



# PCAL9538A

Low-voltage 8-bit I<sup>2</sup>C-bus and SMBus low power I/O port with interrupt, reset and Agile I/O

Rev. 3 — 9 August 2013

Product data sheet

## 1. General description

The PCAL9538A is a low-voltage 8-bit General Purpose Input/Output (GPIO) expander with interrupt and reset for I<sup>2</sup>C-bus/SMBus applications. NXP I/O expanders provide a simple solution when additional I/Os are needed while keeping interconnections to a minimum, for example, in ACPI power switches, sensors, push buttons, LEDs, fan control, etc.

In addition to providing a flexible set of GPIOs, the wide  $V_{DD}$  range of 1.65 V to 5.5 V allows the PCAL9538A to interface with next-generation microprocessors and microcontrollers where supply levels are dropping down to conserve power.

The PCAL9538A contains the PCA9538A register set of four 8-bit Configuration, Input, Output, and Polarity Inversion registers, and additionally, the PCAL9538A has Agile I/O, which are additional features specifically designed to enhance the I/O. These additional features are: programmable output drive strength, latchable inputs, programmable pull-up/pull-down resistors, maskable interrupt, interrupt status register, programmable open-drain or push-pull outputs.

The PCAL9538A is a pin-to-pin replacement for the PCA9538, however, the PCAL9538A powers up with all I/O interrupts masked. This mask default allows for a board bring-up free of spurious interrupts at power-up.

The PCAL9538A open-drain interrupt ( $\overline{INT}$ ) output is activated when any input state differs from its corresponding Input Port register state and is used to indicate to the system master that an input state has changed.

$\overline{INT}$  can be connected to the interrupt input of a microcontroller. By sending an interrupt signal on this line, the remote I/O can inform the microcontroller if there is incoming data on its ports without having to communicate via the I<sup>2</sup>C-bus. Thus, the PCAL9538A can remain a simple slave device.

The device outputs have 25 mA sink capabilities for directly driving LEDs while consuming low device current.

The power-on reset sets the registers to their default values and initializes the device state machine. In the PCAL9538A, the  $\overline{RESET}$  pin causes the same reset/default I/O input configuration to occur without de-powering the device, holding the registers and I<sup>2</sup>C-bus state machine in their default state until the  $\overline{RESET}$  input is once again HIGH. This input requires a pull-up to  $V_{DD}$ .

Two hardware pins (A0, A1) select the fixed I<sup>2</sup>C-bus address and allow up to four devices to share the same I<sup>2</sup>C-bus/SMBus.



## 2. Features and benefits

- I<sup>2</sup>C-bus to parallel port expander
- Operating power supply voltage range of 1.65 V to 5.5 V
- Low standby current consumption:
  - ◆ 1.5  $\mu$ A (typical at 5 V  $V_{DD}$ )
  - ◆ 1.0  $\mu$ A (typical at 3.3 V  $V_{DD}$ )
- Schmitt-trigger action allows slow input transition and better switching noise immunity at the SCL and SDA inputs
  - ◆  $V_{hys} = 0.10 \times V_{DD}$  (typical)
- 5 V tolerant I/Os
- Active LOW reset input ( $\overline{RESET}$ )
- Open-drain active LOW interrupt output ( $\overline{INT}$ )
- 400 kHz Fast-mode I<sup>2</sup>C-bus
- Internal power-on reset
- Power-up with all channels configured as inputs
- No glitch on power-up
- Latched outputs with 25 mA drive maximum capability for directly driving LEDs
- Latch-up performance exceeds 100 mA per JESD78, Class II
- ESD protection exceeds JESD22
  - ◆ 2000 V Human Body Model (A114-A)
  - ◆ 1000 V Charged-Device Model (C101)
- Packages offered: TSSOP16 and HVQFN16

### 2.1 Agile I/O features

- Pin to pin replacement for PCA9538 and PCA9538A with interrupts disabled at power-up
  - ◆ Software backward compatible with PCA9539 and PCA9539A
- Output port configuration: bank selectable push-pull or open-drain output stages
- Interrupt status: read-only register identifies the source of an interrupt
- Bit-wise I/O programming features:
  - ◆ Output drive strength: four programmable drive strengths to reduce rise and fall times in low capacitance applications
  - ◆ Input latch: Input Port register values changes are kept until the Input Port register is read
  - ◆ Pull-up/pull-down enable: floating input or pull-up/down resistor enable
  - ◆ Pull-up/pull-down selection: 100 k $\Omega$  pull-up/down resistor selection
  - ◆ Interrupt mask: mask prevents the generation of the interrupt when input changes state

3. Ordering information

Table 1. Ordering information

| Type number | Topside mark | Package |                                                                                                    | Version  |
|-------------|--------------|---------|----------------------------------------------------------------------------------------------------|----------|
|             |              | Name    | Description                                                                                        |          |
| PCAL9538ABS | L3A          | HVQFN16 | plastic thermal enhanced very thin quad flat package; no leads; 16 terminals; body 3 × 3 × 0.85 mm | SOT758-1 |
| PCAL9538APW | PL9538A      | TSSOP16 | plastic thin shrink small outline package; 16 leads; body width 4.4 mm                             | SOT403-1 |

3.1 Ordering options

Table 2. Ordering options

| Type number | Orderable part number | Package | Packing method                       | Minimum order quantity | Temperature range                   |
|-------------|-----------------------|---------|--------------------------------------|------------------------|-------------------------------------|
| PCAL9538ABS | PCAL9538ABSHP         | HVQFN16 | Reel 13" Q2/T3<br>*Standard mark SMD | 6000                   | T <sub>amb</sub> = −40 °C to +85 °C |
| PCAL9538APW | PCAL9538APWJ          | TSSOP16 | Reel 13" Q1/T1<br>*Standard mark SMD | 2500                   | T <sub>amb</sub> = −40 °C to +85 °C |

4. Block diagram

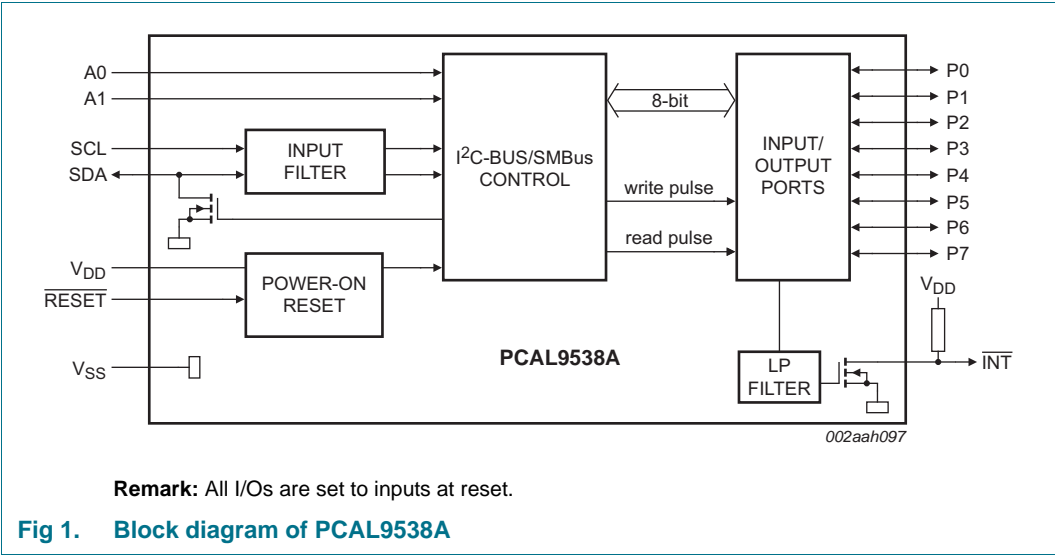
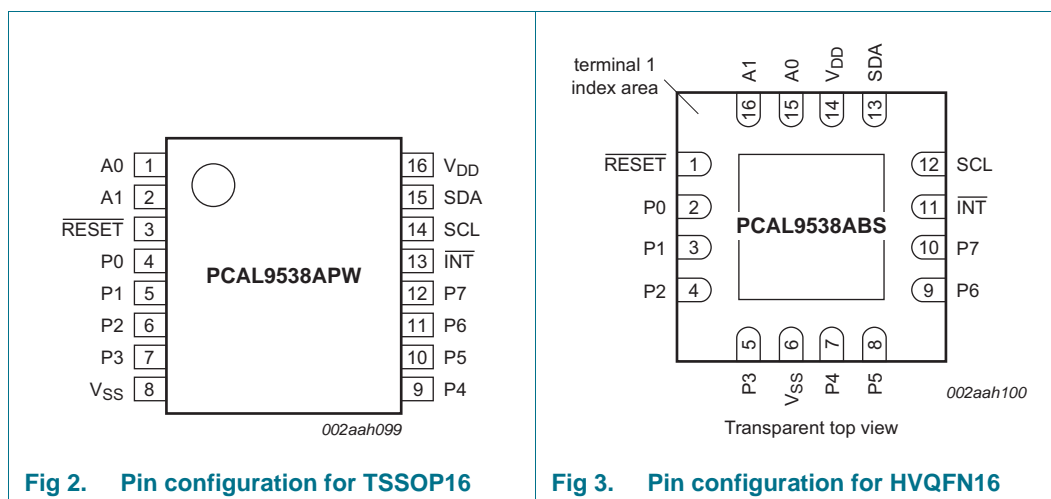


Fig 1. Block diagram of PCAL9538A

## 5. Pinning information

### 5.1 Pinning



### 5.2 Pin description

Table 3. Pin description

| Symbol            | Pin     |                  | Description                   |
|-------------------|---------|------------------|-------------------------------|
|                   | TSSOP16 | HVQFN16          |                               |
| A0                | 1       | 15               | address input 0               |
| A1                | 2       | 16               | address input 1               |
| RESET             | 3       | 1                | active LOW reset input        |
| P0 <sup>[1]</sup> | 4       | 2                | Port P input/output 0         |
| P1 <sup>[1]</sup> | 5       | 3                | Port P input/output 1         |
| P2 <sup>[1]</sup> | 6       | 4                | Port P input/output 2         |
| P3 <sup>[1]</sup> | 7       | 5                | Port P input/output 3         |
| V <sub>SS</sub>   | 8       | 6 <sup>[2]</sup> | supply ground                 |
| P4 <sup>[1]</sup> | 9       | 7                | Port P input/output 4         |
| P5 <sup>[1]</sup> | 10      | 8                | Port P input/output 5         |
| P6 <sup>[1]</sup> | 11      | 9                | Port P input/output 6         |
| P7 <sup>[1]</sup> | 12      | 10               | Port P input/output 7         |
| INT               | 13      | 11               | interrupt output (open-drain) |
| SCL               | 14      | 12               | serial clock line             |
| SDA               | 15      | 13               | serial data line              |
| V <sub>DD</sub>   | 16      | 14               | supply voltage                |

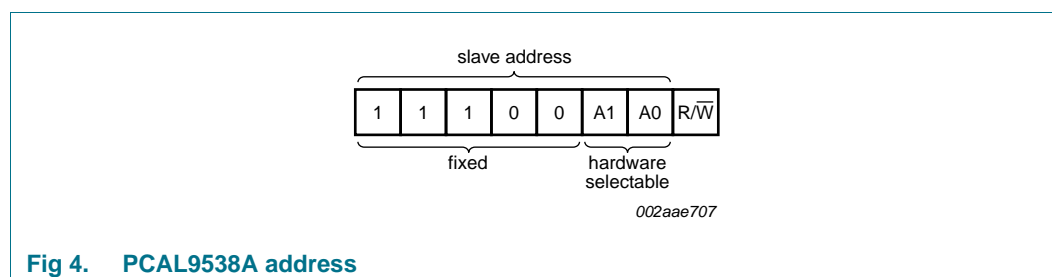
[1] All I/O are configured as input at power-on.

[2] HVQFN16 package die supply ground is connected to both the V<sub>SS</sub> pin and the exposed center pad. The 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 printed-circuit board in the thermal pad region.

## 6. Functional description

Refer to [Figure 1 “Block diagram of PCAL9538A”](#).

### 6.1 Device address

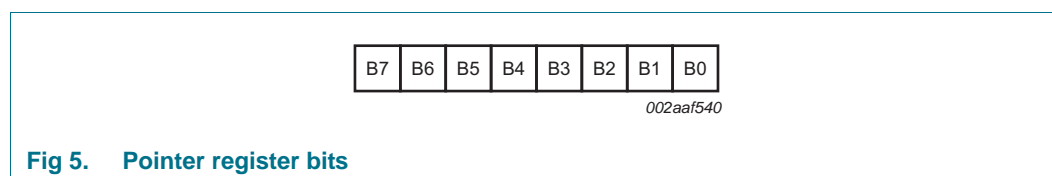


**Fig 4. PCAL9538A address**

A1 and A0 are the hardware address package pins and are held to either HIGH (logic 1) or LOW (logic 0) to assign one of the four possible slave addresses. The last bit of the slave address ( $\overline{R/W}$ ) defines the operation (read or write) to be performed. A HIGH (logic 1) selects a read operation, while a LOW (logic 0) selects a write operation.

### 6.2 Pointer register and command byte

Following the successful acknowledgement of the address byte, the bus master sends a command byte, which is stored in the Pointer register in the PCAL9538A. Two bits of this data byte state the operation (read or write) and the internal registers (Input, Output, Polarity Inversion, or Configuration) that will be affected. Bit 6 in conjunction with the lower three bits of the Command byte are used to point to the extended features of the device (Agile I/O). This register is write only.



**Fig 5. Pointer register bits**

Table 4. Command byte

| Pointer register bits |    |    |    |    |    |    |    | Command byte<br>(hexadecimal) | Register                    | Protocol        | Power-up<br>default      |
|-----------------------|----|----|----|----|----|----|----|-------------------------------|-----------------------------|-----------------|--------------------------|
| B7                    | B6 | B5 | B4 | B3 | B2 | B1 | B0 |                               |                             |                 |                          |
| 0                     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 00h                           | Input port                  | read byte       | xxxx xxxx <sup>[1]</sup> |
| 0                     | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 01h                           | Output port                 | read/write byte | 1111 1111                |
| 0                     | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 02h                           | Polarity Inversion          | read/write byte | 0000 0000                |
| 0                     | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 03h                           | Configuration               | read/write byte | 1111 1111                |
| 0                     | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 40h                           | Output drive strength 0     | read/write byte | 1111 1111                |
| 0                     | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 41h                           | Output drive strength 1     | read/write byte | 1111 1111                |
| 0                     | 1  | 0  | 0  | 0  | 0  | 1  | 0  | 42h                           | Input latch                 | read/write byte | 0000 0000                |
| 0                     | 1  | 0  | 0  | 0  | 0  | 1  | 1  | 43h                           | Pull-up/pull-down enable    | read/write byte | 0000 0000                |
| 0                     | 1  | 0  | 0  | 0  | 1  | 0  | 0  | 44h                           | Pull-up/pull-down selection | read/write byte | 1111 1111                |
| 0                     | 1  | 0  | 0  | 0  | 1  | 0  | 1  | 45h                           | Interrupt mask              | read/write byte | 1111 1111                |
| 0                     | 1  | 0  | 0  | 0  | 1  | 1  | 0  | 46h                           | Interrupt status            | read byte       | 0000 0000                |
| 0                     | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 4Fh                           | Output port configuration   | read/write byte | 0000 0000                |

[1] Undefined.

## 6.3 Interface definition

Table 5. Interface definition

| Byte                               | Bit     |    |    |    |    |    |    |         |
|------------------------------------|---------|----|----|----|----|----|----|---------|
|                                    | 7 (MSB) | 6  | 5  | 4  | 3  | 2  | 1  | 0 (LSB) |
| I <sup>2</sup> C-bus slave address | H       | H  | H  | L  | L  | A1 | A0 | R/W     |
| I/O data bus                       | P7      | P6 | P5 | P4 | P3 | P2 | P1 | P0      |

## 6.4 Register descriptions

### 6.4.1 Input port register (00h)

The Input port register (register 0) reflects the incoming logic levels of the pins, regardless of whether the pin is defined as an input or an output by the Configuration register. The Input port register is read only; writes to this register have no effect. The default value 'X' is determined by the externally applied logic level. An Input port register read operation is performed as described in [Section 7.2 "Read commands"](#).

Table 6. Input port register (address 00h)

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | I7 | I6 | I5 | I4 | I3 | I2 | I1 | I0 |
| Default | X  | X  | X  | X  | X  | X  | X  | X  |

### 6.4.2 Output port register (01h)

The Output port register (register 1) shows the outgoing logic levels of the pins defined as outputs by the Configuration register. Bit values in these registers have no effect on pins defined as inputs. In turn, reads from this register reflect the value that was written to this register, **not** the actual pin value.

Table 7. Output port register (address 01h)

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | O7 | O6 | O5 | O4 | O3 | O2 | O1 | O0 |
| Default | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

#### 6.4.3 Polarity inversion register (02h)

The Polarity inversion register (register 2) allows polarity inversion of pins defined as inputs by the Configuration register. If a bit in this register is set (written with '1'), the corresponding port pin's polarity is inverted. If a bit in this register is cleared (written with a '0'), the corresponding port pin's original polarity is retained.

Table 8. Polarity inversion register (address 02h)

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | N7 | N6 | N5 | N4 | N3 | N2 | N1 | N0 |
| Default | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

#### 6.4.4 Configuration register (03h)

The Configuration register (register 3) configures the direction of the I/O pins. If a bit in this register is set to 1, the corresponding port pin is enabled as a high-impedance input. If a bit in this register is cleared to 0, the corresponding port pin is enabled as an output.

Table 9. Configuration register (address 03h)

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | C7 | C6 | C5 | C4 | C3 | C2 | C1 | C0 |
| Default | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

#### 6.4.5 Output drive strength registers (40h, 41h)

The Output drive strength registers control the output drive level of the GPIO. Each GPIO can be configured independently to a certain output current level by two register control bits. For example, Port 7 is controlled by register 41 CC7 (bits [7:6]), Port 6 is controlled by register 41 CC6 (bits [5:4]). The output drive level of the GPIO is programmed 00b = 0.25×, 01b = 0.5×, 10b = 0.75× or 11b = 1× of the drive capability of the I/O. See [Section 8.2 "Output drive strength control"](#) for more details.

Table 10. Current control register (address 40h)

| Bit     | 7   | 6 | 5   | 4 | 3   | 2 | 1   | 0 |
|---------|-----|---|-----|---|-----|---|-----|---|
| Symbol  | CC3 |   | CC2 |   | CC1 |   | CC0 |   |
| Default | 1   | 1 | 1   | 1 | 1   | 1 | 1   | 1 |

Table 11. Current control register (address 41h)

| Bit     | 7   | 6 | 5   | 4 | 3   | 2 | 1   | 0 |
|---------|-----|---|-----|---|-----|---|-----|---|
| Symbol  | CC7 |   | CC6 |   | CC5 |   | CC4 |   |
| Default | 1   | 1 | 1   | 1 | 1   | 1 | 1   | 1 |

#### 6.4.6 Input latch register (42h)

The Input latch register enables and disables the input latch of the I/O pins. These registers are effective only when the pin is configured as an input port. When an input latch register bit is 0, the corresponding input pin state is not latched. A state change in the corresponding input pin generates an interrupt. A read of the input port register clears the interrupt. If the input goes back to its initial logic state before the input port register is read, then the interrupt is cleared.

When an input latch register bit is 1, the corresponding input pin state is latched. A change of state of the input generates an interrupt and the input logic value is loaded into the corresponding bit of the input port register (registers 0). A read of the input port register clears the interrupt. If the input pin returns to its initial logic state before the input port register is read, then the interrupt is not cleared and the corresponding bit of the input port register keeps the logic value that initiated the interrupt. See [Figure 11](#). For example, if the P4 input was as logic 0 and the input goes to logic 1 then back to logic 0, the input port register will capture this change and an interrupt is generated (if unmasked). When the read is performed on the input port register, the interrupt is cleared, assuming there were no additional input(s) that have changed, and bit 4 of the input port register will read '1'. The next read of the input port register bit 4 should now read '0'.

An interrupt remains active when a non-latched input simultaneously switches state with a latched input and then returns to its original state. A read of the input port register reflects only the change of state of the latched input and also clears the interrupt. The interrupt is not cleared if the input latch register changes from latched to non-latched configuration.

If the input pin is changed from latched to non-latched input, a read from the input port register reflects the current port logic level. If the input pin is changed from non-latched to latched input, the read from the input port register reflects the latched logic level.

**Table 12. Input latch register (address 42h)**

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | L7 | L6 | L5 | L4 | L3 | L2 | L1 | L0 |
| Default | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

#### 6.4.7 Pull-up/pull-down enable register (43h)

This register allows the user to enable or disable pull-up/pull-down resistors on the I/O pins. Setting the bit to logic 1 enables the selection of pull-up/pull-down resistors. Setting the bit to logic 0 disconnects the pull-up/pull-down resistors from the I/O pins. Use the pull-up/pull-down registers to select either a pull-up or pull-down resistor.

**Table 13. Pull-up/pull-down enable register (address 43h)**

| Bit     | 7   | 6   | 5   | 4   | 3   | 2   | 1   | 0   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| Symbol  | PE7 | PE6 | PE5 | PE4 | PE3 | PE2 | PE1 | PE0 |
| Default | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |



### 6.4.8 Pull-up/pull-down selection register (44h)

The I/O port can be configured to have pull-up or pull-down resistor by programming the pull-up/pull-down selection register. Setting a bit to logic 1 selects a 100 k $\Omega$  pull-up resistor for that I/O pin. Setting a bit to logic 0 selects a 100 k $\Omega$  pull-down resistor for that I/O pin. If the pull-up/down feature is disconnected, writing to this register will have no effect on I/O pin. Typical value is 100 k $\Omega$  with minimum of 50 k $\Omega$  and maximum of 150 k $\Omega$ .

**Table 14. Pull-up/pull-down selection register (address 44h)**

| Bit     | 7    | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|---------|------|------|------|------|------|------|------|------|
| Symbol  | PUD7 | PUD6 | PUD5 | PUD4 | PUD3 | PUD2 | PUD1 | PUD0 |
| Default | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    |

### 6.4.9 Interrupt mask register (45h)

Interrupt mask register is set to logic 1 upon power-on, disabling interrupts during system start-up. Interrupts may be enabled by setting corresponding mask bits to logic 0. If an input changes state and the corresponding bit in the Interrupt mask register is set to 1, the interrupt is masked and the interrupt pin (INT) will not be asserted. If the corresponding bit in the Interrupt mask register is set to 0, the interrupt pin will be asserted.

When an input changes state and the resulting interrupt is masked (interrupt mask bit is 1), setting the input mask register bit to 0 will cause the interrupt pin to be asserted. If the interrupt mask bit of an input that is currently the source of an interrupt is set to 1, the interrupt pin will be de-asserted.

**Table 15. Interrupt mask register (address 45h)**

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | M7 | M6 | M5 | M4 | M3 | M2 | M1 | M0 |
| Default | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |

### 6.4.10 Interrupt status register (46h)

This read-only register is used to identify the source of an interrupt. When read, a logic 1 indicates that the corresponding input pin was the source of the interrupt. A logic 0 indicates that the input pin is not the source of an interrupt.

When a corresponding bit in the interrupt mask register is set to 1 (masked), the interrupt status bit will return logic 0.

**Table 16. Interrupt status register (address 46h)**

| Bit     | 7  | 6  | 5  | 4  | 3  | 2  | 1  | 0  |
|---------|----|----|----|----|----|----|----|----|
| Symbol  | S7 | S6 | S5 | S4 | S3 | S2 | S1 | S0 |
| Default | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

#### 6.4.11 Output port configuration register (4Fh)

The output port configuration register selects port-wise push-pull or open-drain I/O stage. A logic 0 configures the I/O as push-pull (Q1 and Q2 are active, see [Figure 6](#)). A logic 1 configures the I/O as open-drain (Q1 is disabled, Q2 is active). The recommended command sequence is to program this register (4Fh) before the Configuration register (03h) sets the port pins as outputs.

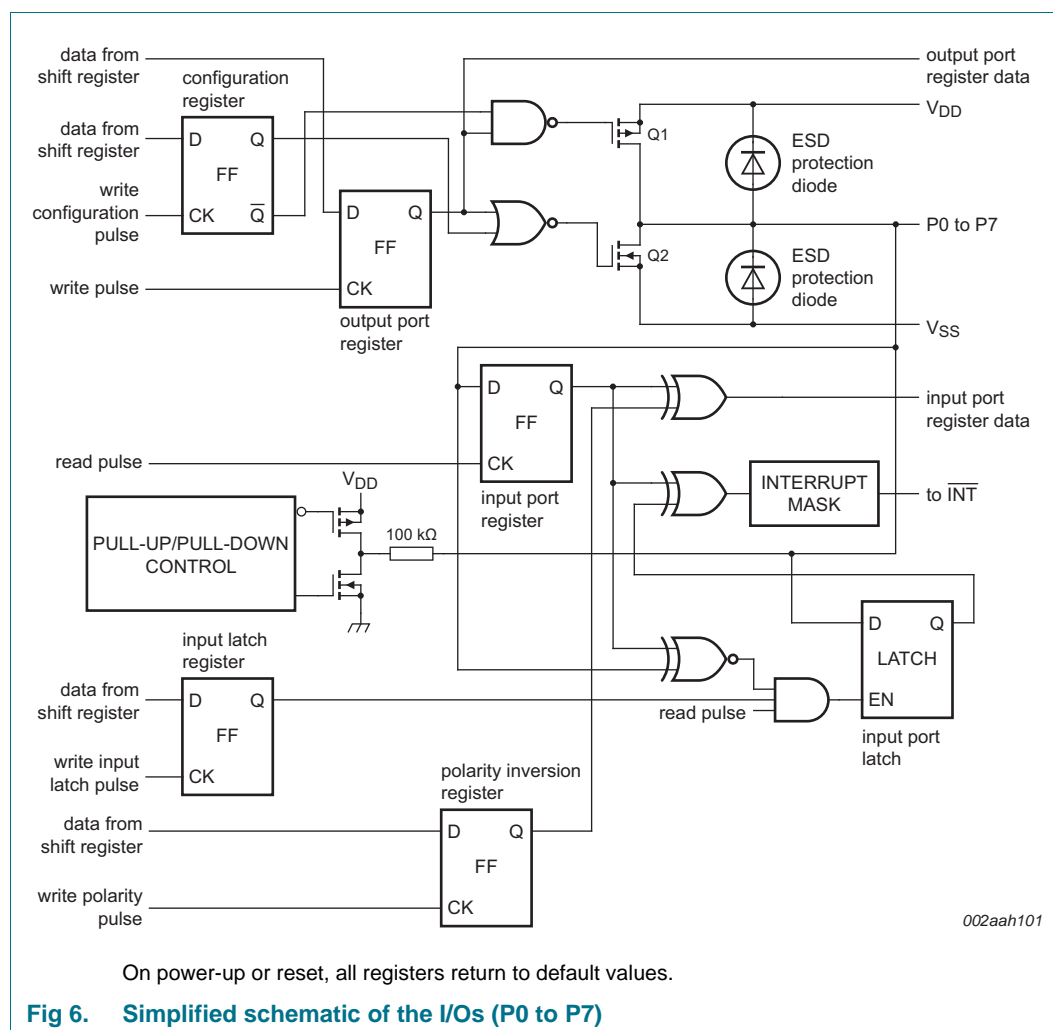
**Table 17. Output port configuration register (address 4Fh)**

| Bit     | 7        | 6 | 5 | 4 | 3 | 2 | 1 | 0     |
|---------|----------|---|---|---|---|---|---|-------|
| Symbol  | reserved |   |   |   |   |   |   | ODEN0 |
| Default | 0        | 0 | 0 | 0 | 0 | 0 | 0 | 0     |

## 6.5 I/O port

When an I/O is configured as an input, FETs Q1 and Q2 are off, which creates a high-impedance input. The input voltage may be raised above  $V_{DD}$  to a maximum of 5.5 V.

If the I/O is configured as an output, Q1 or Q2 is enabled, depending on the state of the Output port register. In this case, there are low-impedance paths between the I/O pin and either  $V_{DD}$  or  $V_{SS}$ . The external voltage applied to this I/O pin should not exceed the recommended levels for proper operation.



## 6.6 Power-on reset

When power (from 0 V) is applied to  $V_{DD}$ , an internal power-on reset holds the PCAL9538A in a reset condition until  $V_{DD}$  has reached  $V_{POR}$ . At that time, the reset condition is released and the PCAL9538A registers and I<sup>2</sup>C-bus/SMBus state machine initialize to their default states. After that,  $V_{DD}$  must be lowered to below  $V_{POR}$  and back up to the operating voltage for a power-reset cycle. See [Section 8.4 “Power-on reset requirements”](#).

## 6.7 Reset input ( $\overline{\text{RESET}}$ )

The  $\overline{\text{RESET}}$  input can be asserted to initialize the system while keeping the  $V_{DD}$  at its operating level. A reset can be accomplished by holding the  $\overline{\text{RESET}}$  pin LOW for a minimum of  $t_{w(\text{rst})}$ . The PCAL9538A registers and I<sup>2</sup>C-bus/SMBus state machine are changed to their default state once  $\overline{\text{RESET}}$  is LOW (0). When  $\overline{\text{RESET}}$  is HIGH (1), the I/O levels at the P port can be changed externally or through the master. This input requires a pull-up resistor to  $V_{DD}$  if no active connection is used.

## 6.8 Interrupt output ( $\overline{\text{INT}}$ )

An interrupt is generated by any rising or falling edge of the port inputs in the Input mode. After time  $t_{v(\text{INT})}$ , the signal  $\overline{\text{INT}}$  is valid. Resetting the interrupt circuit is achieved when data on the port is changed to the original setting or when data is read from the port that generated the interrupt (see [Figure 10](#)). Resetting occurs in the Read mode at the acknowledge (ACK) or not acknowledge (NACK) bit after the rising edge of the SCL signal. Interrupts that occur during the ACK or NACK clock pulse can be lost (or be very short) due to the resetting of the interrupt during this pulse. Each change of the I/Os after resetting is detected and is transmitted as  $\overline{\text{INT}}$ .

A pin configured as an output cannot cause an interrupt. Changing an I/O from an output to an input may cause a false interrupt to occur, if the state of the pin does not match the contents of the Input port register.

The  $\overline{\text{INT}}$  output has an open-drain structure and requires a pull-up resistor to  $V_{DD}$ .  $\overline{\text{INT}}$  should be connected to the voltage source of the device that requires the interrupt information. When using the input latch feature, the input pin state is latched. The interrupt is reset only when data is read from the port that generated the interrupt. The reset occurs in the Read mode at the acknowledge (ACK) or not acknowledge (NACK) bit after the rising edge of the SCL signal.

7. Bus transactions

The PCAL9538A is an I<sup>2</sup>C-bus slave device. Data is exchanged between the master and PCAL9538A through write and read commands using I<sup>2</sup>C-bus. The two communication 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.

7.1 Write commands

Data is transmitted to the PCAL9538A by sending the device address and setting the Least Significant Bit (LSB) to a logic 0 (see [Figure 4](#) for device address). The command byte is sent after the address and determines which register receives the data that follows the command byte. There is no limitation on the number of data bytes sent in one write transmission.

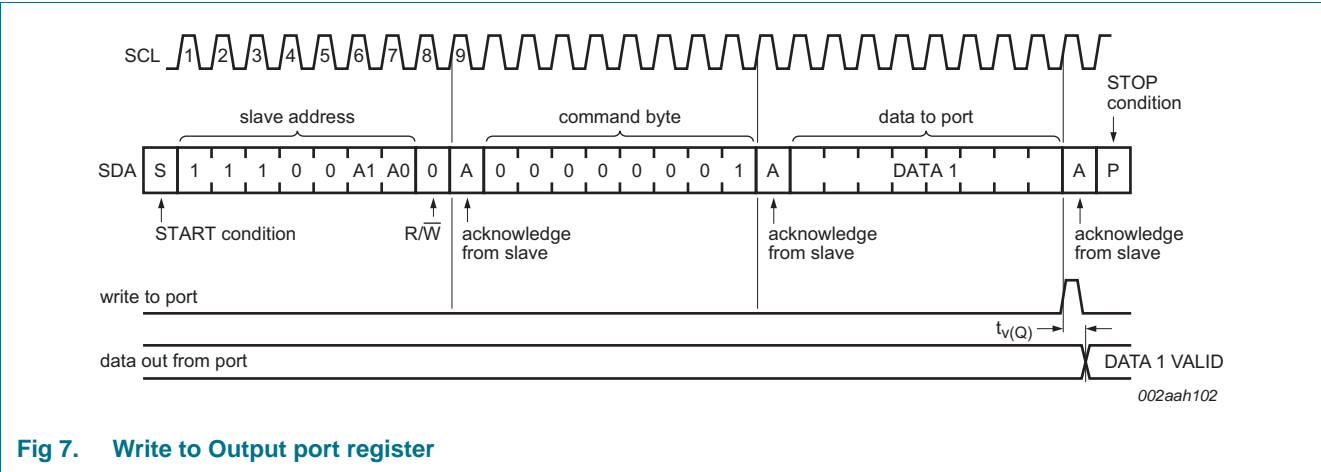


Fig 7. Write to Output port register

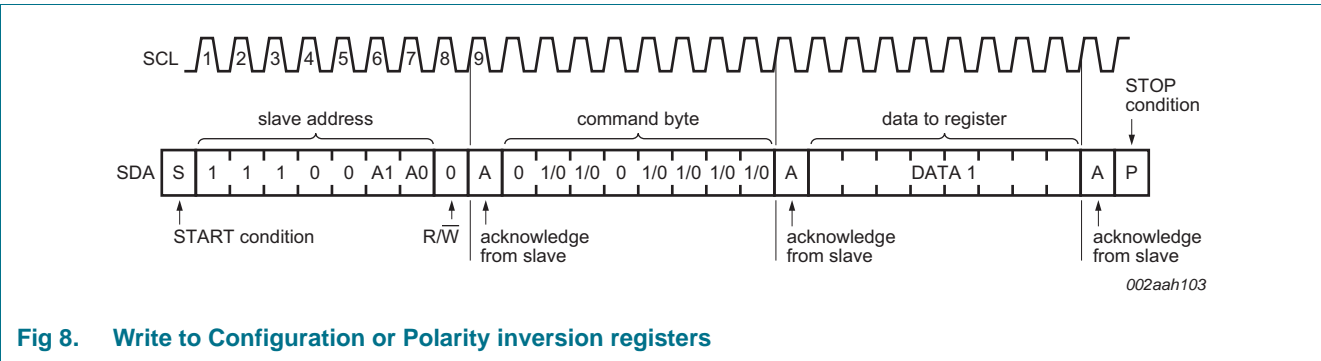


Fig 8. Write to Configuration or Polarity inversion registers

## 7.2 Read commands

To read data from the PCAL9538A, the bus master must first send the PCAL9538A address with the least significant bit set to a logic 0 (see [Figure 4](#) for device address). The command byte is sent after the address and determines which register is to be accessed.

After a restart the device address is sent again, but this time the LSB is set to a logic 1. Data from the register defined by the command byte then is sent by the PCAL9538A (see [Figure 9](#) and [Figure 10](#)).

Data is clocked into the register on the rising edge of the ACK clock pulse. There is no limit on the number of data bytes received in one read transmission, but on the final byte received the bus master must not acknowledge the data.

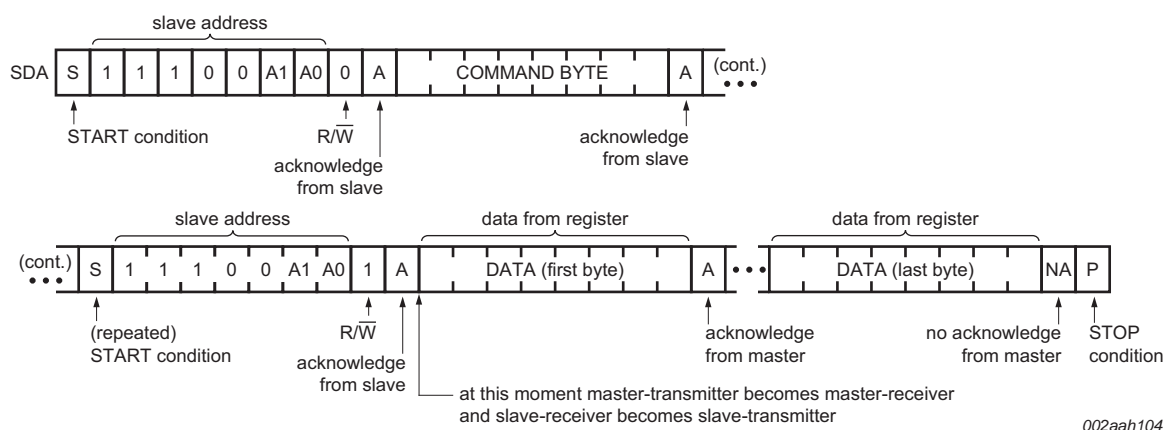
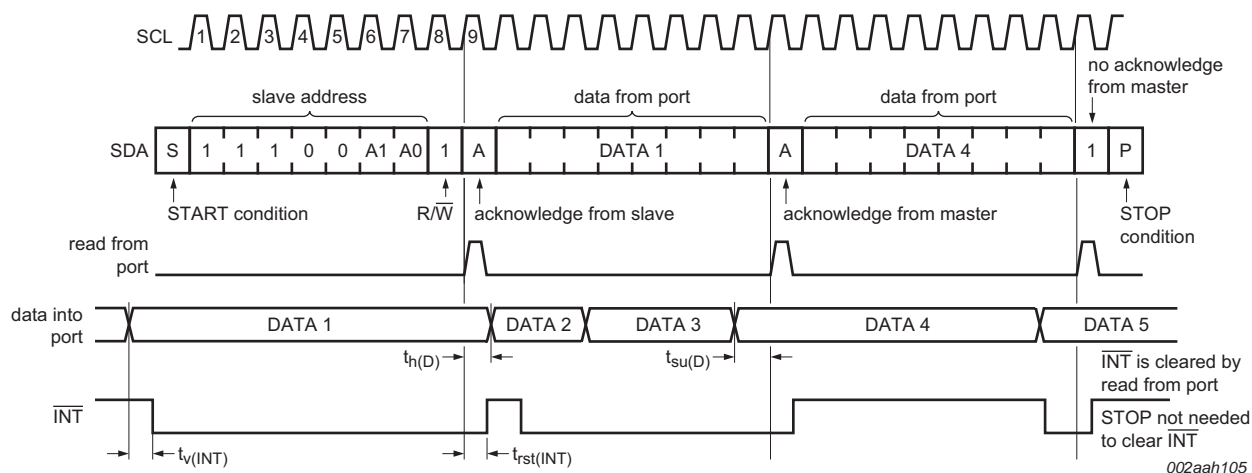


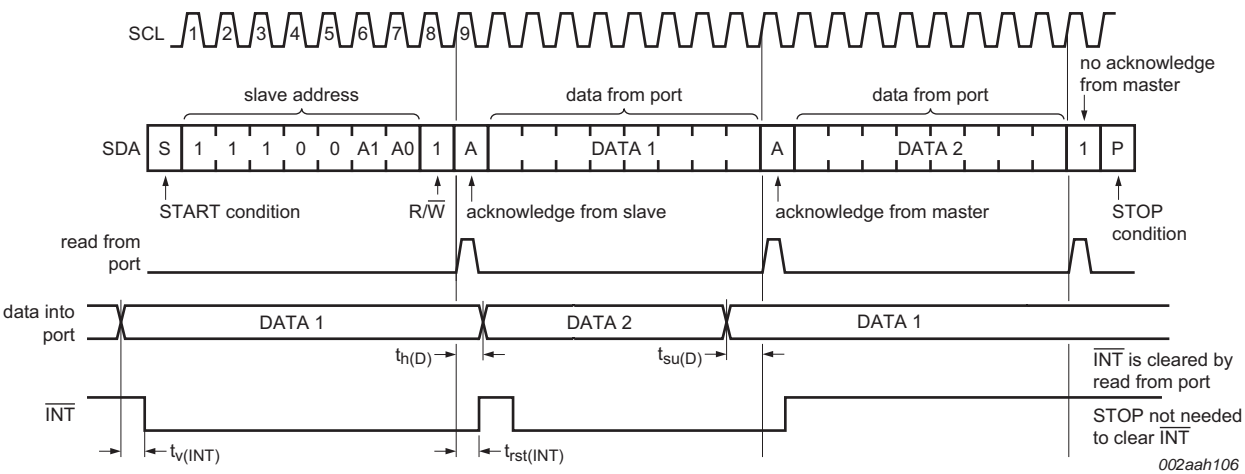
Fig 9. Read from register



Transfer of data can be stopped at any time by a STOP condition. When this occurs, data present at the latest acknowledge phase is valid (output mode). It is assumed that the command byte has previously been programmed with 00h (read Input port register).

This figure eliminates the command byte transfer, a restart, and slave address call between the initial slave address call and actual data transfer from P port (see [Figure 9](#)).

Fig 10. Read Input port register (non-latched)

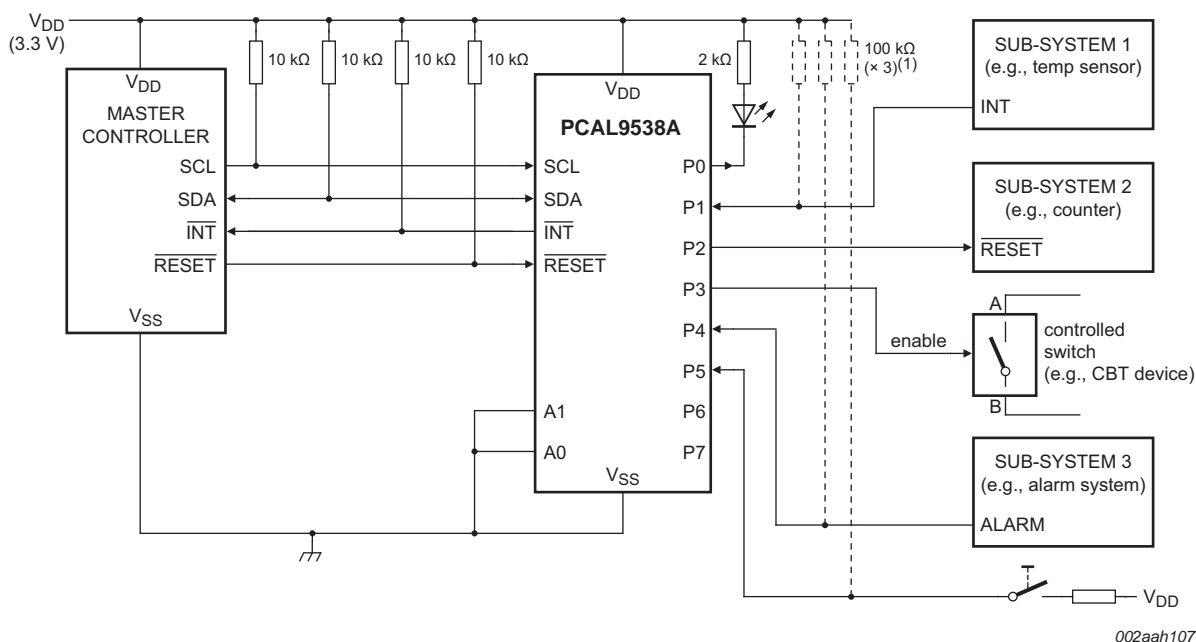


Transfer of data can be stopped at any time by a STOP condition. When this occurs, data present at the latest acknowledge phase is valid (output mode). It is assumed that the command byte has previously been programmed with 00h (read Input port register).

This figure eliminates the command byte transfer, a restart, and slave address call between the initial slave address call and actual data transfer from P port (see [Figure 9](#)).

Fig 11. Read Input port register (latch enabled)

## 8. Application design-in information



Device address is 1110 000x for this example.

P0, P2, P3 configured as outputs.

P1, P4, P5 configured as inputs.

P6, P7 are not used and need 100 kΩ pull-up resistors to protect them from floating or the internal pull-up or pull-down selected.

- (1) Resistors are required for inputs (on P port) that may float. If a driver to an input will never let the input float, a resistor is not needed. Outputs (in the P port) do not need pull-up resistors.

002aah107

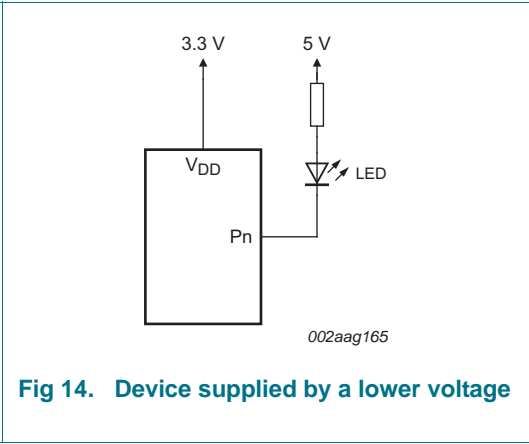
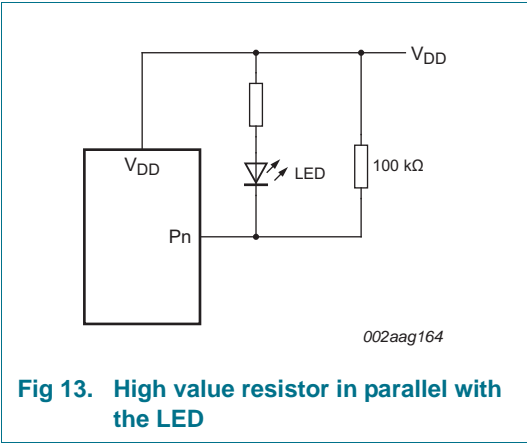
**Fig 12. Typical application**

### 8.1 Minimizing $I_{DD}$ when the I/Os are used to control LEDs

When the I/Os are used to control LEDs, they are normally connected to  $V_{DD}$  through a resistor as shown in [Figure 12](#). Since the LED acts as a diode, when the LED is off the I/O  $V_I$  is about 1.2 V less than  $V_{DD}$ . The supply current,  $I_{DD}$ , increases as  $V_I$  becomes lower than  $V_{DD}$ .

Designs needing to minimize current consumption, such as battery power applications, should consider maintaining the I/O pins greater than or equal to  $V_{DD}$  when the LED is off. [Figure 13](#) shows a high value resistor in parallel with the LED. [Figure 14](#) shows  $V_{DD}$  less than the LED supply voltage by at least 1.2 V. Both of these methods maintain the I/O  $V_I$  at or above  $V_{DD}$  and prevents additional supply current consumption when the LED is off.

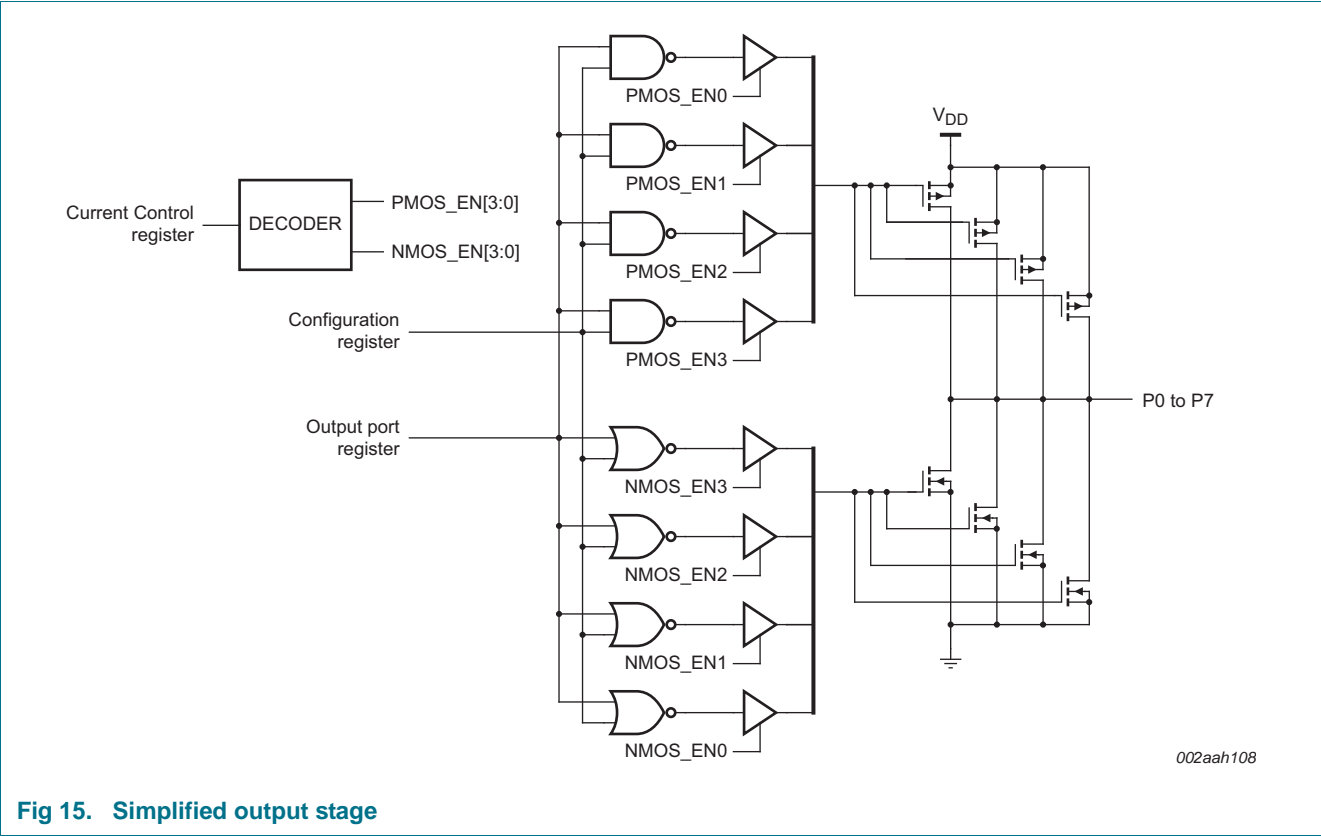




8.2 Output drive strength control

The Output drive strength registers allow the user to control the output drive level of the GPIO. Each GPIO can be configured independently to one of the four possible output current levels. By programming these bits the user is changing the number of transistor pairs or ‘fingers’ that drive the I/O pad.

Figure 15 shows a simplified output stage. The behavior of the pad is affected by the Configuration register, the output port data, and the current control register. When the Current Control register bits are programmed to 10b, then only two of the fingers are active, reducing the current drive capability by 50 %.



Reducing the current drive capability may be desirable to reduce system noise. When the output switches (transitions from H/L), there is a peak current that is a function of the output drive selection. This peak current runs through  $V_{DD}$  and  $V_{SS}$  package inductance and will create noise (some radiated, but more critically Simultaneous Switching Noise (SSN)). In other words, switching many outputs at the same time will create ground and supply noise. The output drive strength control through the Current Control registers allows the user to mitigate SSN issues without the need of additional external components.

### 8.3 12 V tolerant I/Os

The PCAL9538A device SCR group reference diode can go up to 10 V before latch back to 8 V. The ESD gate oxide will protect the device, but not if used continually. Therefore, to achieve 12 V tolerant I/Os, the external protection circuitry (diode) must be used as shown in [Figure 16](#).

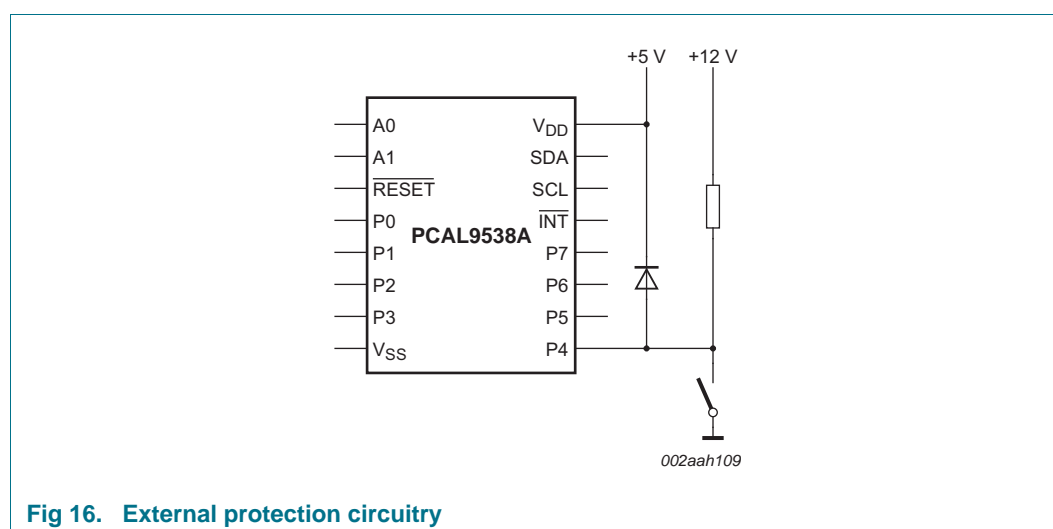
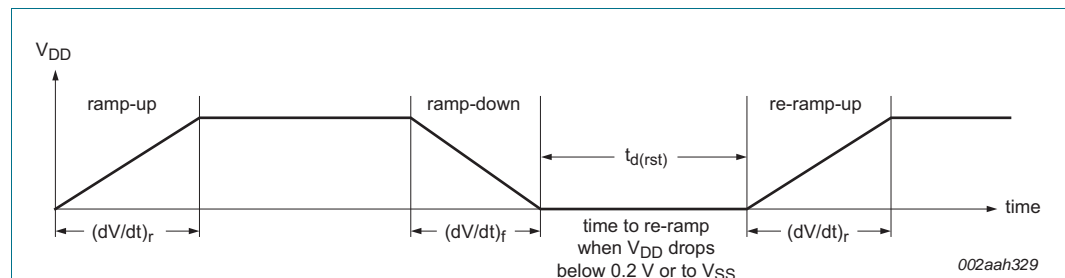


Fig 16. External protection circuitry

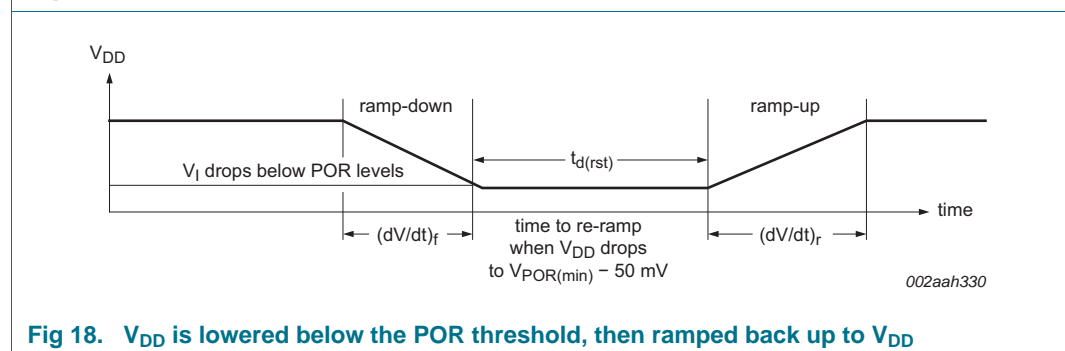
## 8.4 Power-on reset requirements

In the event of a glitch or data corruption, PCAL9538A can be reset to its default conditions by using the power-on reset feature. Power-on reset requires that the device go through a power cycle to be completely reset. This reset also happens when the device is powered on for the first time in an application.

The two types of power-on reset are shown in [Figure 17](#) and [Figure 18](#).



**Fig 17.**  $V_{DD}$  is lowered below 0.2 V or 0 V and then ramped up to  $V_{DD}$



**Fig 18.**  $V_{DD}$  is lowered below the POR threshold, then ramped back up to  $V_{DD}$

[Table 18](#) specifies the performance of the power-on reset feature for PCAL9538A for both types of power-on reset.

**Table 18.** Recommended supply sequencing and ramp rates

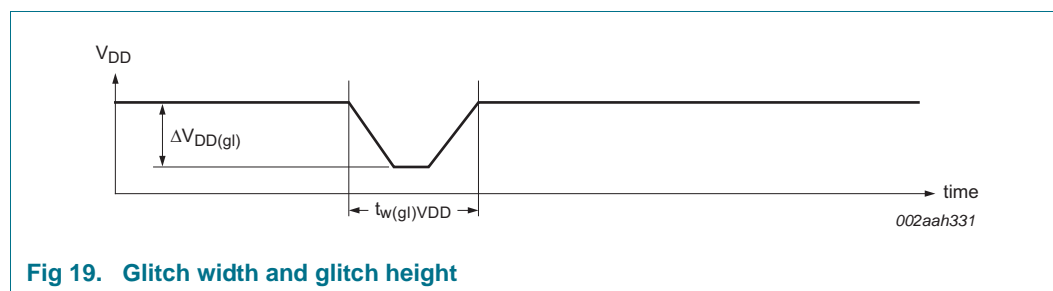
$T_{amb} = 25\text{ }^{\circ}\text{C}$  (unless otherwise noted). Not tested; specified by design.

| Symbol              | Parameter                         | Condition                                                                                     | Min | Typ | Max  | Unit          |
|---------------------|-----------------------------------|-----------------------------------------------------------------------------------------------|-----|-----|------|---------------|
| $(dV/dt)_f$         | fall rate of change of voltage    | <a href="#">Figure 17</a>                                                                     | 0.1 | -   | 2000 | ms            |
| $(dV/dt)_r$         | rise rate of change of voltage    | <a href="#">Figure 17</a>                                                                     | 0.1 | -   | 2000 | ms            |
| $t_{d(rst)}$        | reset delay time                  | <a href="#">Figure 17</a> ; re-ramp time when $V_{DD}$ drops to $V_{SS}$                      | 1   | -   | -    | $\mu\text{s}$ |
|                     |                                   | <a href="#">Figure 18</a> ; re-ramp time when $V_{DD}$ drops to $V_{POR(min)} - 50\text{ mV}$ | 1   | -   | -    | $\mu\text{s}$ |
| $\Delta V_{DD(gl)}$ | glitch supply voltage difference  | <a href="#">Figure 19</a>                                                                     | [1] | -   | 1.0  | V             |
| $t_{w(gl)VDD}$      | supply voltage glitch pulse width | <a href="#">Figure 19</a>                                                                     | [2] | -   | 10   | $\mu\text{s}$ |
| $V_{POR(trip)}$     | power-on reset trip voltage       | falling $V_{DD}$                                                                              | 0.7 | -   | -    | V             |
|                     |                                   | rising $V_{DD}$                                                                               | -   | -   | 1.4  | V             |

[1] Level that  $V_{DD}$  can glitch down to, but not cause a functional disruption when  $t_{w(gl)VDD} < 1\text{ }\mu\text{s}$ .

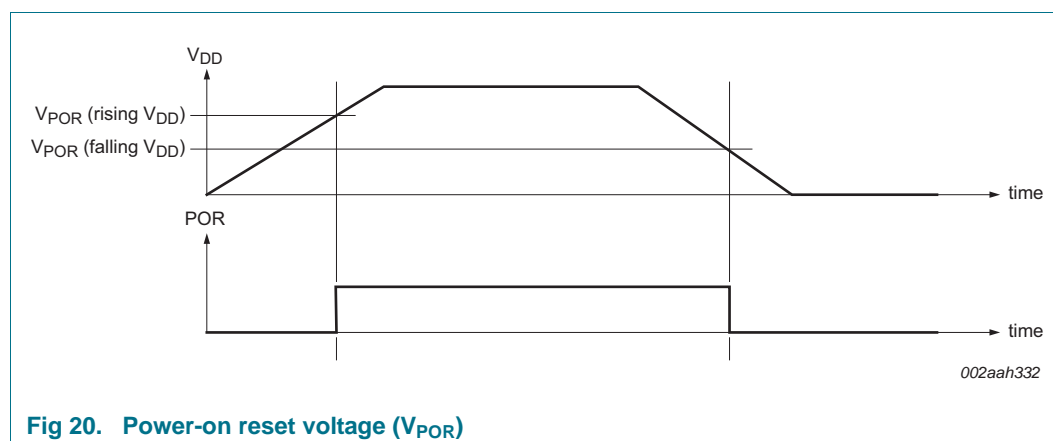
[2] Glitch width that will not cause a functional disruption when  $\Delta V_{DD(gl)} = 0.5 \times V_{DD}$ .

Glitches in the power supply can also affect the power-on reset performance of this device. The glitch width ( $t_{w(gl)}V_{DD}$ ) and glitch height ( $\Delta V_{DD(gl)}$ ) are dependent on each other. The bypass capacitance, source impedance, and device impedance are factors that affect power-on reset performance. [Figure 19](#) and [Table 18](#) provide more information on how to measure these specifications.



**Fig 19. Glitch width and glitch height**

$V_{POR}$  is critical to the power-on reset.  $V_{POR}$  is the voltage level at which the reset condition is released and all the registers and the I<sup>2</sup>C-bus/SMBus state machine are initialized to their default states. The value of  $V_{POR}$  differs based on the  $V_{DD}$  being lowered to or from 0 V. [Figure 20](#) and [Table 18](#) provide more details on this specification.



**Fig 20. Power-on reset voltage ( $V_{POR}$ )**

## 8.5 Device current consumption with internal pull-up and pull-down resistors

The PCAL9538A integrates programmable pull-up and pull-down resistors to eliminate external components when pins are configured as inputs and pull-up or pull-down resistors are required (for example, nothing is driving the inputs to the power supply rails). Since these pull-up and pull-down resistors are internal to the device itself, they contribute to the current consumption of the device and must be considered in the overall system design.

The pull-up or pull-down function is selected in register 44h, while the resistor is connected by the enable register 43h. The configuration of the resistors is shown in [Figure 6](#).

If the resistor is configured as a pull-up, that is, connected to  $V_{DD}$ , a current will flow from the  $V_{DD}$  pin through the resistor to ground when the pin is held LOW. This current will appear as additional  $I_{DD}$  upsetting any current consumption measurements.

In the same manner, if the resistor is configured as a pull-down and the pin is held HIGH, current will flow from the power supply through the pin to the  $V_{SS}$  pin. While this current will not be measured as part of  $I_{DD}$ , one must be mindful of the 200 mA limiting value through  $V_{SS}$ .

The pull-up and pull-down resistors are simple resistors and the current is linear with voltage. The resistance specification for these devices spans from 50 k $\Omega$  with a nominal 100 k $\Omega$  value. Any current flow through these resistors is additive by the number of pins held HIGH or LOW and the current can be calculated by Ohm's law. See [Figure 24](#) for a graph of supply current versus the number of pull-up resistors.

## 9. Limiting values

**Table 19. 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                 |                                                                  | [1] -0.5 | +6.5 | V    |
| V <sub>O</sub>      | output voltage                |                                                                  | [1] -0.5 | +6.5 | V    |
| I <sub>IK</sub>     | input clamping current        | A0, A1, $\overline{\text{RESET}}$ , SCL; V <sub>I</sub> < 0 V    | -        | ±20  | mA   |
| I <sub>OK</sub>     | output clamping current       | $\overline{\text{INT}}$ ; V <sub>O</sub> < 0 V                   | -        | ±20  | mA   |
| I <sub>IOK</sub>    | input/output clamping current | P port; V <sub>O</sub> < 0 V or V <sub>O</sub> > V <sub>DD</sub> | -        | ±20  | mA   |
|                     |                               | SDA; V <sub>O</sub> < 0 V or V <sub>O</sub> > V <sub>DD</sub>    | -        | ±20  | mA   |
| I <sub>OL</sub>     | LOW-level output current      | continuous; I/O port                                             | -        | 50   | mA   |
|                     |                               | continuous; SDA, $\overline{\text{INT}}$                         | -        | 25   | mA   |
| I <sub>OH</sub>     | HIGH-level output current     | continuous; P port                                               | -        | 25   | mA   |
| I <sub>DD</sub>     | supply current                |                                                                  | -        | 160  | mA   |
| I <sub>SS</sub>     | ground supply current         |                                                                  | -        | 200  | mA   |
| P <sub>tot</sub>    | total power dissipation       |                                                                  | -        | 200  | mW   |
| T <sub>stg</sub>    | storage temperature           |                                                                  | -65      | +150 | °C   |
| T <sub>j(max)</sub> | maximum junction temperature  |                                                                  | -        | 125  | °C   |

[1] The input negative-voltage and output voltage ratings may be exceeded if the input and output current ratings are observed.

## 10. Recommended operating conditions

**Table 20. Operating conditions**

| Symbol           | Parameter                 | Conditions                          | Min                   | Max                   | Unit |
|------------------|---------------------------|-------------------------------------|-----------------------|-----------------------|------|
| V <sub>DD</sub>  | supply voltage            |                                     | 1.65                  | 5.5                   | V    |
| V <sub>IH</sub>  | HIGH-level input voltage  | SCL, SDA, $\overline{\text{RESET}}$ | 0.7 × V <sub>DD</sub> | 5.5                   | V    |
|                  |                           | A0, A1, P port                      | 0.7 × V <sub>DD</sub> | 5.5                   | V    |
| V <sub>IL</sub>  | LOW-level input voltage   | SCL, SDA, $\overline{\text{RESET}}$ | -0.5                  | 0.3 × V <sub>DD</sub> | V    |
|                  |                           | A0, A1, P port                      | -0.5                  | 0.3 × V <sub>DD</sub> | V    |
| I <sub>OH</sub>  | HIGH-level output current | P port                              | -                     | 10                    | mA   |
| I <sub>OL</sub>  | LOW-level output current  | P port                              | -                     | 25                    | mA   |
| T <sub>amb</sub> | ambient temperature       | operating in free air               | -40                   | +85                   | °C   |

## 11. Thermal characteristics

**Table 21. Thermal characteristics**

| Symbol               | Parameter                                            | Conditions      | Max     | Unit |
|----------------------|------------------------------------------------------|-----------------|---------|------|
| Z <sub>th(j-a)</sub> | transient thermal impedance from junction to ambient | HVQFN16 package | [1] 53  | K/W  |
|                      |                                                      | TSSOP16 package | [1] 108 | K/W  |

[1] The package thermal impedance is calculated in accordance with JESD 51-7.

## 12. Static characteristics

**Table 22. Static characteristics**

$T_{amb} = -40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ;  $V_{DD} = 1.65\text{ V}$  to  $5.5\text{ V}$ ; unless otherwise specified.

| Symbol    | Parameter                                | Conditions                                                                                                                                                                       | Min  | Typ <sup>[1]</sup> | Max     | Unit          |
|-----------|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------------------|---------|---------------|
| $V_{IK}$  | input clamping voltage                   | $I_I = -18\text{ mA}$                                                                                                                                                            | -1.2 | -                  | -       | V             |
| $V_{POR}$ | power-on reset voltage                   | $V_I = V_{DD}$ or $V_{SS}$ ; $I_O = 0\text{ mA}$                                                                                                                                 | -    | 1.1                | 1.4     | V             |
| $V_{OH}$  | HIGH-level output voltage <sup>[2]</sup> | P port; $I_{OH} = -8\text{ mA}$ ; CCX = 11b                                                                                                                                      |      |                    |         |               |
|           |                                          | $V_{DD} = 1.65\text{ V}$                                                                                                                                                         | 1.2  | -                  | -       | V             |
|           |                                          | $V_{DD} = 2.3\text{ V}$                                                                                                                                                          | 1.8  | -                  | -       | V             |
|           |                                          | $V_{DD} = 3\text{ V}$                                                                                                                                                            | 2.6  | -                  | -       | V             |
|           |                                          | $V_{DD} = 4.5\text{ V}$                                                                                                                                                          | 4.1  | -                  | -       | V             |
|           |                                          | P port; $I_{OH} = -2.5\text{ mA}$ and CCX = 00b;<br>$I_{OH} = -5\text{ mA}$ and CCX = 01b;<br>$I_{OH} = -7.5\text{ mA}$ and CCX = 10b;<br>$I_{OH} = -10\text{ mA}$ and CCX = 11b |      |                    |         |               |
|           |                                          | $V_{DD} = 1.65\text{ V}$                                                                                                                                                         | 1.1  | -                  | -       | V             |
|           |                                          | $V_{DD} = 2.3\text{ V}$                                                                                                                                                          | 1.7  | -                  | -       | V             |
|           |                                          | $V_{DD} = 3\text{ V}$                                                                                                                                                            | 2.5  | -                  | -       | V             |
|           |                                          | $V_{DD} = 4.5\text{ V}$                                                                                                                                                          | 4.0  | -                  | -       | V             |
| $V_{OL}$  | LOW-level output voltage <sup>[2]</sup>  | P port; $I_{OL} = 8\text{ mA}$ ; CCX = 11b                                                                                                                                       |      |                    |         |               |
|           |                                          | $V_{DD} = 1.65\text{ V}$                                                                                                                                                         | -    | -                  | 0.45    | V             |
|           |                                          | $V_{DD} = 2.3\text{ V}$                                                                                                                                                          | -    | -                  | 0.25    | V             |
|           |                                          | $V_{DD} = 3\text{ V}$                                                                                                                                                            | -    | -                  | 0.25    | V             |
|           |                                          | $V_{DD} = 4.5\text{ V}$                                                                                                                                                          | -    | -                  | 0.2     | V             |
|           |                                          | P port; $I_{OL} = 2.5\text{ mA}$ and CCX = 00b;<br>$I_{OL} = 5\text{ mA}$ and CCX = 01b;<br>$I_{OL} = 7.5\text{ mA}$ and CCX = 10b;<br>$I_{OL} = 10\text{ mA}$ and CCX = 11b     |      |                    |         |               |
|           |                                          | $V_{DD} = 1.65\text{ V}$                                                                                                                                                         | -    | -                  | 0.5     | V             |
|           |                                          | $V_{DD} = 2.3\text{ V}$                                                                                                                                                          | -    | -                  | 0.3     | V             |
|           |                                          | $V_{DD} = 3\text{ V}$                                                                                                                                                            | -    | -                  | 0.25    | V             |
|           |                                          | $V_{DD} = 4.5\text{ V}$                                                                                                                                                          | -    | -                  | 0.2     | V             |
| $I_{OL}$  | LOW-level output current                 | $V_{OL} = 0.4\text{ V}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                             |      |                    |         |               |
|           |                                          | SDA                                                                                                                                                                              | 3    | -                  | -       | mA            |
|           |                                          | $\overline{\text{INT}}$                                                                                                                                                          | 3    | 15 <sup>[3]</sup>  | -       | mA            |
| $I_I$     | input current                            | $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                                                       |      |                    |         |               |
|           |                                          | SCL, SDA, $\overline{\text{RESET}}$ ; $V_I = V_{DD}$ or $V_{SS}$                                                                                                                 | -    | -                  | 0.1     | $\mu\text{A}$ |
|           |                                          | A0, A1; $V_I = V_{DD}$ or $V_{SS}$                                                                                                                                               | -    | -                  | $\pm 1$ | $\mu\text{A}$ |
| $I_{IH}$  | HIGH-level input current                 | P port; $V_I = V_{DD}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                              | -    | -                  | 1       | $\mu\text{A}$ |
| $I_{IL}$  | LOW-level input current                  | P port; $V_I = V_{SS}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                              | -    | -                  | 1       | $\mu\text{A}$ |

**Table 22. Static characteristics ...continued** $T_{amb} = -40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ;  $V_{DD} = 1.65\text{ V}$  to  $5.5\text{ V}$ ; unless otherwise specified.

| Symbol          | Parameter                           | Conditions                                                                                                                                                                                                                                 | Min | Typ <sup>[1]</sup> | Max | Unit             |
|-----------------|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|-----|------------------|
| $I_{DD}$        | supply current                      | SDA, P port, A0, A1, $\overline{\text{RESET}}$ ;<br>$V_I$ on SDA and $\overline{\text{RESET}} = V_{DD}$ or $V_{SS}$ ;<br>$V_I$ on P port and A0, A1 = $V_{DD}$ ;<br>$I_O = 0\text{ mA}$ ; I/O = inputs; $f_{SCL} = 400\text{ kHz}$         |     |                    |     |                  |
|                 |                                     | $V_{DD} = 3.6\text{ V}$ to $5.5\text{ V}$                                                                                                                                                                                                  | -   | 10                 | 25  | $\mu\text{A}$    |
|                 |                                     | $V_{DD} = 2.3\text{ V}$ to $3.6\text{ V}$                                                                                                                                                                                                  | -   | 6.5                | 15  | $\mu\text{A}$    |
|                 |                                     | $V_{DD} = 1.65\text{ V}$ to $2.3\text{ V}$                                                                                                                                                                                                 | -   | 4                  | 9   | $\mu\text{A}$    |
|                 |                                     | SCL, SDA, P port, A0, A1, $\overline{\text{RESET}}$ ;<br>$V_I$ on SCL, SDA and $\overline{\text{RESET}} = V_{DD}$ or $V_{SS}$ ;<br>$V_I$ on P port and A0, A1 = $V_{DD}$ ;<br>$I_O = 0\text{ mA}$ ; I/O = inputs; $f_{SCL} = 0\text{ kHz}$ |     |                    |     |                  |
|                 |                                     | $V_{DD} = 3.6\text{ V}$ to $5.5\text{ V}$                                                                                                                                                                                                  | -   | 1.5                | 7   | $\mu\text{A}$    |
|                 |                                     | $V_{DD} = 2.3\text{ V}$ to $3.6\text{ V}$                                                                                                                                                                                                  | -   | 1                  | 3.2 | $\mu\text{A}$    |
|                 |                                     | $V_{DD} = 1.65\text{ V}$ to $2.3\text{ V}$                                                                                                                                                                                                 | -   | 0.5                | 1.7 | $\mu\text{A}$    |
|                 |                                     |                                                                                                                                                                                                                                            |     |                    |     |                  |
| $\Delta I_{DD}$ | additional quiescent supply current | SCL, SDA, $\overline{\text{RESET}}$ ; one input at $V_{DD} - 0.6\text{ V}$ ,<br>other inputs at $V_{DD}$ or $V_{SS}$ ;<br>$V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                       | -   | -                  | 25  | $\mu\text{A}$    |
|                 |                                     | P port, A0, A1; one input at $V_{DD} - 0.6\text{ V}$ ,<br>other inputs at $V_{DD}$ or $V_{SS}$ ;<br>$V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                             | -   | -                  | 80  | $\mu\text{A}$    |
|                 |                                     |                                                                                                                                                                                                                                            |     |                    |     |                  |
| $C_i$           | input capacitance                   | $V_I = V_{DD}$ or $V_{SS}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                                                                                    | -   | 6                  | 7   | pF               |
| $C_{io}$        | input/output capacitance            | $V_{I/O} = V_{DD}$ or $V_{SS}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                                                                                | -   | 7                  | 8   | pF               |
|                 |                                     | $V_{I/O} = V_{DD}$ or $V_{SS}$ ; $V_{DD} = 1.65\text{ V}$ to $5.5\text{ V}$                                                                                                                                                                | -   | 7.5                | 8.5 | pF               |
| $R_{pu(int)}$   | internal pull-up resistance         | input/output                                                                                                                                                                                                                               | 50  | 100                | 150 | $\text{k}\Omega$ |
| $R_{pd(int)}$   | internal pull-down resistance       | input/output                                                                                                                                                                                                                               | 50  | 100                | 150 | $\text{k}\Omega$ |

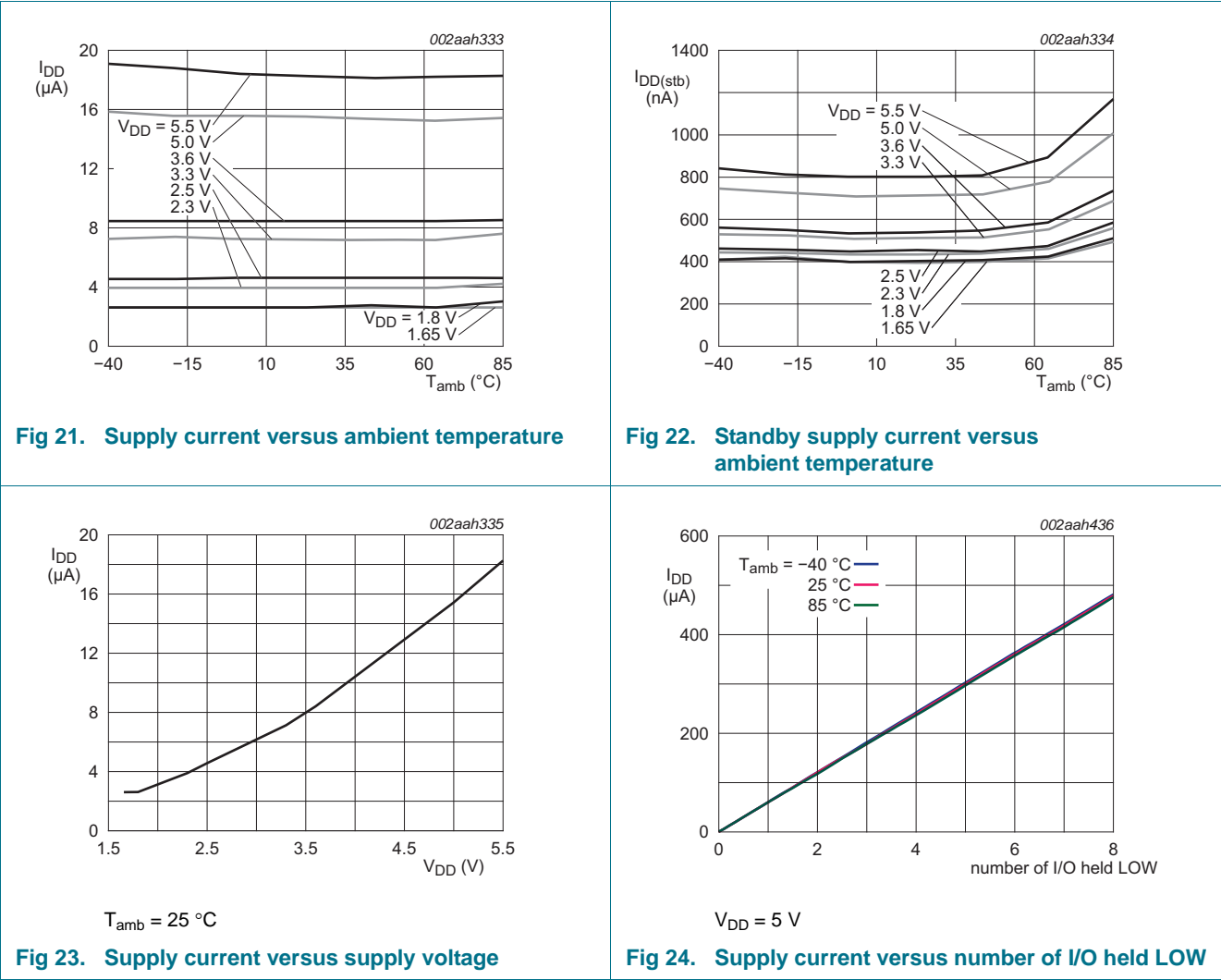
[1] For  $I_{DD}$ , all typical values are at nominal supply voltage (1.8 V, 2.5 V, 3.3 V, 3.6 V or 5 V  $V_{DD}$ ) and  $T_{amb} = 25\text{ }^{\circ}\text{C}$ . Except for  $I_{DD}$ , the typical values are at  $V_{DD} = 3.3\text{ V}$  and  $T_{amb} = 25\text{ }^{\circ}\text{C}$ .

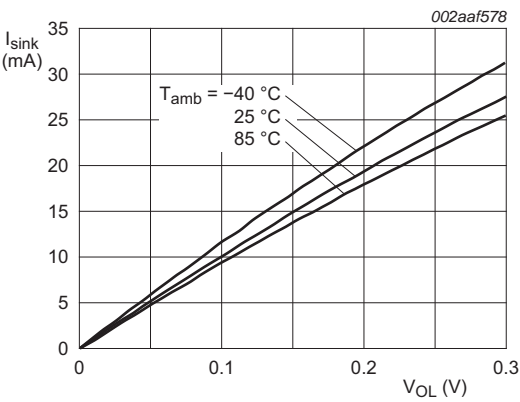
[2] The total current sourced by all I/Os must be limited to 160 mA, and total current sunk by all I/Os must be limited to 200 mA.

[3] Typical value for  $T_{amb} = 25\text{ }^{\circ}\text{C}$ .  $V_{OL} = 0.4\text{ V}$  and  $V_{DD} = 3.3\text{ V}$ . Typical value for  $V_{DD} < 2.5\text{ V}$ ,  $V_{OL} = 0.6\text{ V}$ .

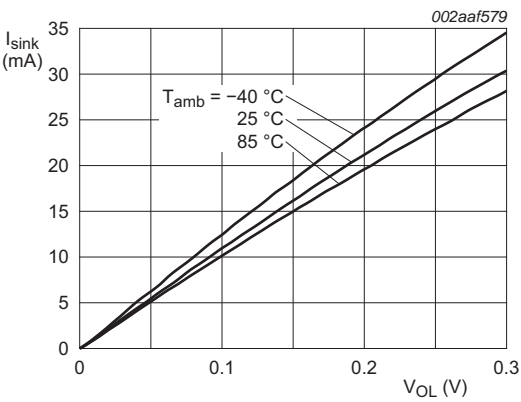


12.1 Typical characteristics

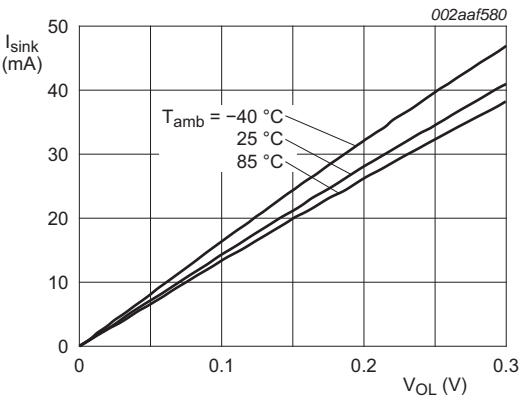




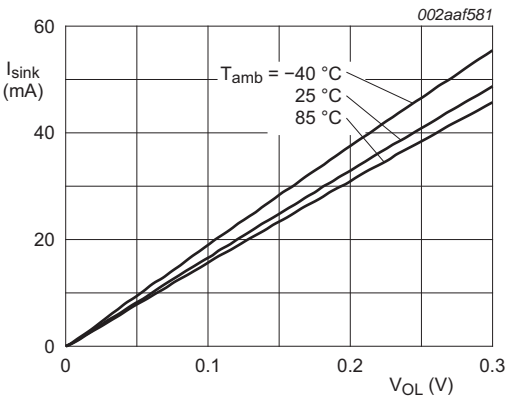
a.  $V_{\text{DD}} = 1.65\text{ V}$



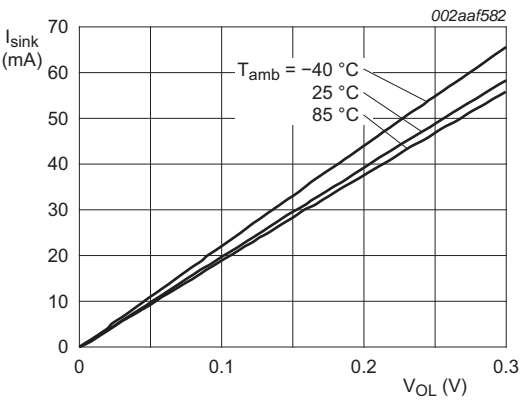
b.  $V_{\text{DD}} = 1.8\text{ V}$



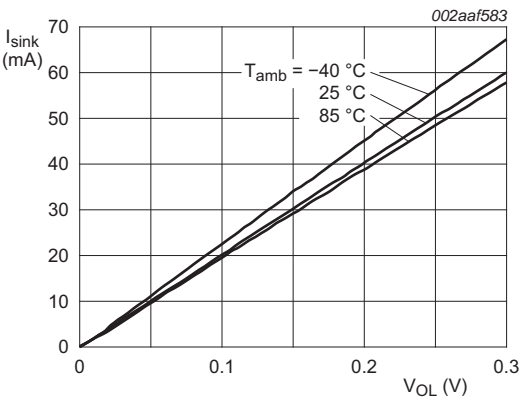
c.  $V_{\text{DD}} = 2.5\text{ V}$



d.  $V_{\text{DD}} = 3.3\text{ V}$

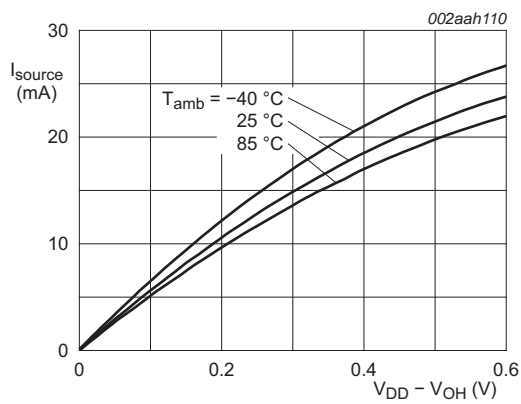


e.  $V_{\text{DD}} = 5.0\text{ V}$

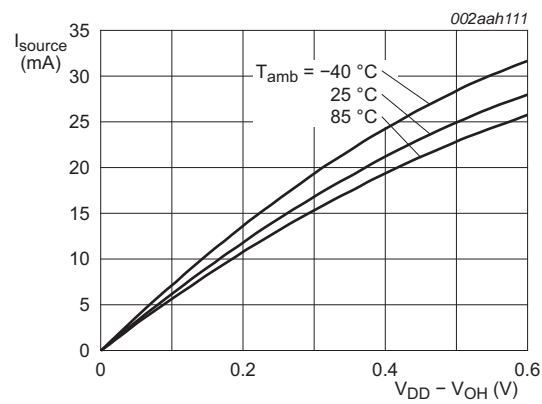


f.  $V_{\text{DD}} = 5.5\text{ V}$

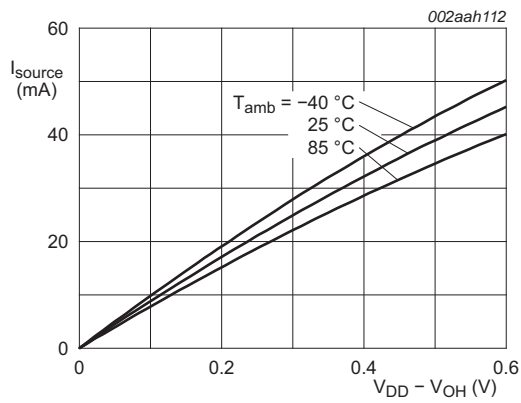
Fig 25. I/O sink current versus LOW-level output voltage with CCX.X = 11b



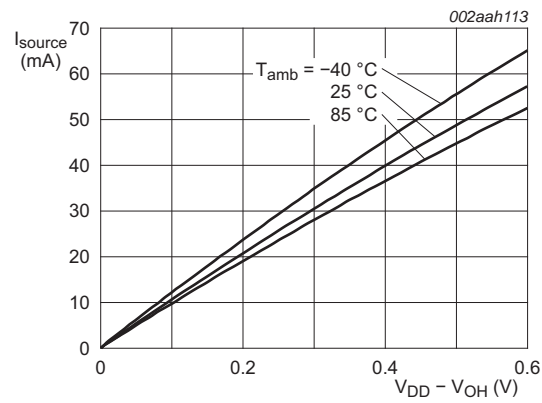
a.  $V_{\text{DD}} = 1.65\text{ V}$



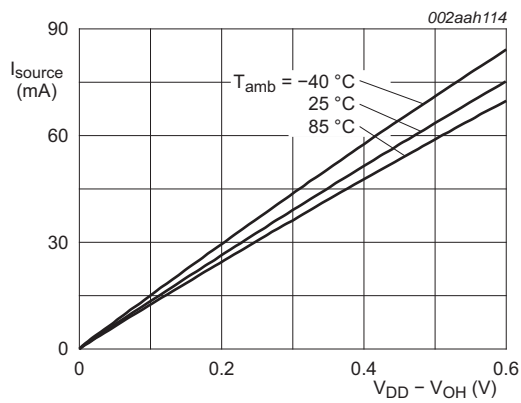
b.  $V_{\text{DD}} = 1.8\text{ V}$



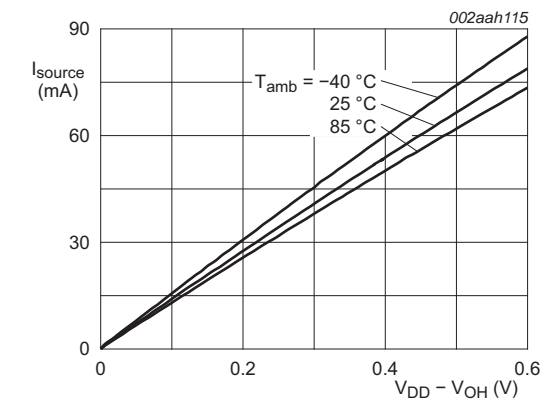
c.  $V_{\text{DD}} = 2.5\text{ V}$



d.  $V_{\text{DD}} = 3.3\text{ V}$

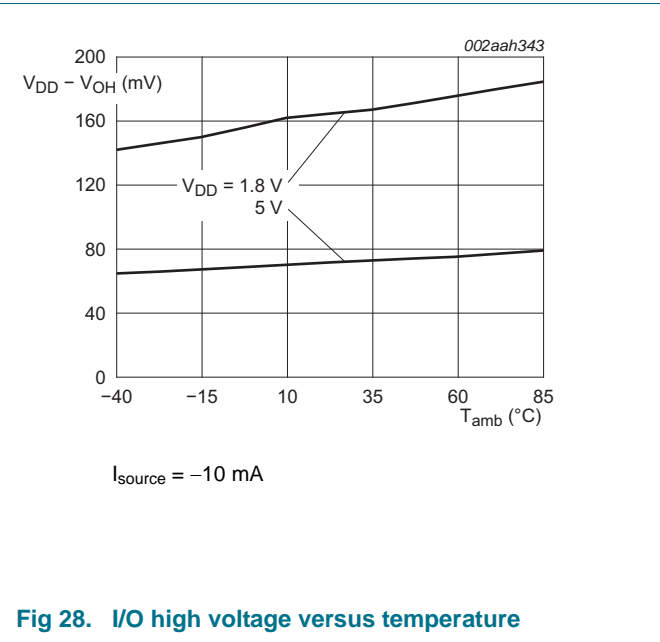
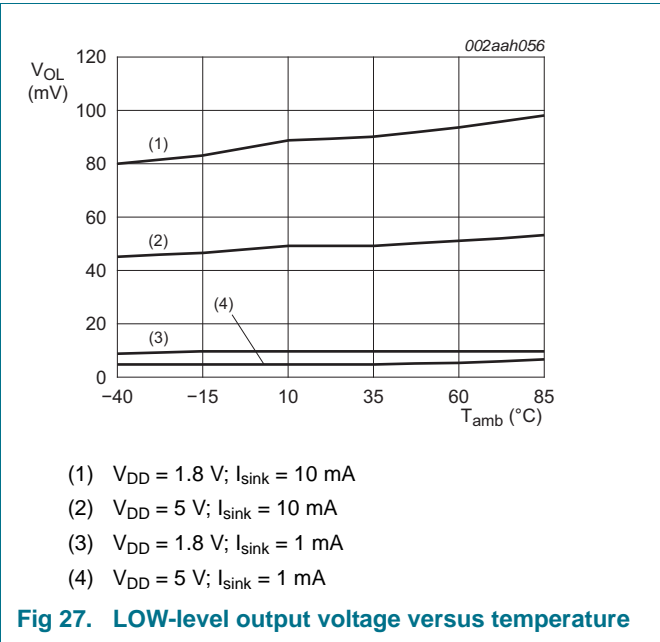


e.  $V_{\text{DD}} = 5.0\text{ V}$



f.  $V_{\text{DD}} = 5.5\text{ V}$

Fig 26. I/O source current versus HIGH-level output voltage with CCX.X = 11b



## 13. Dynamic characteristics

**Table 23. I<sup>2</sup>C-bus interface timing requirements**

Over recommended operating free air temperature range, unless otherwise specified. See [Figure 29](#).

| Symbol              | Parameter                                                         | Conditions                               | Standard-mode I <sup>2</sup> C-bus |      | Fast-mode I <sup>2</sup> C-bus    |     | Unit |
|---------------------|-------------------------------------------------------------------|------------------------------------------|------------------------------------|------|-----------------------------------|-----|------|
|                     |                                                                   |                                          | Min                                | Max  | Min                               | Max |      |
| f <sub>SCL</sub>    | SCL clock frequency                                               |                                          | 0                                  | 100  | 0                                 | 400 | kHz  |
| t <sub>HIGH</sub>   | HIGH period of the SCL clock                                      |                                          | 4                                  | -    | 0.6                               | -   | μs   |
| t <sub>LOW</sub>    | LOW period of the SCL clock                                       |                                          | 4.7                                | -    | 1.3                               | -   | μs   |
| t <sub>SP</sub>     | pulse width of spikes that must be suppressed by the input filter |                                          | 0                                  | 50   | 0                                 | 50  | ns   |
| t <sub>SU,DAT</sub> | data set-up time                                                  |                                          | 250                                | -    | 100                               | -   | ns   |
| t <sub>HD,DAT</sub> | data hold time                                                    |                                          | 0                                  | -    | 0                                 | -   | ns   |
| t <sub>r</sub>      | rise time of both SDA and SCL signals                             |                                          | -                                  | 1000 | 20                                | 300 | ns   |
| t <sub>f</sub>      | fall time of both SDA and SCL signals                             |                                          | -                                  | 300  | 20 ×<br>(V <sub>DD</sub> / 5.5 V) | 300 | ns   |
| t <sub>BUF</sub>    | bus free time between a STOP and START condition                  |                                          | 4.7                                | -    | 1.3                               | -   | μs   |
| t <sub>SU,STA</sub> | set-up time for a repeated START condition                        |                                          | 4.7                                | -    | 0.6                               | -   | μs   |
| t <sub>HD,STA</sub> | hold time (repeated) START condition                              |                                          | 4                                  | -    | 0.6                               | -   | μs   |
| t <sub>SU,STO</sub> | set-up time for STOP condition                                    |                                          | 4                                  | -    | 0.6                               | -   | μs   |
| t <sub>VD,DAT</sub> | data valid time                                                   | SCL LOW to SDA output valid              | -                                  | 3.45 | -                                 | 0.9 | μs   |
| t <sub>VD,ACK</sub> | data valid acknowledge time                                       | ACK signal from SCL LOW to SDA (out) LOW | -                                  | 3.45 | -                                 | 0.9 | μs   |

**Table 24. Reset timing requirements**

Over recommended operating free air temperature range, unless otherwise specified. See [Figure 32](#).

| Symbol                | Parameter           | Conditions          | Standard-mode I <sup>2</sup> C-bus |     | Fast-mode I <sup>2</sup> C-bus |     | Unit |
|-----------------------|---------------------|---------------------|------------------------------------|-----|--------------------------------|-----|------|
|                       |                     |                     | Min                                | Max | Min                            | Max |      |
| t <sub>w(rst)</sub>   | reset pulse width   |                     | 30                                 | -   | 30                             | -   | ns   |
| t <sub>rec(rst)</sub> | reset recovery time |                     | 200                                | -   | 200                            | -   | ns   |
| t <sub>rst</sub>      | reset time          | <a href="#">[1]</a> | 600                                | -   | 600                            | -   | ns   |

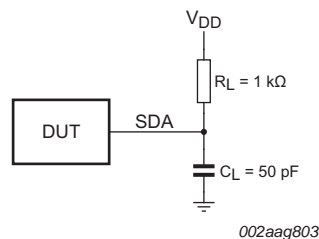
[1] Minimum time for SDA to become HIGH or minimum time to wait before doing a START.

**Table 25. Switching characteristics**

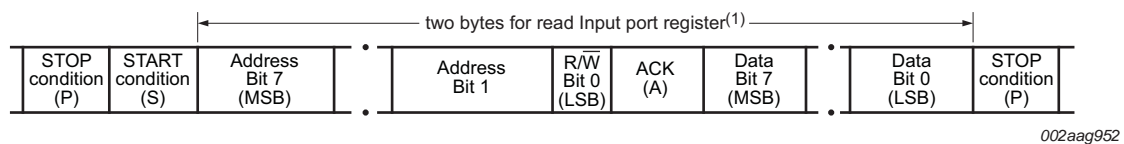
Over recommended operating free air temperature range;  $C_L \leq 100$  pF; unless otherwise specified. See [Figure 29](#).

| Symbol         | Parameter                          | Conditions                      | Standard-mode I <sup>2</sup> C-bus |     | Fast-mode I <sup>2</sup> C-bus |     | Unit    |
|----------------|------------------------------------|---------------------------------|------------------------------------|-----|--------------------------------|-----|---------|
|                |                                    |                                 | Min                                | Max | Min                            | Max |         |
| $t_{V(INT)}$   | valid time on pin $\overline{INT}$ | from P port to $\overline{INT}$ | -                                  | 1   | -                              | 1   | $\mu$ s |
| $t_{rst(INT)}$ | reset time on pin $\overline{INT}$ | from SCL to $\overline{INT}$    | -                                  | 1   | -                              | 1   | $\mu$ s |
| $t_{V(Q)}$     | data output valid time             | from SCL to P port              | -                                  | 400 | -                              | 400 | ns      |
| $t_{su(D)}$    | data input set-up time             | from P port to SCL              | 0                                  | -   | 0                              | -   | ns      |
| $t_h(D)$       | data input hold time               | from P port to SCL              | 300                                | -   | 300                            | -   | ns      |

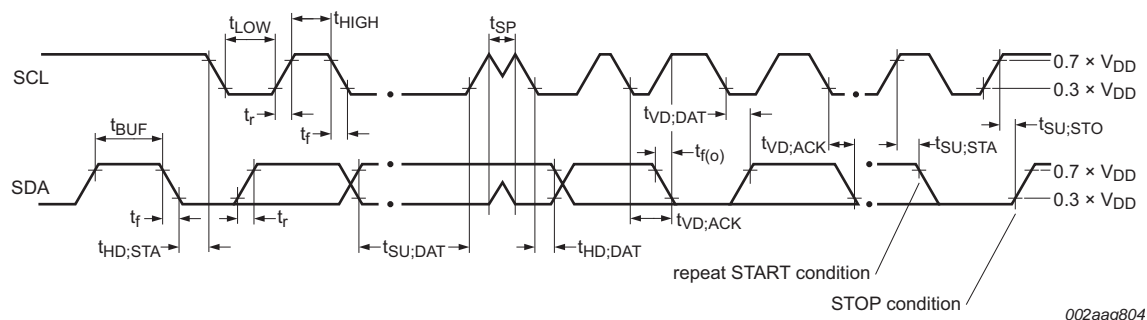
## 14. Parameter measurement information



### a. SDA load configuration



### b. Transaction format



### c. Voltage waveforms

$C_L$  includes probe and jig capacitance.

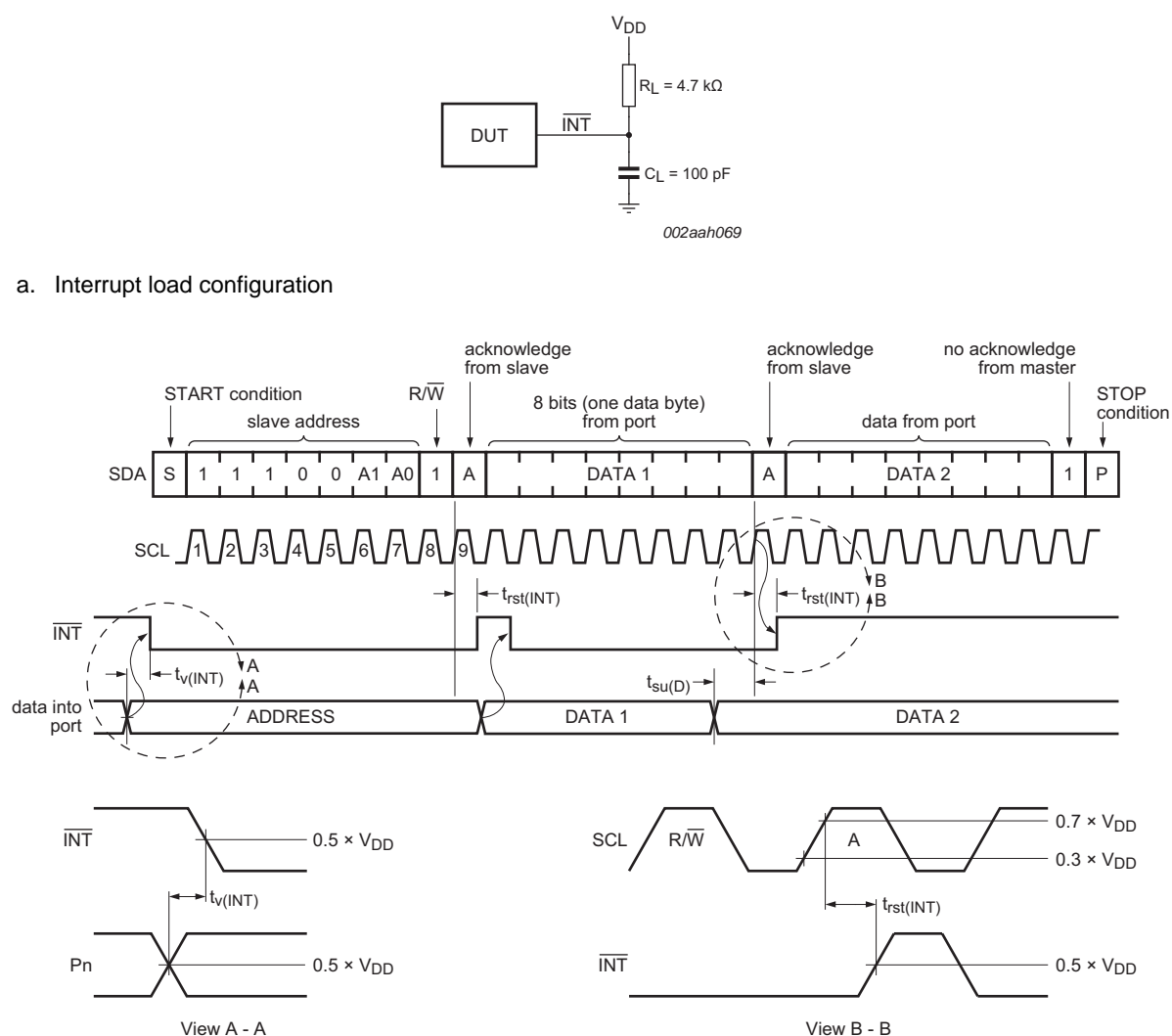
All inputs are supplied by generators having the following characteristics:  $PRR \leq 10$  MHz;  $Z_o = 50 \Omega$ ;  $t_r/t_f \leq 30$  ns.

All parameters and waveforms are not applicable to all devices.

Byte 1 = I<sup>2</sup>C-bus address; Byte 2, byte 3 = P port data.

(1) See [Figure 9](#).

**Fig 29. I<sup>2</sup>C-bus interface load circuit and voltage waveforms**



002aah116

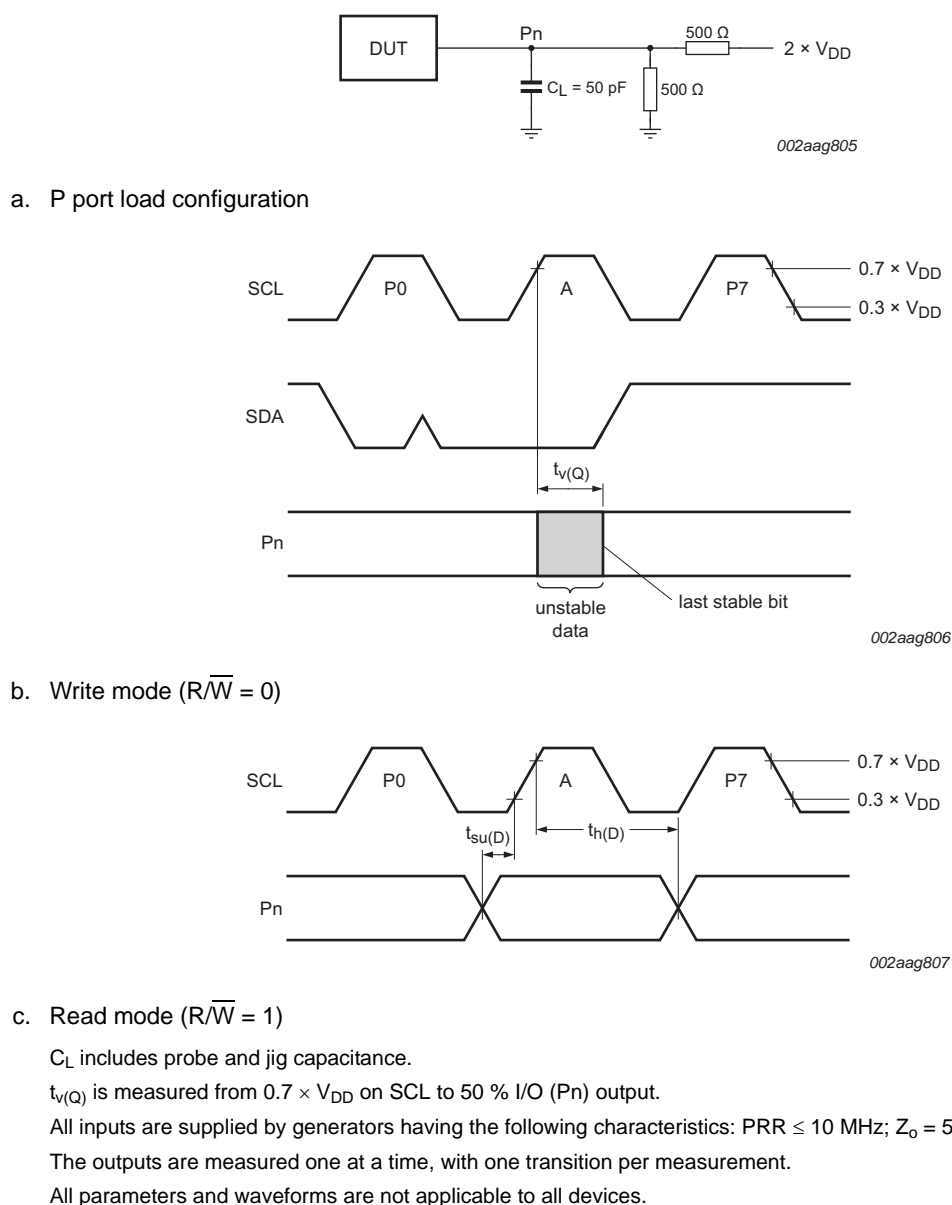
## b. Voltage waveforms

$C_L$  includes probe and jig capacitance.

All inputs are supplied by generators having the following characteristics:  $PRR \leq 10$  MHz;  $Z_o = 50 \Omega$ ;  $t_r/t_f \leq 30$  ns.

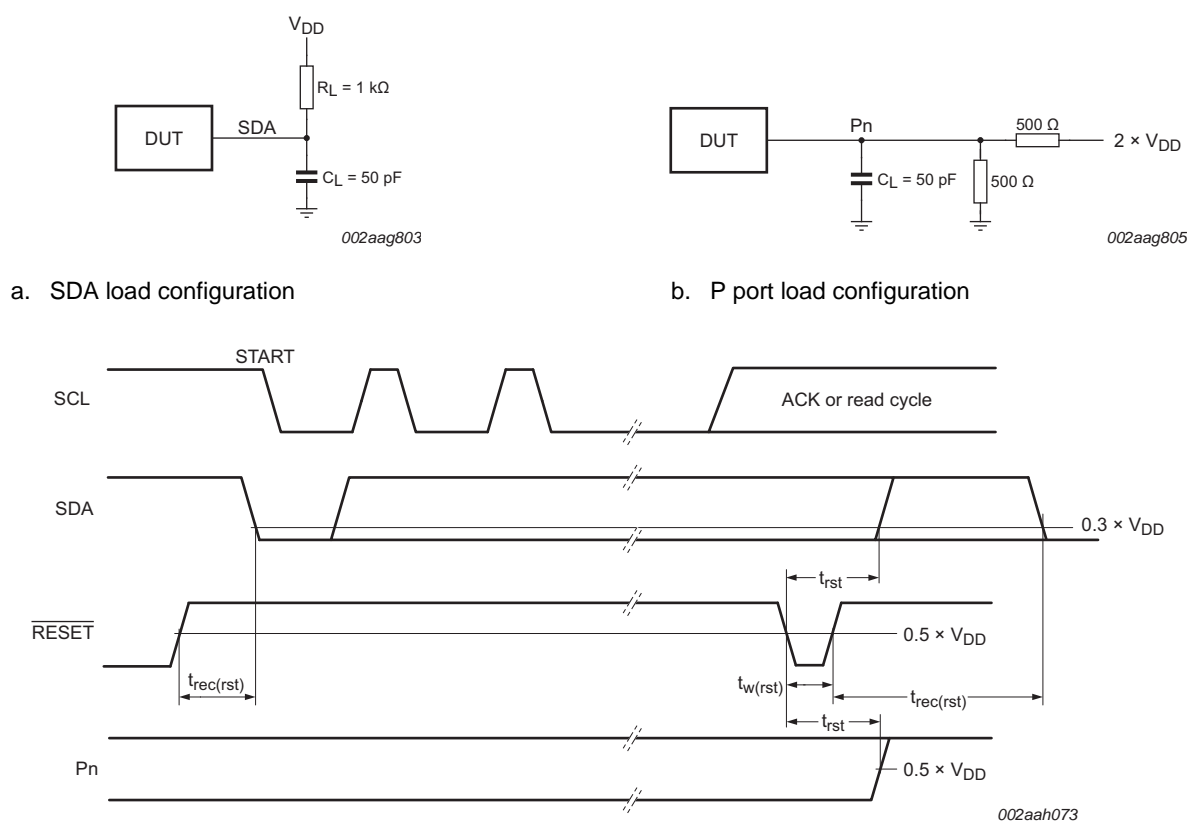
All parameters and waveforms are not applicable to all devices.

**Fig 30. Interrupt load circuit and voltage waveforms**



**Fig 31. P port load circuit and voltage waveforms**





### c. RESET timing

$C_L$  includes probe and jig capacitance.

All inputs are supplied by generators having the following characteristics:  $PRR \leq 10$  MHz;  $Z_o = 50 \Omega$ ;  $t_r/t_f \leq 30$  ns.

The outputs are measured one at a time, with one transition per measurement.

I/Os are configured as inputs.

All parameters and waveforms are not applicable to all devices.

**Fig 32. Reset load circuits and voltage waveforms**

15. Package outline

HVQFN16: plastic thermal enhanced very thin quad flat package; no leads;  
16 terminals; body 3 x 3 x 0.85 mm

SOT758-1

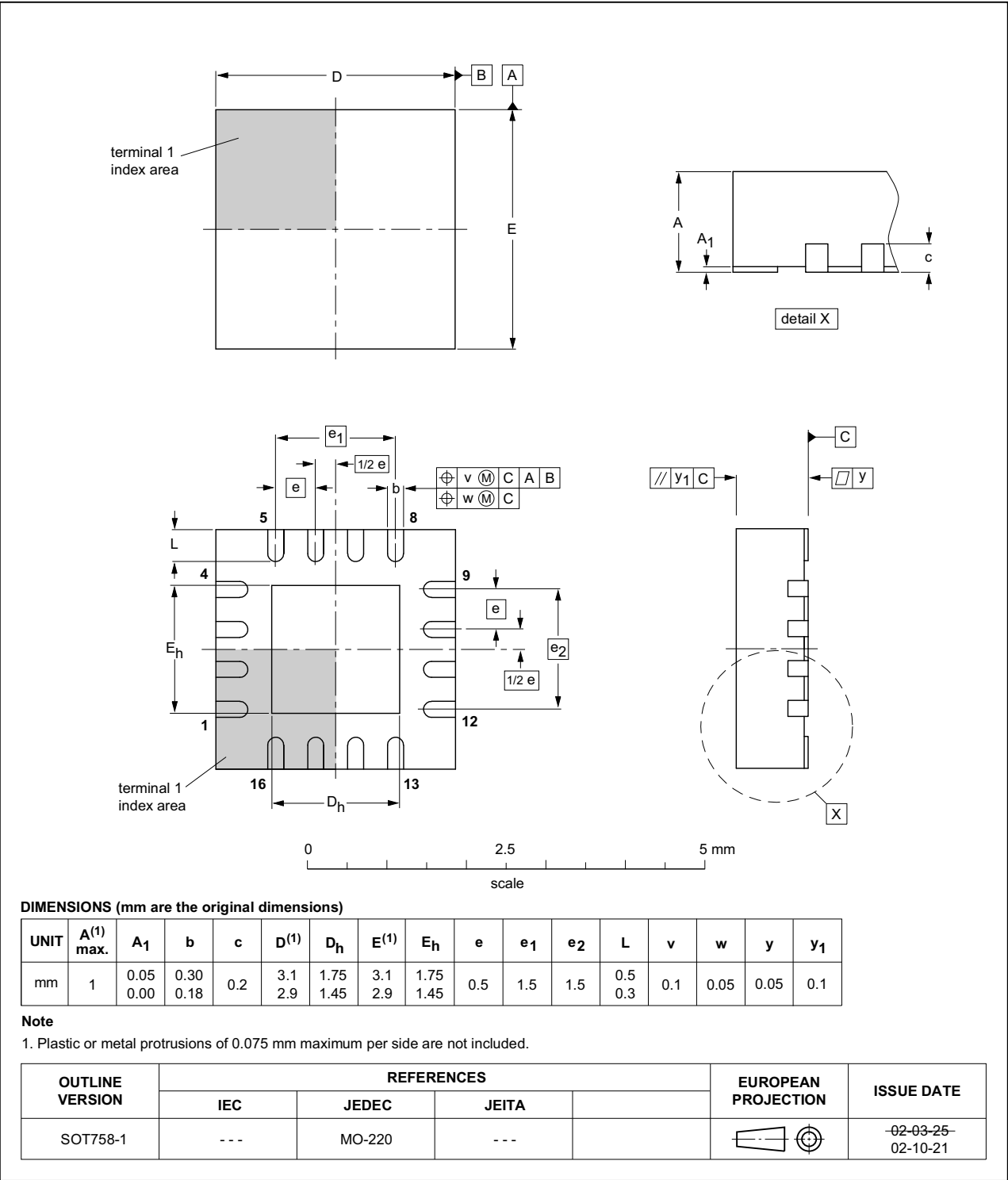


Fig 33. Package outline SOT758-1 (HVQFN16)

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

SOT403-1

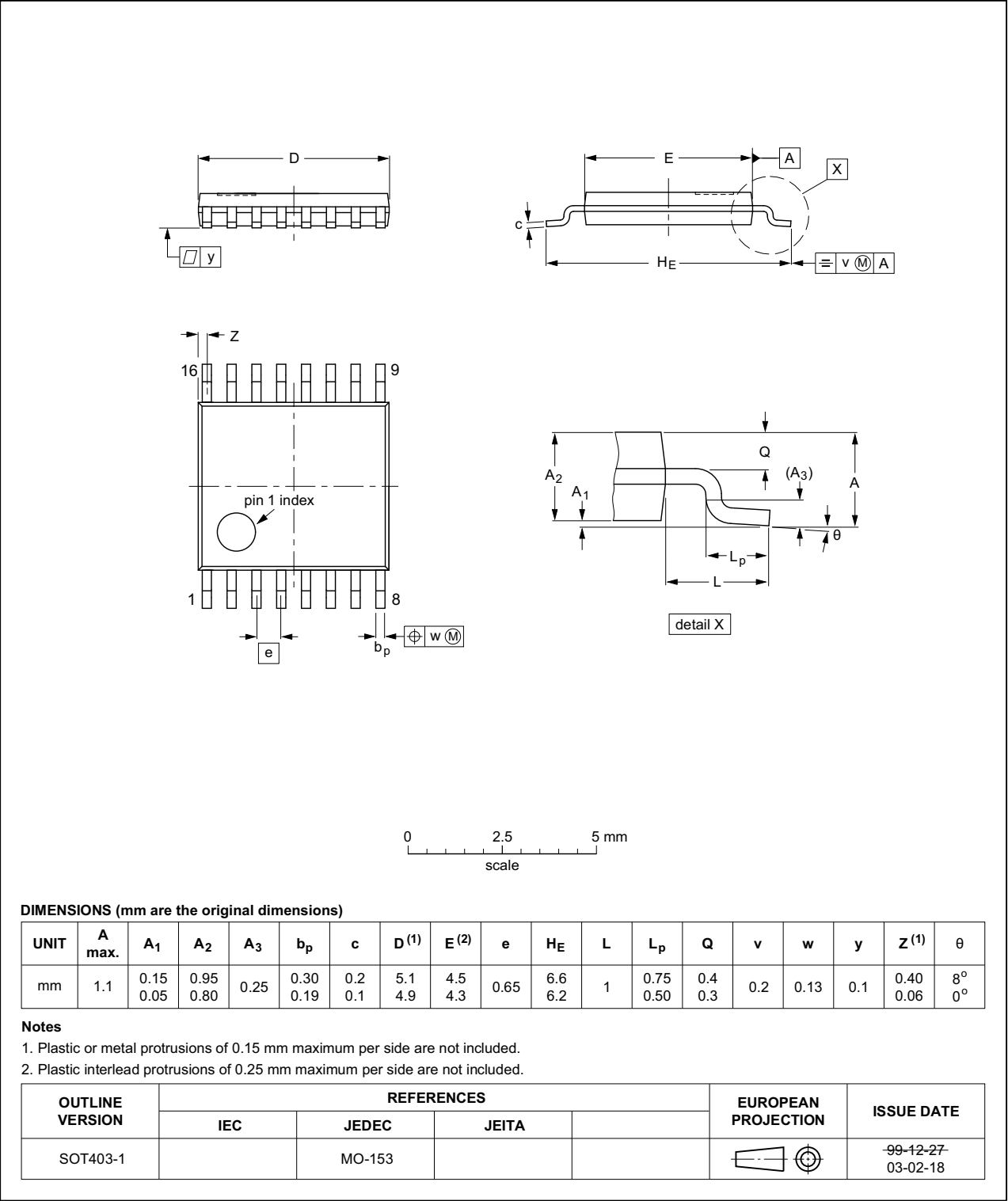


Fig 34. Package outline SOT403-1 (TSSOP16)

## 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 35](#)) 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 26](#) and [27](#)

**Table 26. SnPb eutectic process (from J-STD-020D)**

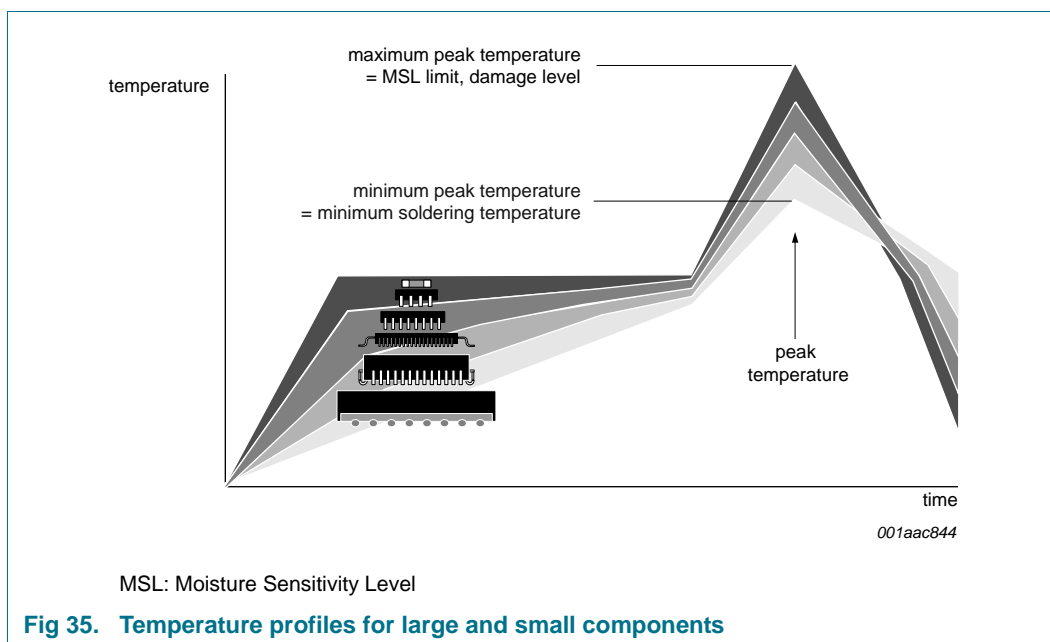
| Package thickness (mm) | Package reflow temperature (°C) |       |
|------------------------|---------------------------------|-------|
|                        | Volume (mm <sup>3</sup> )       |       |
|                        | < 350                           | ≥ 350 |
| < 2.5                 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

**Table 27. 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 35](#).



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

18. Soldering: PCB footprints

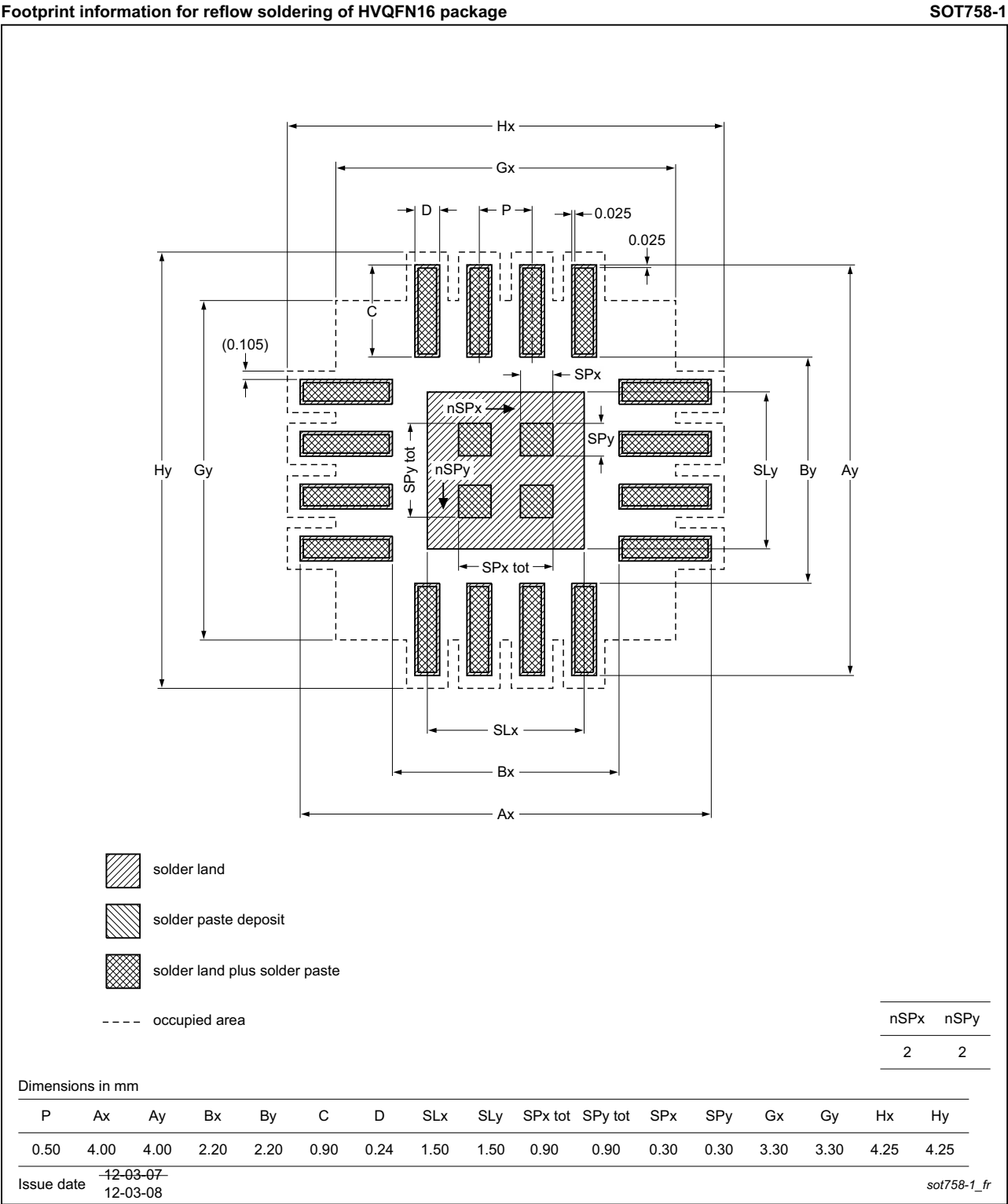


Fig 36. PCB footprint for SOT758-1 (HVQFN16); reflow soldering

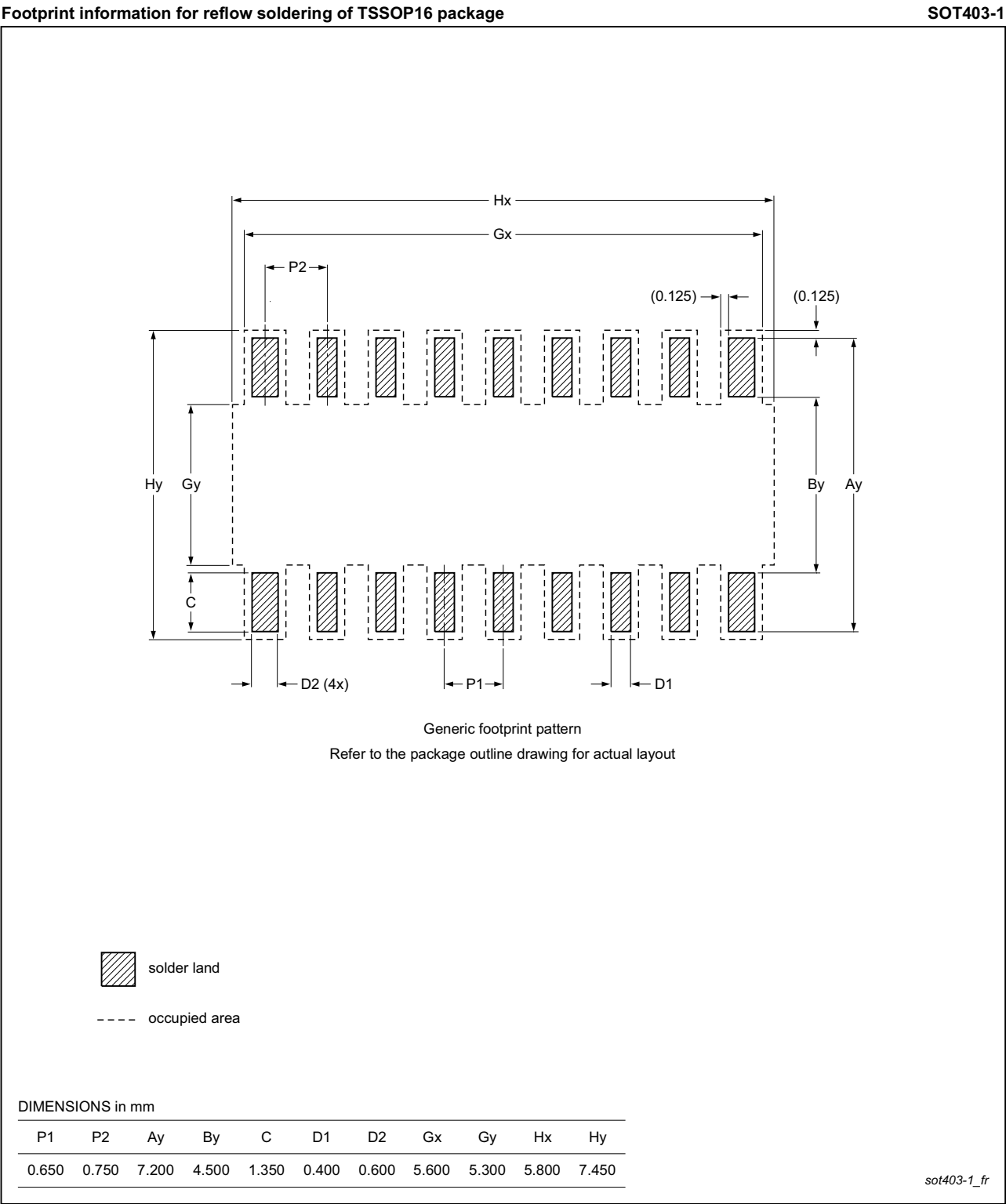


Fig 37. PCB footprint for SOT403-1 (TSSOP16); reflow soldering



## 19. Abbreviations

Table 28. Abbreviations

| Acronym              | Description                                |
|----------------------|--------------------------------------------|
| ACPI                 | Advanced Configuration and Power Interface |
| CBT                  | Cross-Bar Technology                       |
| CDM                  | Charged-Device Model                       |
| CMOS                 | Complementary Metal-Oxide Semiconductor    |
| ESD                  | ElectroStatic Discharge                    |
| FET                  | Field-Effect Transistor                    |
| FF                   | Flip-Flop                                  |
| GPIO                 | General Purpose Input/Output               |
| HBM                  | Human Body Model                           |
| I <sup>2</sup> C-bus | Inter-Integrated Circuit bus               |
| I/O                  | Input/Output                               |
| LED                  | Light Emitting Diode                       |
| LP                   | Low-Pass                                   |
| LSB                  | Least Significant Bit                      |
| MSB                  | Most Significant Bit                       |
| POR                  | Power-On Reset                             |
| PRR                  | Pulse Repetition Rate                      |
| SCR                  | Silicon Controlled Rectifier               |
| SMBus                | System Management Bus                      |

## 20. Revision history

Table 29. Revision history

| Document ID                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Release date | Data sheet status  | Change notice | Supersedes    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------------|---------------|---------------|
| PCAL9538A v.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 20130809     | Product data sheet | -             | PCAL9538A v.2 |
| Modifications:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |              |                    |               |               |
| <ul style="list-style-type: none"> <li>• <a href="#">Table 4 “Command byte”</a>, register “Output port configuration”:               <ul style="list-style-type: none"> <li>– Pointer register bits corrected from “0100 0111” to “0100 1111” (correction to documentation, no functional change to device)</li> <li>– Command byte corrected from “47h” to “4Fh” (correction to documentation, no functional change to device)</li> </ul> </li> <li>• <a href="#">Section 6.4.11 “Output port configuration register (4Fh)”</a>:               <ul style="list-style-type: none"> <li>– register number corrected from “47h” to “4Fh” in Section title (correction to documentation, no functional change to device)</li> <li>– first paragraph: added new fourth sentence (application suggestion)</li> <li>– register number corrected from “47h” to “4Fh” in title of <a href="#">Table 17</a> (correction to documentation, no functional change to device)</li> </ul> </li> </ul> |              |                    |               |               |
| PCAL9538A v.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 20121210     | Product data sheet | -             | PCAL9538A v.1 |
| PCAL9538A v.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 20120928     | Product data sheet | -             | -             |

## 21. Legal information

### 21.1 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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