# PCAL6416A

## Low-voltage translating 16-bit I²C-bus/SMBus I/O expander with interrupt output, reset, and configuration registers

Rev. 7 — 30 March 2021 Product data sheet

## 1 General description

The PCAL6416A is a 16-bit general-purpose I/O expander that provides remote I/O expansion for most microcontroller families via the I²C-bus interface.

NXP I/O expanders provide a simple solution when additional I/Os are needed while keeping interconnections to a minimum, for example, in battery-powered mobile applications for interfacing to sensors, push buttons, keypad, etc. In addition to providing a flexible set of GPIOs, it simplifies interconnection of a processor running at one voltage level to I/O devices operating at a different (usually higher) voltage level. The PCAL6416A has built-in level shifting feature that makes these devices extremely flexible in mixed signal environments where communication between incompatible I/O voltages is required. Its wide $V_{DD}$ range of 1.65 V to 5.5 V on the dual power rail allows seamless communications with next-generation low voltage microprocessors and microcontrollers on the interface side (SDA/SCL) and peripherals at a higher voltage on the port side.

There are two supply voltages for PCAL6416A: $V_{DD(I2C\text{-}bus)}$ and $V_{DD(P)}$. $V_{DD(I2C\text{-}bus)}$ provides the supply voltage for the interface at the master side (for example, a microcontroller) and the $V_{DD(P)}$ provides the supply for core circuits and Port P. The bidirectional voltage level translation in the PCAL6416A is provided through $V_{DD(I2C\text{-}bus)}$. $V_{DD(I2C\text{-}bus)}$ should be connected to the $V_{DD}$ of the external SCL/SDA lines. This indicates the $V_{DD}$ level of the I²C-bus to the PCAL6416A, while the voltage level on Port P of the PCAL6416A is determined by the $V_{DD(P)}$.

The PCAL6416A contains the PCA6416A register set of four pairs of 8-bit Configuration, Input, Output, and Polarity Inversion registers and additionally, the PCAL6416A 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 PCAL6416A is a pin-to-pin replacement to the PCA6416A, however, the PCAL6416A powers up with all I/O interrupts masked. This mask default allows for a board bring-up free of spurious interrupts at power-up.

At power-on, the I/Os are configured as inputs. However, the system master can enable the I/Os as either inputs or outputs by writing to the I/O configuration bits. The data for each input or output is kept in the corresponding input or output register. The polarity of the Input Port register can be inverted with the Polarity Inversion register, saving external logic gates. Programmable pull-up and pull-down resistors eliminate the need for discrete components.

The system master can reset the PCAL6416A in the event of a time-out or other improper operation by asserting a LOW in the $\overline{\text{RESET}}$ input. The power-on reset puts the registers in their default state and initializes the I²C-bus/SMBus state machine. The $\overline{\text{RESET}}$ pin causes the same reset/initialization to occur without depowering the part.

The PCAL6416A 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 I²C-bus. Thus, the PCAL6416A can remain a simple slave device. The input latch feature holds or latches the input pin state and keeps the logic values that created the interrupt until the master can service the interrupt. This minimizes the host's interrupt service response for fast moving inputs.

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

One hardware pin (ADDR) can be used to program and vary the fixed I²C-bus address and allow up to two devices to share the same I²C-bus or SMBus.

## 2 Features and benefits

- I²C-bus to parallel port expander
- Operating power supply voltage range of 1.65 V to 5.5 V
- Allows bidirectional voltage-level translation and GPIO expansion between:
  - 1.8 V SCL/SDA and 1.8 V, 2.5 V, 3.3 V or 5 V Port P
  - 2.5 V SCL/SDA and 1.8 V, 2.5 V, 3.3 V or 5 V Port P
  - 3.3 V SCL/SDA and 1.8 V, 2.5 V, 3.3 V or 5 V Port P
  - 5 V SCL/SDA and 1.8 V, 2.5 V, 3.3 V or 5 V Port P
- Low standby current consumption:
  - 1.5 µA typical at 5 V $V_{DD}$
  - 1.0 µA 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
  - $V_{hys}$ = 0.18 V (typical) at 1.8 V
  - $V_{hys}$ = 0.25 V (typical) at 2.5 V
  - $V_{hys}$ = 0.33 V (typical) at 3.3 V
  - $V_{hys}$ = 0.5 V (typical) at 5 V
- 5 V tolerant I/O ports
- Active LOW reset input ($\overline{RESET}$)
- Open-drain active LOW interrupt output ($\overline{INT}$)
- 400 kHz Fast-mode I²C-bus
- Internal power-on reset
- Power-up with all channels configured as inputs
- No glitch on power-up
- Noise filter on SCL/SDA inputs
- Latched outputs with 25 mA drive maximum capability for directly driving LEDs
- Latch-up performance exceeds 100 mA per JESD 78, Class II
- ESD protection exceeds JESD 22
  - 2000 V Human-Body Model (A114-A)
  - 1000 V Charged-Device Model (C101)
- Packages offered: TSSOP24, HWQFN24, VFBGA24, X2QFN24 (LGA, Land Grid Array)


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### 2.1 Agile I/O features

- Software backward compatible with PCA6416A with interrupts disabled at power-up
- Pin-to-pin drop-in replacement with PCA6416A
- 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/pull-down resistor enable
  - Pull-up/pull-down selection: 100 kΩ pull-up/pull-down resistor selection
  - Interrupt mask: mask prevents the generation of the interrupt when input changes state to prevent spurious interrupts

## 3 Ordering information

**Table 1. Ordering information**

| Type number | Topside mark | Package | | |
|---|---|---|---|---|
| | | Name | Description | Version |
| PCAL6416AEV | L16A | VFBGA24 | plastic very thin fine-pitch ball grid array package; 24 balls; body 3 × 3 × 0.85 mm | SOT1199-1 |
| PCAL6416AEX1 | 16X[1] | X2QFN24 | plastic, thermal enhanced super thin land grid array or quad flat package; no leads; 24 terminals; body 2.0 × 2.0 × 0.35 mm | SOT1895-1 |
| PCAL6416AHF | L16A | HWQFN24 | plastic thermal enhanced very very thin quad flat package; no leads; 24 terminals; body 4 × 4 × 0.75 mm | SOT994-1 |
| PCAL6416APW | PCAL6416A | TSSOP24 | plastic thin shrink small outline package; 24 leads; body width 4.4 mm | SOT355-1 |

[1] 'X' rotates from 1 to 5 and indicates the work week of the indicated month

### 3.1 Ordering options

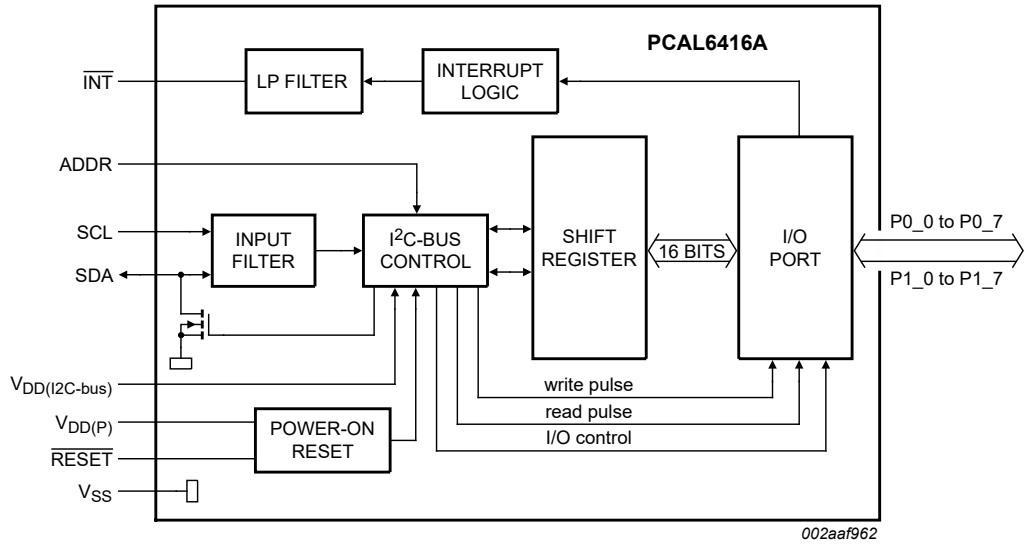
**Table 2. Ordering options**

| Type number | Orderable part number | Package | Packing method | Minimum order quantity | Temperature range |
|---|---|---|---|---|---|
| PCAL6416AEV | PCAL6416AEVJ | VFBGA24 | Reel 13" Q1/T1 *Standard mark SMD | 6000 | $T_{amb}$ = -40 °C to +85 °C |
| PCAL6416AEX1 | PCAL6416AEX1Z | X2QFN24 | Reel 7" Q2/T3 *Standard mark SMD | 5000 | $T_{amb}$ = -40 °C to +85 °C |
| PCAL6416AHF | PCAL6416AHF,128 | HWQFN24 | Reel 13" Q2/T3 *Standard mark SMD | 6000 | $T_{amb}$ = -40 °C to +85 °C |
| PCAL6416APW | PCAL6416APW,118 | TSSOP24 | Reel 13" Q1/T1 *Standard mark SMD | 2500 | $T_{amb}$ = -40 °C to +85 °C |


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# 4 Block diagram

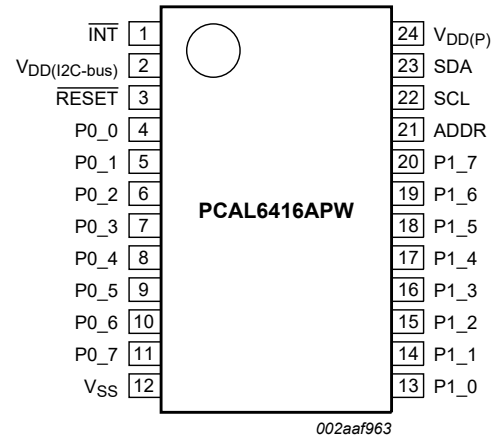



All I/Os are set to inputs at reset.

**Figure 1. Block diagram of PCAL6416A (positive logic)**

# 5 Pinning information

## 5.1 Pinning




The exposed center pad, if used, must be connected only as a secondary ground or must be left electrically open.

**Figure 2. Pin configuration for TSSOP24**

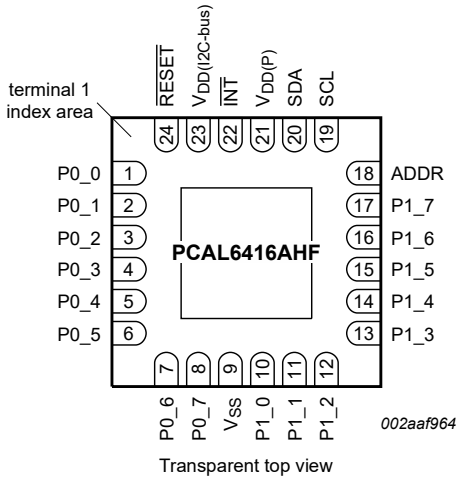
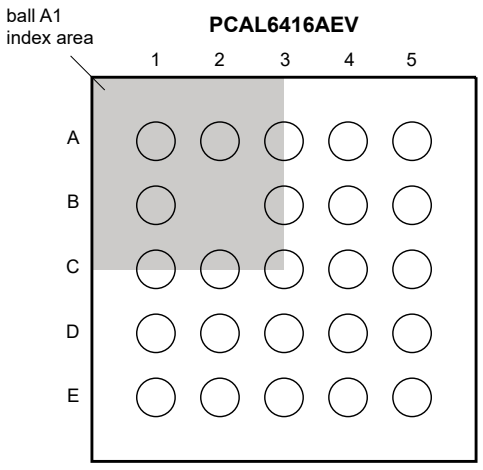



**Figure 3. Pin configuration for HWQFN24**


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Transparent top view

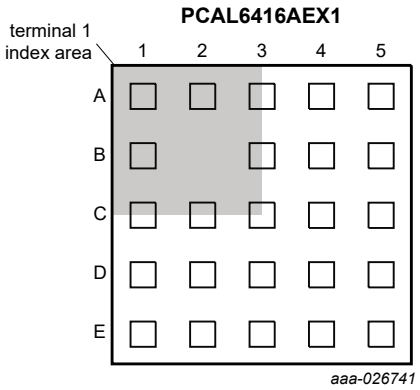
An empty cell indicates no ball is populated at that grid point.

**Figure 4. Pin configuration for VFBGA24 (3 mm × 3 mm)**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| A | P0_0 | $\overline{\text{RESET}}$ | $\overline{\text{INT}}$ | SDA | SCL |
| B | P0_2 | | $V_{DD(I2C\text{-}bus)}$ | $V_{DD(P)}$ | ADDR |
| C | P0_3 | P0_4 | P0_1 | P1_7 | P1_6 |
| D | P0_5 | P0_7 | P1_2 | P1_4 | P1_5 |
| E | P0_6 | $V_{SS}$ | P1_0 | P1_1 | P1_3 |

002aag244

**Figure 5. Ball mapping for VFBGA24 (3 mm × 3 mm) (transparent top view)**




Transparent top view

An empty cell indicates no ball is populated at that grid point.

**Figure 6. Pin configuration for X2QFN24 (2 mm × 2 mm); EX1 land grid array option**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| A | $\overline{\text{RESET}}$ | $V_{DD(I2C\text{-}bus)}$ | $V_{DD(P)}$ | SCL | ADDR |
| B | P0_0 | | $\overline{\text{INT}}$ | SDA | P1_7 |
| C | P0_2 | P0_3 | P0_1 | P1_6 | P1_5 |
| D | P0_4 | P0_7 | P1_0 | P1_4 | P1_3 |
| E | P0_5 | P0_6 | $V_{SS}$ | P1_1 | P1_2 |

002aah145

**Figure 7. Ball mapping for X2QFN24 (2 mm × 2 mm) (transparent top view)**

## 5.2 Pin description

**Table 3. Pin description**

| Symbol | Pin | | | | Description |
|---|---|---|---|---|---|
| | TSSOP24 | HWQFN24 | VFBGA24 | X2QFN24 | |
| $\overline{\text{INT}}$ | 1 | 22 | A3 | B3 | Interrupt output. Connect to $V_{DD(I2C\text{-}bus)}$ or $V_{DD(P)}$ through a pull-up resistor. |
| $V_{DD(I2C\text{-}bus)}$ | 2 | 23 | B3 | A2 | Supply voltage of I²C-bus. Connect directly to the $V_{DD}$ of the external I²C master. Provides voltage-level translation. |


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**Table 3. Pin description**...*continued*

| Symbol | Pin | | | | Description |
|---|---|---|---|---|---|
| | TSSOP24 | HWQFN24 | VFBGA24 | X2QFN24 | |
| $\overline{RESET}$ | 3 | 24 | A2 | A1 | Active LOW reset input. Connect to $V_{DD(I2C\text{-}bus)}$ through a pull-up resistor if no active connection is used. |
| P0_0[1] | 4 | 1 | A1 | B1 | Port 0 input/output 0 |
| P0_1[1] | 5 | 2 | C3 | C3 | Port 0 input/output 1 |
| P0_2[1] | 6 | 3 | B1 | C1 | Port 0 input/output 2 |
| P0_3[1] | 7 | 4 | C1 | C2 | Port 0 input/output 3 |
| P0_4[1] | 8 | 5 | C2 | D1 | Port 0 input/output 4 |
| P0_5[1] | 9 | 6 | D1 | E1 | Port 0 input/output 5 |
| P0_6[1] | 10 | 7 | E1 | E2 | Port 0 input/output 6 |
| P0_7[1] | 11 | 8 | D2 | D2 | Port 0 input/output 7 |
| $V_{SS}$ | 12 | 9 | E2 | E3 | Ground |
| P1_0[2] | 13 | 10 | E3 | D3 | Port 1 input/output 0 |
| P1_1[2] | 14 | 11 | E4 | E4 | Port 1 input/output 1 |
| P1_2[2] | 15 | 12 | D3 | E5 | Port 1 input/output 2 |
| P1_3[2] | 16 | 13 | E5 | D5 | Port 1 input/output 3 |
| P1_4[2] | 17 | 14 | D4 | D4 | Port 1 input/output 4 |
| P1_5[2] | 18 | 15 | D5 | C5 | Port 1 input/output 5 |
| P1_6[2] | 19 | 16 | C5 | C4 | Port 1 input/output 6 |
| P1_7[2] | 20 | 17 | C4 | B5 | Port 1 input/output 7 |
| ADDR | 21 | 18 | B5 | A5 | Address input. Connect directly to $V_{DD(P)}$ or ground. |
| SCL | 22 | 19 | A5 | A4 | Serial clock bus. Connect to $V_{DD(I2C\text{-}bus)}$ through a pull-up resistor. |
| SDA | 23 | 20 | A4 | B4 | Serial data bus. Connect to $V_{DD(I2C\text{-}bus)}$ through a pull-up resistor. |
| $V_{DD(P)}$ | 24 | 21 | B4 | A3 | Supply voltage of PCAL6416A for Port P. |

[1] Pins P0_0 to P0_7 correspond to bits P0.0 to P0.7. At power-on, all I/O are configured as input.
[2] Pins P1_0 to P1_7 correspond to bits P1.0 to P1.7. At power-on, all I/O are configured as input.

# 6 Voltage translation

Table 4 shows how to set up $V_{DD}$ levels for the necessary voltage translation between the I²C-bus and the PCAL6416A.

**Table 4. Voltage translation**

| $V_{DD(I2C\text{-}bus)}$ (SDA and SCL of I²C master) | $V_{DD(P)}$ (Port P) |
|---|---|
| 1.8 V | 1.8 V |
| 1.8 V | 2.5 V |
| 1.8 V | 3.3 V |


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Table 4. Voltage translation...*continued*

| $V_{DD(I2C-bus)}$ (SDA and SCL of $I^2C$ master) | $V_{DD(P)}$ (Port P) |
|---|---|
| 1.8 V | 5 V |
| 2.5 V | 1.8 V |
| 2.5 V | 2.5 V |
| 2.5 V | 3.3 V |
| 2.5 V | 5 V |
| 3.3 V | 1.8 V |
| 3.3 V | 2.5 V |
| 3.3 V | 3.3 V |
| 3.3 V | 5 V |
| 5 V | 1.8 V |
| 5 V | 2.5 V |
| 5 V | 3.3 V |
| 5 V | 5 V |

# 7 Functional description

Refer to Figure 1.

## 7.1 Device address

The address of the PCAL6416A is shown in Figure 8.

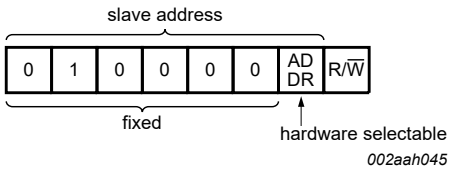



**Figure 8. PCAL6416A address**

ADDR is the hardware address package pin and is held to either HIGH (logic 1) or LOW (logic 0) to assign one of the two possible slave addresses. The last bit of the slave address (R/$\overline{W}$) 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.

## 7.2 Interface definition

Table 5. Interface definition

| Byte | Bit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 (MSB) | 6 | 5 | 4 | 3 | 2 | 1 | 0 (LSB) |
| $I^2C$-bus slave address | L | H | L | L | L | L | ADDR | R/$\overline{W}$ |
| I/O data bus | P0.7 | P0.6 | P0.5 | P0.4 | P0.3 | P0.2 | P0.1 | P0.0 |
| | P1.7 | P1.6 | P1.5 | P1.4 | P1.3 | P1.2 | P1.1 | P1.0 |


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## 7.3 Pointer register and command byte

Following the successful acknowledgment of the address byte, the bus master sends a command byte, which is stored in the Pointer register in the PCAL6416A. The lower three 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 IO). This register is write only.

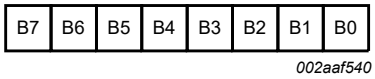



**Figure 9. Pointer register bits**

**Table 6. Command byte**

| Pointer register bits | | | | | | | | Command byte (hexadecimal) | Register | Protocol | Power-up default |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 00h | Input port 0 | read byte | xxxx xxxx[1] |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 01h | Input port 1 | read byte | xxxx xxxx |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 02h | Output port 0 | read/write byte | 1111 1111 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 03h | Output port 1 | read/write byte | 1111 1111 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 04h | Polarity Inversion port 0 | read/write byte | 0000 0000 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 05h | Polarity Inversion port 1 | read/write byte | 0000 0000 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 06h | Configuration port 0 | read/write byte | 1111 1111 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 07h | Configuration port 1 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 40h | Output drive strength register 0 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 41h | Output drive strength register 0 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 42h | Output drive strength register 1 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 43h | Output drive strength register 1 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 44h | Input latch register 0 | read/write byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 45h | Input latch register 1 | read/write byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 46h | Pull-up/pull-down enable register 0 | read/write byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 47h | Pull-up/pull-down enable register 1 | read/write byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 48h | Pull-up/pull-down selection register 0 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 49h | Pull-up/pull-down selection register 1 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 4Ah | Interrupt mask register 0 | read/write byte | 1111 1111 |


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**Table 6. Command byte**...*continued*

| Pointer register bits | | | | | | | | Command byte (hexadecimal) | Register | Protocol | Power-up default |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | | | | |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 4Bh | Interrupt mask register 1 | read/write byte | 1111 1111 |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 4Ch | Interrupt status register 0 | read byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 4Dh | Interrupt status register 1 | read byte | 0000 0000 |
| 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 4Fh | Output port configuration register | read/write byte | 0000 0000 |

[1] Undefined.

## 7.4 Register descriptions

### 7.4.1 Input port register pair (00h, 01h)

The Input port registers (registers 0 and 1) reflect 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 registers are read only; writes to these registers 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 8.2.

**Table 7. Input port 0 register (address 00h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | I0.7 | I0.6 | I0.5 | I0.4 | I0.3 | I0.2 | I0.1 | I0.0 |
| **Default** | X | X | X | X | X | X | X | X |

**Table 8. Input port 1 register (address 01h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | I1.7 | I1.6 | I1.5 | I1.4 | I1.3 | I1.2 | I1.1 | I1.0 |
| **Default** | X | X | X | X | X | X | X | X |

### 7.4.2 Output port register pair (02h, 03h)

The Output port registers (registers 2 and 3) 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 these registers reflect the value that was written to these registers, **not** the actual pin value. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 9. Output port 0 register (address 02h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | O0.7 | O0.6 | O0.5 | O0.4 | O0.3 | O0.2 | O0.1 | O0.0 |
| **Default** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |


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Table 10. Output port 1 register (address 03h)

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | O1.7 | O1.6 | O1.5 | O1.4 | O1.3 | O1.2 | O1.1 | O1.0 |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

### 7.4.3 Polarity inversion register pair (04h, 05h)

The Polarity inversion registers (registers 4 and 5) allow polarity inversion of pins defined as inputs by the Configuration register. If a bit in these registers is set (written with '1'), the corresponding port pin's polarity is inverted in the input register. If a bit in this register is cleared (written with a '0'), the corresponding port pin's polarity is retained. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

Table 11. Polarity inversion port 0 register (address 04h)

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | N0.7 | N0.6 | N0.5 | N0.4 | N0.3 | N0.2 | N0.1 | N0.0 |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 12. Polarity inversion port 1 register (address 05h)

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | N1.7 | N1.6 | N1.5 | N1.4 | N1.3 | N1.2 | N1.1 | N1.0 |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 7.4.4 Configuration register pair (06h, 07h)

The Configuration registers (registers 6 and 7) configure the direction of the I/O pins. If a bit in these registers is set to 1, the corresponding port pin is enabled as a high-impedance input. If a bit in these registers is cleared to 0, the corresponding port pin is enabled as an output. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

Table 13. Configuration port 0 register (address 06h)

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | C0.7 | C0.6 | C0.5 | C0.4 | C0.3 | C0.2 | C0.1 | C0.0 |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 14. Configuration port 1 register (address 07h)

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | C1.7 | C1.6 | C1.5 | C1.4 | C1.3 | C1.2 | C1.1 | C1.0 |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |


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### 7.4.5 Output drive strength register pairs (40h, 41h, 42h, 43h)

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 0.7 is controlled by register 41 CC0.7 (bits [7:6]), Port 0.6 is controlled by register 41 CC0.6 (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 9.2 for more details. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 15. Current control port 0 register (address 40h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | CC0.3 | | CC0.2 | | CC0.1 | | CC0.0 | |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 16. Current control port 0 register (address 41h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | CC0.7 | | CC0.6 | | CC0.5 | | CC0.4 | |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 17. Current control port 1 register (address 42h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | CC1.3 | | CC1.2 | | CC1.1 | | CC1.0 | |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 18. Current control port 1 register (address 43h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| Symbol | CC1.7 | | CC1.6 | | CC1.5 | | CC1.4 | |
| Default | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

### 7.4.6 Input latch register pair (44h, 45h)

The input latch registers (registers 44 and 45) enable and disable 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 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 and 1). 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 16.


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For example, if the P0_4 input was as logic 0 and the input goes to logic 1 then back to logic 0, the input port 0 register will capture this change and an interrupt is generated (if unmasked). When the read is performed on the input port 0 register, the interrupt is cleared, assuming there were no additional input(s) that have changed, and bit 4 of the input port 0 register will read '1'. The next read of the input port register bit 4 register 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 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 register reflects the latched logic level. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 19. Input latch port 0 register (address 44h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | L0.7 | L0.6 | L0.5 | L0.4 | L0.3 | L0.2 | L0.1 | L0.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 20. Input latch port 1 register (address 45h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | L1.7 | L1.6 | L1.5 | L1.4 | L1.3 | L1.2 | L1.1 | L1.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 7.4.7 Pull-up/pull-down enable register pair (46h, 47h)

These registers allow 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. Also, the resistors will be disconnected when the outputs are configured as open-drain outputs (see Section 7.4.11). Use the pull-up/pull-down registers to select either a pull-up or pull-down resistor. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 21. Pull-up/pull-down enable port 0 register (address 46h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | PE0.7 | PE0.6 | PE0.5 | PE0.4 | PE0.3 | PE0.2 | PE0.1 | PE0.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 22. Pull-up/pull-down enable port 1 register (address 47h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | PE1.7 | PE1.6 | PE1.5 | PE1.4 | PE1.3 | PE1.2 | PE1.1 | PE1.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |


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### 7.4.8 Pull-up/pull-down selection register pair (48h, 49h)

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 kΩ pull-up resistor for that I/O pin. Setting a bit to logic 0 selects a 100 kΩ 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 kΩ with minimum of 50 kΩ and maximum of 150 kΩ. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 23. Pull-up/pull-down selection port 0 register (address 48h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | PUD0.7 | PUD0.6 | PUD0.5 | PUD0.4 | PUD0.3 | PUD0.2 | PUD0.1 | PUD0.0 |
| **Default** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 24. Pull-up/pull-down selection port 1 register (address 49h)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | PUD1.7 | PUD1.6 | PUD1.5 | PUD1.4 | PUD1.3 | PUD1.2 | PUD1.1 | PUD1.0 |
| **Default** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

### 7.4.9 Interrupt mask register pair (4Ah, 4Bh)

Interrupt mask registers are 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 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. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 25. Interrupt mask port 0 register (address 4Ah) bit description**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | M0.7 | M0.6 | M0.5 | M0.4 | M0.3 | M0.2 | M0.1 | M0.0 |
| **Default** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 26. Interrupt mask port 1 register (address 4Bh) bit description**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | M1.7 | M1.6 | M1.5 | M1.4 | M1.3 | M1.2 | M1.1 | M1.0 |
| **Default** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |


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### 7.4.10 Interrupt status register pair (4Ch, 4Dh)

These read-only registers are 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. A register pair write operation is described in Section 8.1. A register pair read operation is described in Section 8.2.

**Table 27. Interrupt status port 0 register (address 4Ch) bit description**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | S0.7 | S0.6 | S0.5 | S0.4 | S0.3 | S0.2 | S0.1 | S0.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 28. Interrupt status port 1 register (address 4Dh) bit description**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | S1.7 | S1.6 | S1.5 | S1.4 | S1.3 | S1.2 | S1.1 | S1.0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### 7.4.11 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 10). A logic 1 configures the I/O as open-drain (Q1 is disabled, Q2 is active) and the recommended command sequence is to program this register (4Fh) before the configuration register (06h and 07h) sets the port pins as outputs.

ODEN0 configures Port 0_x and ODEN1 configures Port 1_x.

**Table 29. Output port configuration register (address 4Fh)**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|
| **Symbol** | reserved | | | | | | ODEN1 | ODEN0 |
| **Default** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

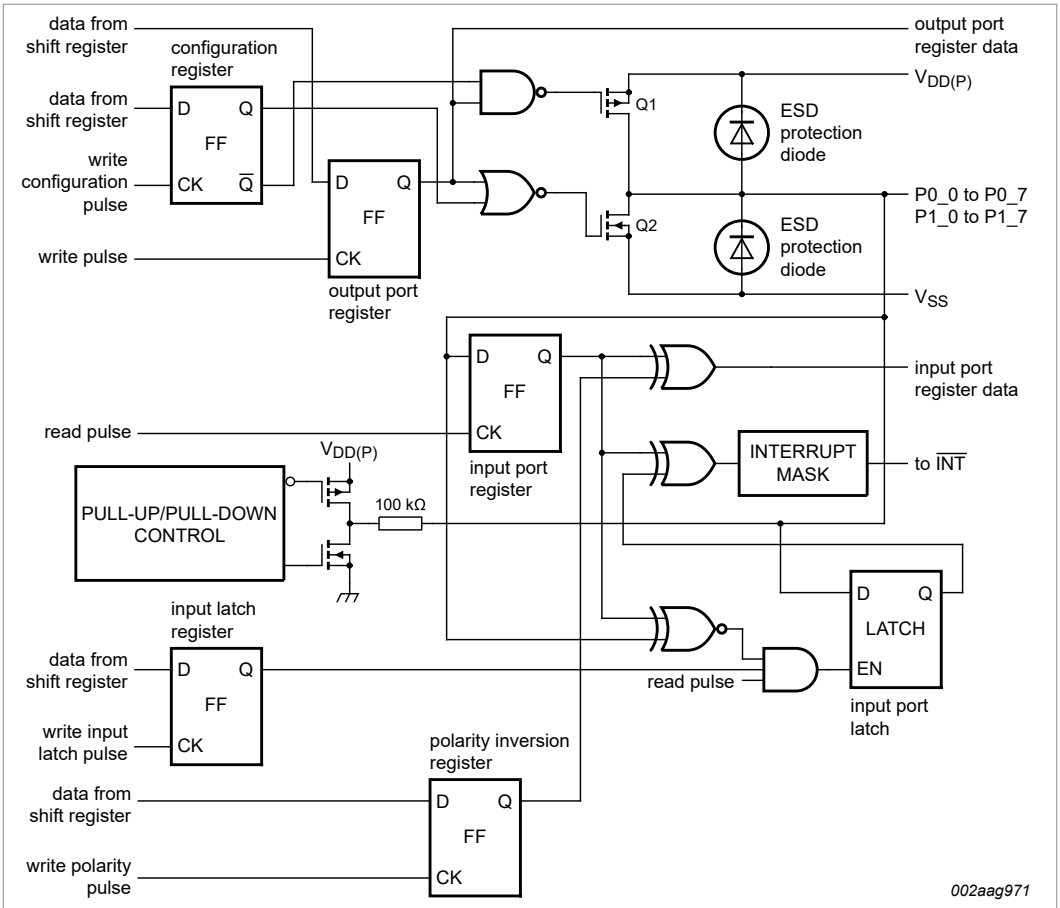
## 7.5 I/O port

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 $V_{DD(P)}$ 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 $V_{DD(P)}$ or $V_{SS}$. The external voltage applied to this I/O pin should not exceed the recommended levels for proper operation.


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On power-up or reset, all registers return to default values.

**Figure 10. Simplified schematic of the I/Os (P0_0 to P0_7, P1_0 to P1_7)**

## 7.6 Power-on reset

When power (from 0 V) is applied to $V_{DD(P)}$, an internal power-on reset holds the PCAL6416A in a reset condition until $V_{DD(P)}$ has reached $V_{POR}$. At that time, the reset condition is released and the PCAL6416A registers and I²C-bus/SMBus state machine initializes to their default states. After that, $V_{DD(P)}$ must be lowered to below $V_{POR}$ and back up to the operating voltage for a power-reset cycle. See Section 9.3 "Power-on reset requirements".

## 7.7 Reset input (RESET)

The $\overline{RESET}$ input can be asserted to initialize the system while keeping the $V_{DD(P)}$ at its operating level. A reset can be accomplished by holding the $\overline{RESET}$ pin LOW for a minimum of $t_{w(rst)}$. The PCAL6416A registers and I²C-bus/SMBus state machine are changed to their default state once $\overline{RESET}$ is LOW (0). When $\overline{RESET}$ 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 $V_{DD(I2C-bus)}$ if no active connection is used.


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### 7.8 Interrupt output (INT)

An interrupt is generated by any rising or falling edge of the port inputs in the Input mode. After time $t_{v(INT)}$, the signal $\overline{INT}$ is valid. The interrupt is reset when data on the port changes back to the original value or when data is read from the port that generated the interrupt (see Figure 16). 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. Any change of the I/Os after resetting is detected and is transmitted as $\overline{INT}$.

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 $\overline{INT}$ output has an open-drain structure and requires pull-up resistor to $V_{DD(P)}$ or $V_{DD(I2C\text{-}bus)}$, depending on the application. $\overline{INT}$ 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.

## 8 Bus transactions

The PCAL6416A is an I²C-bus slave device. Data is exchanged between the master and PCAL6416A through write and read commands using I²C-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.

### 8.1 Write commands

Data is transmitted to the PCAL6416A by sending the device address and setting the Least Significant Bit (LSB) to a logic 0 (see Figure 8 for device address). The command byte is sent after the address and determines which register receives the data that follows the command byte.

Twenty-two registers within the PCAL6416A are configured to operate as eleven register pairs. The eleven pairs are input port, output port, polarity inversion, configuration, output drive strength (two 16-bit registers), input latch, pull-up/pull-down enable, pull-up/pull-down selection, interrupt mask, and interrupt status registers. After sending data to one register, the next data byte is sent to the other register in the pair (see Figure 11 and Figure 12). For example, if the first byte is sent to Output Port 1 (register 3), the next byte is stored in Output Port 0 (register 2).

There is no limit on the number of data bytes sent in one write transmission. In this way, the host can continuously update a register pair independently of the other registers.


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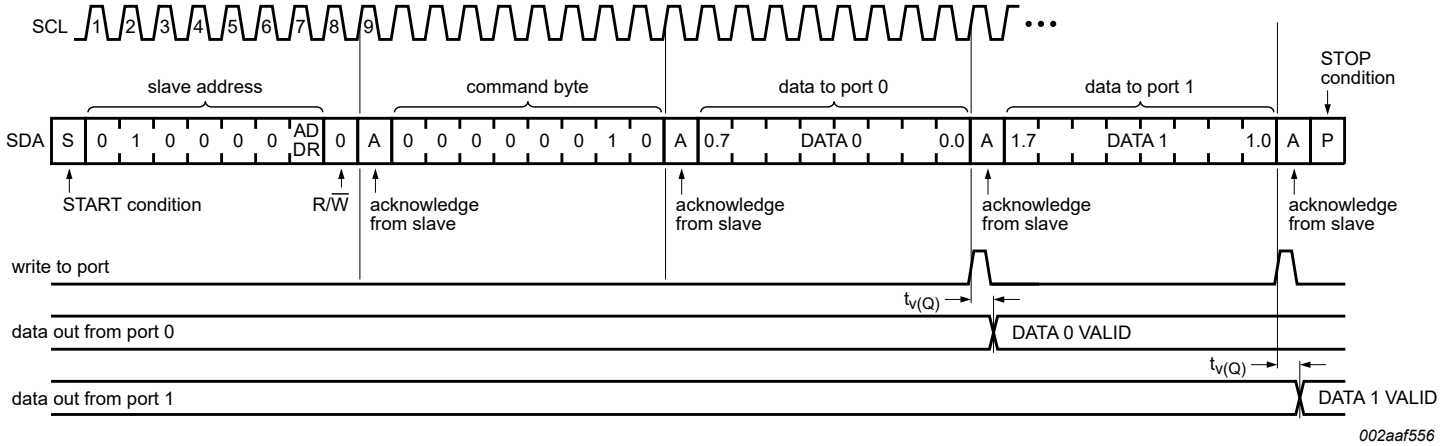



**Figure 11. Write to Output port register**

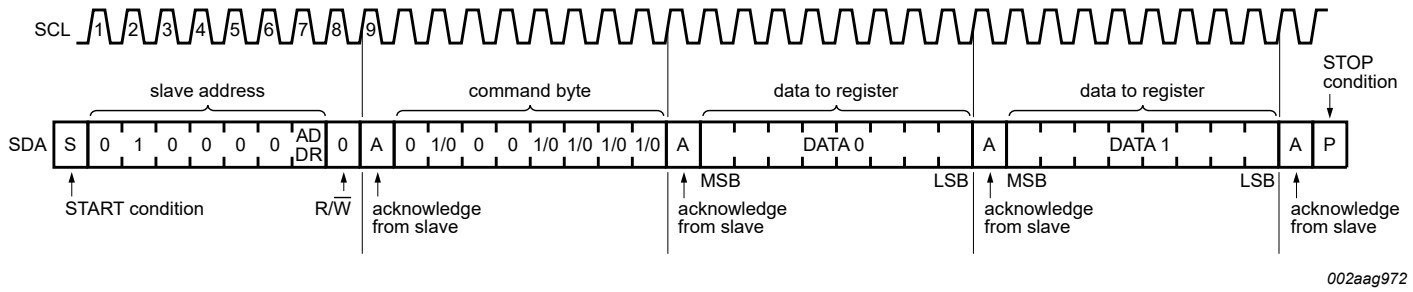



**Figure 12. Write to device registers**


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## 8.2 Read commands

To read data from the PCAL6416A, the bus master must first send the PCAL6416A address with the least significant bit set to a logic 0 (see Figure 8 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 least significant bit is set to a logic 1. Data from the register defined by the command byte is sent by the PCAL6416A (see Figure 13 and Figure 16). Data is clocked into the register on the rising edge of the ACK clock pulse. After the first byte is read, additional bytes may be read, but the data now reflects the information in the other register in the pair. For example, if Input Port 1 is read, the next byte read is Input Port 0.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.

After a subsequent restart, the command byte contains the value of the next register to be read in the pair. For example, if Input Port 1 was read last before the restart, the register that is read after the restart is the Input Port 0.

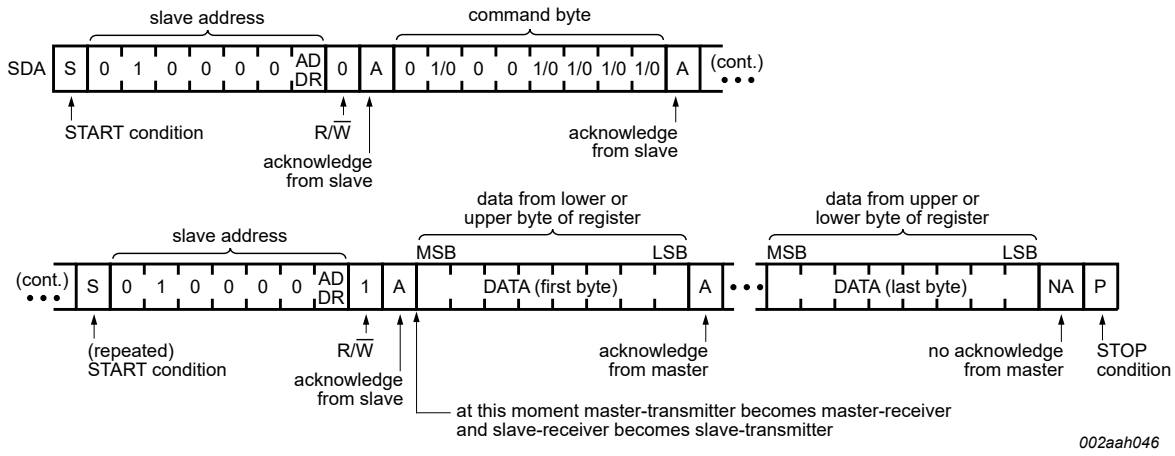
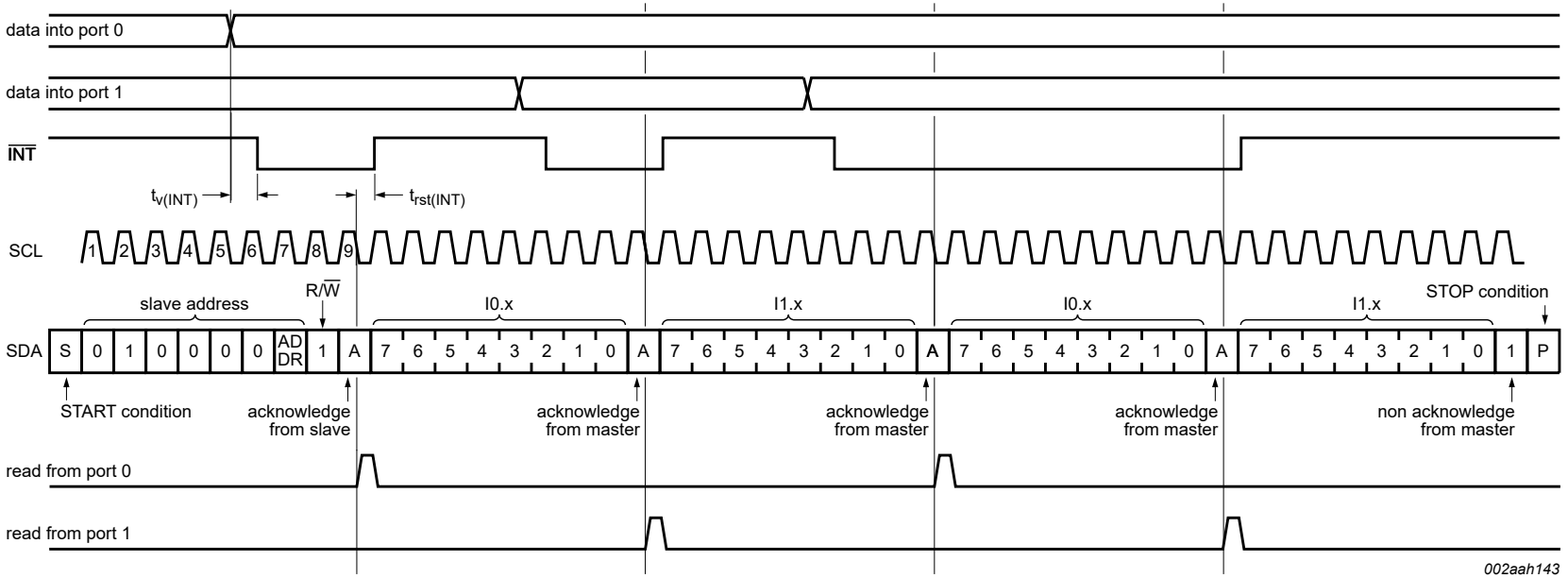



**Figure 13. Read from device registers**


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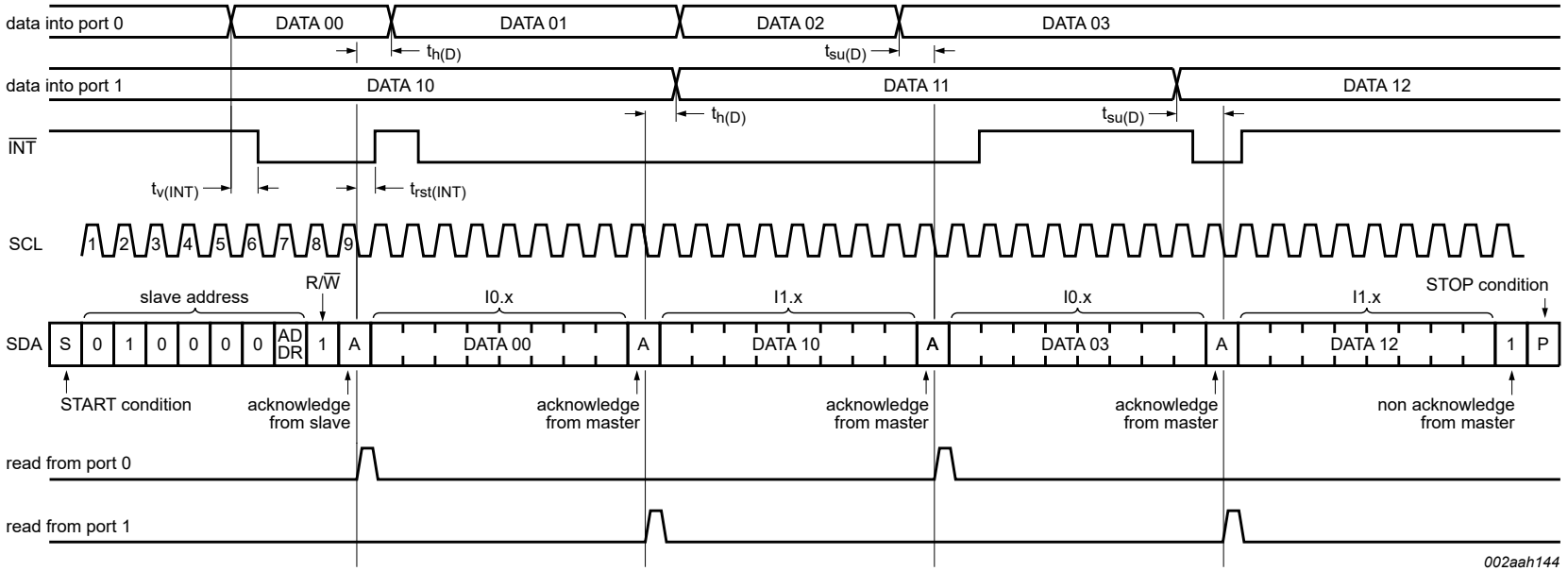

**Remark:** Transfer of data can be stopped at any moment by a STOP condition. When this occurs, data present at the latest acknowledge phase is valid (output mode). It is assumed that the command byte has previously been set to '00' (read input port register).

This figure eliminates the command byte transfers and a restart between the initial slave address call and actual data transfer from P port (see Figure 13).

**Figure 14. Read input port register (non-latched), scenario 1**


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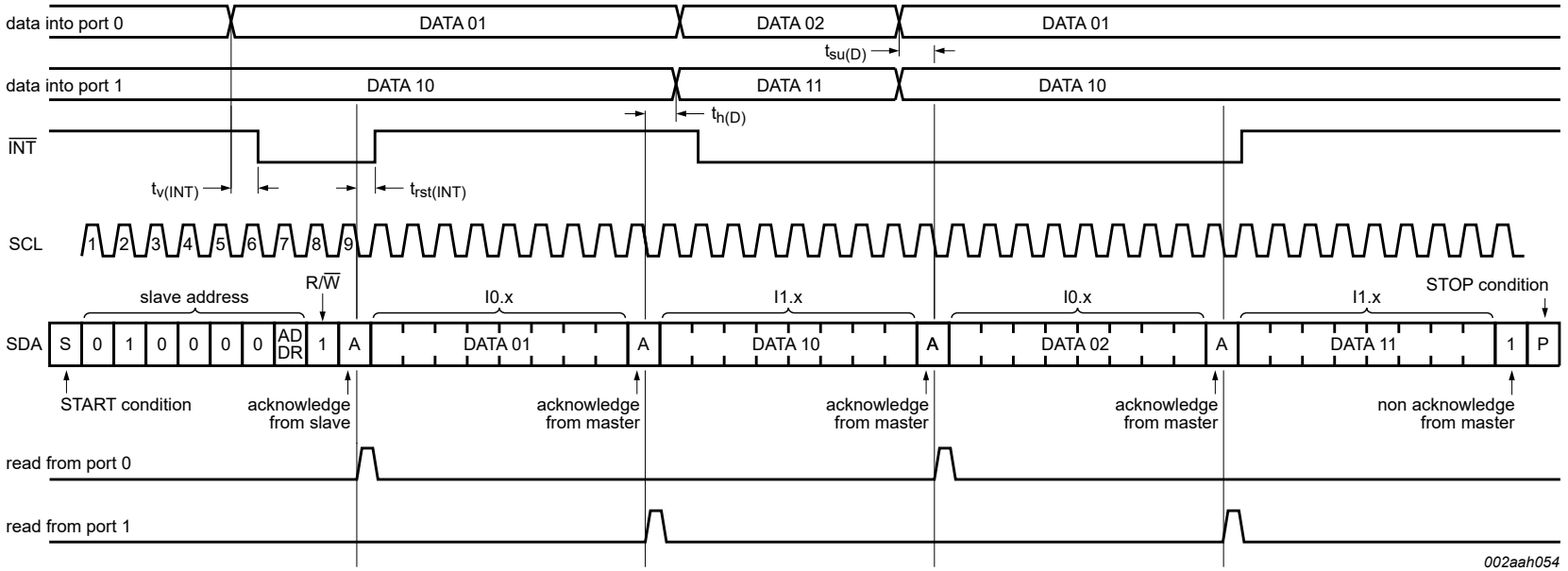

**Remark:** Transfer of data can be stopped at any moment by a STOP condition. When this occurs, data present at the latest acknowledge phase is valid (output mode). It is assumed that the command byte has previously been set to '00' (read input port register).

This figure eliminates the command byte transfers and a restart between the initial slave address call and actual data transfer from P port (see Figure 13).

**Figure 15. Read input port register (non-latched), scenario 2**


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**Remark:** Transfer of data can be stopped at any moment 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 set to '00' (read input port register).

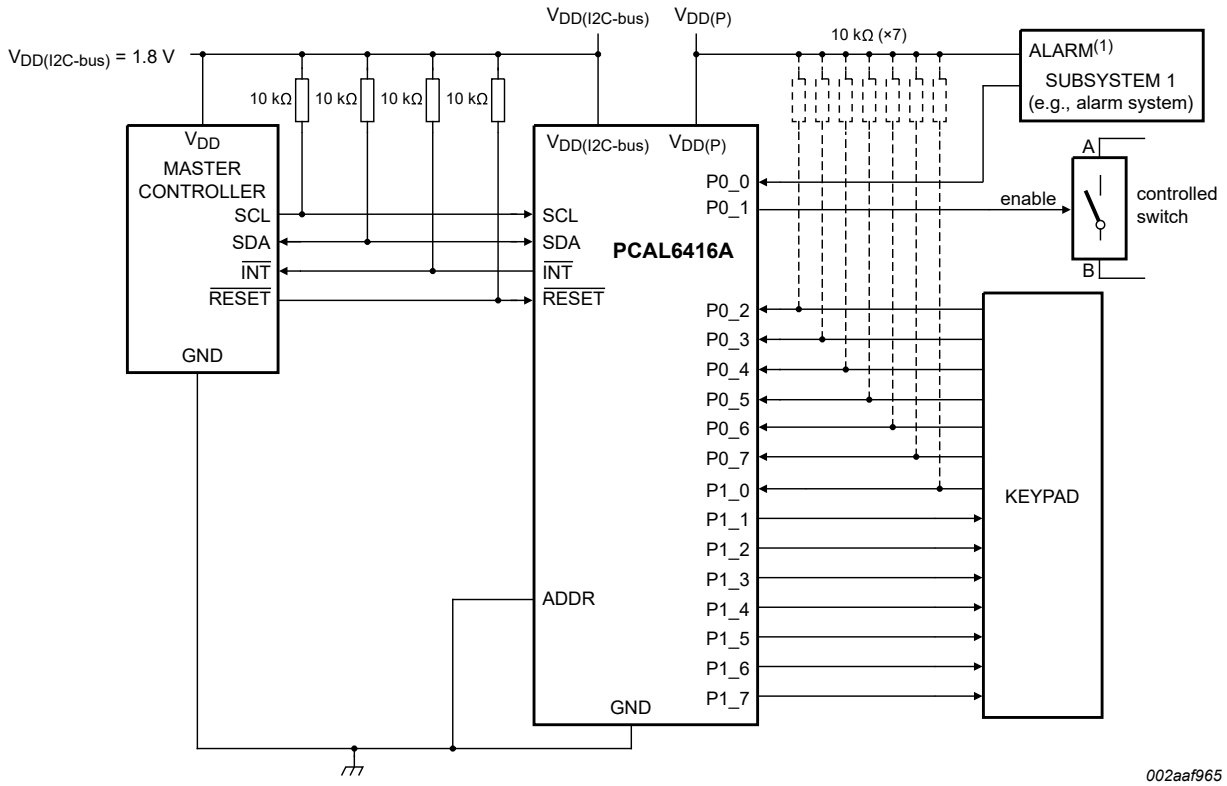
This figure eliminates the command byte transfers and a restart between the initial slave address call and actual data transfer from P port (see Figure 13).

**Figure 16. Read input port register (latch enabled), scenario 3**


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# 9 Application design-in information




Device address configured as 0100 000x for this example.

P0_0 and P0_2 through P1_0 are configured as inputs.

P0_1 and P1_1 through P1_7 are configured as outputs.

1. External resistors are required for inputs (on P port) that may float. Also, internal pull-up or pull-down may be used to eliminate the need for external components. If a driver to an input will never let the input float, a resistor is not needed. If an output in the P port is configured as a push-pull output there is no need for external pull-up resistors. If an output in the P port is configured as an open-drain output, external pull-up resistors are required.

**Figure 17. Typical application**

## 9.1 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 17. Since the LED acts as a diode, when the LED is off the I/O $V_I$ is about 1.2 V less than $V_{DD(P)}$. The supply current, $I_{DD(P)}$, increases as $V_I$ becomes lower than $V_{DD(P)}$.

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 18 shows a high value resistor in parallel with the LED. Figure 19 shows $V_{DD(P)}$ 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 $V_{DD(P)}$ and prevents additional supply current consumption when the LED is off.


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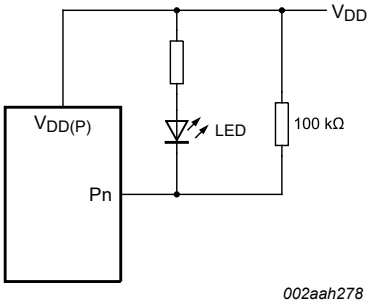



Figure 18. High value resistor in parallel with the LED

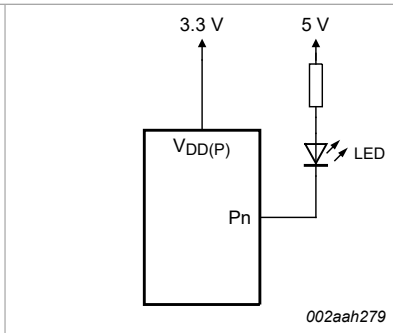



Figure 19. Device supplied by a lower voltage

## 9.2 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 20 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 %.

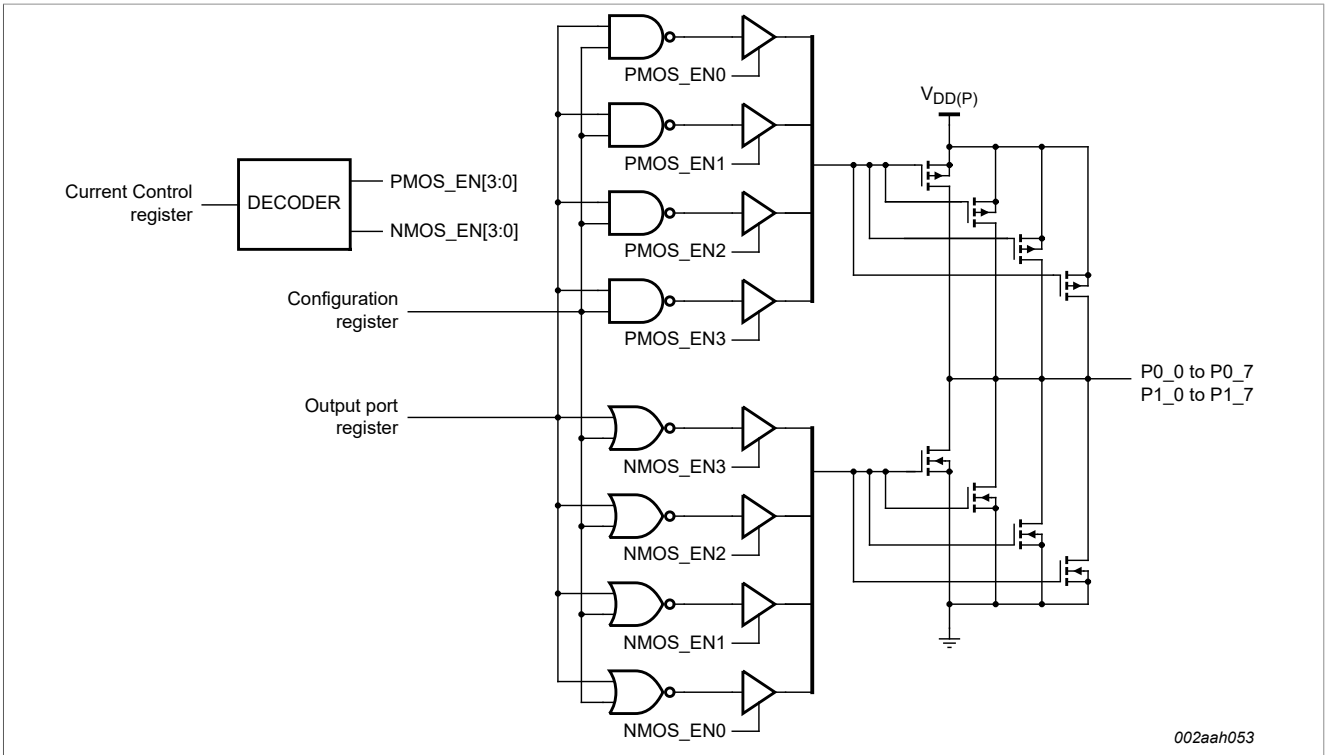



Figure 20. Simplified output stage

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


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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 Output Drive Strength registers allows the user to mitigate SSN issues without the need of additional external components.

## 9.3 Power-on reset requirements

In the event of a glitch or data corruption, PCAL6416A 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 21 and Figure 22.

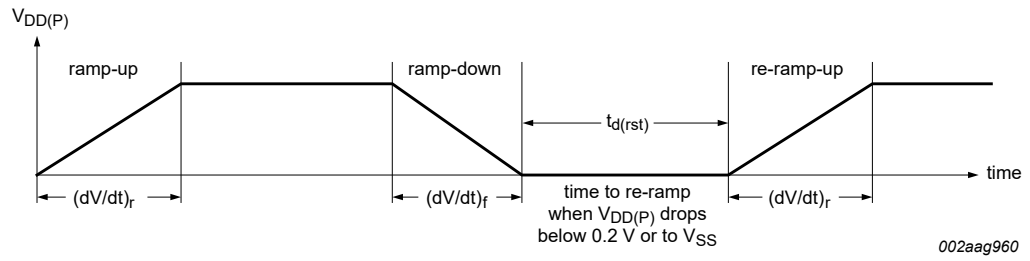



**Figure 21. $V_{DD(P)}$ is lowered below 0.2 V or to 0 V and then ramped up to $V_{DD(P)}$**

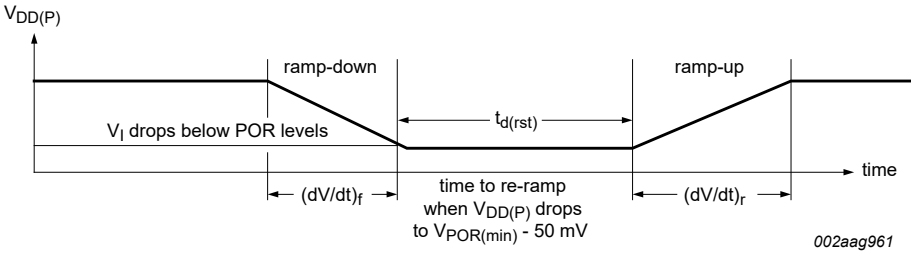



**Figure 22. $V_{DD(P)}$ is lowered below the POR threshold, then ramped back up to $V_{DD(P)}$**

Table 30 specifies the performance of the power-on reset feature for PCAL6416A for both types of power-on reset.

**Table 30. Recommended supply sequencing and ramp rates**

*$T_{amb}$ = 25 °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 | Figure 21 | | 0.1 | - | 2000 | ms |
| $(dV/dt)_r$ | rise rate of change of voltage | Figure 21 | | 0.1 | - | 2000 | ms |
| $t_{d(rst)}$ | reset delay time | Figure 21; re-ramp time when $V_{DD(P)}$ drops below 0.2 V or to $V_{SS}$) | | 1 | - | - | µs |
| | | Figure 22; re-ramp time when $V_{DD(P)}$ drops to $V_{POR(min)}$ - 50 mV) | | 1 | - | - | µs |
| $\Delta V_{DD(gl)}$ | glitch supply voltage difference | Figure 23 | [1] | - | - | 1.0 | V |
| $t_{w(gl)VDD}$ | supply voltage glitch pulse width | Figure 23 | [2] | - | - | 10 | µs |
| $V_{POR(trip)}$ | power-on reset trip voltage | falling $V_{DD(P)}$ | | 0.7 | - | - | V |


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**Table 30. Recommended supply sequencing and ramp rates**...*continued*

*$T_{amb}$ = 25 °C (unless otherwise noted). Not tested; specified by design.*

| Symbol | Parameter | Condition | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| | | rising $V_{DD(P)}$ | | - | - | 1.4 | V |

[1] Level that $V_{DD(P)}$ can glitch down to with a ramp rate = 0.4 µs/V, but not cause a functional disruption when $t_{w(gl)VDD}$ < 1 µs.
[2] Glitch width that will not cause a functional disruption when $\Delta V_{DD(gl)} = 0.5 \times V_{DD(P)}$.

Glitches in the power supply can also affect the power-on reset performance of this device. The glitch width ($t_{w(gl)VDD}$) 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 23 and Table 30 provide more information on how to measure these specifications.

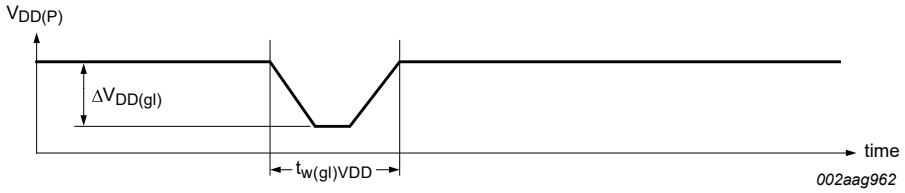



**Figure 23. Glitch width and glitch height**

$V_{POR}$ 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 I²C-bus/SMBus state machine are initialized to their default states. The value of $V_{POR}$ differs based on the $V_{DD(P)}$ being lowered to or from 0 V. Figure 24 and Table 30 provide more details on this specification.

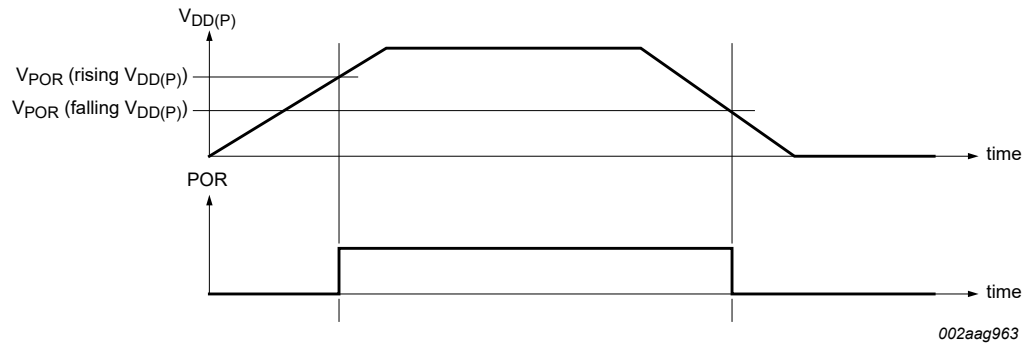



**Figure 24. Power-on reset voltage ($V_{POR}$)**

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

The PCAL6416A 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 registers 48h and 49h, while the resistor is connected by the enable registers 46h and 47h. The configuration of the resistors is shown in Figure 10.


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If the resistor is configured as a pull-up, that is, connected to $V_{DD}$, a current will flow from the $V_{DD(P)}$ 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 kΩ with a nominal 100 kΩ 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 28 for a graph of supply current versus the number of pull-up resistors.

### 9.5 I²C-bus error recovery techniques

There are a number of techniques to recover from error conditions on the I²C-bus. Slave devices like the PCAL6416A use a state machine to implement the I²C protocol and expect a certain sequence of events to occur to function properly. Unexpected events at the I²C master can wreak havoc with the slaves connected on the bus. However, it is usually possible to recover deterministically to a known bus state with careful protocol manipulation.

A hard slave reset, either through power-on reset or by activating the $\overline{\text{RESET}}$ pin, will set the device back into the default state. Of course, this means the input/output pins and their configuration will be lost, which might cause some system issues.

A STOP condition, which is only initiated by the master, will reset the slave state machine into a known condition where SDA is not driven LOW by the slave and logically, the slave is waiting for a START condition. A STOP condition is defined as SDA transitioning from LOW to HIGH while SCL is HIGH.

If the master is interrupted during a packet transmission, the slave may be sending data or performing an Acknowledge, driving the I²C-bus SDA line LOW. Since SDA is LOW, it effectively blocks any other I²C-bus transaction. A deterministic method to clear this situation, once the master recognizes a 'stuck bus' state, is for the master to blindly transmit nine clocks on SCL. If the slave was transmitting data or acknowledging, nine or more clocks ensures the slave state machine returns to a known, idle state since the protocol calls for eight data bits and one ACK bit. It does not matter when the slave state machine finishes its transmission, extra clocks will be recognized as STOP conditions.

The PCAL6416A SCL pin is an input only. If SCL is stuck LOW, then only the bus master or a slave performing a clock stretch operation can cause this condition.

With careful design of the bus master error recovery firmware, many I²C-bus protocol problems can be avoided.

## 10 Limiting values

**Table 31. Limiting values**

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

| Symbol | Parameter | Conditions | | Min | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{DD(I2C\text{-}bus)}$ | I²C-bus supply voltage | | | -0.5 | +6.5 | V |
| $V_{DD(P)}$ | supply voltage port P | | | -0.5 | +6.5 | V |


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**Table 31. Limiting values**...*continued*

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

| Symbol | Parameter | Conditions | | Min | Max | Unit |
|---|---|---|---|---|---|---|
| $V_I$ | input voltage | | [1] | -0.5 | +6.5 | V |
| $V_O$ | output voltage | | [1] | -0.5 | +6.5 | V |
| $I_{IK}$ | input clamping current | ADDR, $\overline{RESET}$, SCL; $V_I < 0$ V | | - | ±20 | mA |
| $I_{OK}$ | output clamping current | $\overline{INT}$; $V_O < 0$ V | | - | ±20 | mA |
| $I_{IOK}$ | input/output clamping current | P port; $V_O < 0$ V or $V_O > V_{DD(P)}$ | | - | ±20 | mA |
| | | SDA; $V_O < 0$ V or $V_O > V_{DD(I2C\text{-}bus)}$ | | - | ±20 | mA |
| $I_{OL}$ | LOW-level output current | continuous; P port; $V_O$ = 0 V to $V_{DD(P)}$ | | - | 50 | mA |
| | | continuous; SDA, $\overline{INT}$; $V_O$ = 0 V to $V_{DD(I2C\text{-}bus)}$ | | - | 25 | mA |
| $I_{OH}$ | HIGH-level output current | continuous; P port; $V_O$ = 0 V to $V_{DD(P)}$ | | - | 25 | mA |
| $I_{DD}$ | supply current | continuous through $V_{SS}$ | | - | 200 | mA |
| $I_{DD(P)}$ | supply current port P | continuous through $V_{DD(P)}$ | | - | 160 | mA |
| $I_{DD(I2C\text{-}bus)}$ | I²C-bus supply current | continuous through $V_{DD(I2C\text{-}bus)}$ | | - | 10 | mA |
| $T_{stg}$ | storage temperature | | | -65 | +150 | °C |
| $T_{j(max)}$ | 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.

# 11 Recommended operating conditions

**Table 32. Operating conditions**

| Symbol | Parameter | Conditions | | Min | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{DD(I2C\text{-}bus)}$ | I²C-bus supply voltage | | | 1.65 | 5.5 | V |
| $V_{DD(P)}$ | supply voltage port P | | | 1.65 | 5.5 | V |
| $V_{IH}$ | HIGH-level input voltage | SCL, SDA, $\overline{RESET}$ | | 0.7 × $V_{DD(I2C\text{-}bus)}$ | 5.5 | V |
| | | ADDR, P1_7 to P0_0 | | 0.7 × $V_{DD(P)}$ | 5.5 | V |
| $V_{IL}$ | LOW-level input voltage | SCL, SDA, $\overline{RESET}$ | | -0.5 | 0.3 × $V_{DD(I2C\text{-}bus)}$ | V |
| | | ADDR, P1_7 to P0_0 | | -0.5 | 0.3 × $V_{DD(P)}$ | V |
| $I_{OH}$ | HIGH-level output current | P1_7 to P0_0 | | - | 10 | mA |
| $I_{OL}$ | LOW-level output current | P1_7 to P0_0 | | - | 25 | mA |
| $T_{amb}$ | ambient temperature | operating in free air | | -40 | +85 | °C |

# 12 Thermal characteristics

**Table 33. Thermal characteristics**

| Symbol | Parameter | Conditions | | Max | Unit |
|---|---|---|---|---|---|
| $Z_{th(j\text{-}a)}$ | transient thermal impedance from junction to ambient | TSSOP24 package | [1] | 88 | K/W |
| | | HWQFN24 package | [1] | 66 | K/W |


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**Table 33. Thermal characteristics**...*continued*

| Symbol | Parameter | Conditions | | Max | Unit |
|---|---|---|---|---|---|
| | | VFBGA24 package | [1] | 171 | K/W |

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

# 13 Static characteristics

**Table 34. Static characteristics**

*$T_{amb}$ = -40 °C to +85 °C; $V_{DD(I2C\text{-}bus)}$ = 1.65 V to 5.5 V; unless otherwise specified.*

| Symbol | Parameter | Conditions | | Min | Typ[1] | Max | Unit |
|---|---|---|---|---|---|---|---|
| $V_{IK}$ | input clamping voltage | $I_I$ = -18 mA | | -1.2 | - | - | V |
| $V_{POR}$ | power-on reset voltage | $V_I = V_{DD(P)}$ or $V_{SS}$; $I_O$ = 0 mA | | - | 1.1 | 1.4 | V |
| $V_{OH}$ | HIGH-level output voltage[2] | P port; $I_{OH}$ = -8 mA; CCX.X = 11b | | | | | |
| | | $V_{DD(P)}$ = 1.65 V | | 1.2 | - | - | V |
| | | $V_{DD(P)}$ = 2.3 V | | 1.8 | - | - | V |
| | | $V_{DD(P)}$ = 3 V | | 2.6 | - | - | V |
| | | $V_{DD(P)}$ = 4.5 V | | 4.1 | - | - | V |
| | | P port; $I_{OH}$ = -2.5 mA and CCX.X = 00b;<br>$I_{OH}$ = -5 mA and CCX.X = 01b;<br>$I_{OH}$ = -7.5 mA and CCX.X = 10b;<br>$I_{OH}$ = -10 mA and CCX.X = 11b; | | | | | |
| | | $V_{DD(P)}$ = 1.65 V | | 1.1 | - | - | V |
| | | $V_{DD(P)}$ = 2.3 V | | 1.7 | - | - | V |
| | | $V_{DD(P)}$ = 3 V | | 2.5 | - | - | V |
| | | $V_{DD(P)}$ = 4.5 V | | 4.0 | - | - | V |
| $V_{OL}$ | LOW-level output voltage[2] | P port; $I_{OL}$ = 8 mA; CCX.X = 11b | | | | | |
| | | $V_{DD(P)}$ = 1.65 V | | - | - | 0.45 | V |
| | | $V_{DD(P)}$ = 2.3 V | | - | - | 0.25 | V |
| | | $V_{DD(P)}$ = 3 V | | - | - | 0.25 | V |
| | | $V_{DD(P)}$ = 4.5 V | | - | - | 0.2 | V |
| | | P port; $I_{OL}$ = 2.5 mA and CCX.X = 00b;<br>$I_{OL}$ = 5 mA and CCX.X = 01b;<br>$I_{OL}$ = 7.5 mA and CCX.X = 10b;<br>$I_{OL}$ = 10 mA and CCX.X = 11b; | | | | | |
| | | $V_{DD(P)}$ = 1.65 V | | - | - | 0.5 | V |
| | | $V_{DD(P)}$ = 2.3 V | | - | - | 0.3 | V |
| | | $V_{DD(P)}$ = 3 V | | - | - | 0.25 | V |
| | | $V_{DD(P)}$ = 4.5 V | | - | - | 0.2 | V |
| $I_{OL}$ | LOW-level output current[3] | $V_{OL}$ = 0.4 V; $V_{DD(P)}$ = 1.65 V to 5.5 V | | | | | |
| | | SDA | | 3 | - | - | mA |


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**Table 34. Static characteristics**...*continued*

*$T_{amb}$ = -40 °C to +85 °C; $V_{DD(I2C\text{-}bus)}$ = 1.65 V to 5.5 V; unless otherwise specified.*

| Symbol | Parameter | Conditions | | Min | Typ[1] | Max | Unit |
|---|---|---|---|---|---|---|---|
| | | $\overline{INT}$ | | 3 | 15[4] | - | mA |
| $I_I$ | input current | $V_{DD(P)}$ = 1.65 V to 5.5 V | | | | | |
| | | SCL, SDA, $\overline{RESET}$; $V_I = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$ | | - | - | ±1 | µA |
| | | ADDR; $V_I = V_{DD(P)}$ or $V_{SS}$ | | - | - | ±1 | µA |
| $I_{IH}$ | HIGH-level input current | P port; $V_I = V_{DD(P)}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | - | 1 | µA |
| $I_{IL}$ | LOW-level input current | P port; $V_I = V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | - | 1 | µA |
| $I_{DD}$ | supply current | $I_{DD(I2C\text{-}bus)} + I_{DD(P)}$;<br>SDA, P port, ADDR, $\overline{RESET}$;<br>$V_I$ on SDA and $\overline{RESET} = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$;<br>$V_I$ on P port and ADDR = $V_{DD(P)}$;<br>$I_O$ = 0 mA; I/O = inputs; $f_{SCL}$ = 400 kHz | | | | | |
| | | $V_{DD(P)}$ = 3.6 V to 5.5 V | | - | 10 | 25 | µA |
| | | $V_{DD(P)}$ = 2.3 V to 3.6 V | | - | 6.5 | 15 | µA |
| | | $V_{DD(P)}$ = 1.65 V to 2.3 V | | - | 4 | 9 | µA |
| | | $I_{DD(I2C\text{-}bus)} + I_{DD(P)}$;<br>SCL, SDA, P port, ADDR, $\overline{RESET}$;<br>$V_I$ on SCL, SDA and $\overline{RESET} = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$;<br>$V_I$ on P port and ADDR = $V_{DD(P)}$;<br>$I_O$ = 0 mA; I/O = inputs; $f_{SCL}$ = 0 kHz | | | | | |
| | | $V_{DD(P)}$ = 3.6 V to 5.5 V | | - | 1.5 | 7 | µA |
| | | $V_{DD(P)}$ = 2.3 V to 3.6 V | | - | 1 | 3.2 | µA |
| | | $V_{DD(P)}$ = 1.65 V to 2.3 V | | - | 0.5 | 1.7 | µA |
| | | Active mode; $I_{DD(I2C\text{-}bus)} + I_{DD(P)}$;<br>P port, ADDR, $\overline{RESET}$;<br>$V_I$ on $\overline{RESET} = V_{DD(I2C\text{-}bus)}$;<br>$V_I$ on P port and ADDR = $V_{DD(P)}$;<br>$I_O$ = 0 mA; I/O = inputs;<br>$f_{SCL}$ = 400 kHz, continuous register read | | | | | |
| | | $V_{DD(P)}$ = 3.6 V to 5.5 V | | - | 60 | 125 | µA |
| | | $V_{DD(P)}$ = 2.3 V to 3.6 V | | - | 40 | 75 | µA |
| | | $V_{DD(P)}$ = 1.65 V to 2.3 V | | - | 20 | 45 | µA |
| | | with pull-ups enabled (PCAL6416A only);<br>$I_{DD(I2C\text{-}bus)} + I_{DD(P)}$; P port, ADDR, $\overline{RESET}$;<br>$V_I$ on SCL, SDA and $\overline{RESET} = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$;<br>$V_I$ on P port = $V_{SS}$;<br>$V_I$ on ADDR = $V_{DD(I2C\text{-}bus)}$ or $V_{SS}$;<br>$I_O$ = 0 mA; I/O = inputs with pull-up enabled;<br>$f_{SCL}$ = 0 kHz | | | | | |
| | | $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | 1.1 | 1.5 | mA |


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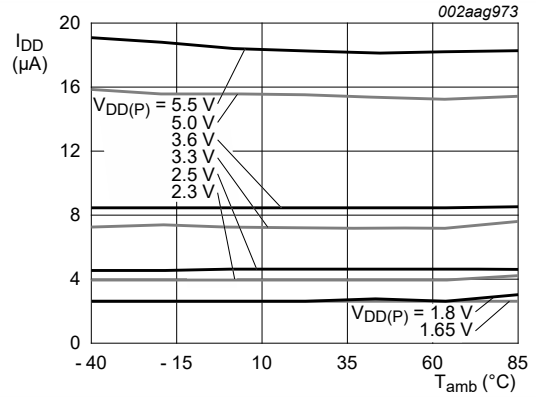
**Table 34. Static characteristics**...*continued*

*$T_{amb}$ = -40 °C to +85 °C; $V_{DD(I2C\text{-}bus)}$ = 1.65 V to 5.5 V; unless otherwise specified.*

| Symbol | Parameter | Conditions | | Min | Typ[1] | Max | Unit |
|---|---|---|---|---|---|---|---|
| $\Delta I_{DD}$ | additional quiescent supply current[5] | SCL, SDA, $\overline{RESET}$; one input at $V_{DD(I2C\text{-}bus)}$ - 0.6 V, other inputs at $V_{DD(I2C\text{-}bus)}$ or $V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | - | 25 | µA |
| | | P port, ADDR; one input at $V_{DD(P)}$ - 0.6 V, other inputs at $V_{DD(P)}$ or $V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | - | 80 | µA |
| $C_i$ | input capacitance | $V_I = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | 6 | 7 | pF |
| $C_{io}$ | input/output capacitance | $V_{I/O} = V_{DD(I2C\text{-}bus)}$ or $V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | 7 | 8 | pF |
| | | $V_{I/O} = V_{DD(P)}$ or $V_{SS}$; $V_{DD(P)}$ = 1.65 V to 5.5 V | | - | 7.5 | 8.5 | pF |
| $R_{pu(int)}$ | internal pull-up resistance | input/output | | 50 | 100 | 150 | kΩ |
| $R_{pd(int)}$ | internal pull-down resistance | input/output | | 50 | 100 | 150 | kΩ |

[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 °C. Except for $I_{DD}$, the typical values are at $V_{DD(P)} = V_{DD(I2C\text{-}bus)}$ = 3.3 V and $T_{amb}$ = 25 °C.
[2] The total current sourced by all I/Os must be limited to 160 mA.
[3] Each I/O must be externally limited to a maximum of 25 mA and each octal (P0_0 to P0_7 and P1_0 to P1_7) must be limited to a maximum current of 100 mA, for a device total of 200 mA.
[4] Typical value for $T_{amb}$ = 25 °C. $V_{OL}$ = 0.4 V and $V_{DD(I2C\text{-}bus)} = V_{DD(P)}$ = 3.3 V. Typical value for $V_{DD(I2C\text{-}bus)} = V_{DD(P)} < 2.5$ V, $V_{OL}$ = 0.6 V.
[5] Internal pull-up/pull-down resistors disabled.

## 13.1 Typical characteristics




$I_{DD} = I_{DD(I2C\text{-}bus)} + I_{DD(P)}$

**Figure 25. Supply current versus ambient temperature**

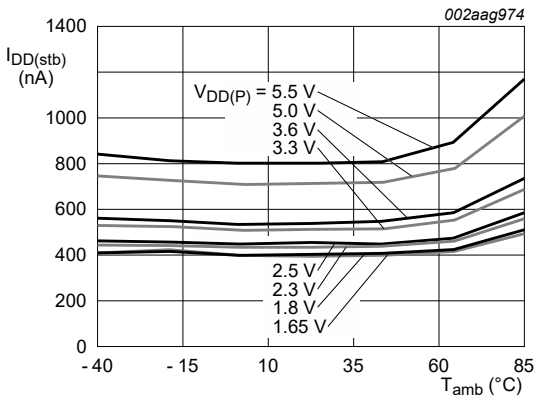
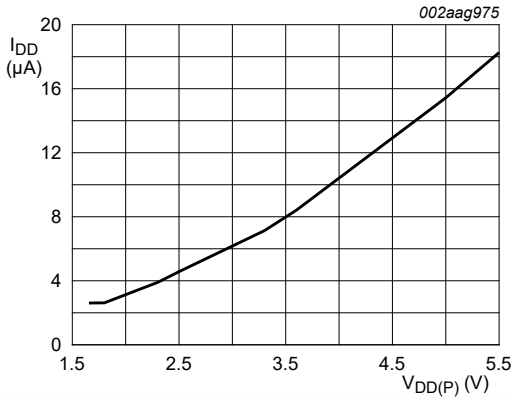



**Figure 26. Standby supply current versus ambient temperature**


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$T_{amb}$ = 25 °C

$I_{DD} = I_{DD(I2C\text{-}bus)} + I_{DD(P)}$

**Figure 27. Supply current versus supply voltage**

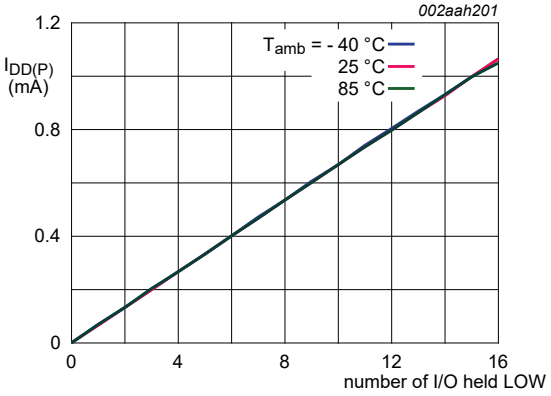
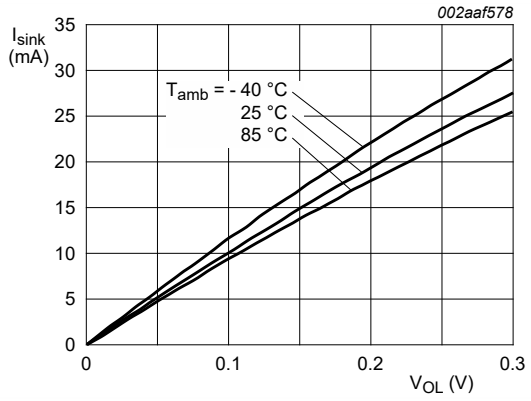


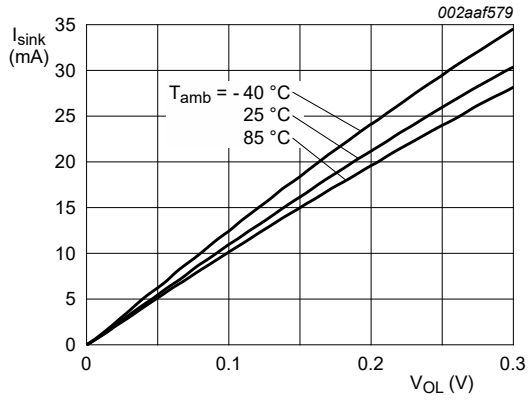

**Figure 28. Supply current versus number of I/O held LOW**


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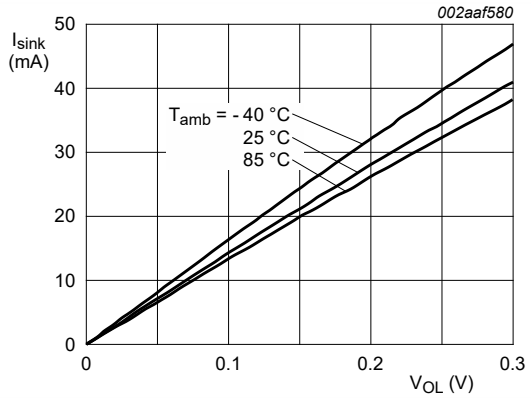
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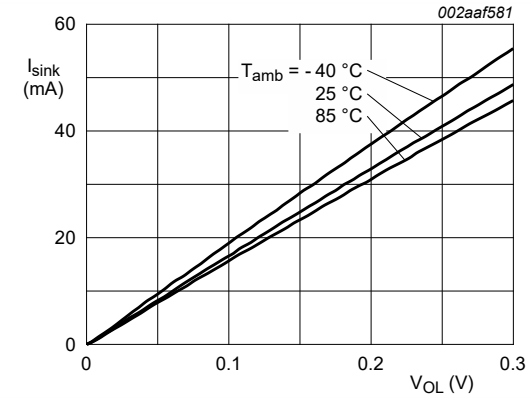

a. $V_{DD(P)}$ = 1.65 V



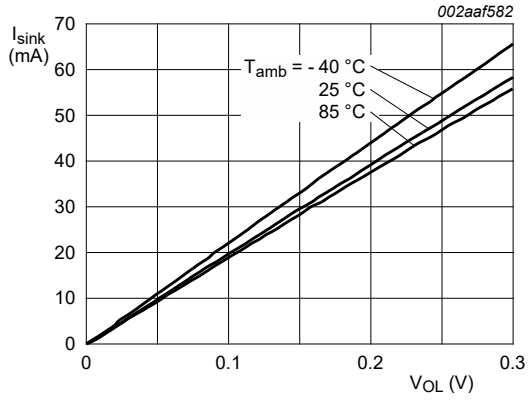

b. $V_{DD(P)}$ = 1.8 V



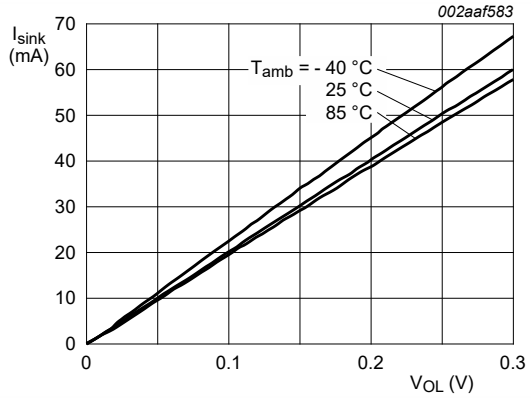

c. $V_{DD(P)}$ = 2.5 V




d. $V_{DD(P)}$ = 3.3 V




e. $V_{DD(P)}$ = 5.0 V

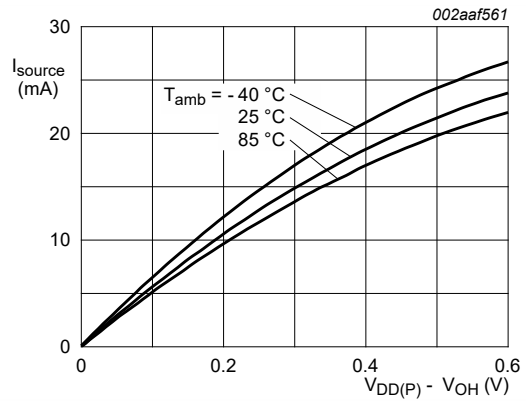



f. $V_{DD(P)}$ = 5.5 V

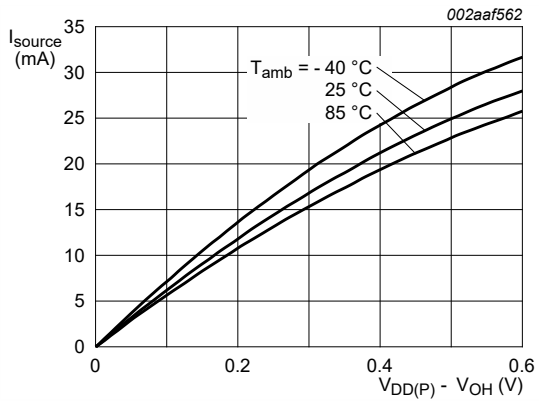
**Figure 29. I/O sink current versus LOW-level output voltage with CCX.X = 11b**


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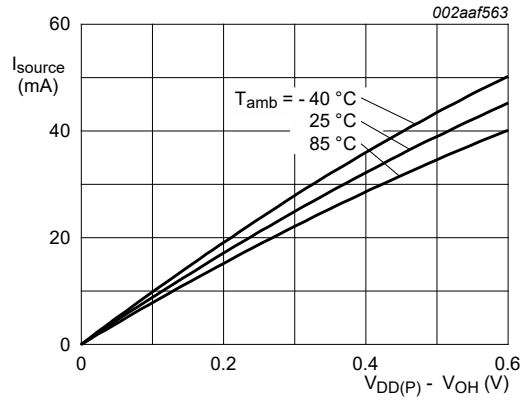
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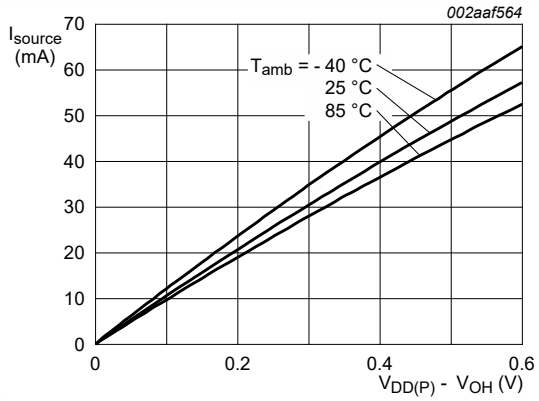

a. $V_{DD(P)}$ = 1.65 V



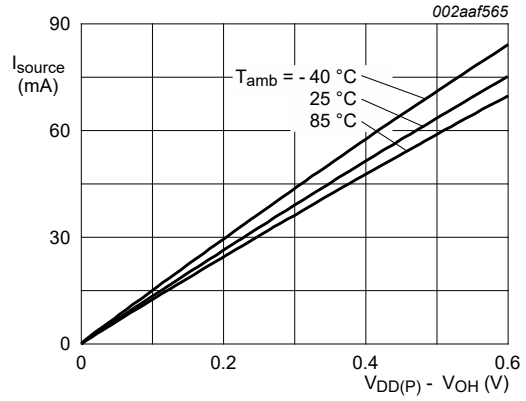

b. $V_{DD(P)}$ = 1.8 V



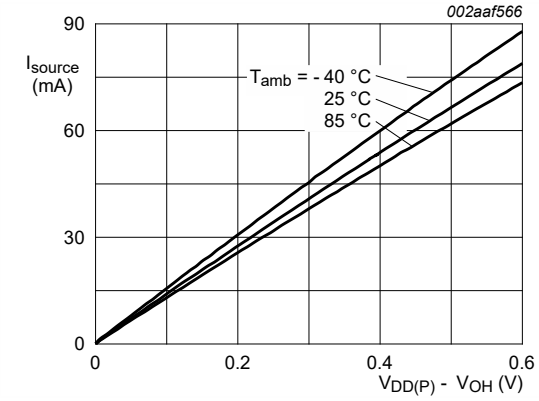

c. $V_{DD(P)}$ = 2.5 V




d. $V_{DD(P)}$ = 3.3 V




e. $V_{DD(P)}$ = 5.0 V

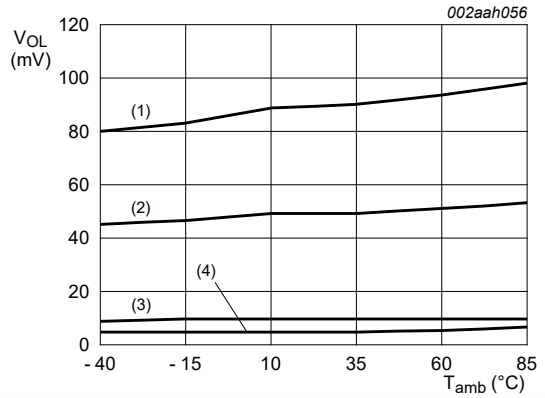



f. $V_{DD(P)}$ = 5.5 V

**Figure 30. I/O source current versus HIGH-level output voltage with CCX.X = 11b**

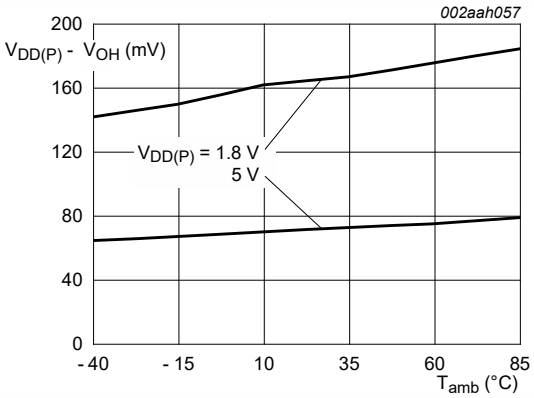

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1. $V_{DD(P)}$ = 1.8 V; $I_{sink}$ = 10 mA
2. $V_{DD(P)}$ = 5 V; $I_{sink}$ = 10 mA
3. $V_{DD(P)}$ = 1.8 V; $I_{sink}$ = 1 mA
4. $V_{DD(P)}$ = 5 V; $I_{sink}$ = 1 mA

**Figure 31. LOW-level output voltage versus temperature with CCX.X = 11b**




$I_{source}$ = -10 mA

**Figure 32. I/O high voltage versus temperature with CCX.X = 11b**

# 14 Dynamic characteristics

**Table 35. I²C-bus interface timing requirements**

*Over recommended operating free air temperature range, unless otherwise specified. See Figure 34.*

| Symbol | Parameter | Conditions | Standard-mode I²C-bus | | Fast-mode I²C-bus | | Unit |
|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | |
| $f_{SCL}$ | SCL clock frequency | | 0 | 100 | 0 | 400 | kHz |
| $t_{HIGH}$ | HIGH period of the SCL clock | | 4 | - | 0.6 | - | µs |
| $t_{LOW}$ | LOW period of the SCL clock | | 4.7 | - | 1.3 | - | µs |
| $t_{SP}$ | pulse width of spikes that must be suppressed by the input filter | | 0 | 50 | 0 | 50 | ns |
| $t_{SU;DAT}$ | data set-up time | | 250 | - | 100 | - | ns |
| $t_{HD;DAT}$ | data hold time | | 0 | - | 0 | - | ns |
| $t_r$ | rise time of both SDA and SCL signals | | - | 1000 | 20 | 300 | ns |
| $t_f$ | fall time of both SDA and SCL signals | | - | 300 | 20 × ($V_{DD}$ / 5.5 V) | 300 | ns |
| $t_{BUF}$ | bus free time between a STOP and START condition | | 4.7 | - | 1.3 | - | µs |
| $t_{SU;STA}$ | set-up time for a repeated START condition | | 4.7 | - | 0.6 | - | µs |
| $t_{HD;STA}$ | hold time (repeated) START condition | | 4 | - | 0.6 | - | µs |
| $t_{SU;STO}$ | set-up time for STOP condition | | 4 | - | 0.6 | - | µs |
| $t_{VD;DAT}$ | data valid time | SCL LOW to SDA output valid | - | 3.45 | - | 0.9 | µs |


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**Table 35. I²C-bus interface timing requirements**...*continued*

*Over recommended operating free air temperature range, unless otherwise specified. See Figure 34.*

| Symbol | Parameter | Conditions | Standard-mode I²C-bus | | Fast-mode I²C-bus | | Unit |
|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | |
| $t_{VD;ACK}$ | data valid acknowledge time | ACK signal from SCL LOW to SDA (out) LOW | - | 3.45 | - | 0.9 | µs |

**Table 36. Reset timing requirements**

*Over recommended operating free air temperature range, unless otherwise specified. See Figure 36.*

| Symbol | Parameter | Conditions | | Standard-mode I²C-bus | | Fast-mode I²C-bus | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | Min | Max | |
| $t_{w(rst)}$ | reset pulse width | | | 30 | - | 30 | - | ns |
| $t_{rec(rst)}$ | reset recovery time | | | 200 | - | 200 | - | ns |
| $t_{rst}$ | reset time | | [1] | 600 | - | 600 | - | ns |

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

**Table 37. Switching characteristics**

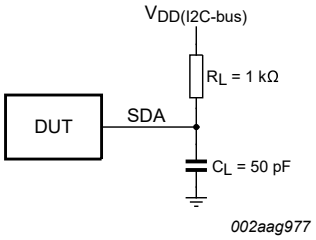
*Over recommended operating free air temperature range; $C_L \leq 100$ pF; unless otherwise specified. See Figure 35.*

| Symbol | Parameter | Conditions | | Standard-mode I²C-bus | | Fast-mode I²C-bus | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | Min | Max | |
| $t_{v(INT)}$ | valid time on pin $\overline{INT}$ | from P port to $\overline{INT}$ | | - | 1 | - | 1 | µs |
| $t_{rst(INT)}$ | reset time on pin $\overline{INT}$ | from SCL to $\overline{INT}$ | | - | 1 | - | 1 | µs |
| $t_{v(Q)}$ | 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 |

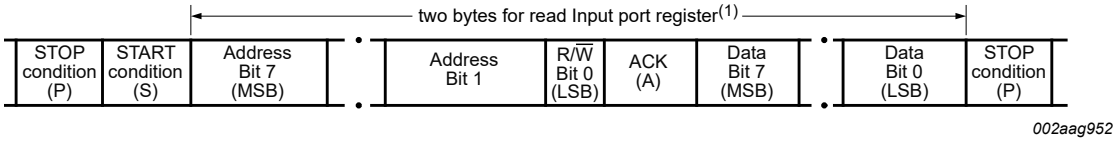

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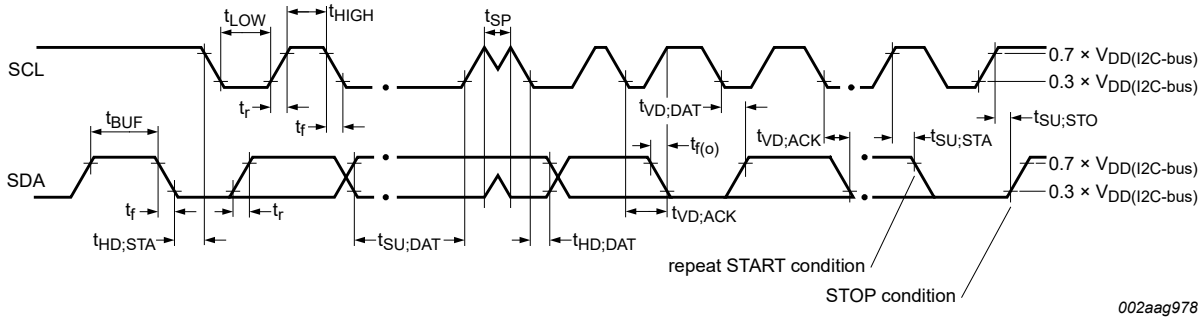
## 15 Parameter measurement information




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 ≤ 10 MHz; $Z_o$ = 50 Ω; $t_r/t_f$ ≤ 30 ns.

All parameters and waveforms are not applicable to all devices.

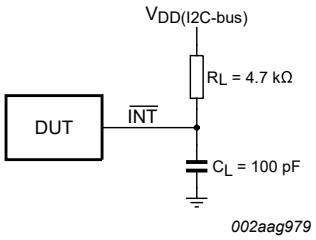
Byte 1 = I²C-bus address; Byte 2, byte 3 = P port data.

1. See Figure 16.

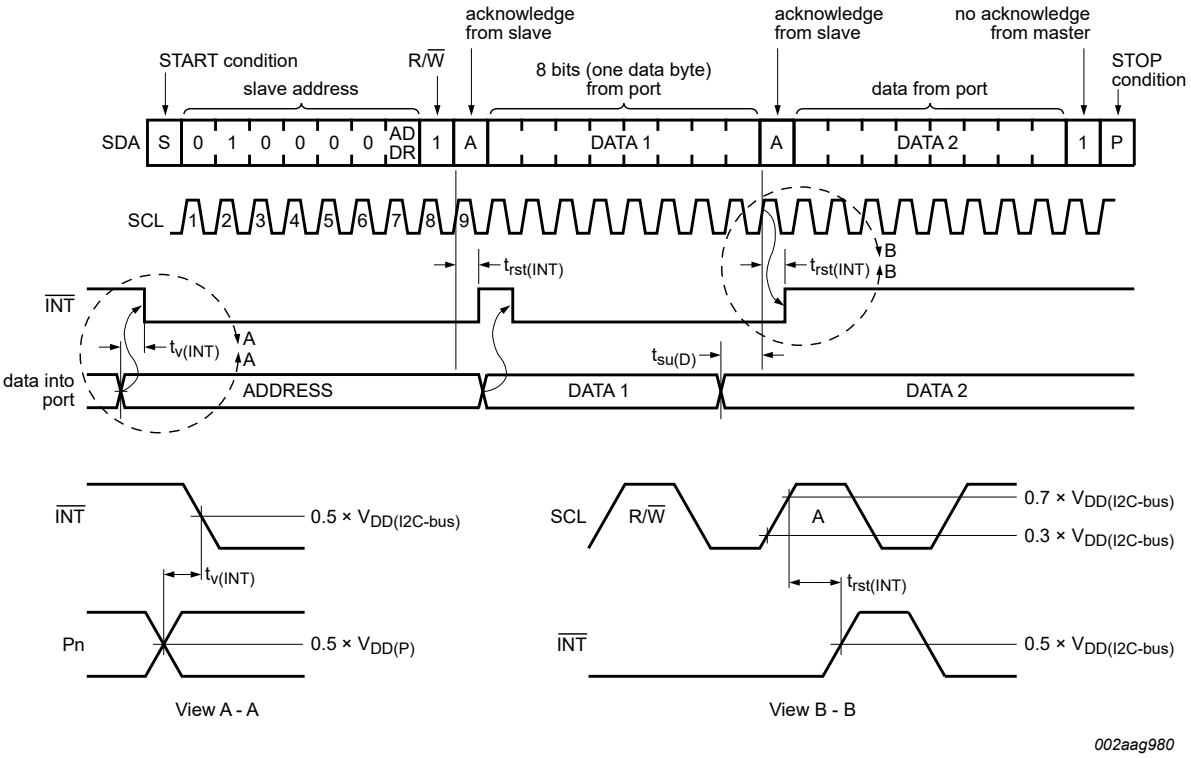
**Figure 33. I²C-bus interface load circuit and voltage waveforms**


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a. Interrupt load configuration




b. Voltage waveforms

$C_L$ includes probe and jig capacitance.

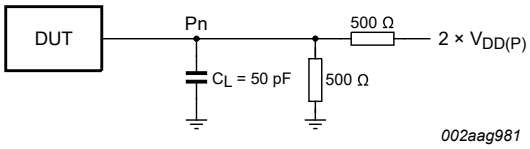
All inputs are supplied by generators having the following characteristics: PRR ≤ 10 MHz; $Z_o$ = 50 Ω; $t_r/t_f$ ≤ 30 ns.

All parameters and waveforms are not applicable to all devices.

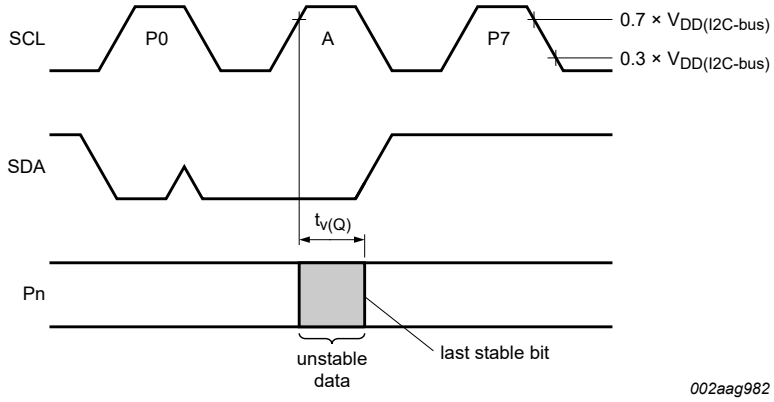
**Figure 34. Interrupt load circuit and voltage waveforms**


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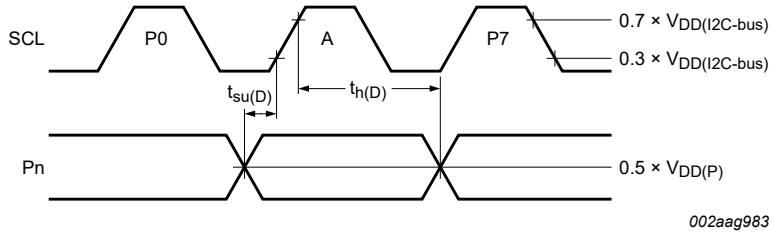
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a. P port load configuration




b. Write mode (R/$\overline{W}$ = 0)




$C_L$ includes probe and jig capacitance.

$t_{v(Q)}$ is measured from 0.7 × $V_{DD}$ on SCL to 50 % I/O (Pn) output.

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

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

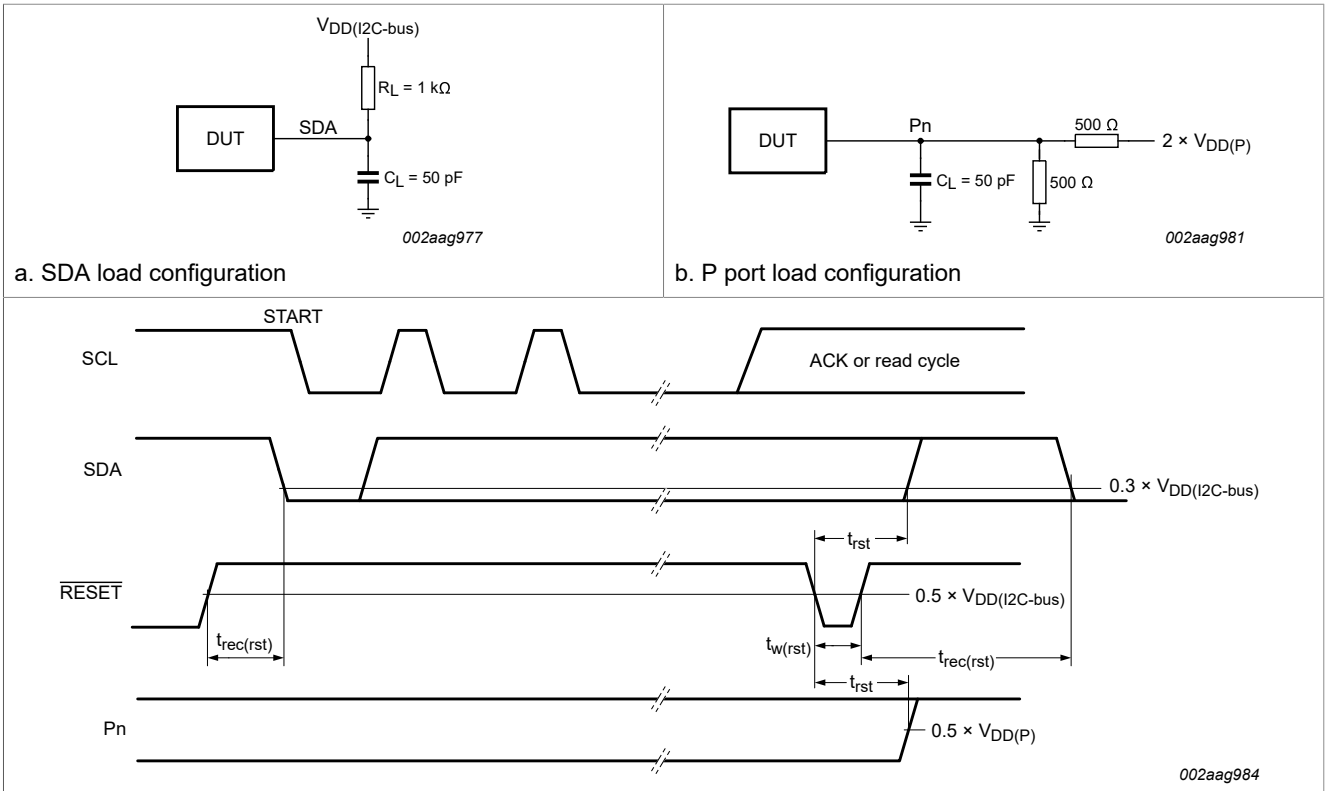
All parameters and waveforms are not applicable to all devices.

c. Read mode (R/$\overline{W}$ = 1)

**Figure 35. P port load circuit and voltage waveforms**


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a. SDA load configuration

b. P port load configuration

$C_L$ includes probe and jig capacitance.

All inputs are supplied by generators having the following characteristics: PRR ≤ 10 MHz; $Z_o$ = 50 Ω; $t_r/t_f$ ≤ 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.

c. $\overline{\text{RESET}}$ timing

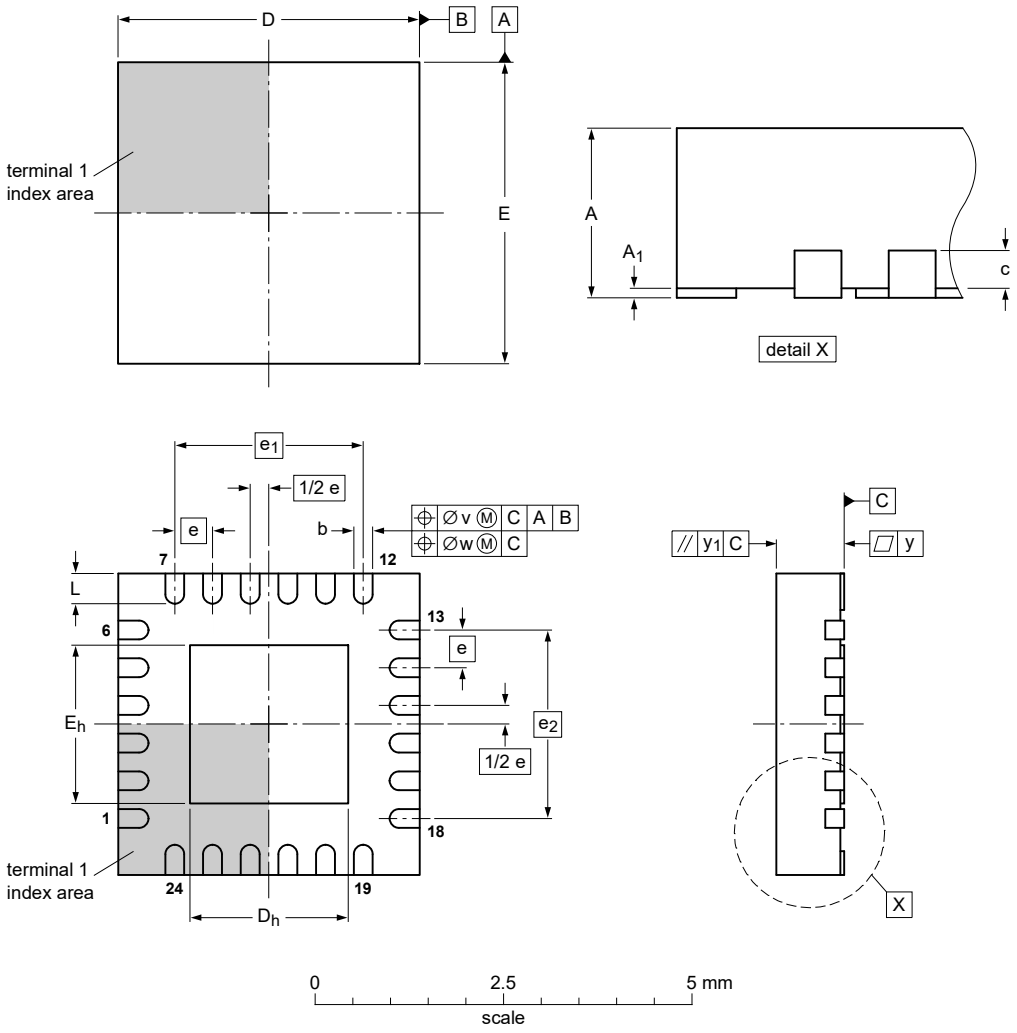
**Figure 36. Reset load circuits and voltage waveforms**


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# 16 Package outline

**HWQFN24: plastic thermal enhanced very very thin quad flat package; no leads; 24 terminals; body 4 x 4 x 0.75 mm** **SOT994-1**




**DIMENSIONS (mm are the original dimensions)**

| UNIT | A(1) max | $A_1$ | b | c | D(1) | $D_h$ | E(1) | $E_h$ | e | $e_1$ | $e_2$ | L | v | w | y | $y_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | 0.8 | 0.05<br>0.00 | 0.30<br>0.18 | 0.2 | 4.1<br>3.9 | 2.25<br>1.95 | 4.1<br>3.9 | 2.25<br>1.95 | 0.5 | 2.5 | 2.5 | 0.5<br>0.3 | 0.1 | 0.05 | 0.05 | 0.1 |

**Note**

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

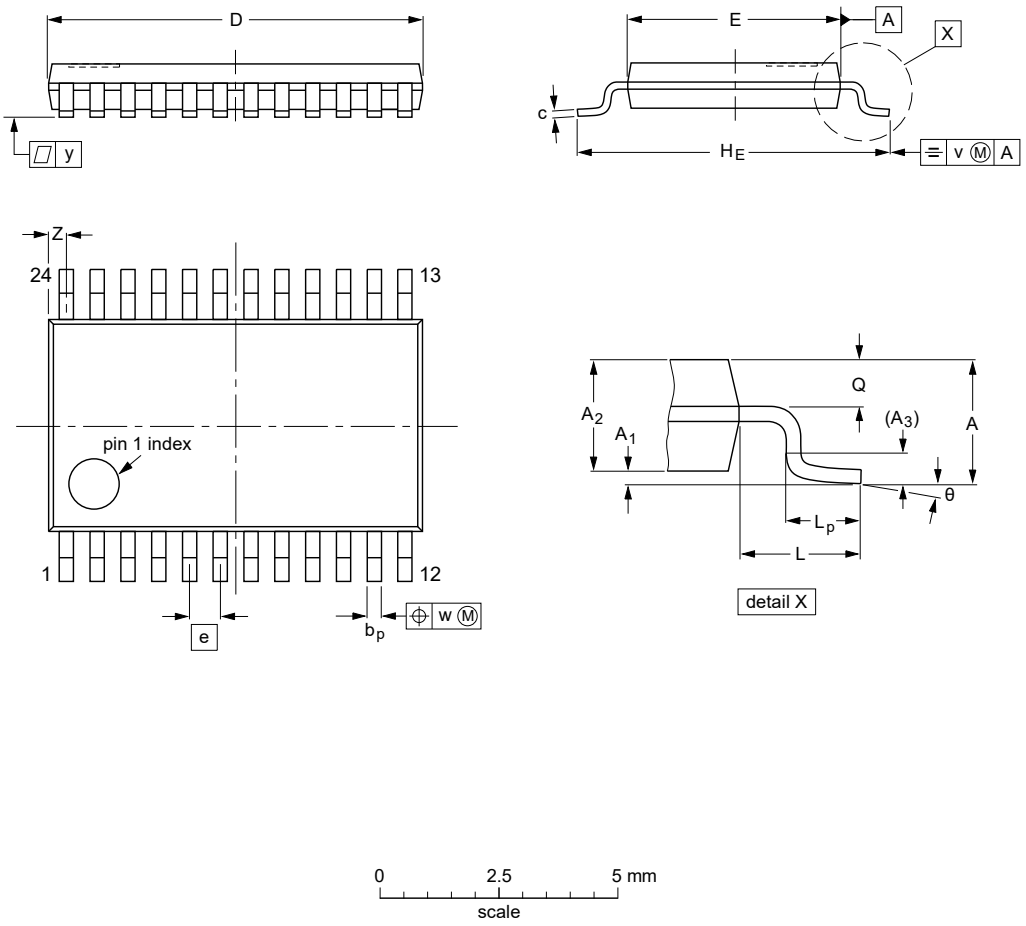
| OUTLINE VERSION | REFERENCES | | | | EUROPEAN PROJECTION | ISSUE DATE |
|---|---|---|---|---|---|---|
| | IEC | JEDEC | JEITA | | | |
| SOT994-1 | - - - | MO-220 | - - - | | | ~~07-02-07~~<br>07-03-03 |

**Figure 37. Package outline SOT994-1 (HWQFN24)**


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**TSSOP24: plastic thin shrink small outline package; 24 leads; body width 4.4 mm** **SOT355-1**




**DIMENSIONS (mm are the original dimensions)**

| UNIT | A max. | $A_1$ | $A_2$ | $A_3$ | $b_p$ | c | $D^{(1)}$ | $E^{(2)}$ | e | $H_E$ | L | $L_p$ | Q | v | w | y | $Z^{(1)}$ | θ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | 1.1 | 0.15<br>0.05 | 0.95<br>0.80 | 0.25 | 0.30<br>0.19 | 0.2<br>0.1 | 7.9<br>7.7 | 4.5<br>4.3 | 0.65 | 6.6<br>6.2 | 1 | 0.75<br>0.50 | 0.4<br>0.3 | 0.2 | 0.13 | 0.1 | 0.5<br>0.2 | $8^o$<br>$0^o$ |

**Notes**

1. Plastic or metal protrusions of 0.15 mm maximum per side are not included.
2. Plastic interlead protrusions of 0.25 mm maximum per side are not included.

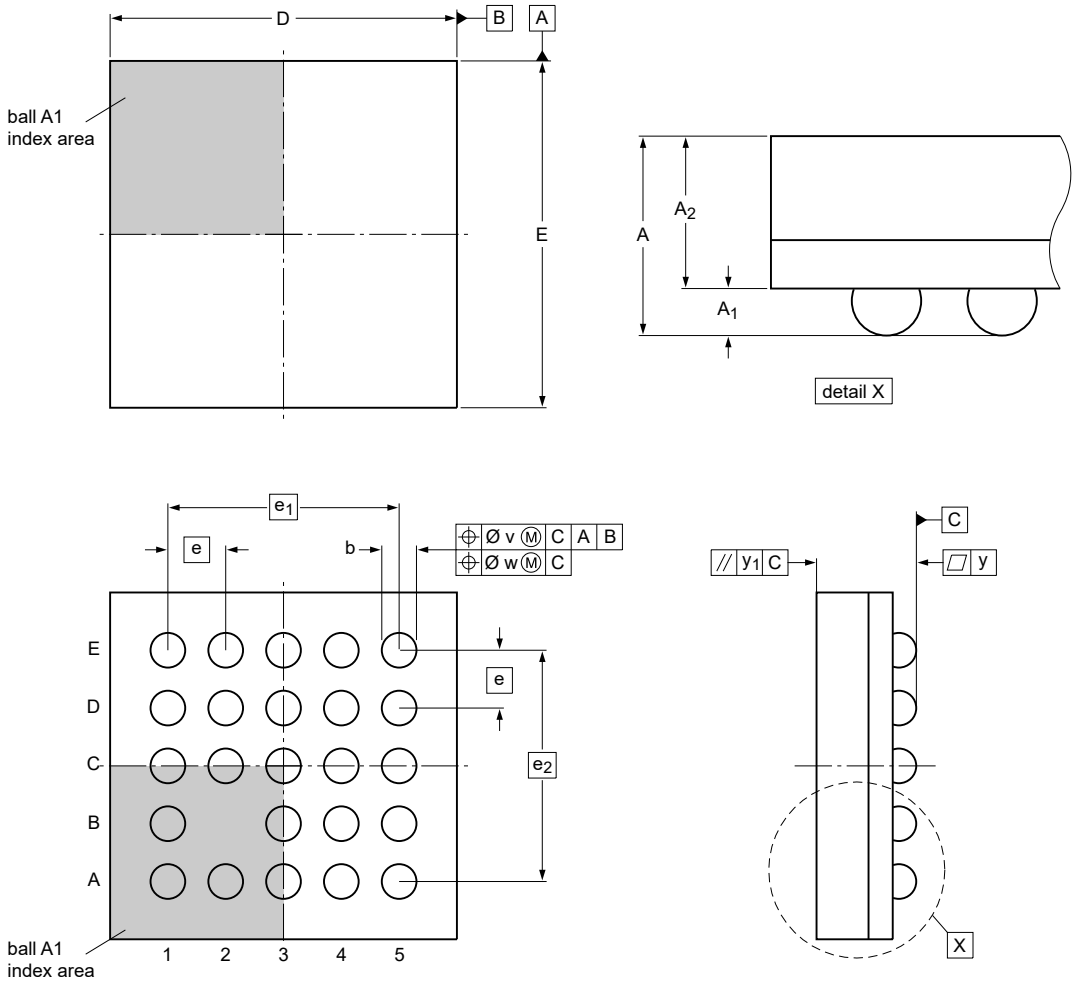
| OUTLINE VERSION | REFERENCES | | | | EUROPEAN PROJECTION | ISSUE DATE |
|---|---|---|---|---|---|---|
| | IEC | JEDEC | JEITA | | | |
| SOT355-1 | | MO-153 | | | | ~~99-12-27~~<br>03-02-19 |

**Figure 38. Package outline SOT355-1 (TSSOP24)**


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**VFBGA24: plastic very thin fine-pitch ball grid array package; 24 balls; body 3 x 3 x 0.85 mm** **SOT1199-1**




Dimensions

| Unit | | A | $A_1$ | $A_2$ | b | D | E | e | $e_1$ | $e_2$ | v | w | y | $y_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | max | 1.00 | 0.25 | 0.75 | 0.35 | 3.1 | 3.1 | | | | | | | |
| | nom | 0.85 | 0.20 | 0.65 | 0.30 | 3.0 | 3.0 | 0.5 | 2 | 2 | 0.15 | 0.05 | 0.08 | 0.1 |
| | min | 0.75 | 0.15 | 0.60 | 0.25 | 2.9 | 2.9 | | | | | | | |

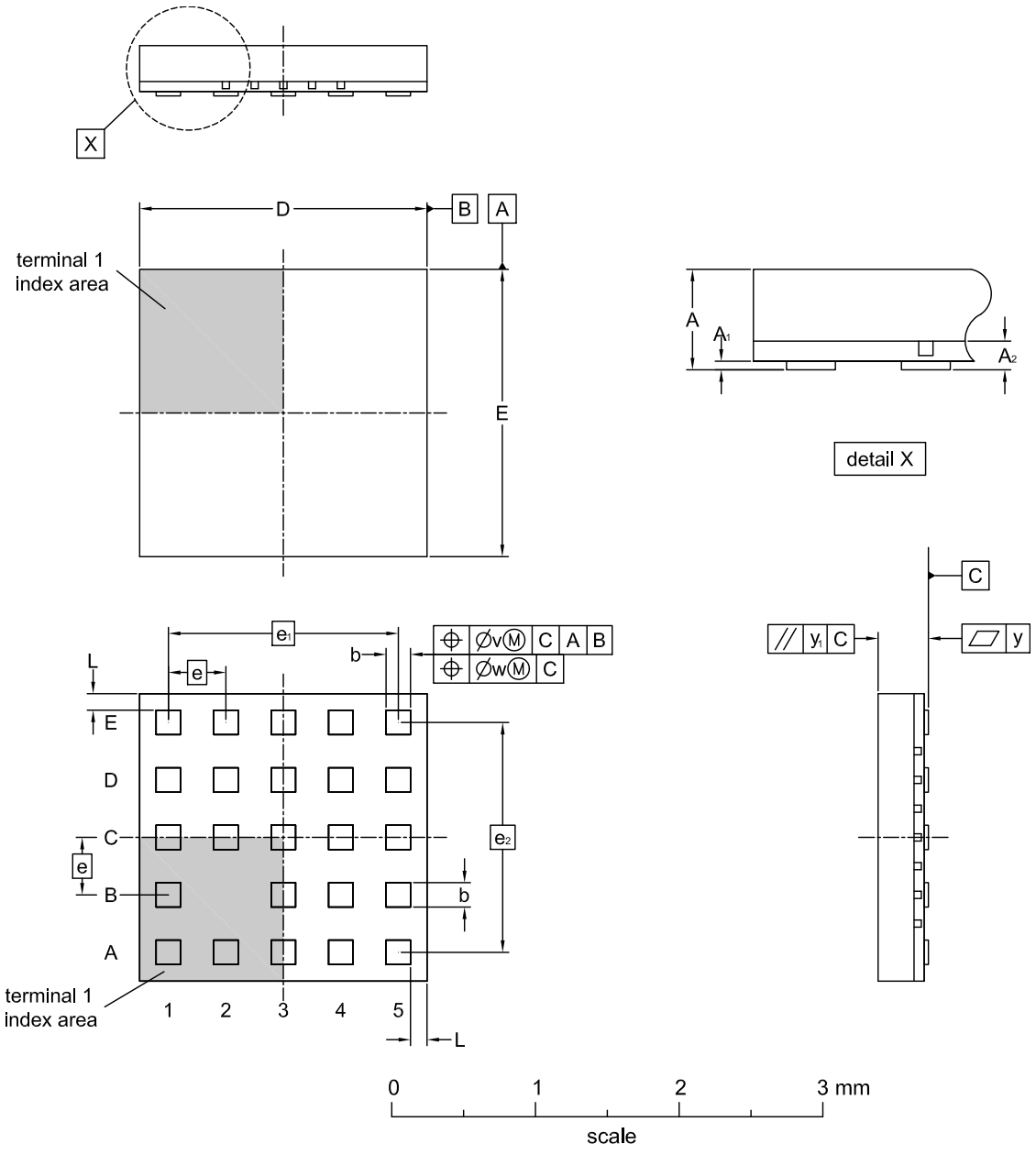
*sot1199-1_po*

| Outline version | References | | | | European projection | Issue date |
|---|---|---|---|---|---|---|
| | IEC | JEDEC | JEITA | | | |
| SOT1199-1 | | - - - | | | | ~~11-02-16~~ 12-03-13 |

**Figure 39. Package outline SOT1199-1 (VFBGA24)**


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Dimensions (mm are the original dimensions)

| UNIT | | A | $A_1$ | $A_2$ | b | D | E | e | $e_1$ | $e_2$ | L | v | w | y | $y_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | MAX | 0.40 | 0.05 | | 0.22 | 2.10 | 2.10 | | | | | | | | |
| | NOM | 0.35 | | 0.10 | 0.17 | 2.00 | 2.00 | 0.4 | 1.6 | 1.6 | 0.12 | 0.15 | 0.05 | 0.10 | 0.10 |
| | MIN | 0.30 | 0.00 | | 0.12 | 1.90 | 1.90 | | | | | | | | |

**Figure 40. Package outline SOT1895-1 (X2QFN24)**


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# 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:


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- Lead-free versus SnPb soldering; note that a lead-free reflow process usually leads to higher minimum peak temperatures (see Figure 41) 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 38 and Table 39

**Table 38. SnPb eutectic process (from J-STD-020D)**

| Package thickness (mm) | Package reflow temperature (°C) | |
|---|---|---|
| | Volume (mm³) | |
| | < 350 | ≥ 350 |
| < 2.5 | 235 | 220 |
| ≥ 2.5 | 220 | 220 |

**Table 39. Lead-free process (from J-STD-020D)**

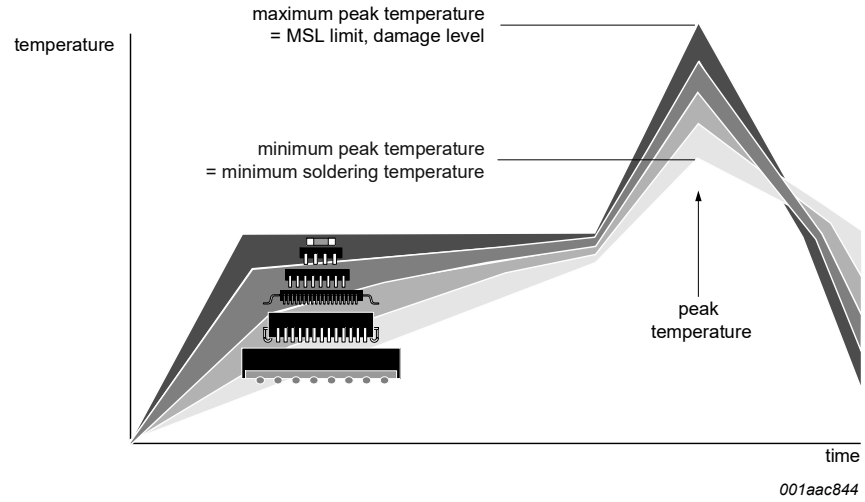
| Package thickness (mm) | Package reflow temperature (°C) | | |
|---|---|---|---|
| | Volume (mm³) | | |
| | < 350 | 350 to 2000 | > 2000 |
| < 1.6 | 260 | 260 | 260 |
| 1.6 to 2.5 | 260 | 250 | 245 |
| > 2.5 | 250 | 245 | 245 |

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 41.


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MSL: Moisture Sensitivity Level

**Figure 41. Temperature profiles for large and small components**

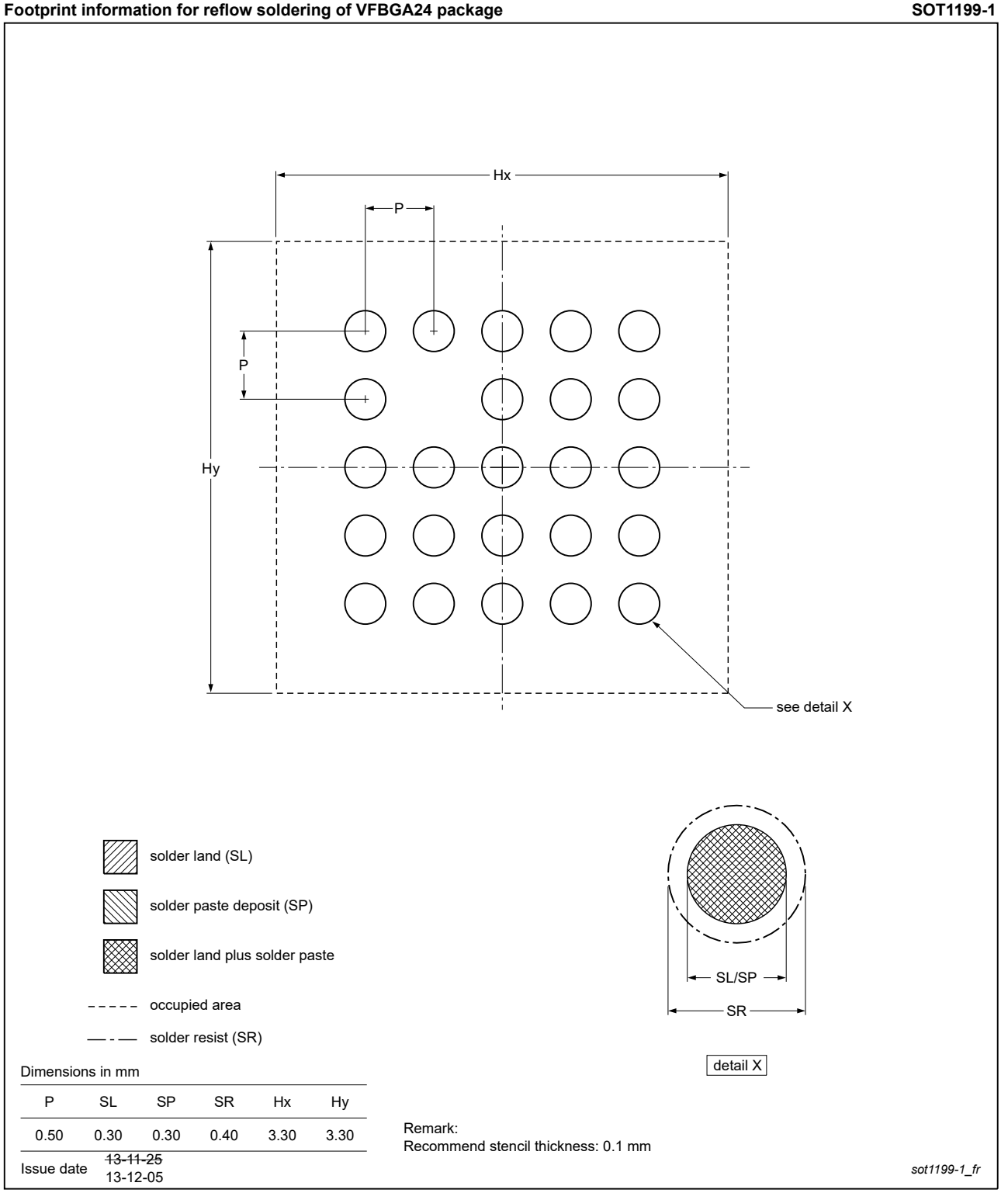
For further information on temperature profiles, refer to Application Note *AN10365 "Surface mount reflow soldering description"*.


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## 18 Soldering: PCB footprints

**Footprint information for reflow soldering of VFBGA24 package** **SOT1199-1**




Dimensions in mm

| P | SL | SP | SR | Hx | Hy |
|---|---|---|---|---|---|
| 0.50 | 0.30 | 0.30 | 0.40 | 3.30 | 3.30 |

Issue date ~~13-11-25~~ 13-12-05

Remark:
Recommend stencil thickness: 0.1 mm

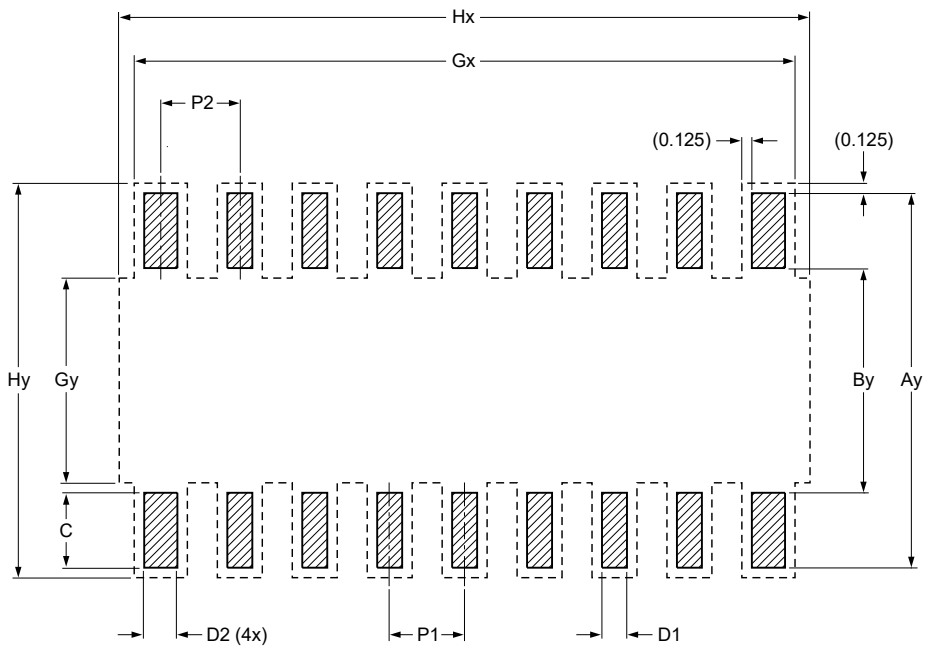
*sot1199-1_fr*

**Figure 42. PCB footprint for SOT1199-1 (VFBGA24); reflow soldering**


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**Footprint information for reflow soldering of TSSOP24 package** **SOT355-1**




Generic footprint pattern

Refer to the package outline drawing for actual layout

solder land

occupied area

DIMENSIONS in mm

| P1 | P2 | Ay | By | C | D1 | D2 | Gx | Gy | Hx | Hy |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.650 | 0.750 | 7.200 | 4.500 | 1.350 | 0.400 | 0.600 | 8.200 | 5.300 | 8.600 | 7.450 |

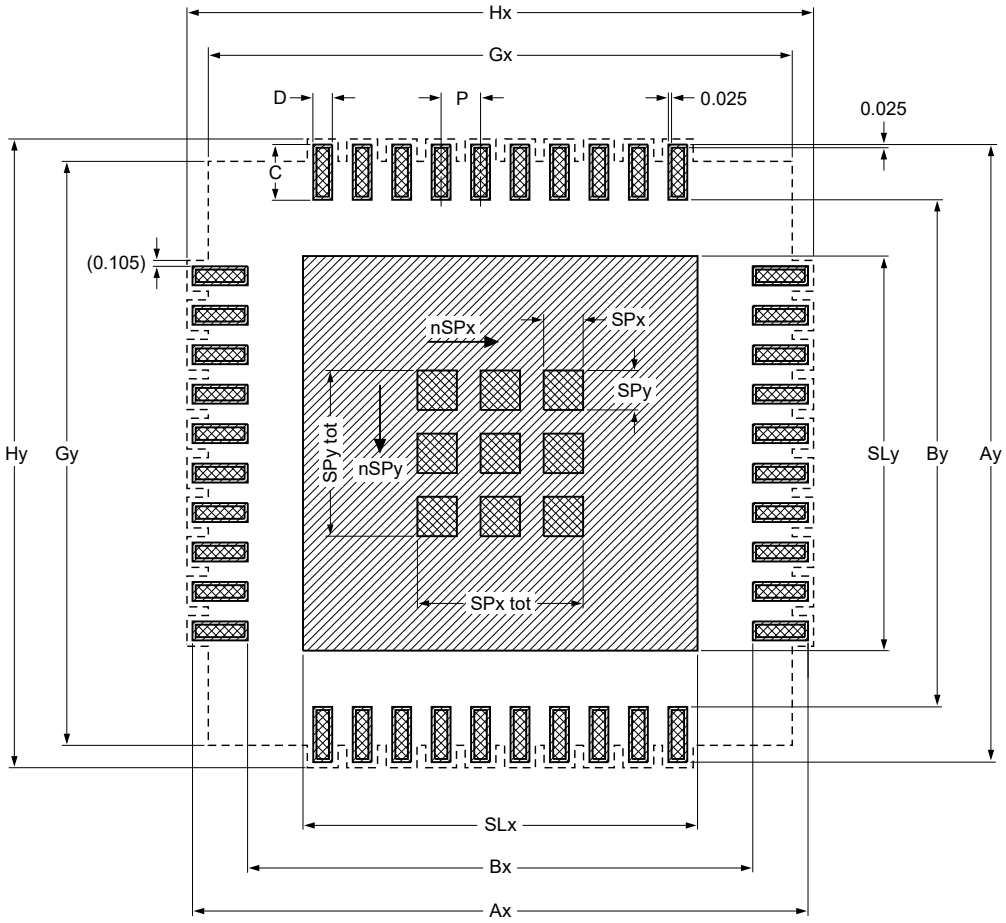
*sot355-1_fr*

**Figure 43. PCB footprint for SOT355-1 (TSSOP24); reflow soldering**


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**Footprint information for reflow soldering of HVQFN24 package** **SOT994-1**




Generic footprint pattern

Refer to the package outline drawing for actual layout

solder land

solder paste deposit

solder land plus solder paste

occupied area

| nSPx | nSPy |
|---|---|
| 2 | 2 |

Dimensions in mm

| P | Ax | Ay | Bx | By | C | D | SLx | SLy | SPx tot | SPy tot | SPx | SPy | Gx | Gy | Hx | Hy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.500 | 5.000 | 5.000 | 3.200 | 3.200 | 0.900 | 0.240 | 2.100 | 2.100 | 1.200 | 1.200 | 0.450 | 0.450 | 4.300 | 4.300 | 5.250 | 5.250 |

Issue date ~~07-09-24~~ 09-06-15 *sot994-1_fr*

**Figure 44. PCB footprint for SOT994-1 (HWQFN24); reflow soldering**


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**Footprint information for reflow soldering of X2QFN24 package** **SOT1895-1**

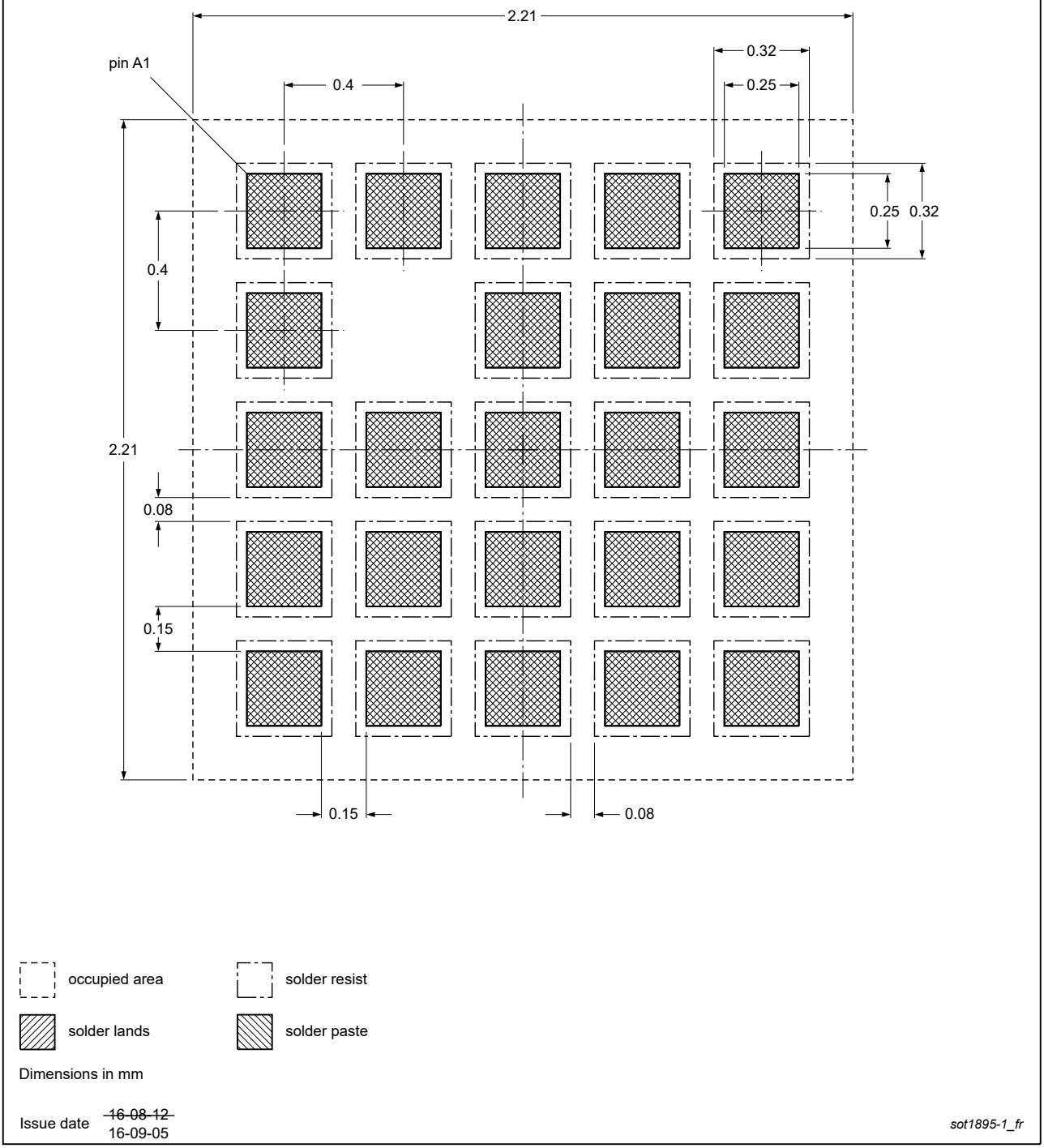



**Figure 45. PCB footprint for SOT1895-1 (X2QFN24); reflow soldering**


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# 19 Abbreviations

**Table 40. Abbreviations**

| Acronym | Description |
|---|---|
| ESD | ElectroStatic Discharge |
| FET | Field-Effect Transistor |
| GPIO | General Purpose Input/Output |
| $I^2C$-bus | Inter-Integrated Circuit bus |
| I/O | Input/Output |
| LED | Light-Emitting Diode |
| LSB | Least Significant Bit |
| MSB | Most Significant Bit |
| PCB | Printed-Circuit Board |
| POR | Power-On Reset |
| SMBus | System Management Bus |

# 20 Revision history

**Table 41. Revision history**

| Document ID | Release date | Data sheet status | Change notice | Supersedes |
|---|---|---|---|---|
| PCAL6416A v.7 | 20210330 | Product data sheet | - | PCAL6416A v.6.2 |
| Modifications: | • Removed discontinued packages PCAL6416AEX, PCAL6416AER<br>• Corrected Figure 6 | | | |
| PCAL6416A v.6.2 | 20170407 | Product data sheet | - | PCAL6416A v.6.1 |
| Modifications: | • Added "land grid array" to description of X2QFN24<br>• Removed "PCAL6416AEX1/X2QFN16" from Figure 6 "Pin configuration for XFBGA24 (2 mm ´ 2 mm); EX option"<br>• Added Figure 7 "Pin configuration for X2QFN24 (2 mm ´ 2 mm); EX1 land grid array option" | | | |
| PCAL6416A v.6.1 | 20161103 | Product data sheet | - | PCAL6416A v.6 |
| Modifications: | • Added PCAL6416AEX1 | | | |
| PCAL6416A v.6 | 20141009 | Product data sheet | - | PCAL6416A v.5 |
| Modifications: | • Table 1: PCAL6416AEX topside mark changed from "L16" to "L6X" | | | |
| PCAL6416A v.5 | 20131210 | Product data sheet | - | PCAL6416A v.4 |
| PCAL6416A v.4 | 20130506 | Product data sheet | - | PCAL6416A v.3 |
| PCAL6416A v.3 | 20121224 | Product data sheet | - | PCAL6416A v.2 |
| PCAL6416A v.2 | 20121005 | Product data sheet | - | PCAL6416A v.1 |
| PCAL6416A v.1 | 20120808 | Product data sheet | - | - |


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# 21 Legal information

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| Document status[1][2] | Product status[3] | 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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