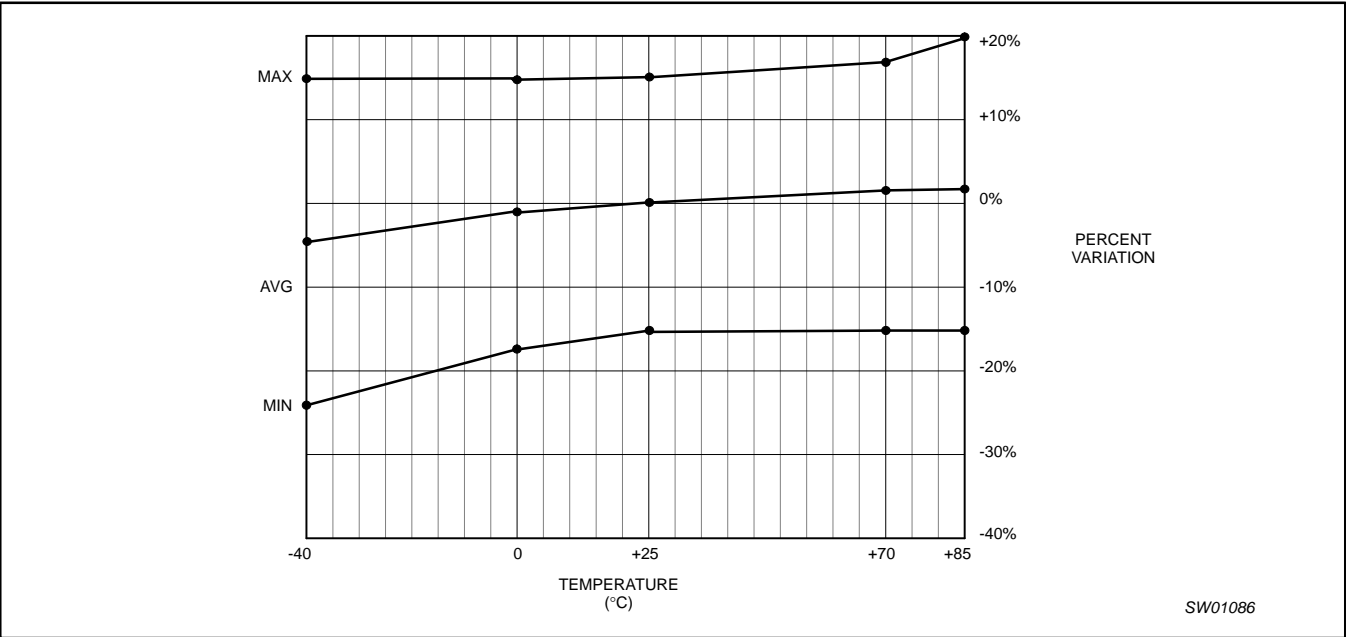


Figure 17. Typical frequency variation over process at  $V_{DD} = 3.0\text{ V to }5.5\text{ V}$

8-bit I<sup>2</sup>C LED dimmer

PCA9531

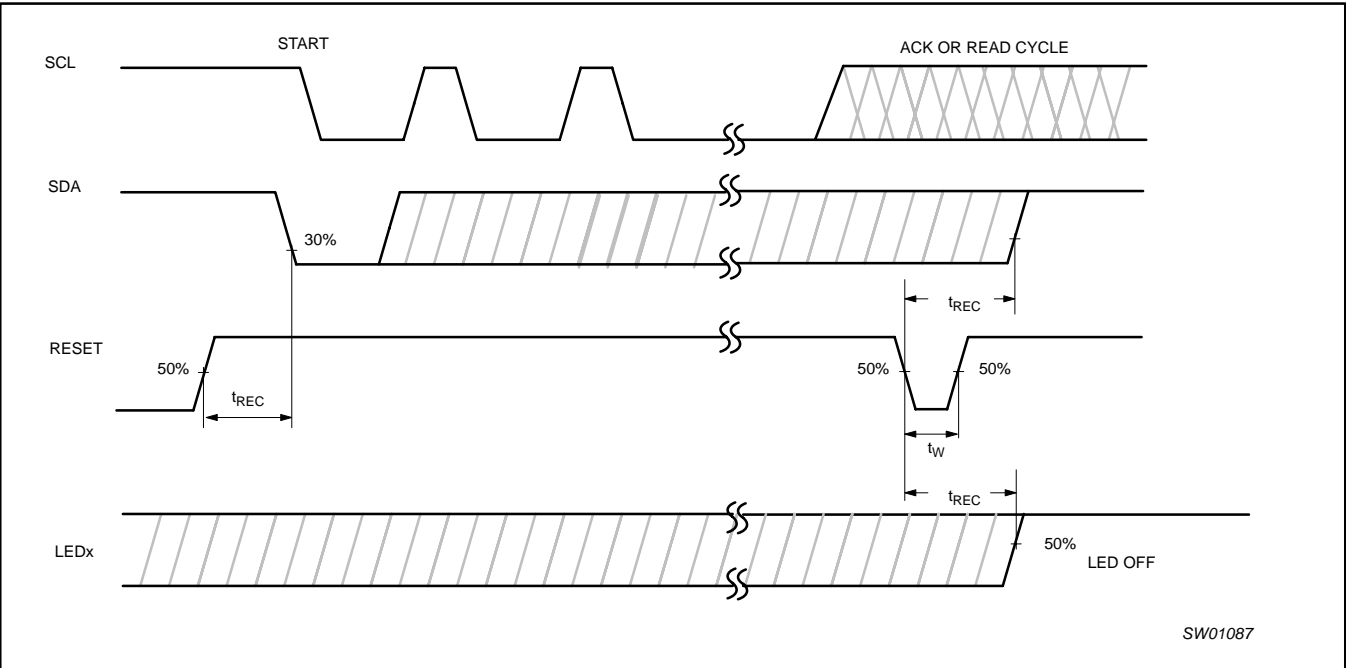


Figure 18. Definition of RESET timing

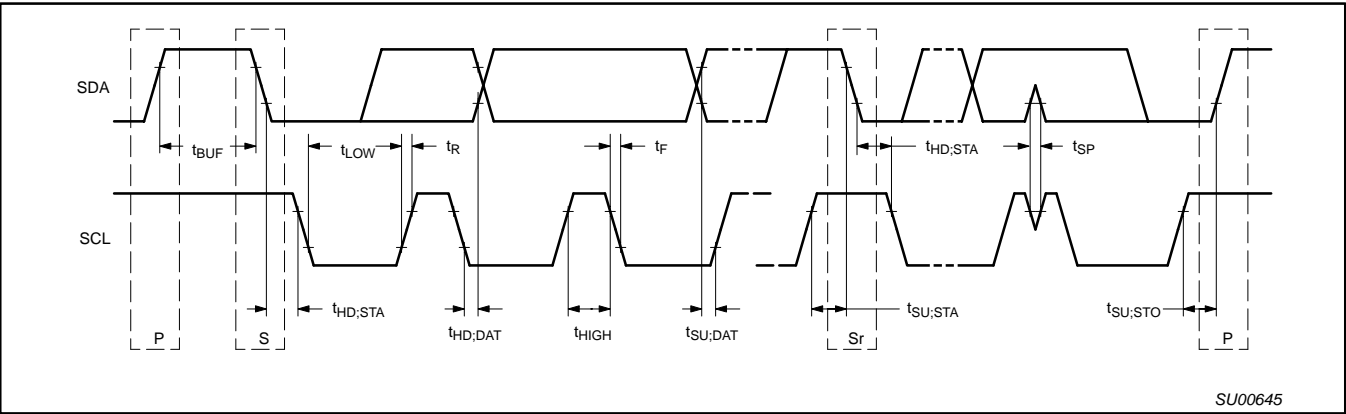


Figure 19. Definition of timing

8-bit I<sup>2</sup>C LED dimmer

PCA9531

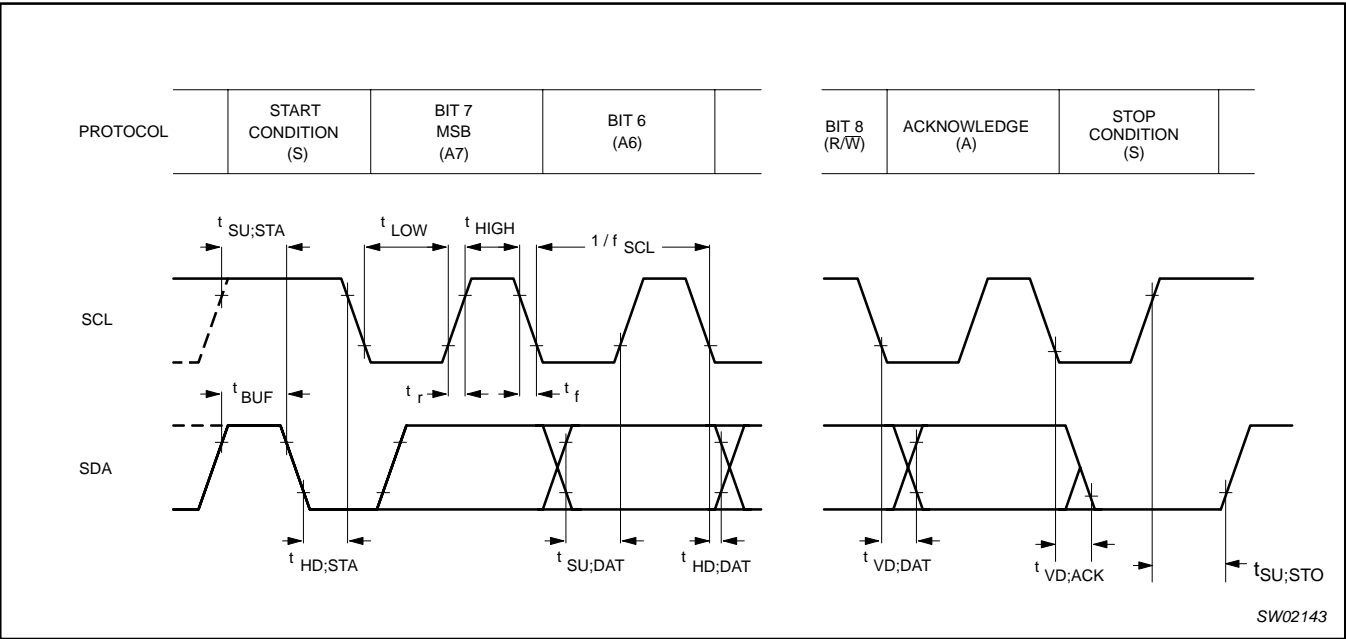


Figure 20. I<sup>2</sup>C-bus timing diagram; rise and fall times refer to  $V_{IL}$  and  $V_{IH}$

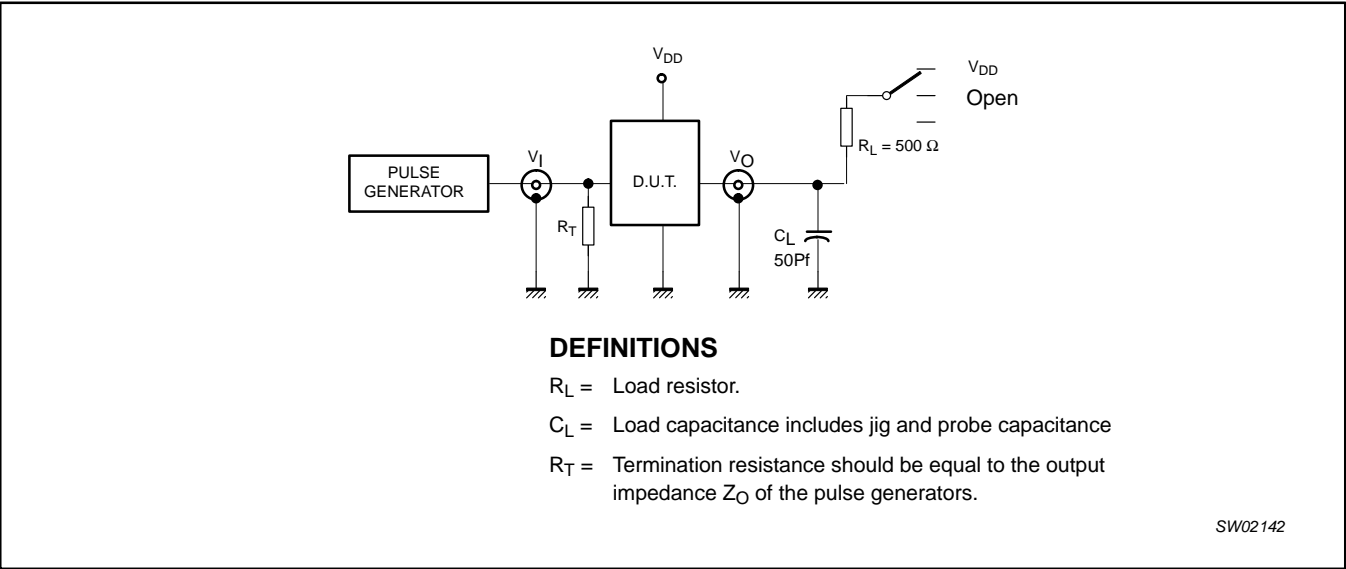


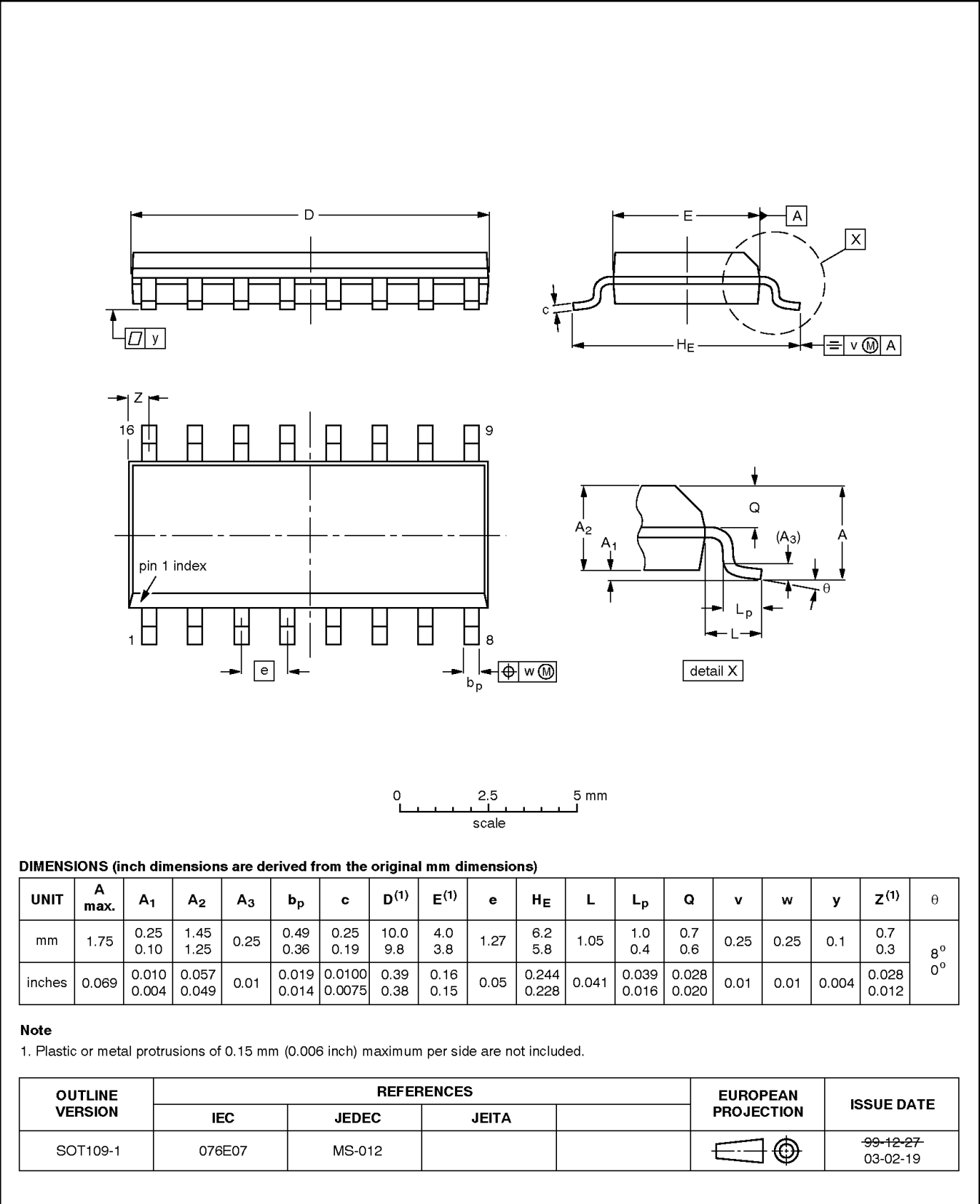
Figure 21. Test circuitry for switching times

8-bit I<sup>2</sup>C LED dimmer

PCA9531

SO16: plastic small outline package; 16 leads; body width 3.9 mm

SOT109-1



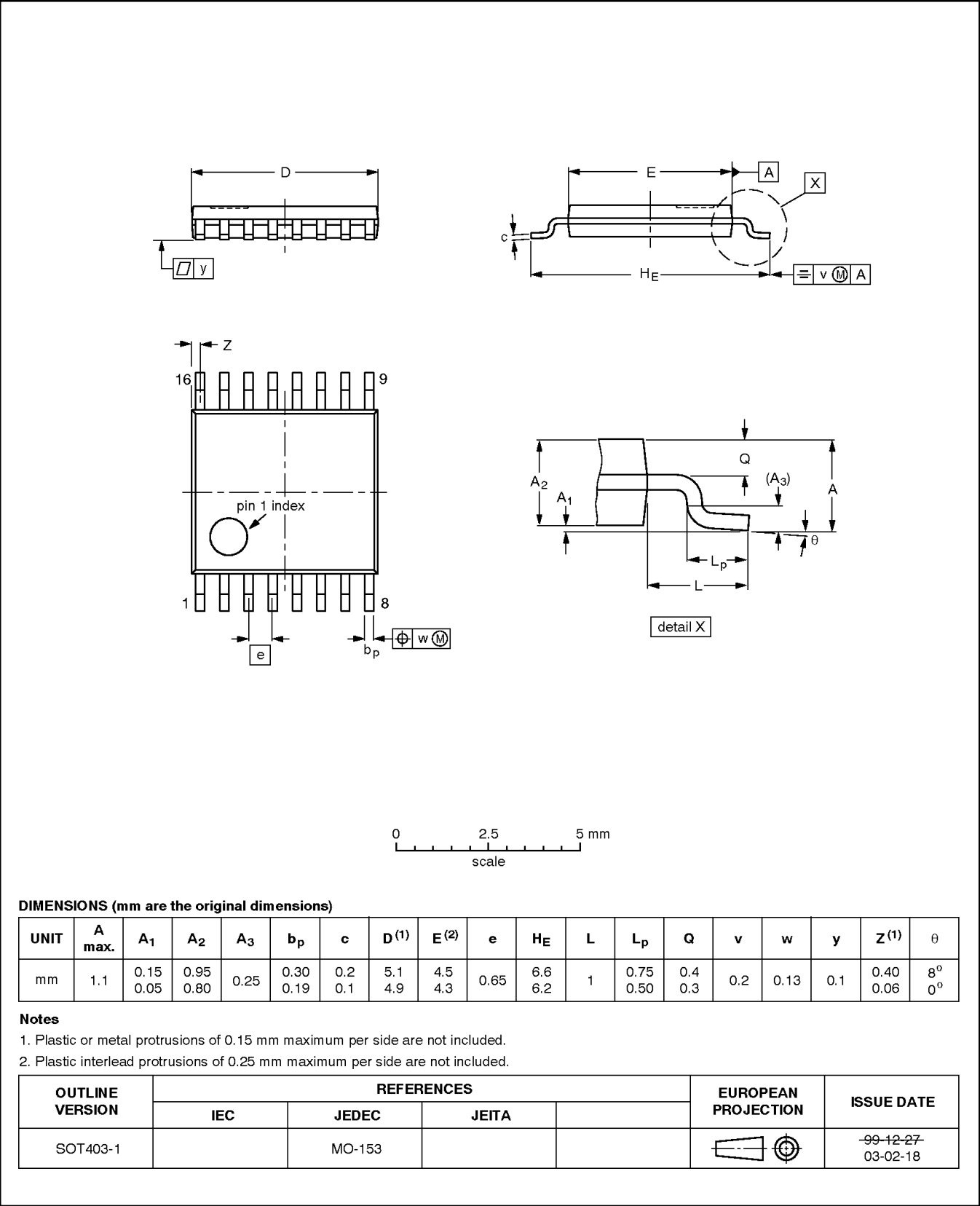


8-bit I<sup>2</sup>C LED dimmer

PCA9531

TSSOP16: plastic thin shrink small outline package; 16 leads; body width 4.4 mm

SOT403-1

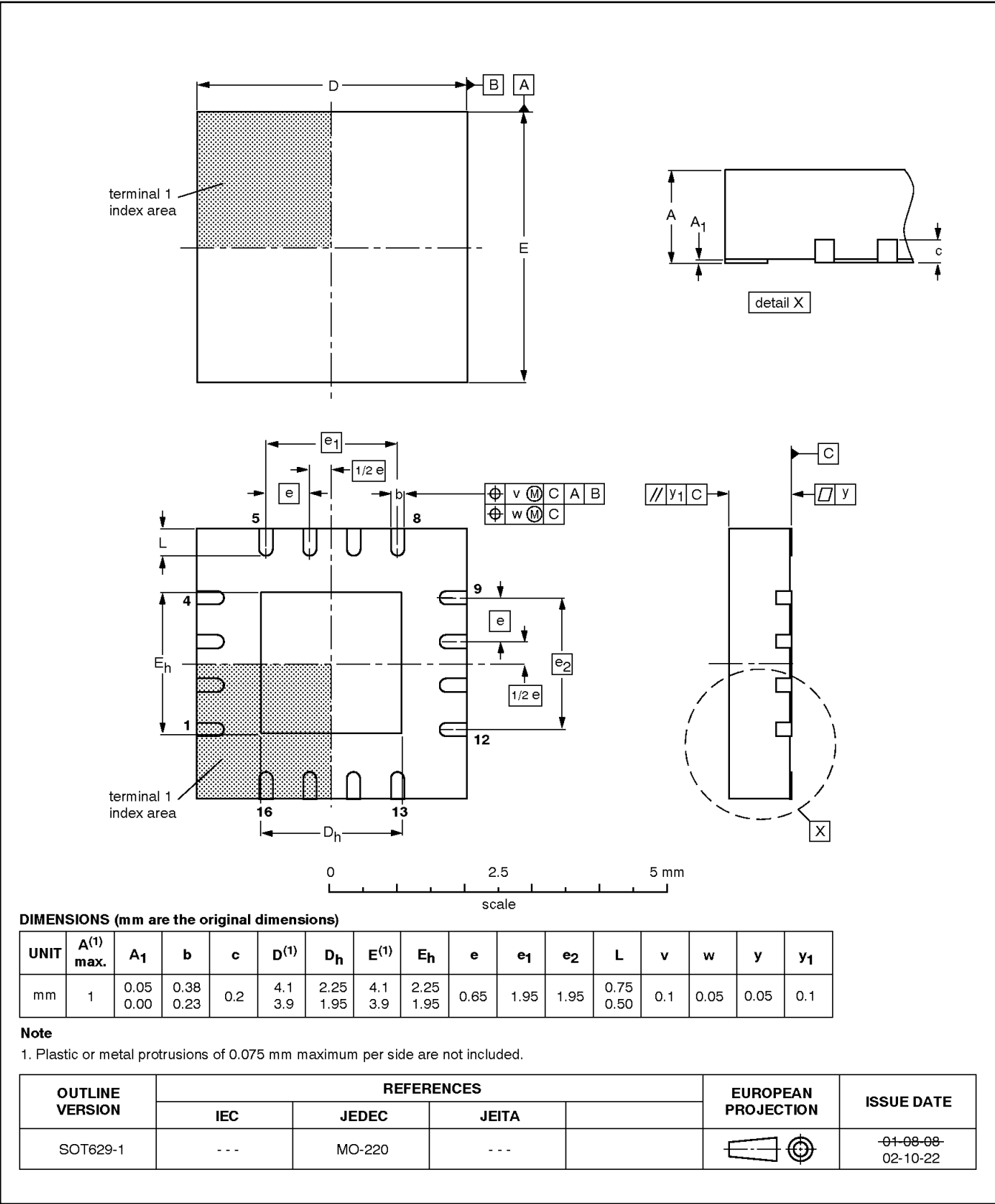


8-bit I<sup>2</sup>C LED dimmer

PCA9531

HVQFN16: plastic thermal enhanced very thin quad flat package; no leads; 16 terminals;  
body 4 x 4 x 0.85 mm

SOT629-1



8-bit I<sup>2</sup>C LED dimmerPCA9531

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**REVISION HISTORY**

Rev	Date	Description
_1	20031110	Product data (9397 750 12292); ECN 853-2407 30411 dated 06 September 2003. Initial version

8-bit I<sup>2</sup>C LED dimmer

PCA9531



Purchase of Philips I<sup>2</sup>C components conveys a license under the Philips' I<sup>2</sup>C patent to use the components in the I<sup>2</sup>C system provided the system conforms to the I<sup>2</sup>C specifications defined by Philips. This specification can be ordered using the code 9398 393 40011.

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