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# PCA9691

## 8-bit A/D and D/A converter

Rev. 02 — 27 January 2010

Product data sheet

## 1. General description

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The PCA9691 is a single chip, single supply, low power, 8-bit CMOS<sup>1</sup> data acquisition device with four analog inputs, one analog output and a serial I<sup>2</sup>C-bus interface. Three address pins (A0, A1, and A2) are used for programming the hardware address, allowing the use of up to 64 PCA9691 devices connected to the I<sup>2</sup>C-bus without additional hardware. Address, control and data to and from the PCA9691 are transferred via the serial two-line bidirectional I<sup>2</sup>C-bus.

The functions of the PCA9691 include:

- Analog input multiplexing
- On-chip sample and hold
- 8-bit Analog-to-Digital (A/D) conversion
- 8-bit Digital-to-Analog (D/A) conversion

The maximum conversion rate is given by the maximum frequency of the I<sup>2</sup>C-bus.

## 2. Features

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- 8-bit successive approximation A/D conversion
- Four analog inputs programmable as single-ended or differential inputs
- 64 different addresses by three hardware address pins
- 1 MHz Fast-mode Plus (Fm+) I<sup>2</sup>C-bus via serial input/output
- Sampling rate given by I<sup>2</sup>C-bus frequency
- Single supply voltage; operating from 2.5 V to 5.5 V
- Low standby current
- Analog voltage from V<sub>SS</sub> to V<sub>DD</sub>
- Multiplying Digital-to-Analog Converter (DAC) with one analog output
- On-chip sample and hold circuit
- Auto-incremented channel selection

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1. The definition of the abbreviations and acronyms used in this data sheet can be found in [Section 14](#).

### 3. Ordering information

Table 1. Ordering information

| Type number | Package |  | Version  |
|-------------|---------|--|----------|
|             | Name    | Description  |          |
| PCA9691BS   | HVQFN16 | plastic thermal enhanced very thin quad flat package; no leads; 16 terminals; body 4 × 4 × 0.85 mm | SOT629-1 |
| PCA9691TS   | TSSOP16 | plastic thin shrink small outline package; 16 leads; body width 4.4 mm                             | SOT403-1 |
| PCA9691T    | SO16    | plastic small outline package; 16 leads; body width 7.5 mm   | SOT162-1 |

### 4. Marking

Table 2. Marking codes

| Type number | Marking code |
|-------------|--------------|
| PCA9691BS   | 9691         |
| PCA9691TS   | PCA9691      |
| PCA9691T    | PCA9691T     |

### 5. Block diagram

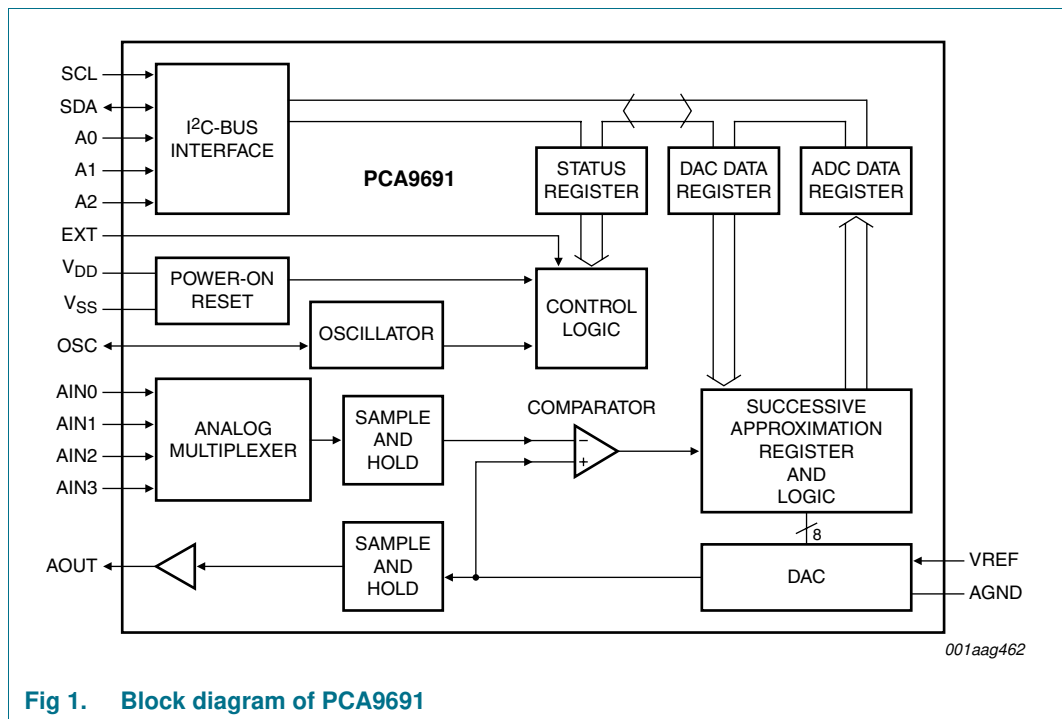
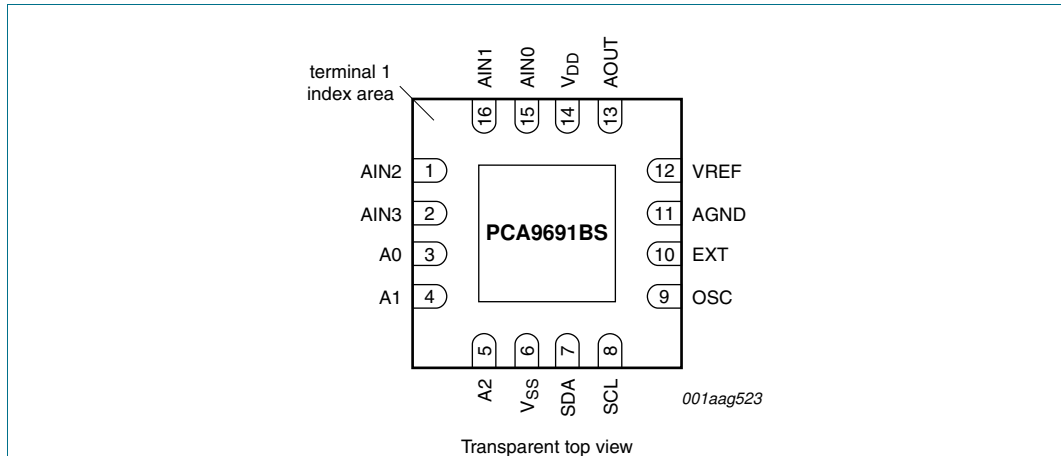


Fig 1. Block diagram of PCA9691

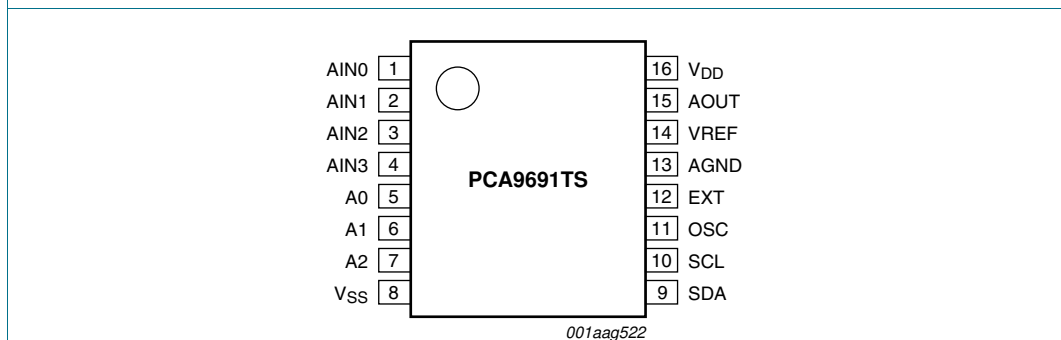
## 6. Pinning information

### 6.1 Pinning



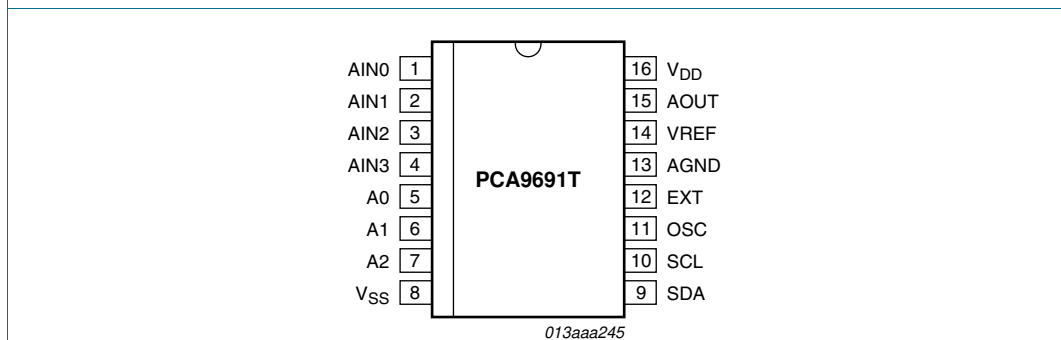
For mechanical details, see [Figure 25](#).

**Fig 2. Pin configuration for HVQFN16 (PCA9691BS)**



Top view. For mechanical details, see [Figure 26](#).

**Fig 3. Pin configuration for TSSOP16 (PCA9691TS)**



Top view. For mechanical details, see [Figure 27](#).

**Fig 4. Pin configuration for SO16 (PCA9691T)**

## 6.2 Pin description

Table 3. Pin description

| Symbol          | Pin                    |                        |                    | Type         | Description  |
|-----------------|------------------------|------------------------|--------------------|--------------|--|
|                 | HVQFN16<br>(PCA9691BS) | TSSOP16<br>(PCA9691TS) | SO16<br>(PCA9691T) |              |  |
| AIN0            | 15                     | 1                      | 1                  | input        | analog input 0   |
| AIN1            | 16                     | 2                      | 2                  | input        | analog input 1   |
| AIN2            | 1                      | 3                      | 3                  | input        | analog input 2   |
| AIN3            | 2                      | 4                      | 4                  | input        | analog input 3   |
| A0              | 3                      | 5                      | 5                  | input        | address input 0  |
| A1              | 4                      | 6                      | 6                  | input        | address input 1  |
| A2              | 5                      | 7                      | 7                  | input        | address input 2  |
| V <sub>SS</sub> | 6 <sup>[1]</sup>       | 8                      | 8                  | ground       | ground supply (analog and digital)   |
| SDA             | 7                      | 9                      | 9                  | input/output | I <sup>2</sup> C-bus data input and output   |
| SCL             | 8                      | 10                     | 10                 | input        | I <sup>2</sup> C-bus clock input   |
| OSC             | 9                      | 11                     | 11                 | input/output | oscillator signal selection:<br>input, if pin EXT is HIGH<br>output, if pin EXT is LOW |
| EXT             | 10                     | 12                     | 12                 | input        | oscillator selection input:<br>HIGH: external oscillator<br>LOW: internal oscillator   |
| AGND            | 11                     | 13                     | 13                 | ground       | DAC analog ground  |
| VREF            | 12                     | 14                     | 14                 | input        | DAC reference voltage input  |
| AOUT            | 13                     | 15                     | 15                 | output       | analog output  |
| V <sub>DD</sub> | 14                     | 16                     | 16                 | supply       | supply voltage   |

[1] The die paddle (exposed pad) is connected to V<sub>SS</sub> and should be electrically isolated.

## 7. Functional description

### 7.1 Addressing

Each PCA9691 device in an I<sup>2</sup>C-bus system is activated by sending a valid address to the device. The address consists of seven programmable bits and one read/write bit. The address must be set according to Table 4. The three input pins (A2, A1, and A0) are used to encode the seven address bits (A[6:0]), where each of the pins can be connected to V<sub>DD</sub>, V<sub>SS</sub>, SCL, or SDA. The address is always sent as the first byte after the start condition in the I<sup>2</sup>C-bus protocol. The last bit of the address byte is the read/write bit which sets the direction of the following data transfer (see Figure 5, Figure 18, and Figure 19).

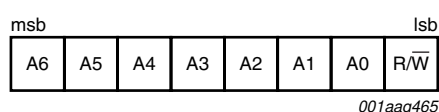


Fig 5. Address byte

## 7.1.1 Address map

Table 4. PCA9691 address map

| Pin             |                 |                 | Bit |    |    |    |    |    |    |     | Address | Number |
|-----------------|-----------------|-----------------|-----|----|----|----|----|----|----|-----|---------|--------|
| A2              | A1              | A0              | A6  | A5 | A4 | A3 | A2 | A1 | A0 | R/W |         |        |
| V <sub>SS</sub> | V <sub>SS</sub> | SDA             | 0   | 1  | 0  | 0  | 0  | 0  | 0  | 0   | 40h     | 1      |
| V <sub>SS</sub> | V <sub>DD</sub> | SDA             | 0   | 1  | 0  | 0  | 0  | 0  | 1  | 0   | 42h     | 2      |
| V <sub>DD</sub> | V <sub>SS</sub> | SDA             | 0   | 1  | 0  | 0  | 0  | 1  | 0  | 0   | 44h     | 3      |
| V <sub>DD</sub> | V <sub>DD</sub> | SDA             | 0   | 1  | 0  | 0  | 0  | 1  | 1  | 0   | 46h     | 4      |
| V <sub>SS</sub> | SDA             | V <sub>SS</sub> | 0   | 1  | 0  | 0  | 1  | 0  | 0  | 0   | 48h     | 5      |
| V <sub>SS</sub> | SDA             | V <sub>DD</sub> | 0   | 1  | 0  | 0  | 1  | 0  | 1  | 0   | 4Ah     | 6      |
| V <sub>DD</sub> | SDA             | V <sub>SS</sub> | 0   | 1  | 0  | 0  | 1  | 1  | 0  | 0   | 4Ch     | 7      |
| V <sub>DD</sub> | SDA             | V <sub>DD</sub> | 0   | 1  | 0  | 0  | 1  | 1  | 1  | 0   | 4Eh     | 8      |
| SDA             | V <sub>SS</sub> | V <sub>SS</sub> | 0   | 1  | 0  | 1  | 0  | 0  | 0  | 0   | 50h     | 9      |
| SDA             | V <sub>SS</sub> | V <sub>DD</sub> | 0   | 1  | 0  | 1  | 0  | 0  | 1  | 0   | 52h     | 10     |
| SDA             | V <sub>DD</sub> | V <sub>SS</sub> | 0   | 1  | 0  | 1  | 0  | 1  | 0  | 0   | 54h     | 11     |
| SDA             | V <sub>DD</sub> | V <sub>DD</sub> | 0   | 1  | 0  | 1  | 0  | 1  | 1  | 0   | 56h     | 12     |
| V <sub>SS</sub> | SDA             | SDA             | 0   | 1  | 0  | 1  | 1  | 0  | 0  | 0   | 58h     | 13     |
| V <sub>DD</sub> | SDA             | SDA             | 0   | 1  | 0  | 1  | 1  | 0  | 1  | 0   | 5Ah     | 14     |
| SDA             | V <sub>SS</sub> | SDA             | 0   | 1  | 0  | 1  | 1  | 1  | 0  | 0   | 5Ch     | 15     |
| SDA             | V <sub>DD</sub> | SDA             | 0   | 1  | 0  | 1  | 1  | 1  | 1  | 0   | 5Eh     | 16     |
| SDA             | SDA             | V <sub>SS</sub> | 0   | 1  | 1  | 0  | 0  | 0  | 0  | 0   | 60h     | 17     |
| SDA             | SDA             | V <sub>DD</sub> | 0   | 1  | 1  | 0  | 0  | 0  | 1  | 0   | 62h     | 18     |
| SDA             | SDA             | SDA             | 0   | 1  | 1  | 0  | 0  | 1  | 0  | 0   | 64h     | 19     |
| SCL             | SCL             | SCL             | 0   | 1  | 1  | 0  | 0  | 1  | 1  | 0   | 66h     | 20     |
| V <sub>SS</sub> | V <sub>SS</sub> | SCL             | 0   | 1  | 1  | 0  | 1  | 0  | 0  | 0   | 68h     | 21     |
| V <sub>SS</sub> | V <sub>DD</sub> | SCL             | 0   | 1  | 1  | 0  | 1  | 0  | 1  | 0   | 6Ah     | 22     |
| V <sub>DD</sub> | V <sub>SS</sub> | SCL             | 0   | 1  | 1  | 0  | 1  | 1  | 0  | 0   | 6Ch     | 23     |
| V <sub>DD</sub> | V <sub>DD</sub> | SCL             | 0   | 1  | 1  | 0  | 1  | 1  | 1  | 0   | 6Eh     | 24     |
| V <sub>SS</sub> | SCL             | V <sub>SS</sub> | 0   | 1  | 1  | 1  | 0  | 0  | 0  | 0   | 70h     | 25     |
| V <sub>SS</sub> | SCL             | V <sub>DD</sub> | 0   | 1  | 1  | 1  | 0  | 0  | 1  | 0   | 72h     | 26     |
| V <sub>DD</sub> | SCL             | V <sub>SS</sub> | 0   | 1  | 1  | 1  | 0  | 1  | 0  | 0   | 74h     | 27     |
| V <sub>DD</sub> | SCL             | V <sub>DD</sub> | 0   | 1  | 1  | 1  | 0  | 1  | 1  | 0   | 76h     | 28     |
| SCL             | V <sub>SS</sub> | V <sub>SS</sub> | 0   | 1  | 1  | 1  | 1  | 0  | 0  | 0   | 78h     | 29     |
| SCL             | V <sub>SS</sub> | V <sub>DD</sub> | 0   | 1  | 1  | 1  | 1  | 0  | 1  | 0   | 7Ah     | 30     |
| SCL             | V <sub>DD</sub> | V <sub>SS</sub> | 0   | 1  | 1  | 1  | 1  | 1  | 0  | 0   | 7Ch     | 31     |
| SCL             | V <sub>DD</sub> | V <sub>DD</sub> | 0   | 1  | 1  | 1  | 1  | 1  | 1  | 0   | 7Eh     | 32     |
| V <sub>SS</sub> | SCL             | SCL             | 1   | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 80h     | 33     |
| V <sub>DD</sub> | SCL             | SCL             | 1   | 0  | 0  | 0  | 0  | 0  | 1  | 0   | 82h     | 34     |
| SCL             | V <sub>SS</sub> | SCL             | 1   | 0  | 0  | 0  | 0  | 1  | 0  | 0   | 84h     | 35     |
| SCL             | V <sub>DD</sub> | SCL             | 1   | 0  | 0  | 0  | 0  | 1  | 1  | 0   | 86h     | 36     |
| SCL             | SCL             | V <sub>SS</sub> | 1   | 0  | 0  | 0  | 1  | 0  | 0  | 0   | 88h     | 37     |
| SCL             | SCL             | V <sub>DD</sub> | 1   | 0  | 0  | 0  | 1  | 0  | 1  | 0   | 8Ah     | 38     |

Table 4. PCA9691 address map ...continued

| Pin             |                 |                 | Bit |    |    |    |    |    |    |     | Address | Number |
|-----------------|-----------------|-----------------|-----|----|----|----|----|----|----|-----|---------|--------|
| A2              | A1              | A0              | A6  | A5 | A4 | A3 | A2 | A1 | A0 | R/W |         |        |
| V <sub>SS</sub> | SCL             | SDA             | 1   | 0  | 0  | 0  | 1  | 1  | 0  | 0   | 8Ch     | 39     |
| V <sub>DD</sub> | SCL             | SDA             | 1   | 0  | 0  | 0  | 1  | 1  | 1  | 0   | 8Eh     | 40     |
| V <sub>SS</sub> | V <sub>SS</sub> | V <sub>SS</sub> | 1   | 0  | 0  | 1  | 0  | 0  | 0  | 0   | 90h     | 41     |
| V <sub>SS</sub> | V <sub>SS</sub> | V <sub>DD</sub> | 1   | 0  | 0  | 1  | 0  | 0  | 1  | 0   | 92h     | 42     |
| V <sub>SS</sub> | V <sub>DD</sub> | V <sub>SS</sub> | 1   | 0  | 0  | 1  | 0  | 1  | 0  | 0   | 94h     | 43     |
| V <sub>SS</sub> | V <sub>DD</sub> | V <sub>DD</sub> | 1   | 0  | 0  | 1  | 0  | 1  | 1  | 0   | 96h     | 44     |
| V <sub>DD</sub> | V <sub>SS</sub> | V <sub>SS</sub> | 1   | 0  | 0  | 1  | 1  | 0  | 0  | 0   | 98h     | 45     |
| V <sub>DD</sub> | V <sub>SS</sub> | V <sub>DD</sub> | 1   | 0  | 0  | 1  | 1  | 0  | 1  | 0   | 9Ah     | 46     |
| V <sub>DD</sub> | V <sub>DD</sub> | V <sub>SS</sub> | 1   | 0  | 0  | 1  | 1  | 1  | 0  | 0   | 9Ch     | 47     |
| V <sub>DD</sub> | V <sub>DD</sub> | V <sub>DD</sub> | 1   | 0  | 0  | 1  | 1  | 1  | 1  | 0   | 9Eh     | 48     |
| V <sub>SS</sub> | SDA             | SCL             | 1   | 0  | 1  | 0  | 0  | 0  | 0  | 0   | A0h     | 49     |
| V <sub>DD</sub> | SDA             | SCL             | 1   | 0  | 1  | 0  | 0  | 0  | 1  | 0   | A2h     | 50     |
| SCL             | SDA             | V <sub>SS</sub> | 1   | 0  | 1  | 0  | 0  | 1  | 0  | 0   | A4h     | 51     |
| SCL             | SDA             | V <sub>DD</sub> | 1   | 0  | 1  | 0  | 0  | 1  | 1  | 0   | A6h     | 52     |
| SDA             | SCL             | V <sub>SS</sub> | 1   | 0  | 1  | 0  | 1  | 0  | 0  | 0   | A8h     | 53     |
| SDA             | SCL             | V <sub>DD</sub> | 1   | 0  | 1  | 0  | 1  | 0  | 1  | 0   | AAh     | 54     |
| SDA             | V <sub>SS</sub> | SCL             | 1   | 0  | 1  | 0  | 1  | 1  | 0  | 0   | ACh     | 55     |
| SDA             | V <sub>DD</sub> | SCL             | 1   | 0  | 1  | 0  | 1  | 1  | 1  | 0   | A Eh    | 56     |
| SCL             | V <sub>SS</sub> | SDA             | 1   | 0  | 1  | 1  | 0  | 0  | 0  | 0   | B0h     | 57     |
| SCL             | V <sub>DD</sub> | SDA             | 1   | 0  | 1  | 1  | 0  | 0  | 1  | 0   | B2h     | 58     |
| SDA             | SCL             | SCL             | 1   | 0  | 1  | 1  | 0  | 1  | 0  | 0   | B4h     | 59     |
| SCL             | SDA             | SCL             | 1   | 0  | 1  | 1  | 0  | 1  | 1  | 0   | B6h     | 60     |
| SCL             | SCL             | SDA             | 1   | 0  | 1  | 1  | 1  | 0  | 0  | 0   | B8h     | 61     |
| SCL             | SDA             | SDA             | 1   | 0  | 1  | 1  | 1  | 0  | 1  | 0   | BAh     | 62     |
| SDA             | SCL             | SDA             | 1   | 0  | 1  | 1  | 1  | 1  | 0  | 0   | BCh     | 63     |
| SDA             | SDA             | SCL             | 1   | 0  | 1  | 1  | 1  | 1  | 1  | 0   | BEh     | 64     |

## 7.2 Control byte

The second byte sent to a PCA9691 is stored in its control register and is required to control the PCA9691 function.

The upper nibble of the control register is used for enabling the analog output, and for programming the analog inputs as single-ended or differential inputs. The lower nibble selects one of the analog input channels defined by the upper nibble (see [Figure 6](#)).

If the auto-increment flag is set, the channel number is incremented automatically after each A/D conversion.

If the auto-increment mode is selected and the internal oscillator is used, the analog output enable flag in the control byte (bit 6) must be set. This allows the internal oscillator to run continuously, thereby preventing conversion errors resulting from oscillator start-up delay. The analog output enable flag can be reset at other times to reduce quiescent power consumption.

The selection of a non-existing input channel results in the highest available channel number being allocated. Therefore, if the auto-increment flag is set, the next selected channel is always channel 0.

After power-on all bits of the control register are reset to logic 0. The DAC and the oscillator are disabled for power saving. The analog output is switched to a high-impedance state.

The most significant bits of both nibbles are reserved for oscillator control. Bit 7 and bit 3 can be set when the interface frequency is  $f_{SCL} \leq 400$  kHz (see [Figure 6](#)). Setting these two bits to logic 1 sets the internal frequency to half and the accuracy of the A/D and D/A conversion is 1 LSB as indicated in [Table 8](#) and [Table 9](#).

The oscillator output is disabled in normal operation (pin OSC is LOW). Setting bit 7 to logic 0 and bit 3 to logic 1 will enable this output in order to observe the oscillator frequency (divided by 4).



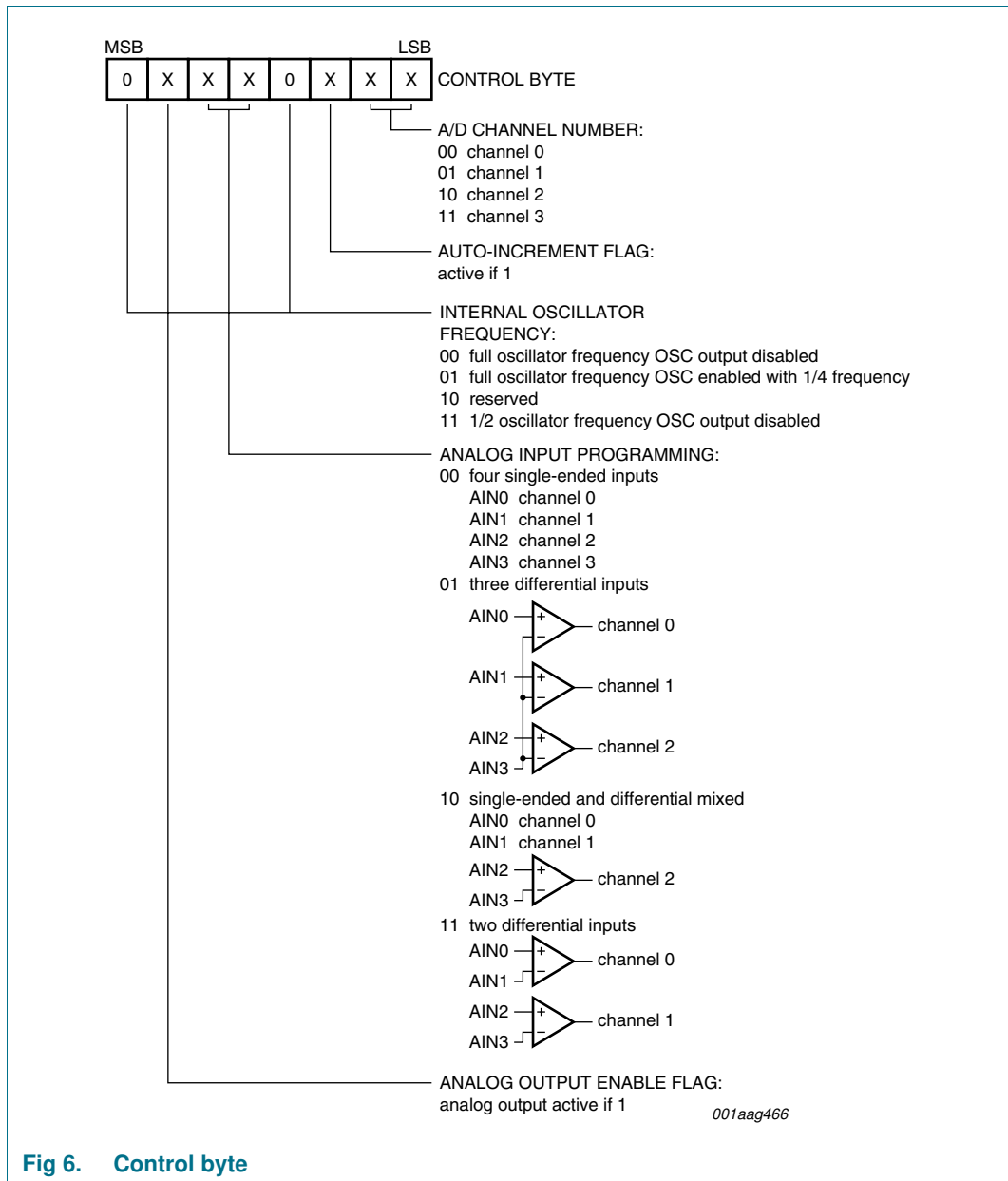


Fig 6. Control byte

### 7.3 D/A conversion

The third byte sent to a PCA9691 is stored in the DAC data register and is converted to the corresponding analog voltage using the on-chip DAC. This DAC consists of a resistor divider chain connected to the external reference voltage (pin VREF) with 256 taps and selection switches. The tap-decoder switches one of these taps to the DAC output line (see [Figure 7](#)).

The analog output voltage is buffered by an auto-zeroed unity gain amplifier. Setting the analog output enable flag of the control register switches this buffer amplifier on or off. In the active state the output voltage is held until a further data byte is sent.

In order to release the DAC for a successive approximation A/D conversion cycle, the unity gain amplifier is equipped with a sample and hold circuit. This circuit holds the output voltage while executing the A/D conversion.

The formula for the output voltage supplied to the analog output pin AOUT is shown in [Figure 8](#).

The waveforms of a D/A conversion sequence are shown in [Figure 9](#).

With the rising edge of the 8th clock bit the DAC register is filled with a new value D7 to D0. After some delay the voltage at the analog output starts to change from the previous value to the new value.

This delay is random but stays within the following limits:

- Minimum  $8T_{osc}$  from the rising edge of the 8th bit
- Maximum  $18T_{osc}$  from the rising edge of the acknowledge bit (9th bit)

Where  $T_{osc}$  is the oscillator period (oscillator frequency is given in [Table 6](#)).

**Remark:** When AOUT starts changing, the DAC settling time  $t_{s(DAC)}$  (specified in [Table 8](#)), is required for AOUT to reach a new accurate value.

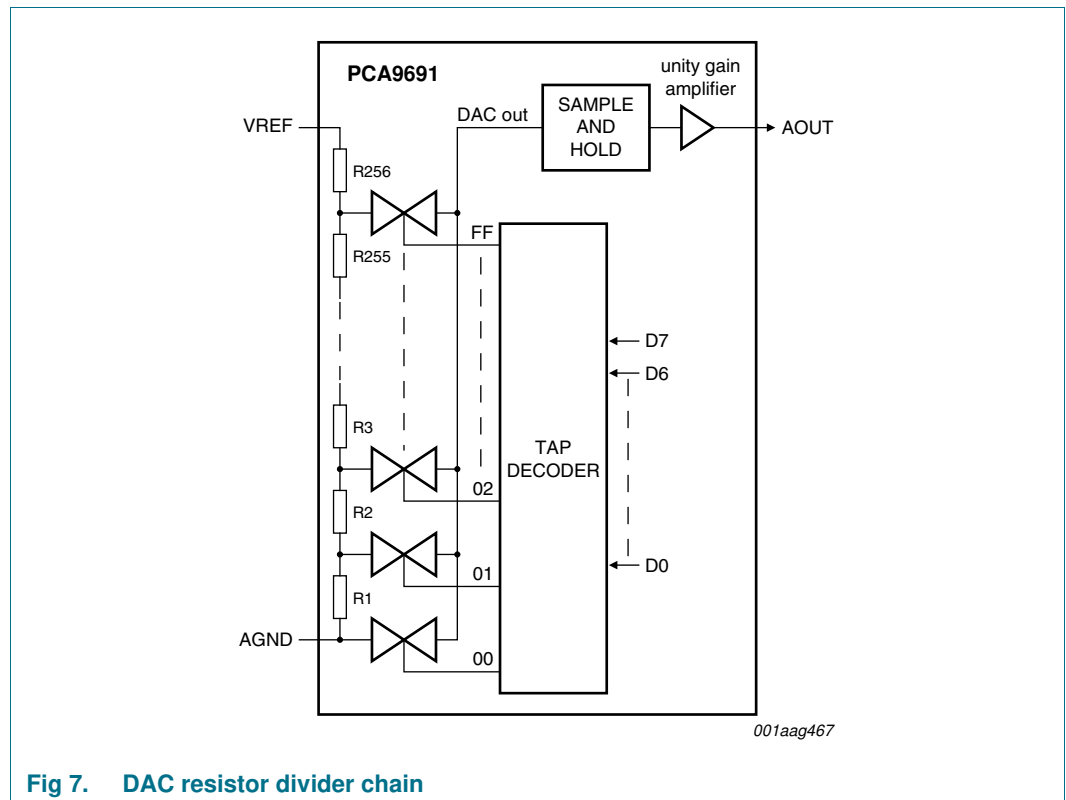


Fig 7. DAC resistor divider chain

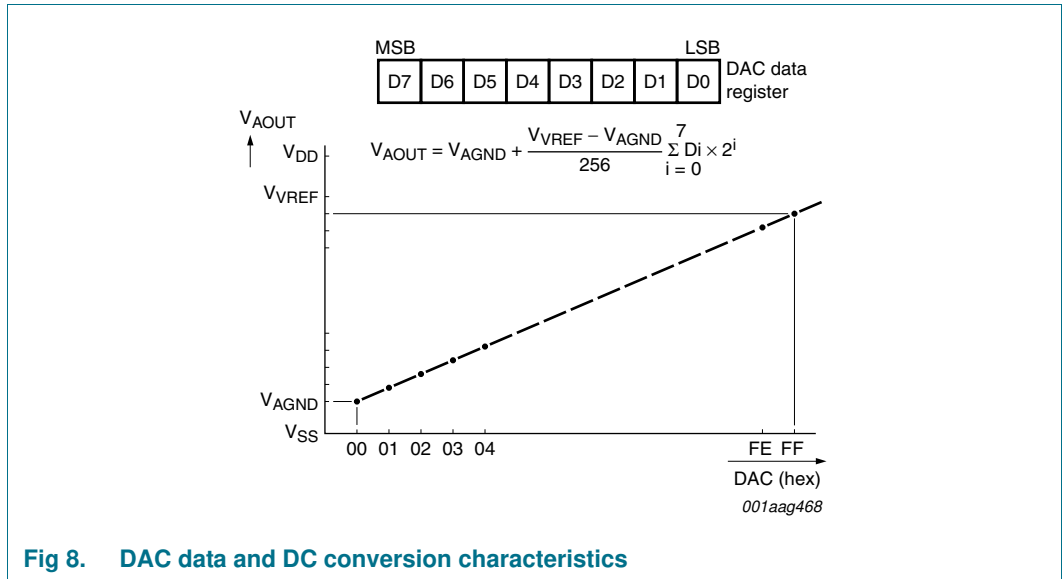


Fig 8. DAC data and DC conversion characteristics

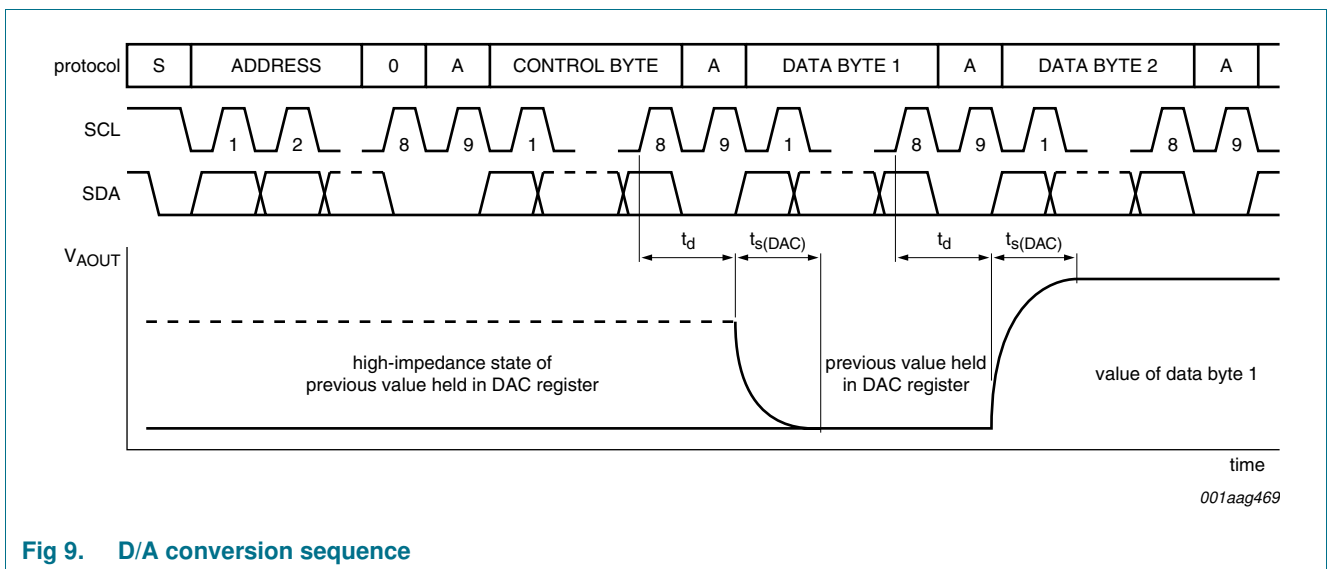


Fig 9. D/A conversion sequence

### 7.3.1 Worst case example

An example of the worst case is shown in [Figure 10](#). The delay time can have a value between  $8T_{osc}$  and  $18T_{osc}$ .

When the I<sup>2</sup>C-bus is driven at 1 MHz (full speed) then the DAC is operating at a rate of 9  $\mu$ s.

The previous AOUT value is valid at least until the rising edge of the acknowledge bit ( $8T_{osc} \geq 1.23 \mu$ s).

The latest start time of the new value is 5.6  $\mu$ s from the rising edge of the acknowledge bit: ( $18T_{osc} \leq 5.6 \mu$ s) so AOUT is stable after  $t_s(DAC) \leq 2.4 \mu$ s.

The new AOOUT value is valid, at the latest, after 8.0  $\mu\text{s}$  so before the rising edge of the 8th bit of the next transferred byte. Therefore, at the full speed of the I<sup>2</sup>C-bus, the analog output is valid under all circumstances between the rising edges of the 8th bit and the acknowledge bit.

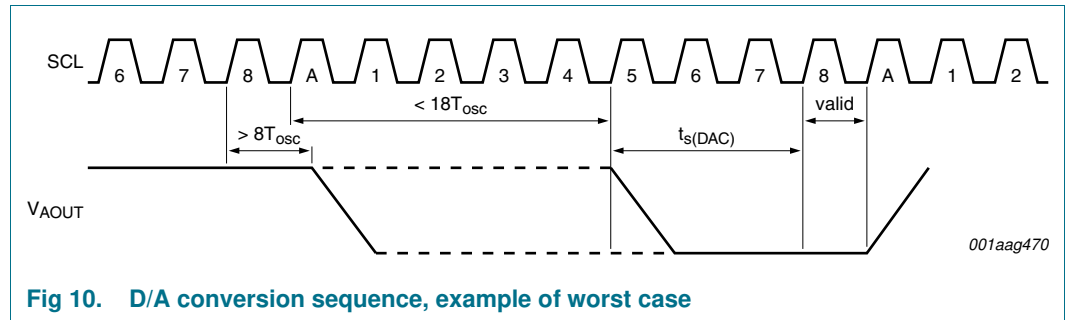


Fig 10. D/A conversion sequence, example of worst case

### 7.4 A/D conversion

The A/D Converter (ADC) makes use of the successive approximation conversion technique. The on-chip DAC and a high-gain comparator are used temporarily during an A/D conversion cycle.

An A/D conversion cycle is always started after sending a valid read mode address to a PCA9691. The A/D conversion cycle is triggered at the trailing edge of the acknowledge clock pulse and is executed while transmitting the result of the previous conversion (see [Figure 11](#)).

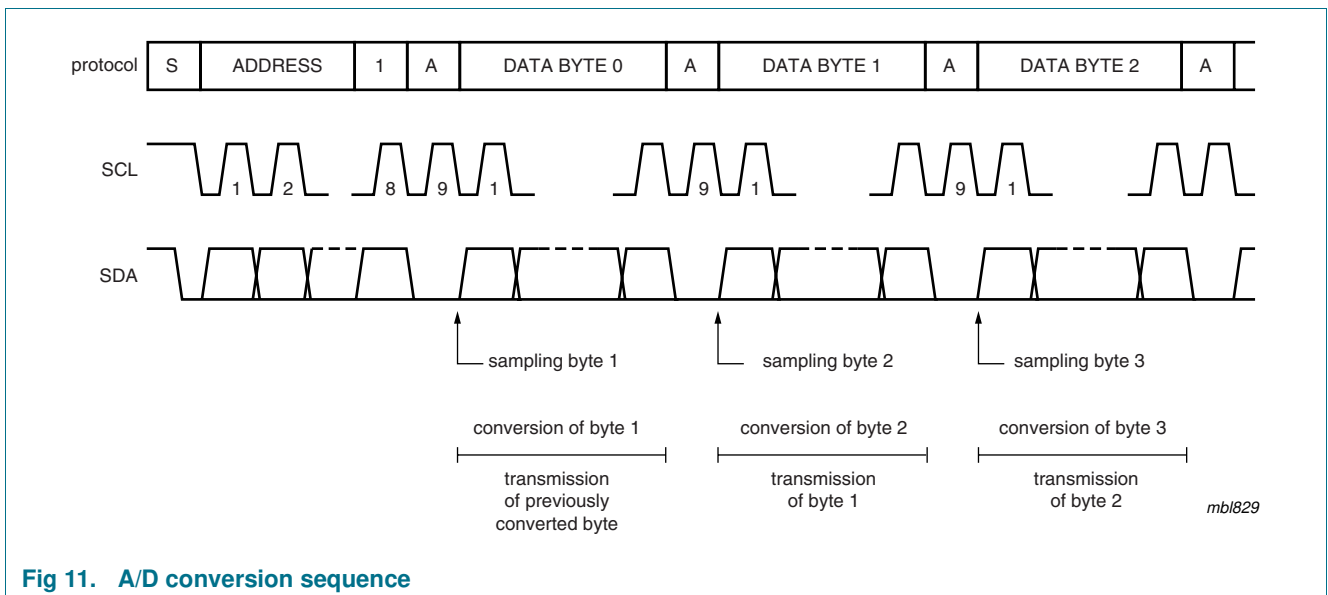


Fig 11. A/D conversion sequence

Once a conversion cycle is triggered, an input voltage sample of the selected channel is stored on the chip and is converted to the corresponding 8-bit binary code. Samples picked up from differential inputs are converted to an 8-bit two's complement code (see [Figure 12](#) and [Figure 13](#)).

The conversion result is stored in the ADC data register and awaits transmission. If the auto-increment flag is set the next channel is selected.

The first byte transmitted in a read cycle contains the conversion result code of the previous read cycle. After a Power-On Reset (POR) condition the first byte read is 80h. The protocol of an I<sup>2</sup>C-bus read cycle is shown in [Figure 19](#).

The actual speed of the I<sup>2</sup>C-bus provides the maximum A/D conversion rate.

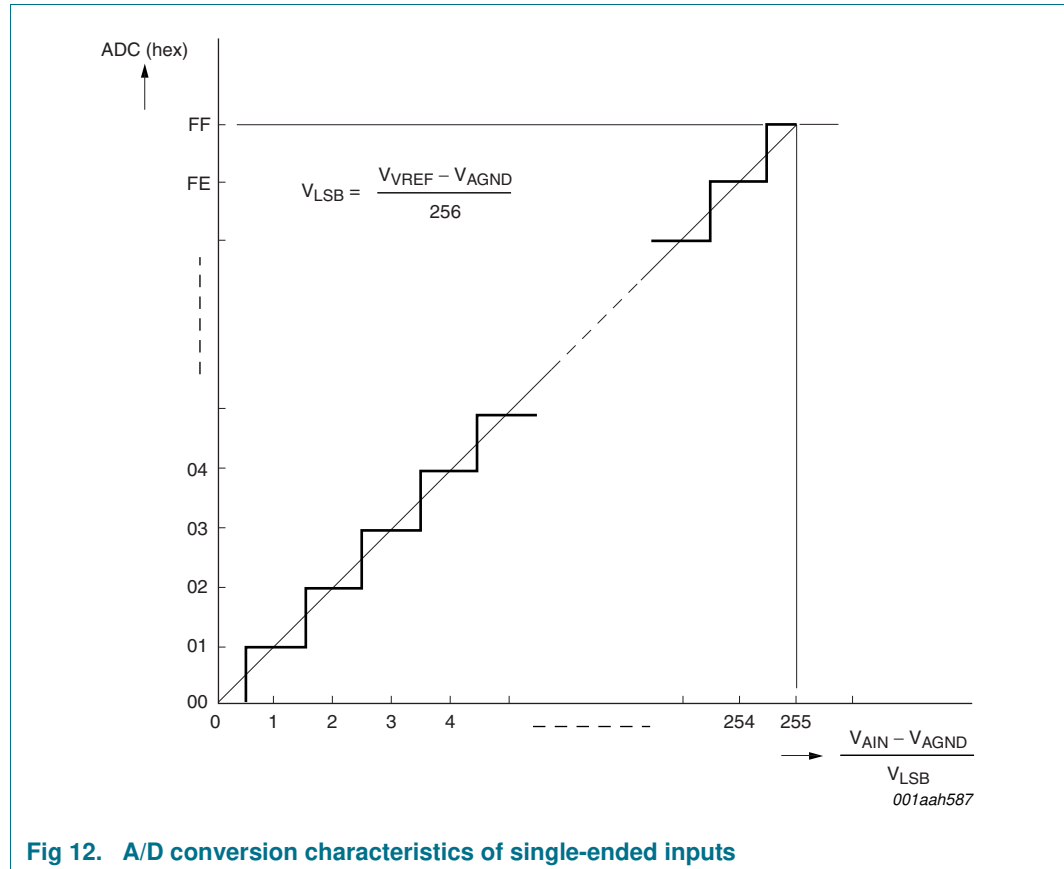


Fig 12. A/D conversion characteristics of single-ended inputs

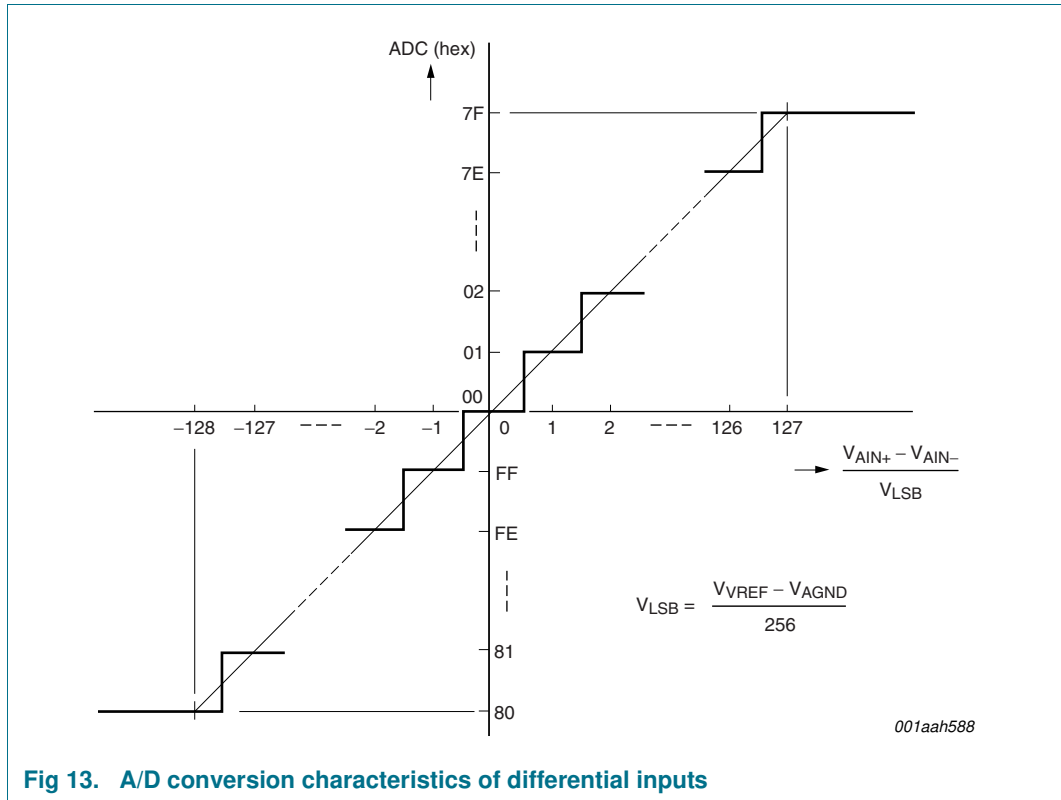


Fig 13. A/D conversion characteristics of differential inputs

### 7.5 Reference voltage

For the D/A and A/D conversion either a stable external voltage reference or the supply voltage has to be applied to the resistor divider chain (pins VREF and AGND). Pin AGND has to be connected to the system analog ground and may have a DC off-set with reference to V<sub>SS</sub>.

A low frequency may be applied to pins VREF and AGND. This allows the use of the DAC as a one-quadrant multiplier (see [Figure 12](#) and [Figure 24](#)).

The ADC may also be used as a one- or two-quadrant analog divider. The analog input voltage is divided by the reference voltage. The result is converted to a binary code. In this application the user has to keep the reference voltage stable during the conversion cycle.

### 7.6 Oscillator

An on-chip oscillator generates the clock signal required for the A/D conversion cycle and for refreshing the auto-zeroed buffer amplifier. When using this oscillator pin EXT has to be connected to V<sub>SS</sub>. The oscillator frequency divided by 4 is available at output pin OSC (see [Section 7.2](#)). However, in normal operation it is recommended that output pin OSC is disabled. In this case the output pin OSC is LOW.

The oscillator starts when a start condition is sent via the I<sup>2</sup>C-bus interface. If the received address is recognized as valid the oscillator continues to run. If the received address is not recognized the oscillator stops.

If a stop condition occurs the oscillator is stopped unless pin AOUT is enabled.

It is recommended that if the I<sup>2</sup>C-bus speed  $f_{SCL} \leq 400$  kHz, you must reduce the oscillator frequency by half (see the definition of the control byte in [Figure 6](#)).

If pin EXT is connected to V<sub>DD</sub> the oscillator output OSC is switched to a high-impedance state allowing to feed an external clock signal to the OSC input. The frequency of the external clock must be in the specified range.

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

The I<sup>2</sup>C-bus is for bidirectional, two-line communication between different IC or modules. The two lines are a Serial DATA Line (SDA) and a Serial Clock Line (SCL). Both lines are connected to a positive supply via a pull-up resistor. Data transfer is initiated only when the bus is not busy.

#### 7.7.1 Bit transfer

One data bit is transferred during each clock pulse. The data on the SDA line remains stable during the HIGH period of the clock pulse as changes in the data line at this time are interpreted as control signals (see [Figure 14](#)).

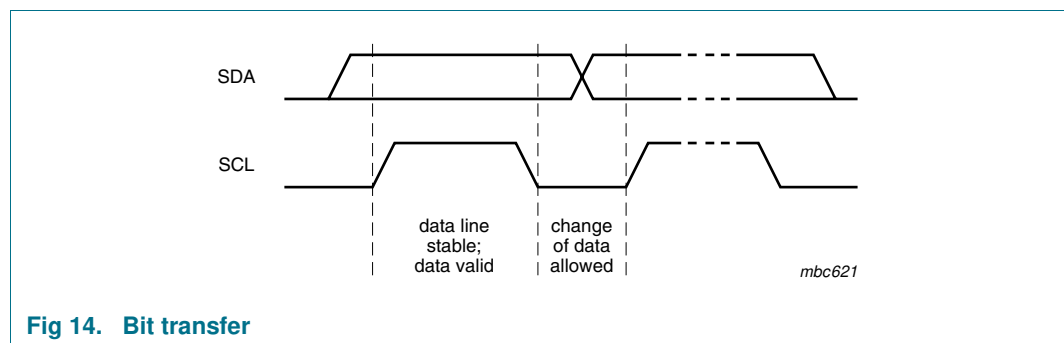


Fig 14. Bit transfer

#### 7.7.2 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 15](#)).

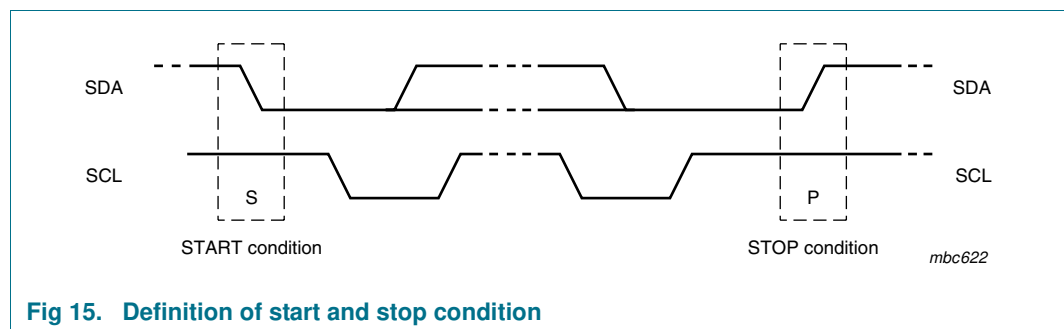


Fig 15. Definition of start and stop condition

7.7.3 System configuration

A device which sends data to the bus is a transmitter, a device which receives data from the bus is a receiver. The device which initiates and terminates a transfer is the master; and the devices which are addressed by the master are the slaves (see [Figure 16](#)).

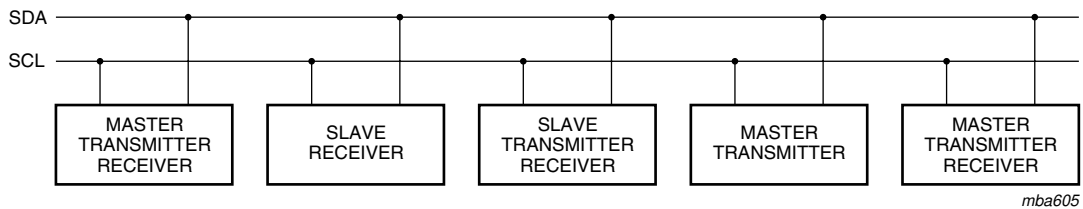


Fig 16. System configuration

7.7.4 Acknowledge

The number of data bytes transferred between the START and STOP conditions from transmitter to receiver is unlimited. Each byte of eight bits is followed by an acknowledge cycle.

- A slave receiver, which is addressed, must generate an acknowledge after the reception of each byte.
- A master receiver must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter.
- The device that acknowledges must 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 consideration).
- 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.

Acknowledgement on the I<sup>2</sup>C-bus is illustrated in [Figure 17](#).

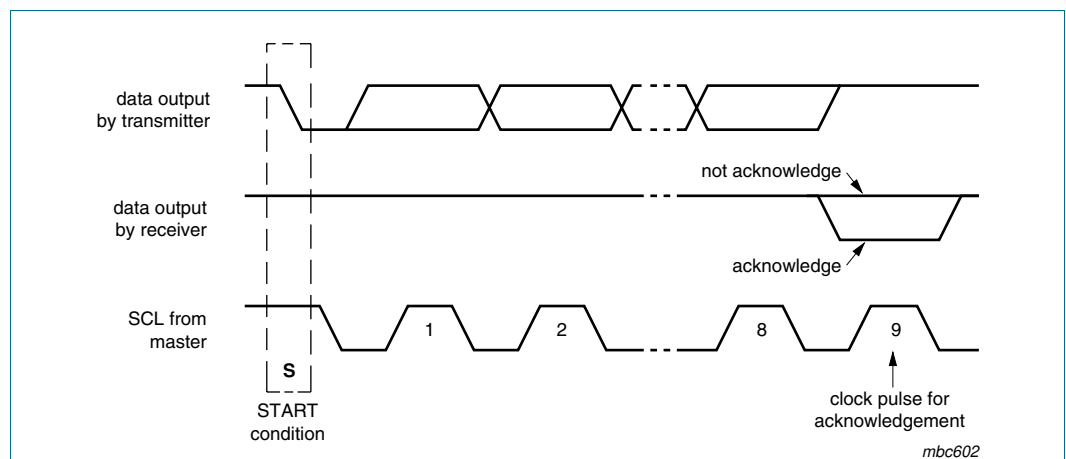


Fig 17. Acknowledgement on the I<sup>2</sup>C-bus



7.7.5 I<sup>2</sup>C-bus protocol

After a start condition a valid hardware address has to be sent to a PCA9691 device. The read/write bit defines the direction of the following single or multiple byte data transfer. For the format and the timing of the start condition (S), the stop condition (P) and the acknowledge bit (A) refer to the I<sup>2</sup>C-bus characteristics. In the write mode a data transfer is terminated by sending either a stop condition or the start condition of the next data transfer.

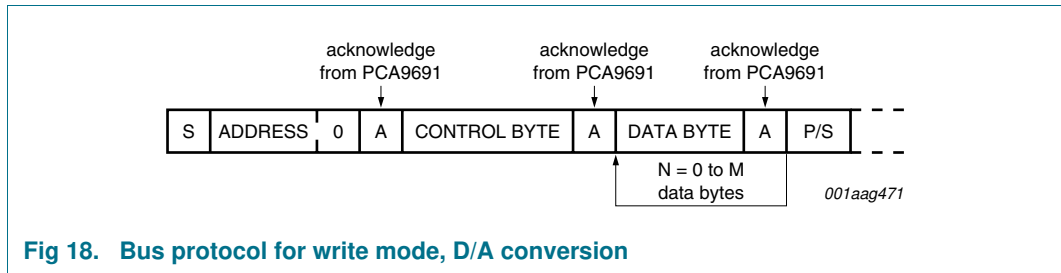


Fig 18. Bus protocol for write mode, D/A conversion

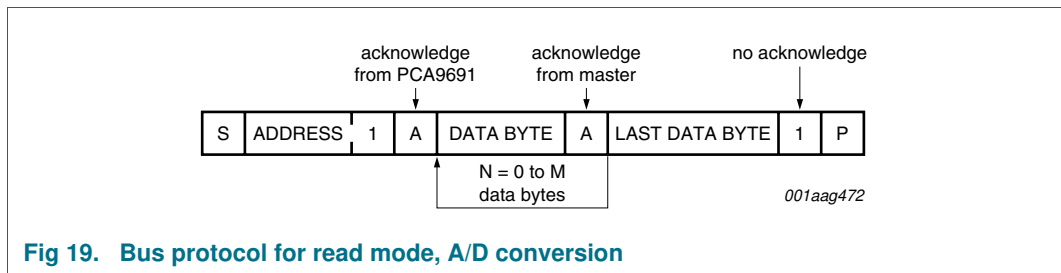


Fig 19. Bus protocol for read mode, A/D conversion

8. Internal circuitry

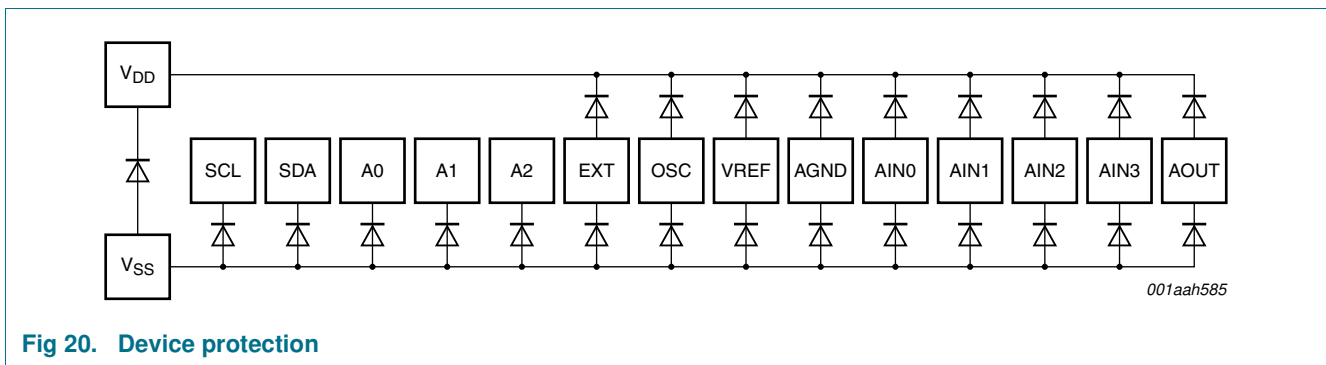


Fig 20. Device protection

9. Limiting values

Table 5. 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 | +6.5                  | V    |
| V <sub>I</sub>  | input voltage  |            | -0.5 | V <sub>DD</sub> + 0.5 | V    |
| I <sub>I</sub>  | input current  |            | -    | ±10                   | mA   |

**Table 5. Limiting values ...continued**  
*In accordance with the Absolute Maximum Rating System (IEC 60134).*

| Symbol    | Parameter                       | Conditions | Min | Max | Unit  |    |
|-----------|---------------------------------|------------|-----|-----|-------|----|
| $I_O$     | output current                  |            | -   | ±20 | mA    |    |
| $I_{DD}$  | supply current                  |            | -   | +50 | mA    |    |
| $I_{SS}$  | ground supply current           |            | -   | -50 | mA    |    |
| $P_{tot}$ | total power dissipation         |            | -   | 300 | mW    |    |
| $P_o$     | output power                    |            | -   | 100 | mW    |    |
| $V_{ESD}$ | electrostatic discharge voltage | HBM        | [1] | -   | ±1500 | V  |
|           |                                 | MM         | [2] | -   | ±200  | V  |
| $I_{lu}$  | latch-up current                |            | [3] | -   | 100   | mA |
| $T_{stg}$ | storage temperature             |            | [4] | -65 | +150  | °C |
| $T_{amb}$ | ambient temperature             |            |     | -40 | +85   | °C |

[1] Pass level; Human Body Model (HBM), according to [Ref. 5 "JESD22-A114"](#).

[2] Pass level; Machine Model (MM), according to [Ref. 6 "JESD22-A115"](#).

[3] Pass level; latch-up testing according to [Ref. 7 "JESD78"](#) at maximum ambient temperature ( $T_{amb(max)}$ ).

[4] According to the NXP store and transport requirements (see [Ref. 9 "NX3-00092"](#)) the devices have to be stored at a temperature of +8 °C to +45 °C and a humidity of 25 % to 75 %. For long term storage products deviant conditions are described in that document.

## 10. Characteristics

### 10.1 Static characteristics

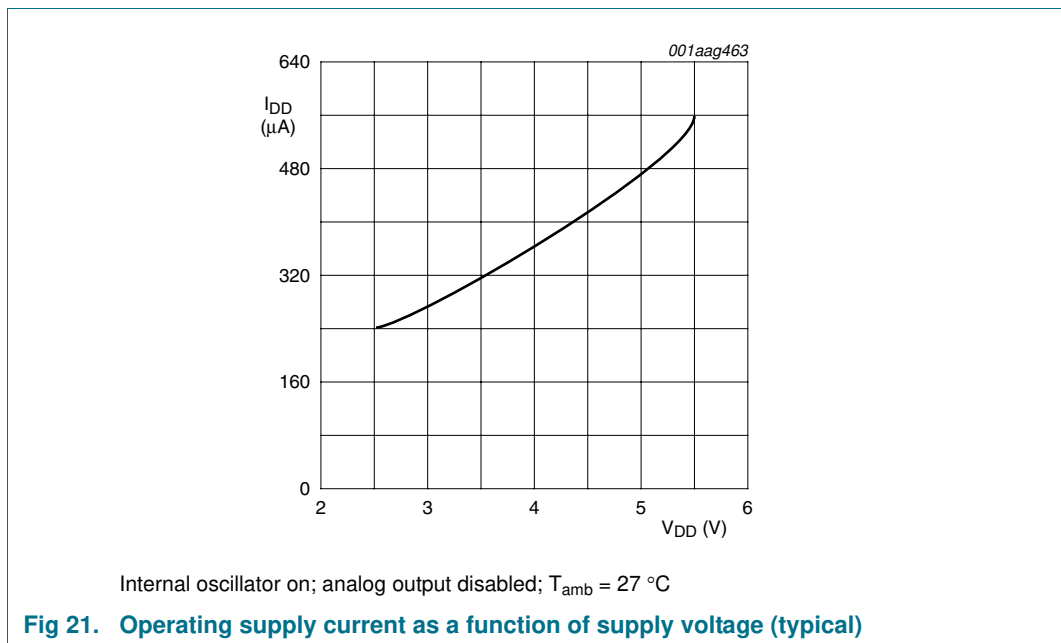
**Table 6. Static characteristic**  
 $V_{DD} = 2.5\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ °C to }+85\text{ °C}$ ; unless otherwise specified.

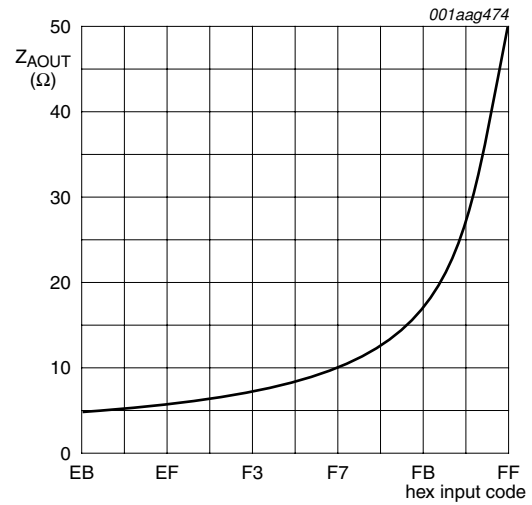
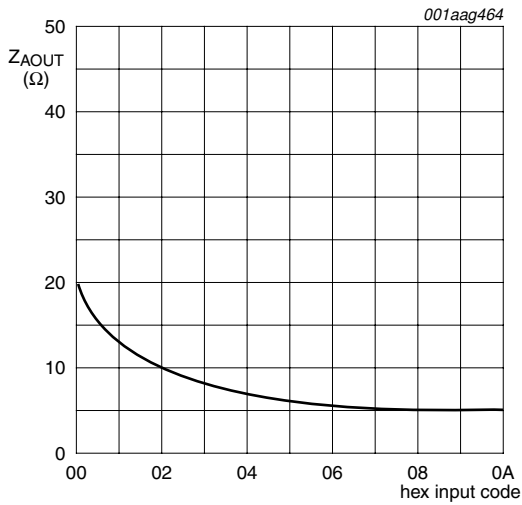
| Symbol  | Parameter                | Conditions  | Min         | Typ  | Max         | Unit |   |
|---|--------------------------|---|-------------|------|-------------|------|---|
| <b>Supply</b>   |                          |   |             |      |             |      |   |
| $V_{DD}$  | supply voltage           |   | 2.5         | 5.0  | 5.5         | V    |   |
| $I_{DD}$  | supply current           | $V_I = V_{SS}$ or $V_{DD}$ ; no load<br>standby   |             |      |             |      |   |
|   |                          | no bus activity   | -           | 1.5  | 10          | µA   |   |
|   |                          | bus activity  | -           | 10   | 100         | µA   |   |
|   |                          | operating; $f_{SCL} = 1\text{ MHz}$   |             |      |             |      |   |
|   |                          | pin AOUT off  | -           | 500  | 1400        | µA   |   |
|   | pin AOUT active          | -   | 1400        | 2500 | µA          |      |   |
| $V_{POR}$   | power-on reset voltage   |   | [1]         | 0.8  | -           | 2.0  | V |
| <b>Digital inputs: pins SCL, SDA, A0, A1, A2, OSC and EXT</b> |                          |   |             |      |             |      |   |
| $V_{IL}$  | LOW-level input voltage  |   | 0           | -    | $0.3V_{DD}$ | V    |   |
| $V_{IH}$  | HIGH-level input voltage |   | $0.7V_{DD}$ | -    | -           | V    |   |
| $I_L$   | leakage current          | $V_I = V_{SS}$ to $V_{DD}$  | -100        | -    | +100        | nA   |   |
| $C_i$   | input capacitance        |   | -           | -    | 550         | pF   |   |
| <b>Digital output: pin SDA</b>                                |                          |   |             |      |             |      |   |
| $I_{OL}$  | LOW-level output current | $V_{OL} = 0.4\text{ V}$ ; $V_{DD} = 5\text{ V}$ ;<br>$C_L = 550\text{ pF}$ ; $f_{SCL} = 1\text{ MHz}$ | 24          | -    | -           | mA   |   |

**Table 6. Static characteristic ...continued**  
 $V_{DD} = 2.5\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C to }+85\text{ }^{\circ}\text{C}$ ; unless otherwise specified.

| Symbol                                      | Parameter                     | Conditions                               | Min      | Typ | Max            | Unit       |
|---|-------------------------------|--|----------|-----|----------------|------------|
| <b>Reference inputs: pins VREF and AGND</b> |                               |  |          |     |                |            |
| $V_{VREF}$                                  | voltage on pin VREF           | $V_{VREF} - V_{AGND} \geq 1.6\text{ V}$  | 1.6      | -   | $V_{DD}$       | V          |
| $V_{AGND}$                                  | voltage on pin AGND           | $V_{VREF} - V_{AGND} \geq 1.6\text{ V}$  | $V_{SS}$ | -   | $V_{DD} - 1.6$ | V          |
| $I_{LI}$                                    | input leakage current         |  | -100     | -   | +100           | nA         |
| $R_{ref}$                                   | reference resistance          | resistance between pin VREF and pin AGND | -        | 40  | -              | k $\Omega$ |
| <b>Oscillator: pin OSC</b>                  |                               |  |          |     |                |            |
| $f_{osc(int)}$                              | internal oscillator frequency | pin EXT is LOW                           | 3.2      | -   | 8.0            | MHz        |
| $f_{osc(ext)}$                              | external oscillator frequency | pin EXT is HIGH                          | 3.5      | -   | 5.5            | MHz        |

[1] The power-on reset circuit resets the I<sup>2</sup>C-bus logic when  $V_{DD} < V_{POR}$ .





- a. Output impedance near negative power rail ( $V_{SS}$ )
  - b. Output impedance near positive power rail ( $V_{DD}$ )
- $T_{amb} = 27\text{ °C}$ ;  $V_{DD} = 5\text{ V}$ ;  $V_{VREF} = 5\text{ V}$ ;  $V_{AGND} = 0\text{ V}$ , (typical values)

**Fig 22. Output impedance of analog output buffer (near power rails)**

## 10.2 Dynamic characteristics

**Table 7. I<sup>2</sup>C-bus characteristics**

$V_{DD} = 2.5\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ °C to }+85\text{ °C}$ ; reference to 30 % and 70 % with an input voltage swing of  $V_{SS}$  to  $V_{DD}$  (see [Figure 23](#)).

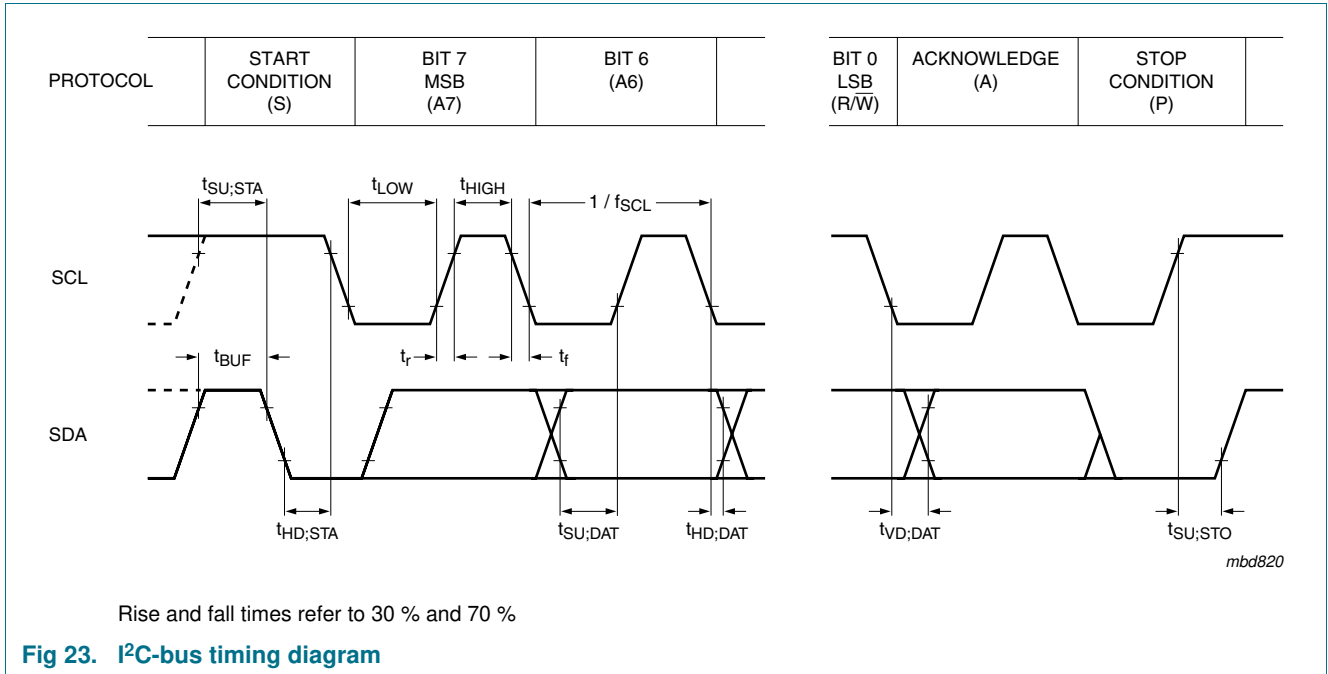
| Symbol       | Parameter  | Conditions | Standard mode |      | Fast mode |     | Fast-mode Plus |      | Unit          |
|--------------|--|------------|---------------|------|-----------|-----|----------------|------|---------------|
|              |  |            | Min           | Max  | Min       | Max | Min            | Max  |               |
| $f_{SCL}$    | SCL clock frequency                              | [1]        | 0             | 100  | 0         | 400 | 0              | 1000 | kHz           |
| $t_{BUF}$    | bus free time between a STOP and START condition |            | 4.7           | -    | 1.3       | -   | 0.5            | -    | $\mu\text{s}$ |
| $t_{HD;STA}$ | hold time (repeated) START condition             |            | 4.0           | -    | 0.6       | -   | 0.26           | -    | $\mu\text{s}$ |
| $t_{SU;STA}$ | set-up time for a repeated START condition       |            | 4.7           | -    | 0.6       | -   | 0.26           | -    | $\mu\text{s}$ |
| $t_{SU;STO}$ | set-up time for STOP condition                   |            | 4.0           | -    | 0.6       | -   | 0.26           | -    | $\mu\text{s}$ |
| $t_{HD;DAT}$ | data hold time                                   |            | 0             | -    | 0         | -   | 0              | -    | ns            |
| $t_{VD;ACK}$ | data valid acknowledge time                      | [2]        | 0.1           | 3.45 | 0.1       | 0.9 | 0.05           | 0.45 | $\mu\text{s}$ |
| $t_{VD;DAT}$ | data valid time                                  | [3]        | 300           | -    | 75        | -   | 75             | 450  | ns            |
| $t_{SU;DAT}$ | data set-up time                                 |            | 250           | -    | 100       | -   | 50             | -    | ns            |
| $t_{LOW}$    | LOW period of the SCL clock                      |            | 4.7           | -    | 1.3       | -   | 0.5            | -    | $\mu\text{s}$ |
| $t_{HIGH}$   | HIGH period of the SCL clock                     |            | 4.0           | -    | 0.6       | -   | 0.26           | -    | $\mu\text{s}$ |

**Table 7. I<sup>2</sup>C-bus characteristics ...continued**

$V_{DD} = 2.5\text{ V to }5.5\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C to }+85\text{ }^{\circ}\text{C}$ ; reference to 30 % and 70 % with an input voltage swing of  $V_{SS}$  to  $V_{DD}$  (see [Figure 23](#)).

| Symbol                | Parameter                             | Conditions | Standard mode |      | Fast mode     |     | Fast-mode Plus |     | Unit |
|-----------------------|---------------------------------------|------------|---------------|------|---------------|-----|----------------|-----|------|
|                       |                                       |            | Min           | Max  | Min           | Max | Min            | Max |      |
| $t_f$                 | fall time of both SDA and SCL signals | [4][5][6]  | -             | 300  | $20 + 0.1C_b$ | 300 | -              | 120 | ns   |
| $t_r$                 | rise time of both SDA and SCL signals | [4][5][6]  | -             | 1000 | $20 + 0.1C_b$ | 300 | -              | 120 | ns   |
| $t_{w(\text{spike})}$ | spike pulse width                     | [7]        | -             | 50   | -             | 50  | -              | 50  | ns   |

- [1] The minimum SCL clock frequency is limited by the bus time-out feature which resets the serial bus interface if either the SDA or SCL is held LOW for a minimum of 25 ms. You must disable the bus time-out feature for DC operation.
- [2]  $t_{VD;ACK}$  = time for acknowledgement signal from SCL LOW to SDA (out) LOW.
- [3]  $t_{VD;DAT}$  = minimum time for valid SDA (out) data 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  $V_{IL}$  of the SCL signal) in order to bridge the undefined region of the SCL's falling edge.
- [5]  $C_b$  = total capacitance of one bus line in pF.
- [6] The maximum  $t_f$  for the SDA and SCL bus lines is 300 ns. The maximum fall time for the SDA output stage,  $t_f$  is 250 ns. This allows series protection resistors to be connected between the SDA pin and the SDA bus line and between the SCL pin and the SCL bus line without exceeding the maximum  $t_f$ .
- [7] Input filters on the SDA and SCL inputs suppress noise spikes of less than 50 ns.



**Table 8. D/A characteristics**

$V_{DD} = 5.0\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $V_{VREF} = 5.0\text{ V}$ ;  $V_{AGND} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ;  $R_L = 10\text{ k}\Omega$ ;  $C_L = 50\text{ pF}$ ; unless otherwise specified.

| Symbol               | Parameter                | Conditions   | Min      | Typ | Max         | Unit          |
|----------------------|--------------------------|--|----------|-----|-------------|---------------|
| <b>Analog output</b> |                          |  |          |     |             |               |
| $V_{AOUT}$           | voltage on pin AOUT      | no resistive load  | $V_{SS}$ | -   | $V_{DD}$    | V             |
|                      |                          | $R_L = 10\text{ k}\Omega$                                  | $V_{SS}$ | -   | $0.9V_{DD}$ | V             |
| $I_{LO}$             | output leakage current   | pin AOUT disabled  | -100     | -   | +100        | nA            |
| <b>Accuracy</b>      |                          |  |          |     |             |               |
| $E_G$                | gain error               | no resistive load  | -        | -   | 1           | %             |
| $E_O$                | offset error             |  | -        | -   | $\pm 20$    | mV            |
| $E_L$                | linearity error          | $f_{SCL} \leq 400\text{ kHz}$                              | [1]      | -   | $\pm 1.0$   | LSB           |
|                      |                          | $f_{SCL} > 400\text{ kHz}$                                 | [1]      | -   | $\pm 1.5$   | LSB           |
| $t_{s(DAC)}$         | DAC settling time        |  | [2]      | -   | 2.4         | $\mu\text{s}$ |
| $f_{c(DAC)}$         | DAC conversion frequency |  | -        | -   | 44          | kHz           |
| $\alpha_{sup(n)}$    | noise suppression        | $f = 100\text{ Hz}$ ;<br>$V_{n(VDD)(p-p)} = 100\text{ mV}$ | -        | 40  | -           | dB            |

[1] The linearity error is assured if the internal frequency is changed by setting bit 7 and bit 3 of the control byte to logic 1 (see [Figure 6](#)).

[2] The time from the start of AOUT to a change of  $\frac{1}{2}$  LSB full scale (see [Section 7.3](#)).

**Table 9. A/D characteristics**

$V_{DD} = 5.0\text{ V}$ ;  $V_{SS} = 0\text{ V}$ ;  $V_{VREF} = 5.0\text{ V}$ ;  $V_{AGND} = 0\text{ V}$ ;  $T_{amb} = -40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ;  $R_L = 10\text{ k}\Omega$ ;  $C_L = 50\text{ pF}$ ; unless otherwise specified.

| Symbol               | Parameter                      | Conditions   | Min           | Typ | Max           | Unit          |
|----------------------|--------------------------------|--|---------------|-----|---------------|---------------|
| <b>Analog inputs</b> |                                |  |               |     |               |               |
| $V_{AIN}$            | voltage on pin AIN             | pins AIN0 to AIN3  | $V_{SS}$      | -   | $V_{DD}$      | V             |
| $I_{LI}$             | input leakage current          |  | -100          | -   | +100          | nA            |
| $C_{i(a)}$           | analog input capacitance       |  | -             | 10  | -             | pF            |
| $C_{i(dif)}$         | differential input capacitance |  | -             | 10  | -             | pF            |
| $V_{i(se)}$          | single-ended input voltage     | measuring range  | $V_{AGND}$    | -   | $V_{VREF}$    | V             |
| $V_{i(dif)}$         | differential input voltage     | measuring range:<br>$V_{FSR} = V_{VREF} - V_{AGND}$        | $-0.5V_{FSR}$ | -   | $+0.5V_{FSR}$ | V             |
| <b>Accuracy</b>      |                                |  |               |     |               |               |
| $E_G$                | gain error                     | $f_{SCL} \leq 400\text{ kHz}$                              | -             | -   | 1             | %             |
|                      |                                | $f_{SCL} > 400\text{ kHz}$                                 | -             | -   | 3             | %             |
| $E_O$                | offset error                   |  | -             | -   | $\pm 20$      | mV            |
| $E_L$                | linearity error                | $f_{SCL} \leq 400\text{ kHz}$                              | [1]           | -   | $\pm 1.0$     | LSB           |
|                      |                                | $f_{SCL} > 400\text{ kHz}$                                 | [1]           | -   | $\pm 2.0$     | LSB           |
| CMRR                 | common-mode rejection ratio    |  | -             | 40  | -             | dB            |
| $\alpha_{sup(n)}$    | noise suppression              | $f = 100\text{ Hz}$ ;<br>$V_{n(VDD)(p-p)} = 100\text{ mV}$ | -             | 40  | -             | dB            |
| $t_{c(ADC)}$         | ADC conversion time            |  | -             | -   | 8.5           | $\mu\text{s}$ |
| $f_{c(ADC)}$         | ADC conversion frequency       | $f_{SCL} = 1\text{ MHz}$                                   | -             | -   | 111           | kHz           |

[1] The linearity error is assured if the internal frequency is changed by setting bit 7 and bit 3 of the control byte to logic 1 (see [Figure 6](#)).

### 11. Application information

Inputs must be connected to  $V_{SS}$  or  $V_{DD}$  when not in use. Analog inputs may also be connected to pins AGND or VREF.

In order to prevent excessive ground and supply noise and to minimize crosstalk of the digital-to-analog signal paths the printed-circuit board layout must be designed very carefully. Noisy digital circuits and ground loops must be avoided on the supply lines common to the PCA9691 device. Decoupling capacitors ( $> 10 \mu\text{F}$ ) are recommended for power supply and reference voltage inputs.

During data transfer the first bit written out is the MSB and the last bit is the LSB.

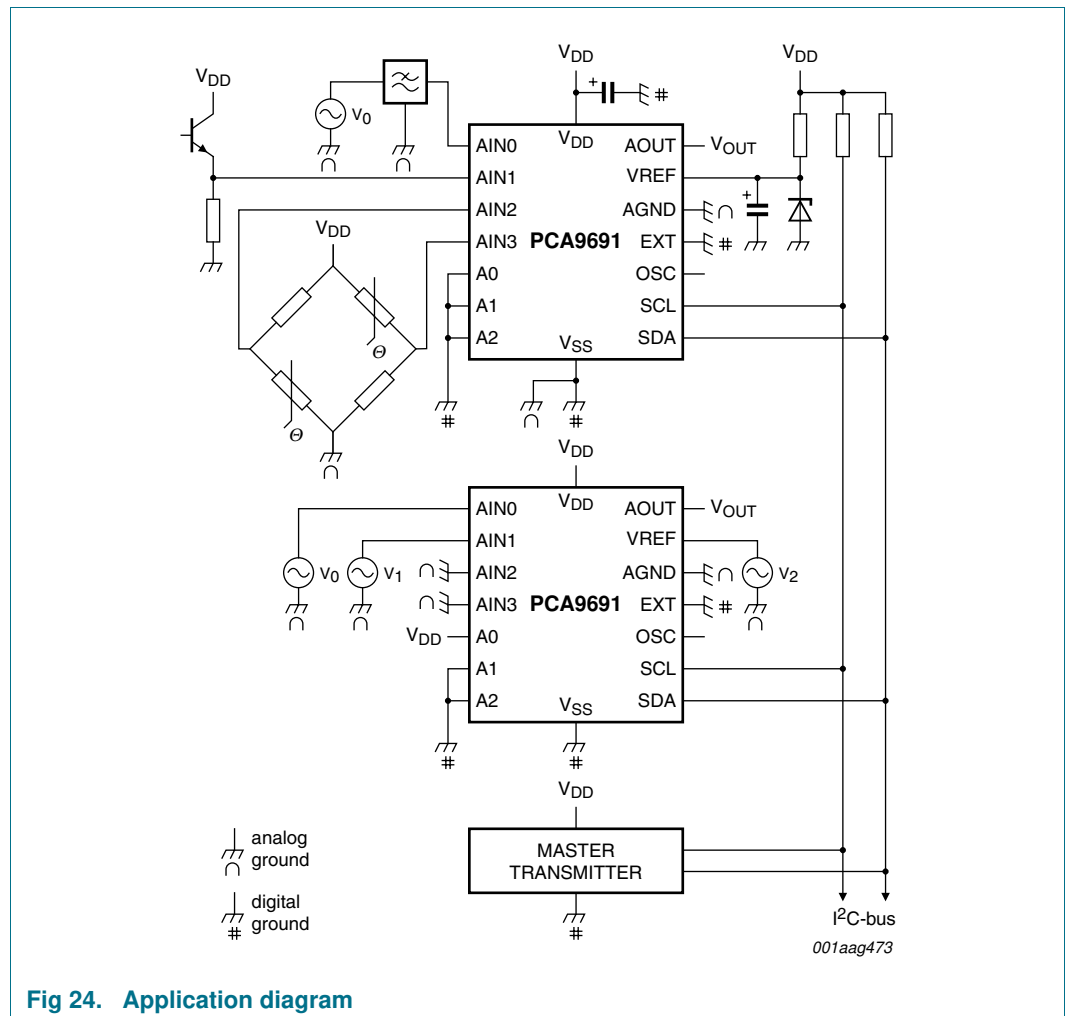
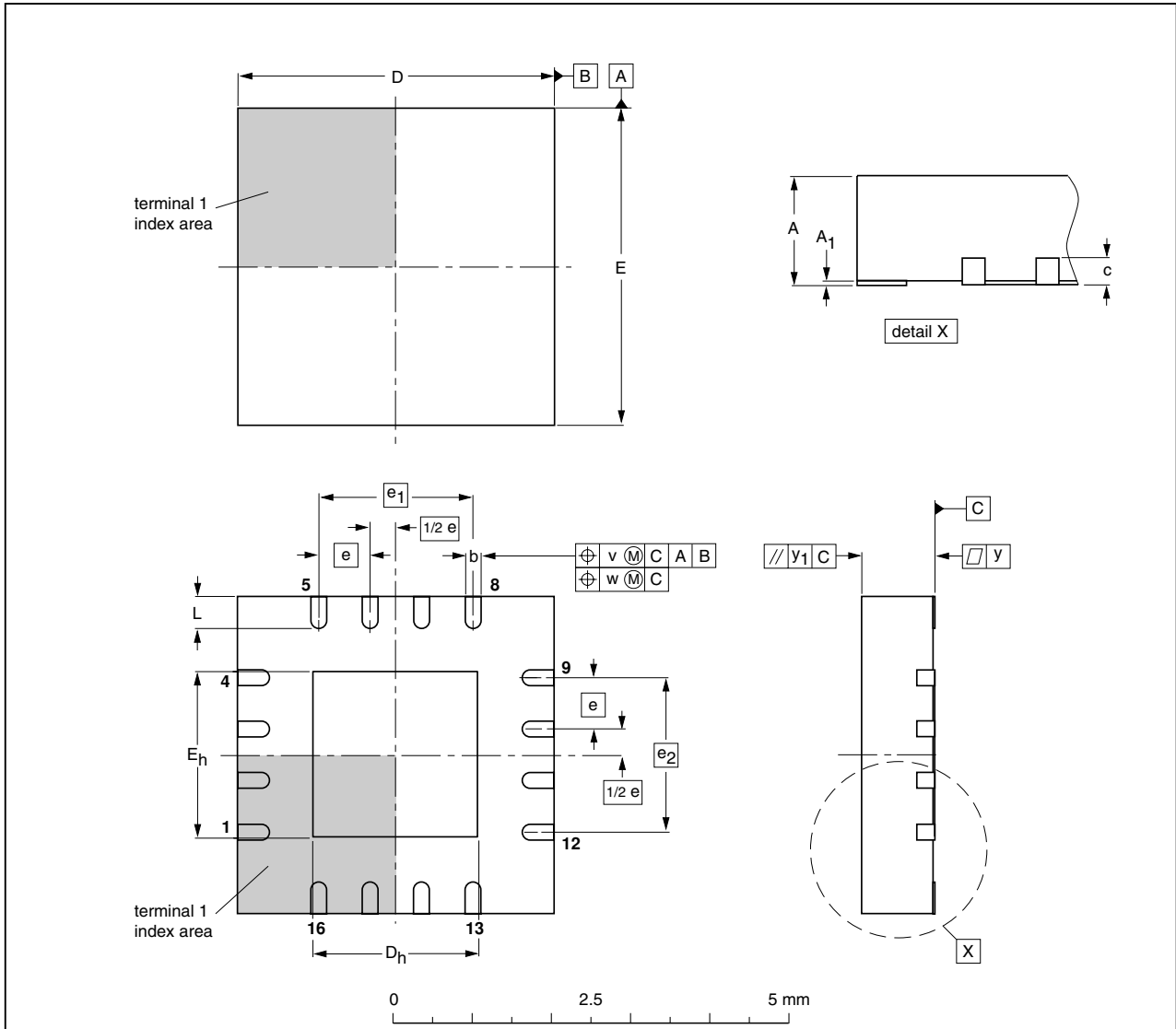


Fig 24. Application diagram

12. Package outline

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

SOT629-1



DIMENSIONS (mm are the original dimensions)

| UNIT | A <sup>(1)</sup> max. | A <sub>1</sub> | b            | c   | D <sup>(1)</sup> | D <sub>h</sub> | E <sup>(1)</sup> | E <sub>h</sub> | e    | e <sub>1</sub> | e <sub>2</sub> | L            | v   | w    | y    | y <sub>1</sub> |
|------|-----------------------|----------------|--------------|-----|------------------|----------------|------------------|----------------|------|----------------|----------------|--------------|-----|------|------|----------------|
| mm   | 1                     | 0.05<br>0.00   | 0.38<br>0.23 | 0.2 | 4.1<br>3.9       | 2.25<br>1.95   | 4.1<br>3.9       | 2.25<br>1.95   | 0.65 | 1.95           | 1.95           | 0.75<br>0.50 | 0.1 | 0.05 | 0.05 | 0.1            |

Note

1. Plastic or metal protrusions of 0.075 mm maximum per side are not included.

| OUTLINE VERSION | REFERENCES |        |       |  | EUROPEAN PROJECTION | ISSUE DATE           |
|-----------------|------------|--------|-------|--|---------------------|----------------------|
|                 | IEC        | JEDEC  | JEITA |  |                     |                      |
| SOT629-1        | ---        | MO-220 | ---   |  |                     | 01-08-08<br>02-10-22 |

Fig 25. Package outline SOT629-1 (HVQFN16) of PCA9691BS



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

SOT403-1

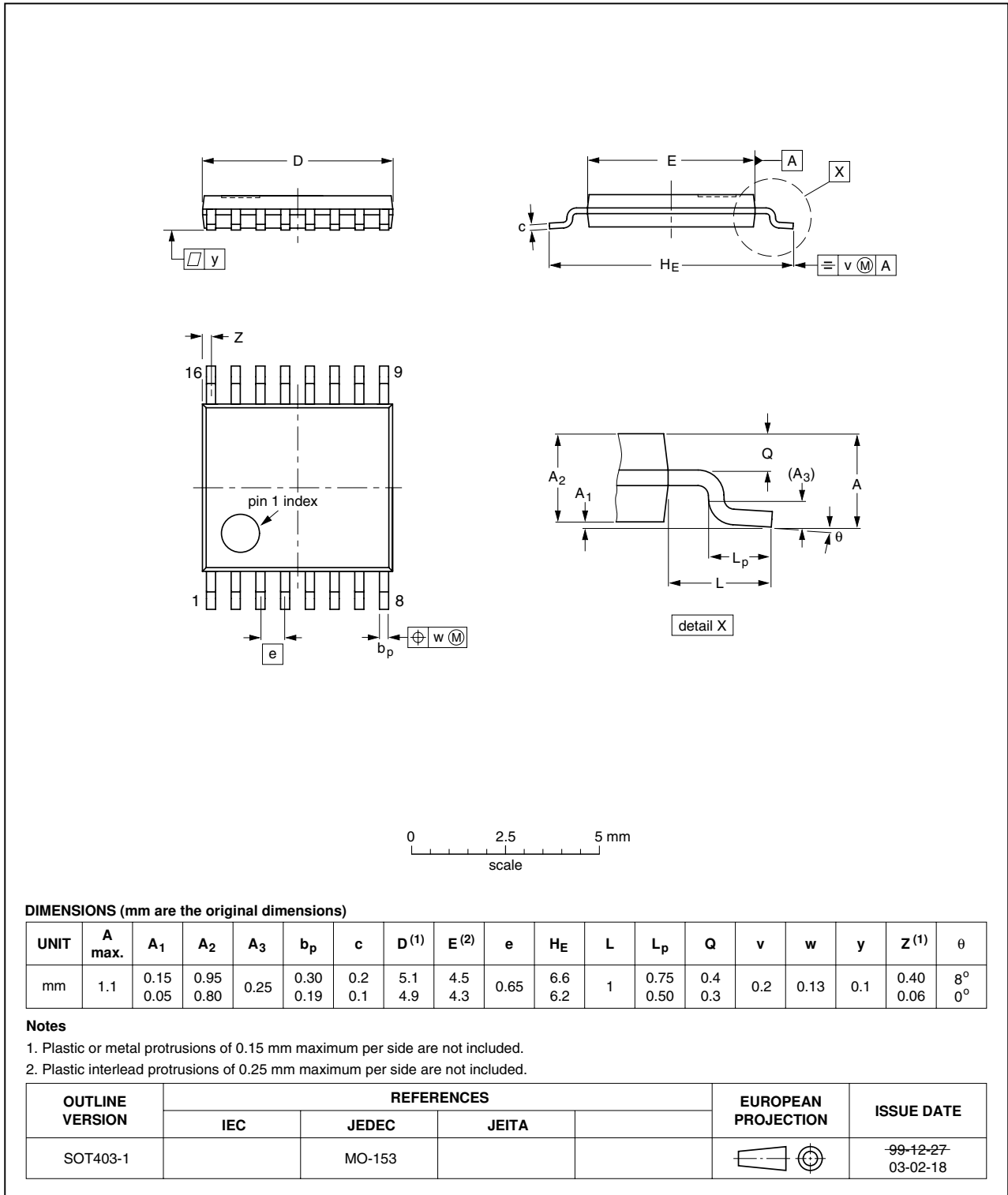


Fig 26. Package outline SOT403-1 (TSSOP16) of PCA9691TS

SO16: plastic small outline package; 16 leads; body width 7.5 mm

SOT162-1

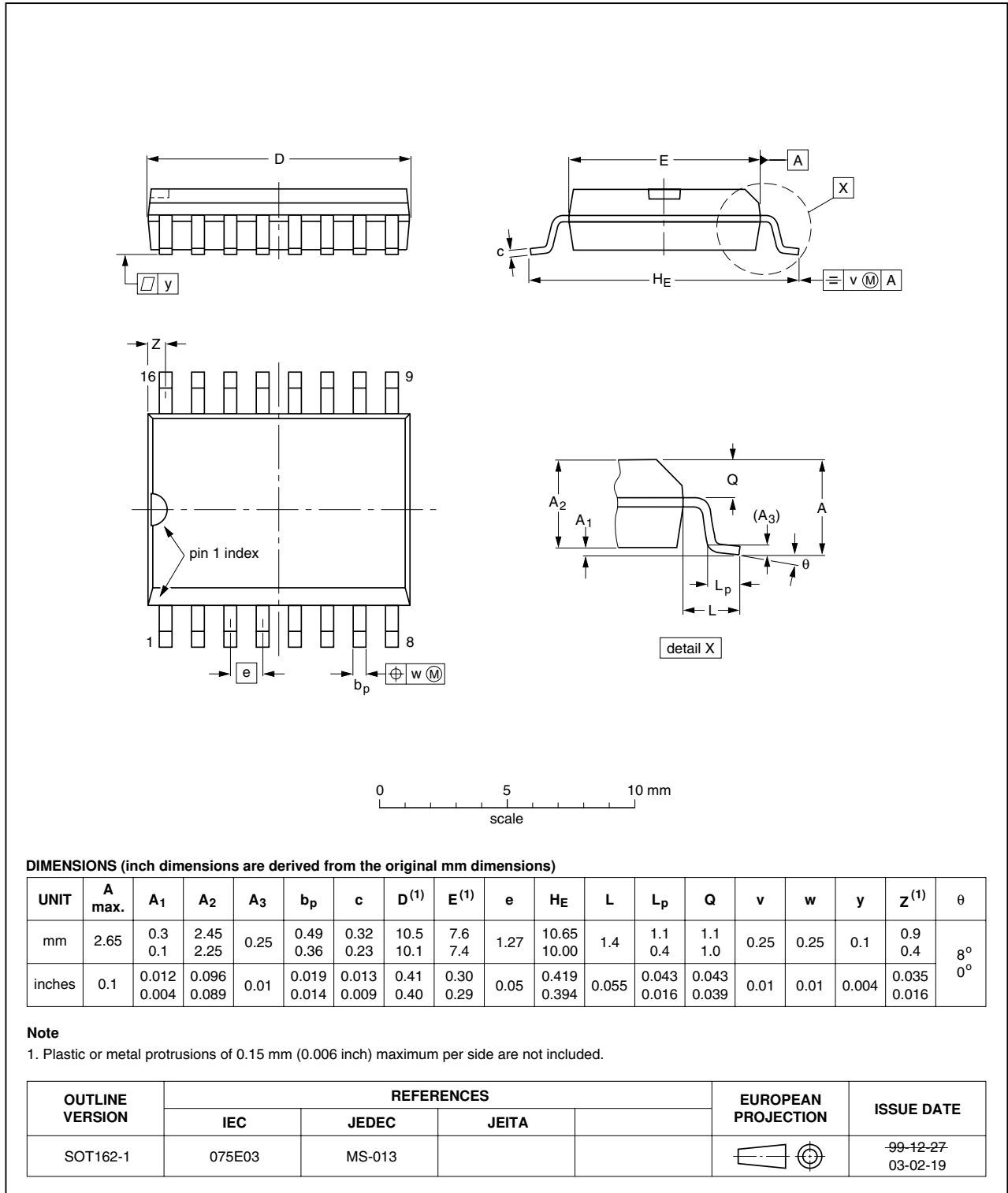


Fig 27. Package outline SOT162-1 (SO16) of PCA9691T