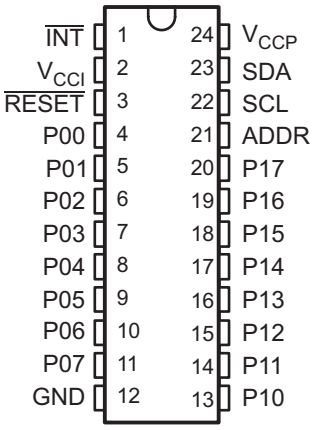
LOW-VOLTAGE 16-BIT I^2C AND SMBus I/O EXPANDER WITH INTERRUPT OUTPUT, RESET, AND CONFIGURATION REGISTERS

Check for Samples: TCA6416A

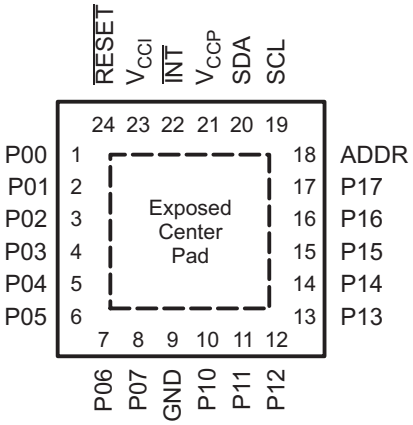
FEATURES

- **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 P Port**
  - **2.5-V SCL/SDA and 1.8-V, 2.5-V, 3.3-V, or 5-V P Port**
  - **3.3-V SCL/SDA and 1.8-V, 2.5-V, 3.3-V, or 5-V P Port**
  - **5-V SCL/SDA and 1.8-V, 2.5-V, 3.3-V, or 5-V P Port**
- **I^2C to Parallel Port Expander**
- **Low Standby Current Consumption of 3 µA**
- **Schmitt-Trigger Action Allows Slow Input Transition and Better Switching Noise Immunity at the SCL and SDA Inputs**
  - **V_{hys} = 0.18 V Typ at 1.8 V**
  - **V_{hys} = 0.25 V Typ at 2.5 V**
  - **V_{hys} = 0.33 V Typ at 3.3 V**
  - **V_{hys} = 0.5 V Typ 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 I^2C Bus**
- **Input/Output Configuration Register**
- **Polarity Inversion Register**
- **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 High-Current 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)**
  - **200-V Machine Model (A115-A)**
  - **1000-V Charged-Device Model (C101)**

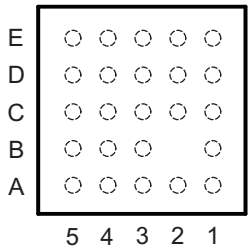
PW PACKAGE (TOP VIEW)



RTW PACKAGE (TOP VIEW)



ZQS PACKAGE (TOP VIEW)



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

DESCRIPTION/ORDERING INFORMATION

This 16-bit I/O expander for the two-line bidirectional bus (I^2C) is designed to provide general-purpose remote I/O expansion for most microcontroller families via the I^2C interface [serial clock (SCL) and serial data (SDA)].

The major benefit of this device is its wide V_{CC} range. It can operate from 1.65 V to 5.5 V on the P-port side and on the SDA/SCL side. This allows the TCA6416AA to interface with next-generation microprocessors and microcontrollers on the SDA/SCL side, where supply levels are dropping down to conserve power. In contrast to the dropping power supplies of microprocessors and microcontrollers, some PCB components, such as LEDs, remain at a 5-V power supply.

The bidirectional voltage level translation in the TCA6416A is provided through V_{CCI}. V_{CCI} should be connected to the V_{CC} of the external SCL/SDA lines. This indicates the V_{CC} level of the I^2C bus to the TCA6416A. The voltage level on the P-port of the TCA6416A is determined by the V_{CCP}.

The TCA6416A consists of two 8-bit Configuration (input or output selection), Input, Output, and Polarity Inversion (active high) registers. 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. All registers can be read by the system master.

The system master can reset the TCA6416A in the event of a timeout 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 I^2C/SMBus state machine. The $\overline{\text{RESET}}$ pin causes the same reset/initialization to occur without depowering the part.

The TCA6416A open-drain interrupt ($\overline{\text{INT}}$) 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.

$\overline{\text{INT}}$ can be connected to the interrupt input of a microcontroller. By sending an interrupt signal on this line, the remote I/O can inform the microcontroller if there is incoming data on its ports without having to communicate via the I^2C bus. Thus, the TCA6416A can remain a simple slave device.

The device P-port outputs have high-current sink capabilities for directly driving LEDs while consuming low device current.

One hardware pin (ADDR) can be used to program and vary the fixed I^2C address and allow up to two devices to share the same I^2C bus or SMBus.

ORDERING INFORMATION

T_A	PACKAGE(1) (2)		ORDERABLE PART NUMBER	TOP-SIDE MARKING
–40°C to 85°C	BGA – ZQS (Pb-free)	Reel of 2500	TCA6416AZQSR	PH416
	QFN – RTW	Reel of 3000	TCA6416ARTWR	PH416
	TSSOP – PW	Reel of 2000	TCA6416APWR	PH416

(1) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.
(2) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

Table 1. ZQS Package Terminal Assignments

E	P13	P11	P10	GND	P06
D	P15	P14	P12	P07	P05
C	P16	P17	P01	P04	P03
B	ADDR	V_{CCP}	V_{CCI}	NB	P02
A	SCL	SDA	$\overline{\text{INT}}$	$\overline{\text{RESET}}$	P00
	5	**4**	**3**	**2**	**1**

Table 2. TERMINAL FUNCTIONS

TERMINAL				DESCRIPTION
NO.			NAME	
TSSOP (PW)	QFN (RTW)	BGA (ZQS)		
1	22	A3	$\overline{INT}$	Interrupt output. Connect to V_{CCI} or V_{CCP} through a pullup resistor.
2	23	B3	V_{CCI}	Supply voltage of I^2C bus. Connect directly to the V_{CC} of the external I^2C master. Provides voltage-level translation.
3	24	A2	$\overline{RESET}$	Active-low reset input. Connect to V_{CCI} through a pullup resistor, if no active connection is used.
4	1	A1	P00	P-port input/output (push-pull design structure). At power on, P00 is configured as an input.
5	2	C3	P01	P-port input/output (push-pull design structure). At power on, P01 is configured as an input.
6	3	B1	P02	P-port input/output (push-pull design structure). At power on, P02 is configured as an input.
7	4	C1	P03	P-port input/output (push-pull design structure). At power on, P03 is configured as an input.
8	5	C2	P04	P-port input/output (push-pull design structure). At power on, P04 is configured as an input.
9	6	D1	P05	P-port input/output (push-pull design structure). At power on, P05 is configured as an input.
10	7	E1	P06	P-port input/output (push-pull design structure). At power on, P06 is configured as an input.
11	8	D2	P07	P-port input/output (push-pull design structure). At power on, P07 is configured as an input.
12	9	E2	GND	Ground
13	10	E3	P10	P-port input/output (push-pull design structure). At power on, P10 is configured as an input.
14	11	E4	P11	P-port input/output (push-pull design structure). At power on, P11 is configured as an input.
15	12	D3	P12	P-port input/output (push-pull design structure). At power on, P12 is configured as an input.
16	13	E5	P13	P-port input/output (push-pull design structure). At power on, P13 is configured as an input.
17	14	D4	P14	P-port input/output (push-pull design structure). At power on, P14 is configured as an input.
18	15	D5	P15	P-port input/output (push-pull design structure). At power on, P15 is configured as an input.
19	16	C5	P16	P-port input/output (push-pull design structure). At power on, P16 is configured as an input.
20	17	C4	P17	P-port input/output (push-pull design structure). At power on, P17 is configured as an input.
21	18	B5	ADDR	Address input. Connect directly to V_{CCP} or ground.
22	19	A5	SCL	Serial clock bus. Connect to V_{CCI} through a pullup resistor.
23	20	A4	SDA	Serial data bus. Connect to V_{CCI} through a pullup resistor.
24	21	B4	V_{CCP}	Supply voltage of TCA6416A for P port

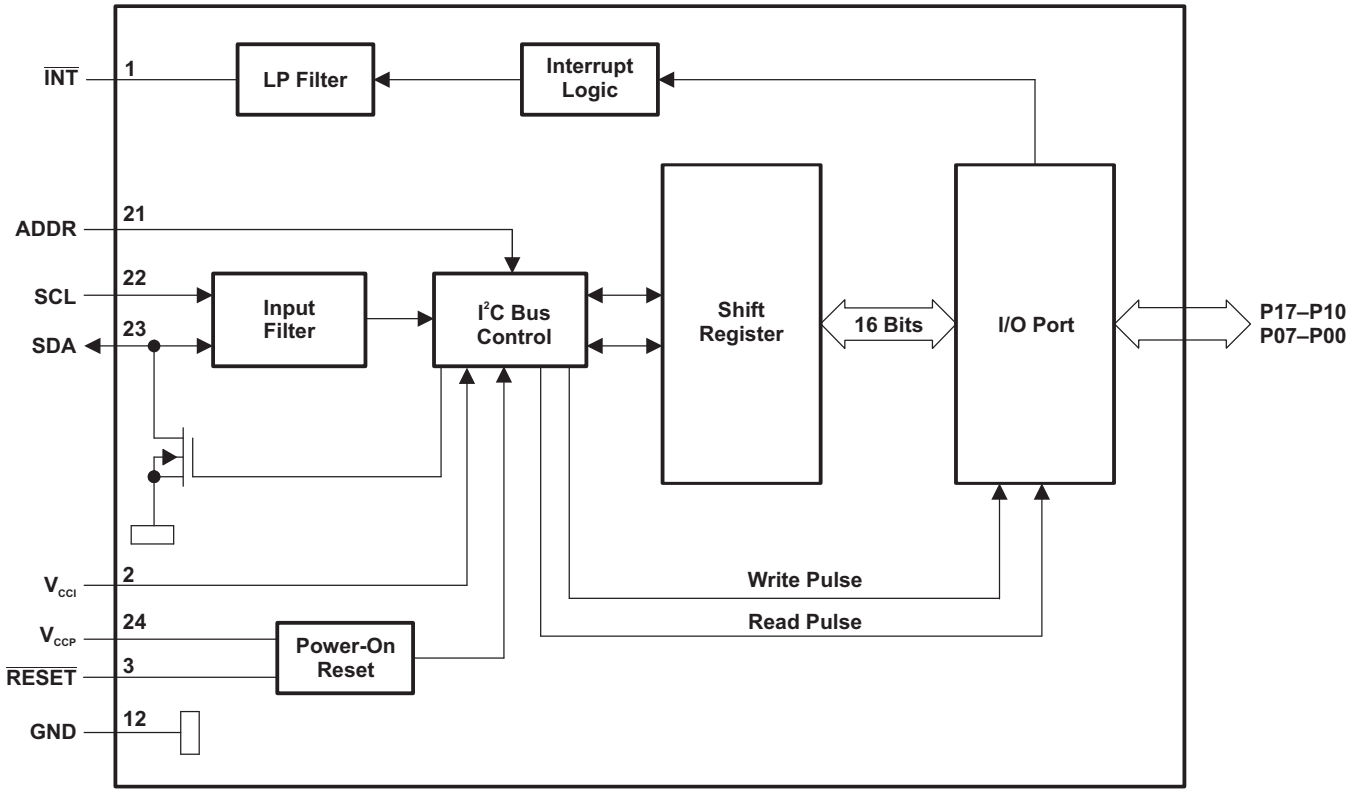
Voltage Translation

Table 3 shows how to set up V_{CC} levels for the necessary voltage translation between the I^2C bus and the TCA6416A.

Table 3. Voltage Translation

V_{CCI} (SDA AND SCL OF I^2C MASTER) (V)	V_{CCP} (P PORT) (V)
1.8	1.8
1.8	2.5
1.8	3.3
1.8	5
2.5	1.8
2.5	2.5
2.5	3.3
2.5	5
3.3	1.8
3.3	2.5
3.3	3.3
3.3	5
5	1.8
5	2.5
5	3.3
5	5

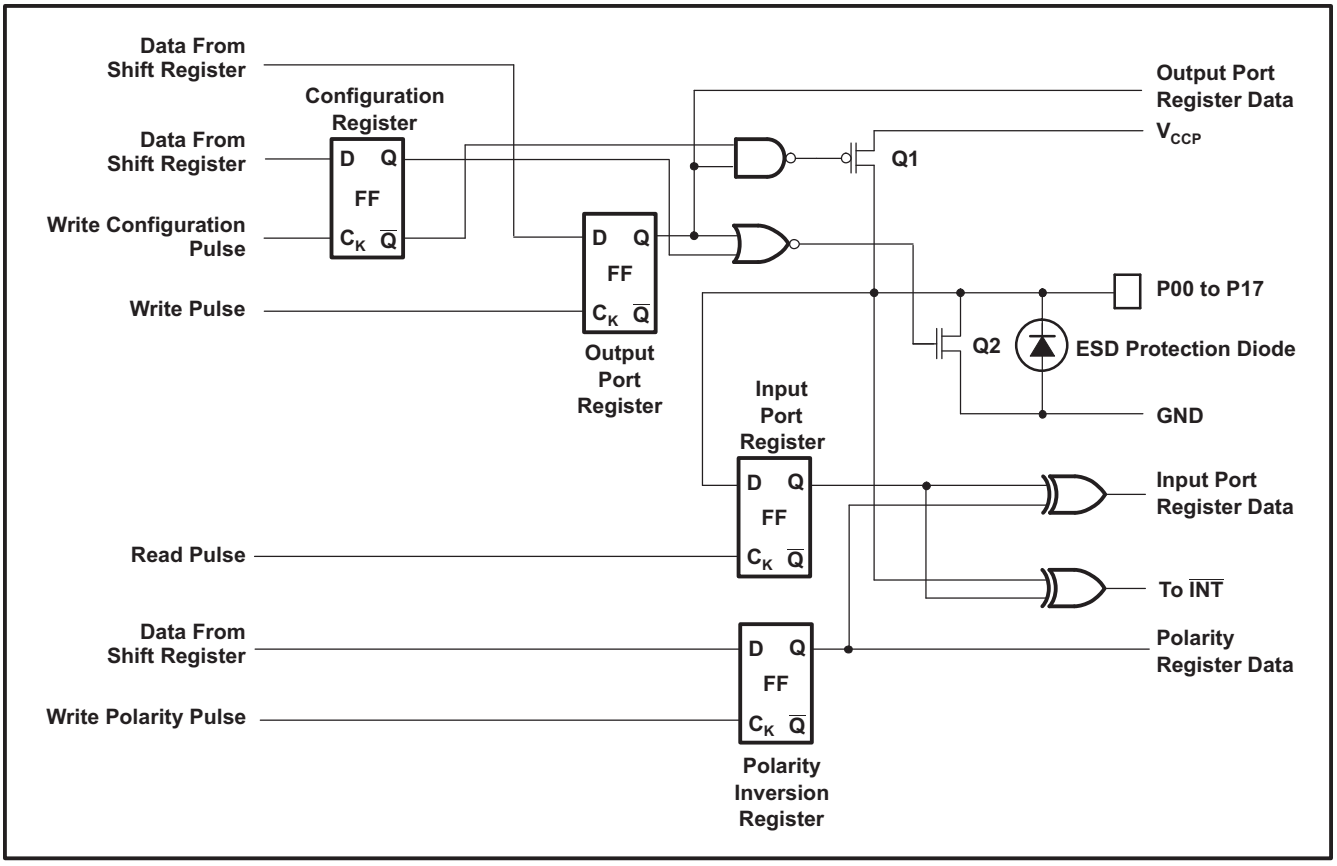
LOGIC DIAGRAM (POSITIVE LOGIC)



A. All I/Os are set to inputs at reset.

B. Pin numbers shown are for the PW package.

Simplified Schematic of P0 to P17



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

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_{CC} 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_{CC} or GND. The external voltage applied to this I/O pin should not exceed the recommended levels for proper operation.

I²C Interface

The bidirectional I^2C bus consists of the serial clock (SCL) and serial data (SDA) lines. Both lines must be connected to a positive supply through a pullup resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

I^2C communication with this device is initiated by a master sending a Start condition, a high-to-low transition on the SDA input/output, while the SCL input is high (see Figure 1). After the Start condition, the device address byte is sent, most significant bit (MSB) first, including the data direction bit (R/$\overline{W}$).

After receiving the valid address byte, this device responds with an acknowledge (ACK), a low on the SDA input/output during the high of the ACK-related clock pulse. The address (ADDR) input of the slave device must not be changed between the Start and the Stop conditions.

On the I^2C bus, only one data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the high pulse of the clock period, as changes in the data line at this time are interpreted as control commands (Start or Stop) (see Figure 2).

A Stop condition, a low-to-high transition on the SDA input/output while the SCL input is high, is sent by the master (see Figure 1).

Any number of data bytes can be transferred from the transmitter to receiver between the Start and the Stop conditions. Each byte of eight bits is followed by one ACK bit. The transmitter must release the SDA line before the receiver can send an ACK bit. The device that acknowledges must pull down the SDA line during the ACK clock pulse, so that the SDA line is stable low during the high pulse of the ACK-related clock period (see Figure 3). When a slave receiver is addressed, it must generate an ACK after each byte is received. Similarly, the master must generate an ACK after each byte that it receives from the slave transmitter. Setup and hold times must be met to ensure proper operation.

A master receiver signals an end of data to the slave transmitter by not generating an acknowledge (NACK) after the last byte has been clocked out of the slave. This is done by the master receiver by holding the SDA line high. In this event, the transmitter must release the data line to enable the master to generate a Stop condition.

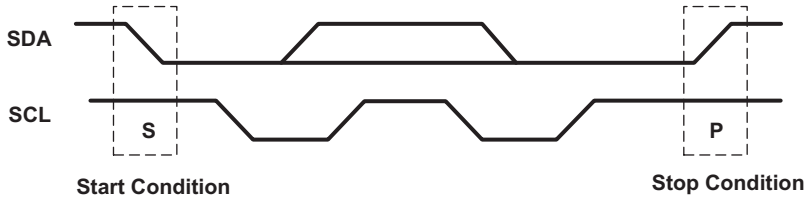


Figure 1. Definition of Start and Stop Conditions

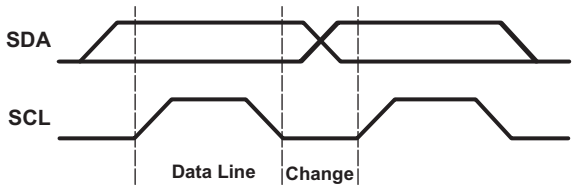


Figure 2. Bit Transfer

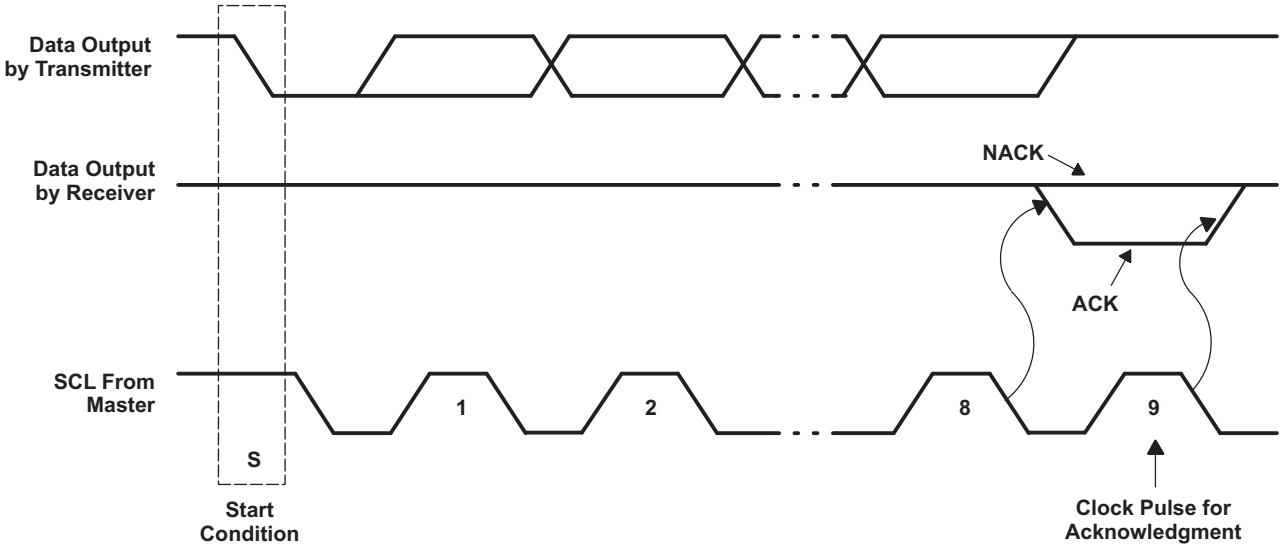


Figure 3. Acknowledgment on the I^2C Bus

Table 4. Interface Definition

BYTE	BIT							
	7 (MSB)	6	5	4	3	2	1	0 (LSB)
I^2C slave address	L	H	L	L	L	L	ADDR	R/$\overline{W}$
I/O data bus	P07	P06	P05	P04	P03	P02	P01	P00
	P17	P16	P15	P14	P13	P12	P11	P10

Device Address

The address of the TCA6416A is shown in Figure 4.

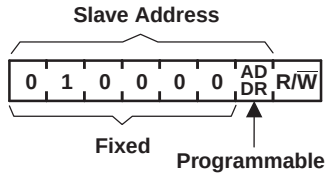


Figure 4. TCA6416A Address

Table 5. Address Reference

ADDR	I^2C BUS SLAVE ADDRESS
L	32 (decimal), 20 (hexadecimal)
H	33 (decimal), 21 (hexadecimal)

The last bit of the slave address defines the operation (read or write) to be performed. A high (1) selects a read operation, while a low (0) selects a write operation.

Control Register and Command Byte

Following the successful acknowledgment of the address byte, the bus master sends a command byte, which is stored in the control register in the TCA6416A. 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. This register can be written or read through the I^2C bus. The command byte is sent only during a write transmission.

Once a new command has been sent, the register that was addressed continues to be accessed by reads until a new command byte has been sent.

B7	B6	B5	B4	B3	B2	B1	B0

Figure 5. Control Register Bits

Table 6. Command Byte

CONTROL REGISTER BITS								COMMAND BYTE (HEX)	REGISTER	PROTOCOL	POWER-UP DEFAULT
B7	B6	B5	B4	B3	B2	B1	B0				
0	0	0	0	0	0	0	0	00	Input Port 0	Read byte	xxxx xxxx(1)
0	0	0	0	0	0	0	1	01	Input Port 1	Read byte	xxxx xxxx
0	0	0	0	0	0	1	0	02	Output Port 0	Read/write byte	1111 1111
0	0	0	0	0	0	1	1	03	Output Port 1	Read/write byte	1111 1111
0	0	0	0	0	1	0	0	04	Polarity Inversion Port 0	Read/write byte	0000 0000
0	0	0	0	0	1	0	1	05	Polarity Inversion Port 1	Read/write byte	0000 0000
0	0	0	0	0	1	1	0	06	Configuration Port 0	Read/write byte	1111 1111
0	0	0	0	0	1	1	1	07	Configuration Port 1	Read/write byte	1111 1111

(1) Undefined

Register Descriptions

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. They act only on read operation. Writes to these registers have no effect. The default value (X) is determined by the externally applied logic level. Before a read operation, a write transmission is sent with the command byte to indicate to the I^2C device that the Input Port register will be accessed next.

Table 7. Registers 0 and 1 (Input Port Registers)

BIT	I-07	I-06	I-05	I-04	I-03	I-02	I-01	I-00
DEFAULT	X	X	X	X	X	X	X	X
BIT	I-17	I-16	I-15	I-14	I-13	I-12	I-11	I-10
DEFAULT	X	X	X	X	X	X	X	X

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 is in the flip-flop controlling the output selection, NOT the actual pin value.

Table 8. Registers 2 and 3 (Output Port Registers)

BIT	O-07	O-06	O-05	O-04	O-03	O-02	O-01	O-00
DEFAULT	1	1	1	1	1	1	1	1
BIT	O-17	O-16	O-15	O-14	O-13	O-12	O-11	O-10
DEFAULT	1	1	1	1	1	1	1	1

The Polarity Inversion registers (register 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. If a bit in these registers is cleared (written with a 0), the corresponding port pin's original polarity is retained.

Table 9. Registers 4 and 5 (Polarity Inversion Registers)

BIT	P-07	P-06	P-05	P-04	P-03	P-02	P-01	P-00
DEFAULT	0	0	0	0	0	0	0	0
BIT	P-17	P-16	P-15	P-14	P-13	P-12	P-11	P-10
DEFAULT	0	0	0	0	0	0	0	0

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 an input with a high-impedance output driver. If a bit in these registers is cleared to 0, the corresponding port pin is enabled as an output.

Table 10. Registers 6 and 7 (Configuration Registers)

BIT	C-07	C-06	C-05	C-04	C-03	C-02	C-01	C-00
DEFAULT	1	1	1	1	1	1	1	1
BIT	C-17	C-16	C-15	C-14	C-13	C-12	C-11	C-10
DEFAULT	1	1	1	1	1	1	1	1

Power-On Reset

When power (from 0 V) is applied to V_{CCP}, an internal power-on reset holds the TCA6416A in a reset condition until V_{CCP} has reached V_{POR}. At that time, the reset condition is released, and the TCA6416A registers and I^2C/SMBus state machine initializes to their default states. After that, V_{CCP} must be lowered to below V_{PORF} and back up to the operating voltage for a power-reset cycle.

Reset Input ($\overline{\text{RESET}}$)

The $\overline{\text{RESET}}$ input can be asserted to initialize the system while keeping the V_{CCP} at its operating level. A reset can be accomplished by holding the $\overline{\text{RESET}}$ pin low for a minimum of t_W. The TCA6416A registers and I^2C/SMBus state machine are changed to their default state once $\overline{\text{RESET}}$ is low (0). When $\overline{\text{RESET}}$ is high (1), the I/O levels at the P port can be changed externally or through the master. This input requires a pullup resistor to V_{CCI}, if no active connection is used.

Interrupt Output ($\overline{\text{INT}}$)

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

Reading from or writing to another device does not affect the interrupt circuit, and a pin configured as an output cannot cause an interrupt. Changing an I/O from an output to an input may cause a false interrupt to occur, if the state of the pin does not match the contents of the Input Port register.

The $\overline{\text{INT}}$ output has an open-drain structure and requires pullup resistor to V_{CCP} or V_{CCI} depending on the application. $\overline{\text{INT}}$ should be connected to the voltage source of the device that requires the interrupt information.

Bus Transactions

Data is exchanged between the master and TCA6416A through write and read commands.

Writes

Data is transmitted to the TCA6416A by sending the device address and setting the least-significant bit (LSB) to a logic 0 (see Figure 4 for device address). The command byte is sent after the address and determines which register receives the data that follows the command byte. There is no limitation on the number of data bytes sent in one write transmission.

The eight registers within the TCA6416A are configured to operate as four register pairs. The four pairs are input ports, output ports, polarity inversion ports and configuration ports. After sending data to one register, the next data byte is sent to the other register in the pair (see Figure 6 and Figure 7). For example, if the first byte is send to Output Port 1 (register 3), the next byte is stored in Output Port 0 (register 2).

There is no limitation on the number of data bytes sent in one write transmission. In this way, each 8-bit register may be updated independently of the other registers.

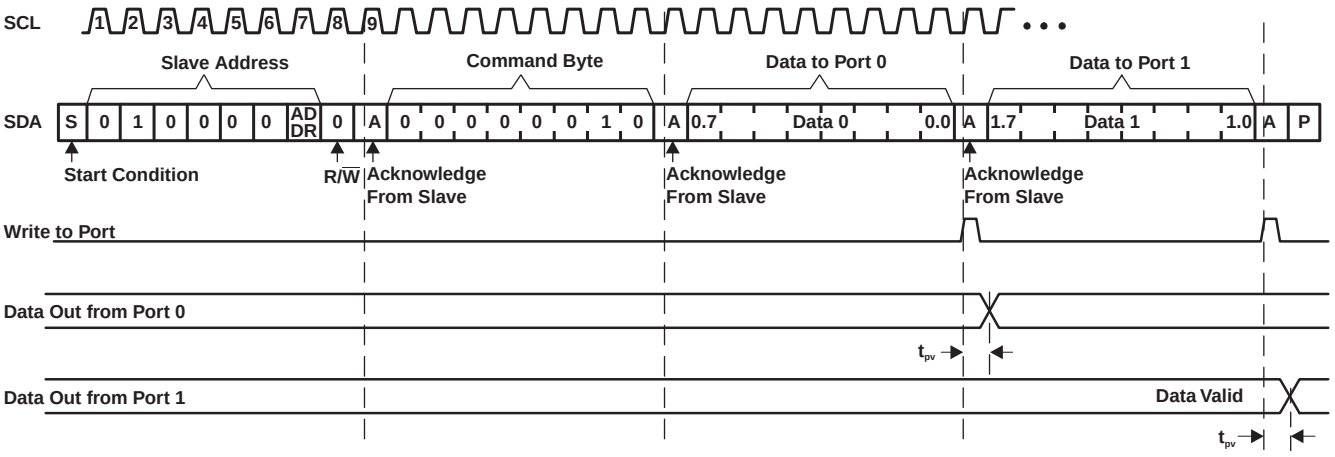


Figure 6. Write to Output Port Register

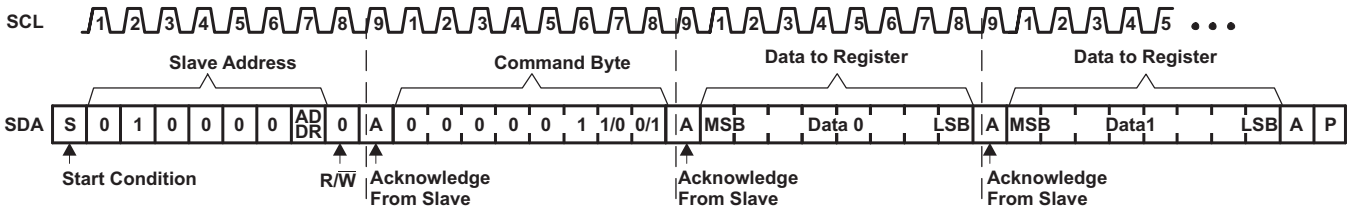


Figure 7. Write to Configuration or Polarity Inversion Registers

Reads

The bus master first must send the TCA6416A address with the LSB set to a logic 0 (see Figure 4 for device address). The command byte is sent after the address and determines which register is accessed.

After a restart, the device address is sent again but, this time, the LSB is set to a logic 1. Data from the register defined by the command byte then is sent by the TCA6416A (see Figure 8 and Figure 9).

After a restart, the value of the register defined by the command byte matches the register being accessed when the restart occurred. For example, if the command byte references Input Port 1 before the restart, and the restart occurs when Input Port 0 is being read, the stored command byte changes to reference Input Port 0. The original command byte is forgotten. If a subsequent restart occurs, Input Port 0 is read first. 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.

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

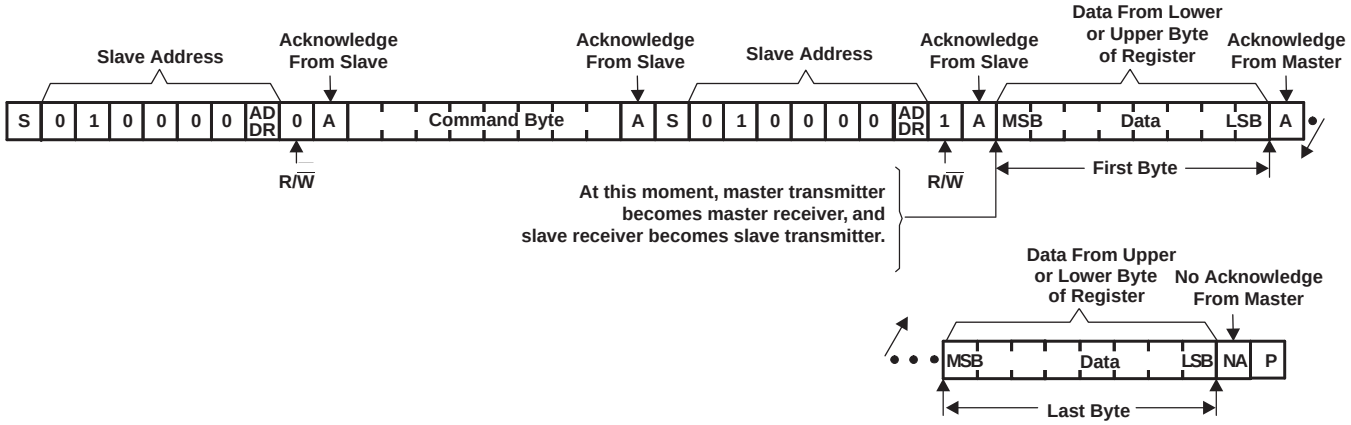
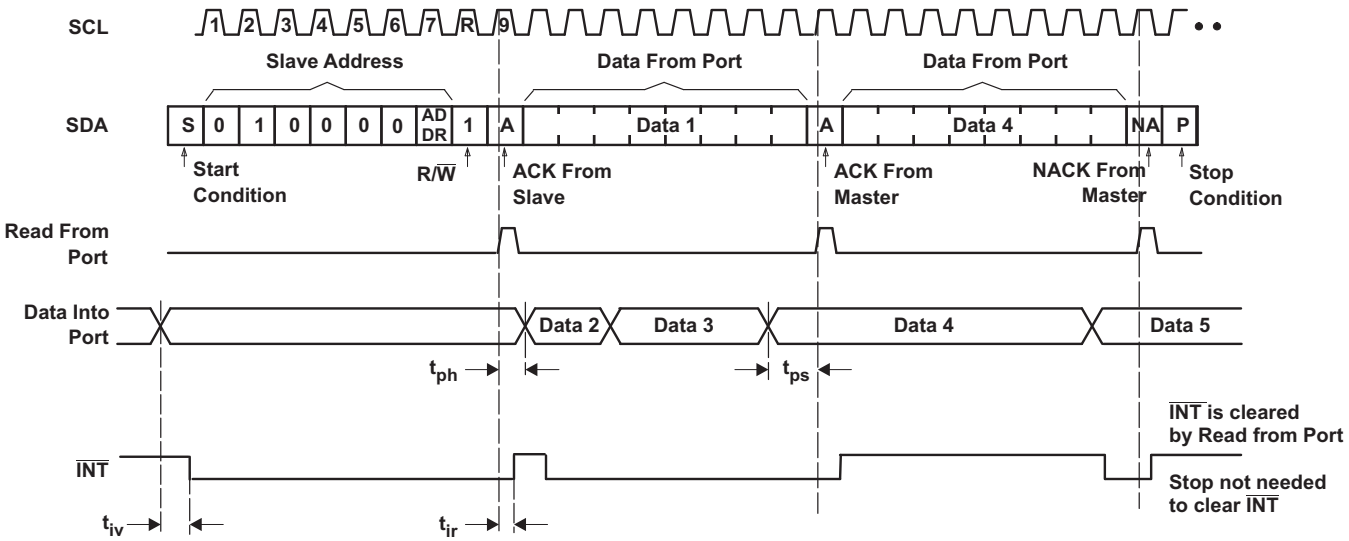


Figure 8. Read From Register



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

B. This figure eliminates the command byte transfer, a restart, and slave address call between the initial slave address call and actual data transfer from P port (see Figure 8).

Figure 9. Read Input Port Register

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

				MIN	MAX	UNIT
V_{CCI}	Supply voltage range			–0.5	6.5	V
V_{CCP}	Supply voltage range			–0.5	6.5	V
V_I	Input voltage range(2)			–0.5	6.5	V
V_O	Output voltage range(2)			–0.5	6.5	V
I_{IK}	Input clamp current	ADDR, $\overline{RESET}$, SCL	$V_I < 0$		±20	mA
I_{OK}	Output clamp current	$\overline{INT}$	$V_O < 0$		±20	mA
I_{IOK}	Input/output clamp current	P port	$V_O < 0$ or $V_O > V_{CCP}$		±20	mA
		SDA	$V_O < 0$ or $V_O > V_{CCI}$		±20	
I_{OL}	Continuous output low current	P port	V_O = 0 to V_{CCP}		50	mA
		SDA, $\overline{INT}$	V_O = 0 to V_{CCI}		25	
I_{OH}	Continuous output high current	P port	V_O = 0 to V_{CCP}		50	mA
I_{CC}	Continuous current through GND				200	mA
	Continuous current through V_{CCP}				160	
	Continuous current through V_{CCI}				10	
θ_{JA}	Package thermal impedance(3)		PW package		88	°C/W
			RTW package		66	
			ZQS package		171	
T_{stg}	Storage temperature range					°C –65 150

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) The input negative-voltage and output voltage ratings may be exceeded if the input and output current ratings are observed.
(3) The package thermal impedance is calculated in accordance with JESD 51-7.

RECOMMENDED OPERATING CONDITIONS

			MIN	MAX	UNIT
V_{CCI}	Supply voltage		1.65	5.5	V
V_{CCP}	Supply voltage		1.65	5.5	
V_{IH}	High-level input voltage	SCL, SDA, $\overline{RESET}$	0.7 × V_{CCI}	5.5	V
		ADDR, P17–P00	0.7 × V_{CCP}	5.5	
V_{IL}	Low-level input voltage	SCL, SDA, $\overline{RESET}$	–0.5	0.3 × V_{CCI}	V
		ADDR, P17–P00	–0.5	0.3 × V_{CCP}	
I_{OH}	High-level output current	P17–P00		10	mA
I_{OL}	Low-level output current	P17–P00		25	mA
T_A	Operating free-air temperature		–40	85	°C

ELECTRICAL CHARACTERISTICS

over recommended operating free-air temperature range, V_{CCI} = 1.65 V to 5.5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	V_{CCP}	MIN	TYP(1)	MAX	UNIT
V_{IK}	Input diode clamp voltage	I_I = –18 mA	1.65 V to 5.5 V	–1.2			V
V_{POR}	Power-on reset voltage	V_I = V_{CCP} or GND, I_O = 0	1.65 V to 5.5 V		1	1.4	V
V_{OH}	P-port high-level output voltage	I_{OH} = –8 mA	1.65 V	1.2			V
			2.3 V	1.8			
			3 V	2.6			
			4.5 V	4.1			
		I_{OH} = –10 mA	1.65 V	1.1			
			2.3 V	1.7			
			3 V	2.5			
			4.5 V	4.0			
V_{OL}	P-port low-level output voltage	I_{OL} = 8 mA	1.65 V			0.45	V
			2.3 V			0.25	
			3 V			0.25	
			4.5 V			0.2	
		I_{OL} = 10 mA	1.65 V			0.6	
			2.3 V			0.3	
			3 V			0.25	
			4.5 V			0.2	
I_{OL}	SDA	V_{OL} = 0.4 V	1.65 V to 5.5 V	3			mA
	$\overline{INT}$	V_{OL} = 0.4 V	1.65 V to 5.5 V	3	15		
I_I	SCL, SDA, $\overline{RESET}$	V_I = V_{CCI} or GND	1.65 V to 5.5 V			±0.1	µA
	ADDR	V_I = V_{CCP} or GND				±0.1	
I_{IH}	P port	V_I = V_{CCP}	1.65 V to 5.5 V			1	µA
I_{IL}	P port	V_I = GND				1	µA
I_{CC} (I_{CCI} + I_{CCP})	SDA, P port, ADDR, $\overline{RESET}$	V_I on SDA and $\overline{RESET}$ = V_{CCI} or GND, V_I on P port and ADDR = V_{CCP}, I_O = 0, I/O = inputs, f_{SCL} = 400 kHz	3.6 V to 5.5 V		10	20	µA
			2.3 V to 3.6 V		6.5	15	
			1.65 V to 2.3 V		4	9	
	SCL, SDA, P port, ADDR, $\overline{RESET}$	V_I on SCL, SDA and $\overline{RESET}$= V_{CCI} or GND, V_I on P port and ADDR = V_{CCP}, I_O = 0, I/O = inputs, f_{SCL} = 0	3.6 V to 5.5 V		1.5	7	
			2.3 V to 3.6 V		1	3.2	
			1.65 V to 2.3 V		0.5	1.7	
ΔI_{CCI} ΔI_{CCP}	SCL,SDA, RESET	One input at V_{CCI} – 0.6 V, Other inputs at V_{CCI} or GND	1.65 V to 5.5 V			25	µA
	P port, ADDR	One input at V_{CCP} – 0.6 V, Other inputs at V_{CCP} or GND				80	
C_i	SCL	V_I = V_{CCI} or GND	1.65 V to 5.5 V		6	7	pF
C_{io}	SDA	V_{IO} = V_{CCI} or GND	1.65 V to 5.5 V		7	8	pF
	P port	V_{IO} = V_{CCP} or GND			7.5	8.5	

(1) Except for I_{CC}, all typical values are at nominal supply voltage (1.8-V, 2.5-V, 3.3-V, or 5-V V_{CC}) and T_A = 25°C. For I_{CC}, the typical values are at V_{CCP} = V_{CCI} = 3.3 V and T_A = 25°C.

I²C INTERFACE TIMING REQUIREMENTS

over recommended operating free-air temperature range (unless otherwise noted) (see Figure 10)

		STANDARD MODE I²C BUS		FAST MODE I²C BUS		UNIT
		MIN	MAX	MIN	MAX	
f_{scl}	I²C clock frequency	0	100	0	400	kHz

I²C INTERFACE TIMING REQUIREMENTS (continued)

over recommended operating free-air temperature range (unless otherwise noted) (see Figure 10)

		STANDARD MODE I²C BUS		FAST MODE I²C BUS		UNIT
		MIN	MAX	MIN	MAX	
t_{sch}	I²C clock high time	4		0.6		µs
t_{scl}	I²C clock low time	4.7		1.3		µs
t_{sp}	I²C spike time	0	50	0	50	ns
t_{sds}	I²C serial data setup time	250		100		ns
t_{sdh}	I²C serial data hold time	0		0		ns
t_{icr}	I²C input rise time		1000	20 + 0.1C_b (1)	300	ns
t_{icf}	I²C input fall time		300	20 + 0.1C_b (1)	300	ns
t_{ocf}	I²C output fall time; 10 pF to 400 pF bus		300	20 + 0.1C_b (1)	300	µs
t_{buf}	I²C bus free time between Stop and Start	4.7		1.3		µs
t_{sts}	I²C Start or repeater Start condition setup time	4.7		0.6		µs
t_{sth}	I²C Start or repeater Start condition hold time	4		0.6		µs
t_{sps}	I²C Stop condition setup time	4		0.6		µs
$t_{vd(data)}$	Valid data time; SCL low to SDA output valid		1		1	µs
$t_{vd(ack)}$	Valid data time of ACK condition; ACK signal from SCL low to SDA (out) low		1		1	µs

(1) C_b = total capacitance of one bus line in pF

RESET TIMING REQUIREMENTS

over recommended operating free-air temperature range (unless otherwise noted) (see Figure 13)

		FAST MODE I²C BUS		STANDARD MODE I²C BUS		UNIT
		MIN	MAX	MIN	MAX	
t_W	Reset pulse duration	4		4		ns
t_{REC}	Reset recovery time	0		0		ns
t_{RESET}	Time to reset (1)	600		600		ns

(1) Minimum time for SDA to become high or minimum time to wait before doing a START

SWITCHING CHARACTERISTICS

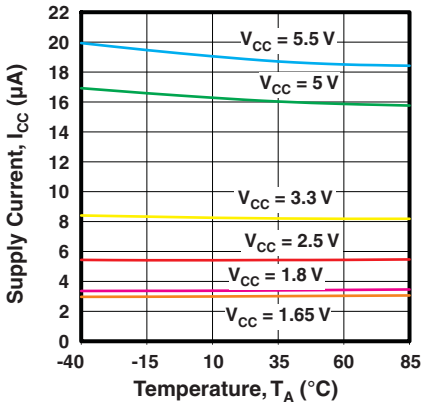
over recommended operating free-air temperature range, C_L ≤ 100 pF (unless otherwise noted) (see Figure 10)

PARAMETER		FROM	TO	STANDARD MODE I²C BUS		FAST MODE I²C BUS		UNIT
				MIN	MAX	MIN	MAX	
t_{IV}	Interrupt valid time	P port	$\overline{INT}$		4		4	µs
t_{IR}	Interrupt reset delay time	SCL	$\overline{INT}$		4		4	µs
t_{PV}	Output data valid	SCL	P7–P0		400		400	ns
t_{PS}	Input data setup time	P port	SCL	0		0		ns
t_{PH}	Input data hold time	P port	SCL	300		300		ns

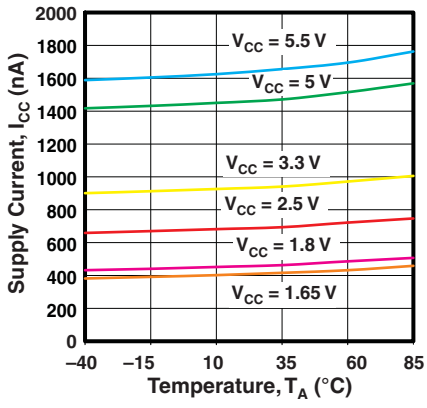
TYPICAL CHARACTERISTICS

T_A = 25°C (unless otherwise noted)

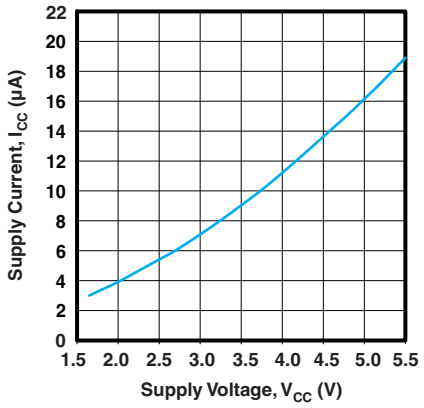
SUPPLY CURRENT vs TEMPERATURE



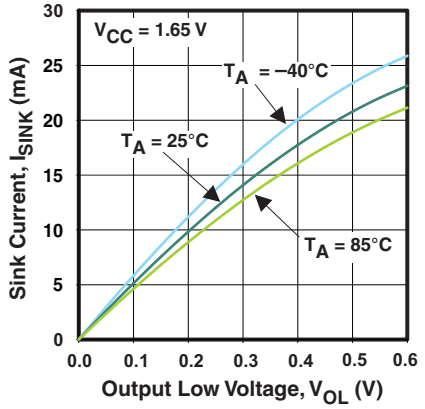
STANDBY SUPPLY CURRENT vs TEMPERATURE



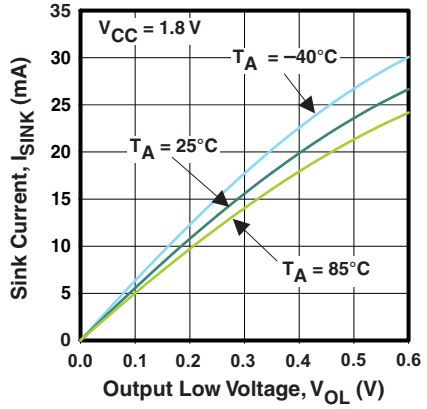
SUPPLY CURRENT vs SUPPLY VOLTAGE



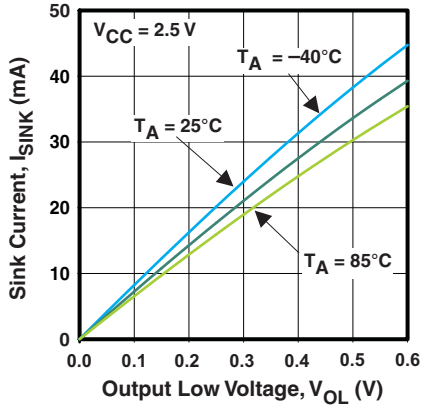
I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



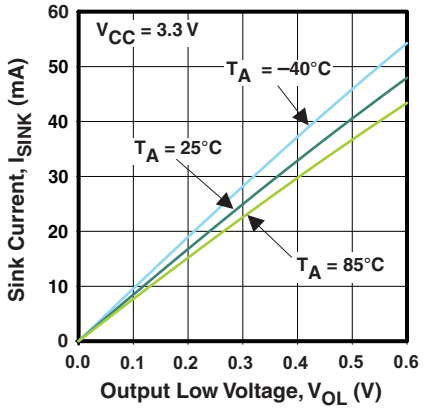
I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



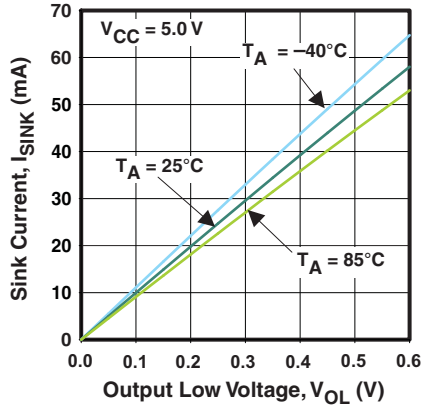
I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



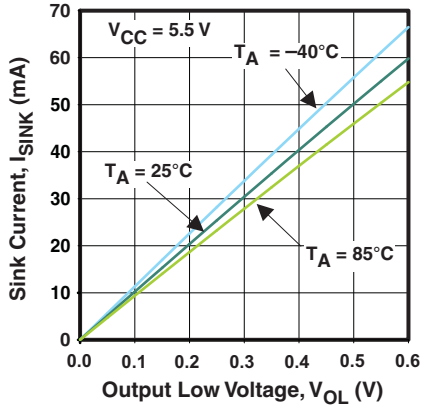
I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



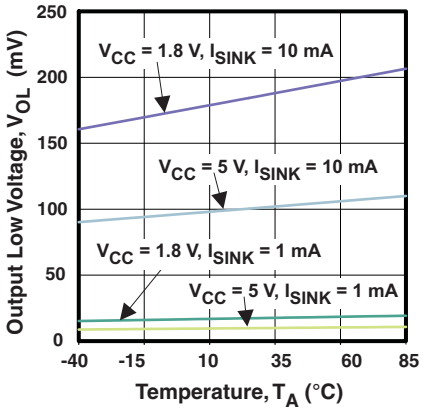
I/O SINK CURRENT vs OUTPUT LOW VOLTAGE



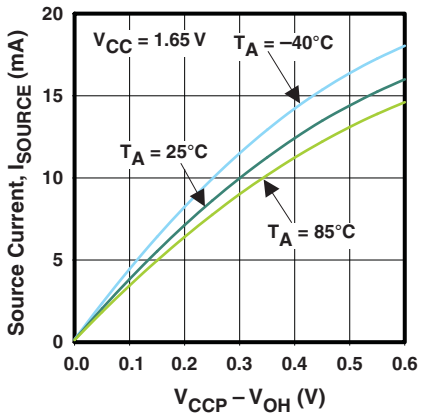
TYPICAL CHARACTERISTICS (continued)

T_A = 25°C (unless otherwise noted)

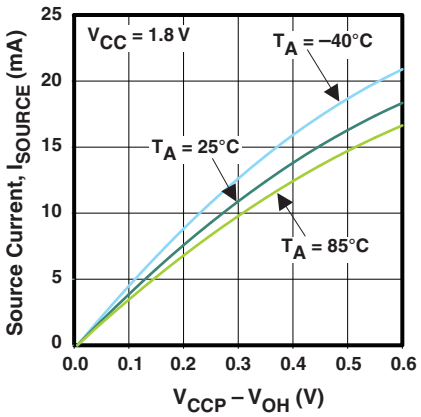
I/O LOW VOLTAGE vs TEMPERATURE



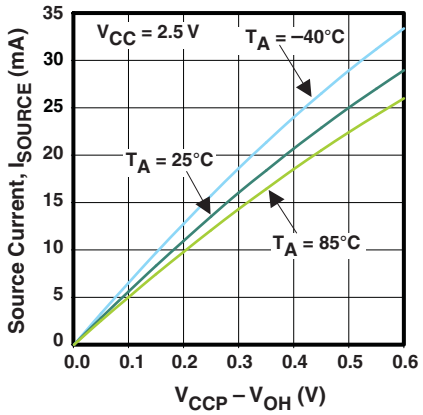
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



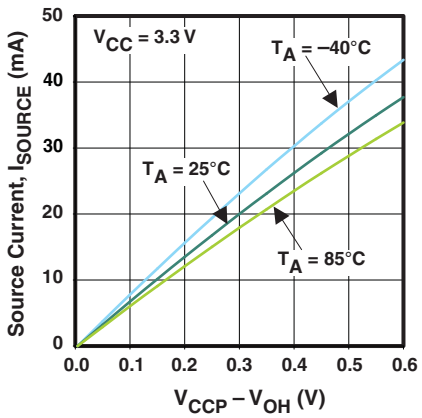
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



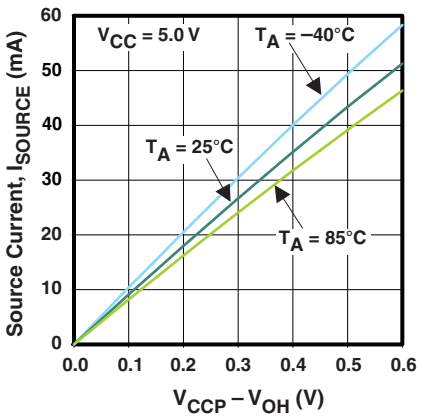
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



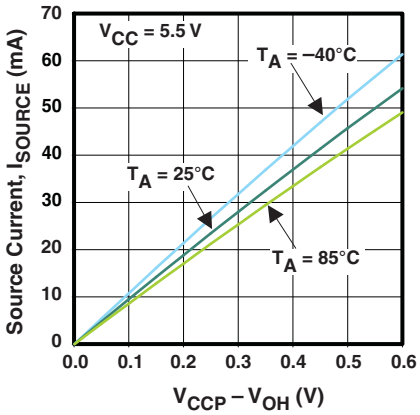
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



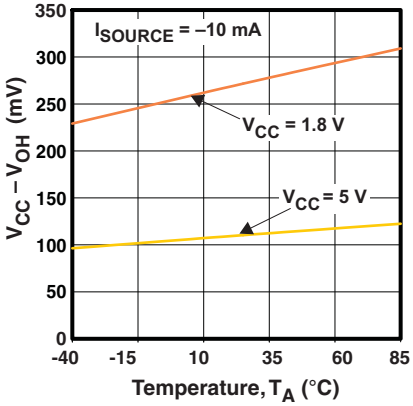
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



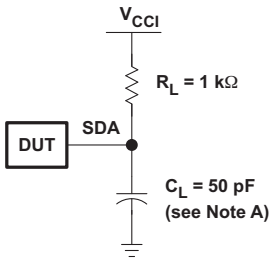
I/O SOURCE CURRENT vs OUTPUT HIGH VOLTAGE



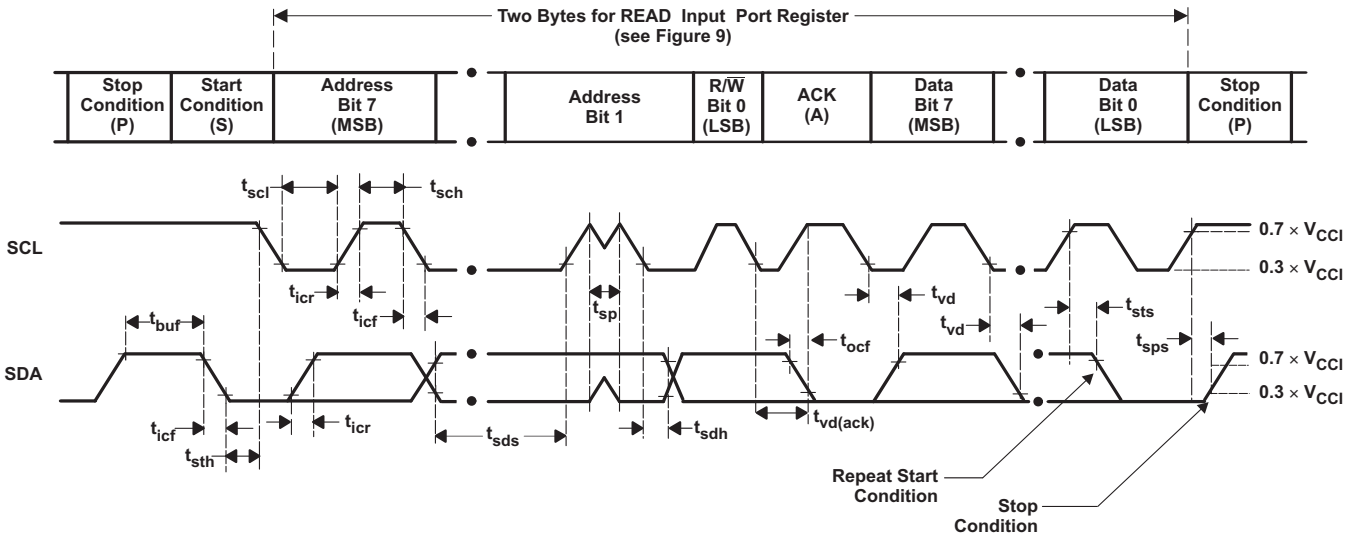
I/O HIGH VOLTAGE vs TEMPERATURE



PARAMETER MEASUREMENT INFORMATION



SDA LOAD CONFIGURATION



VOLTAGE WAVEFORMS

BYTE	DESCRIPTION
1	I^2C address
2	Input register port data

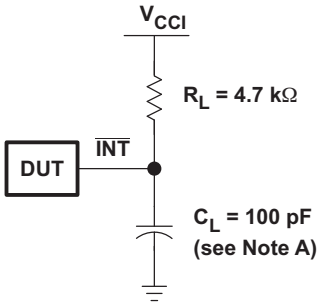
A. C_L includes probe and jig capacitance. tocf is measured with C_L of 10 pF or 400 pF.

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

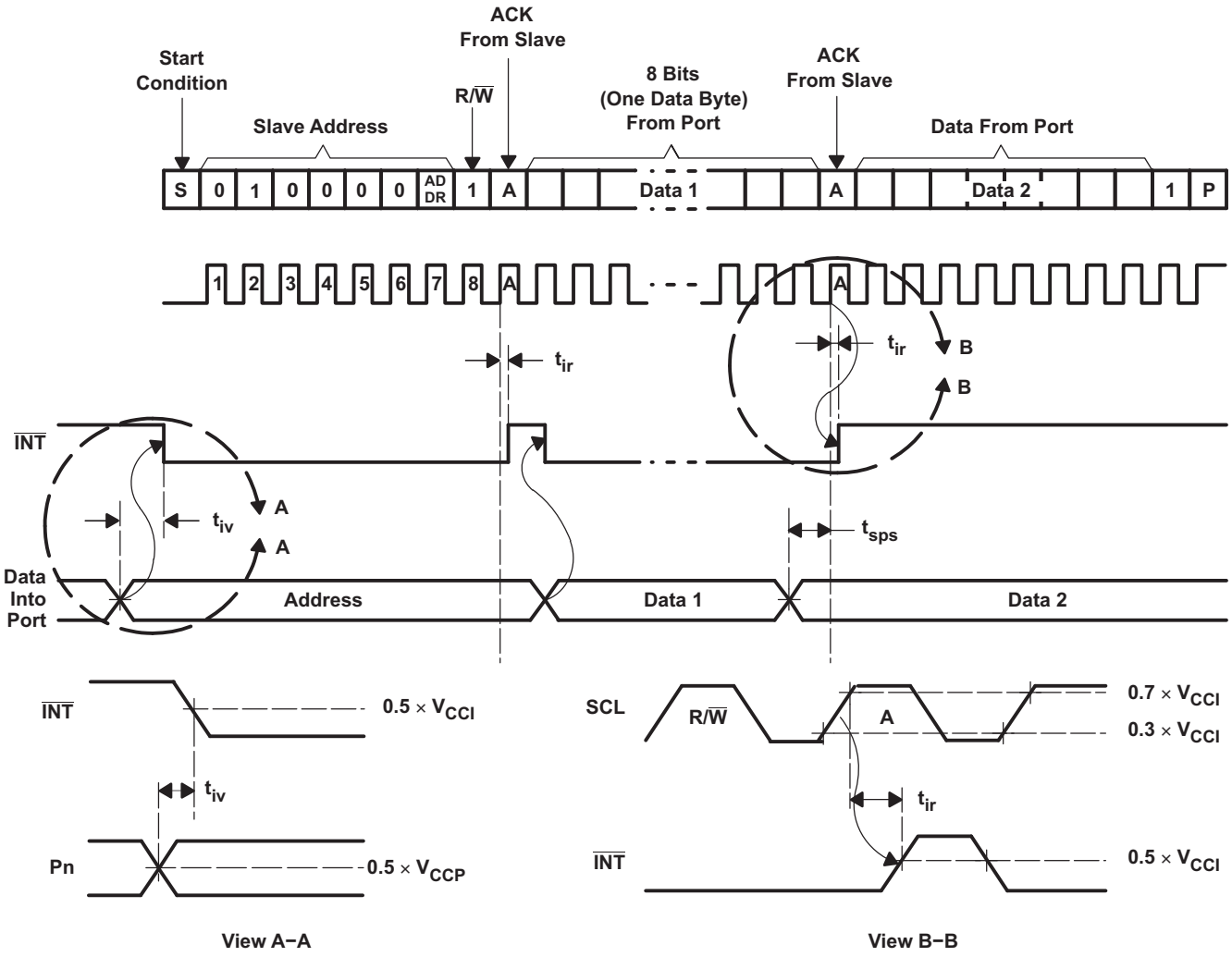
C. All parameters and waveforms are not applicable to all devices.

Figure 10. I^2C Interface Load Circuit and Voltage Waveforms

PARAMETER MEASUREMENT INFORMATION (continued)



INTERRUPT LOAD CONFIGURATION



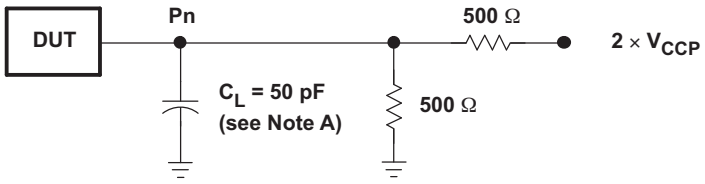
A. C_L includes probe and jig capacitance.

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

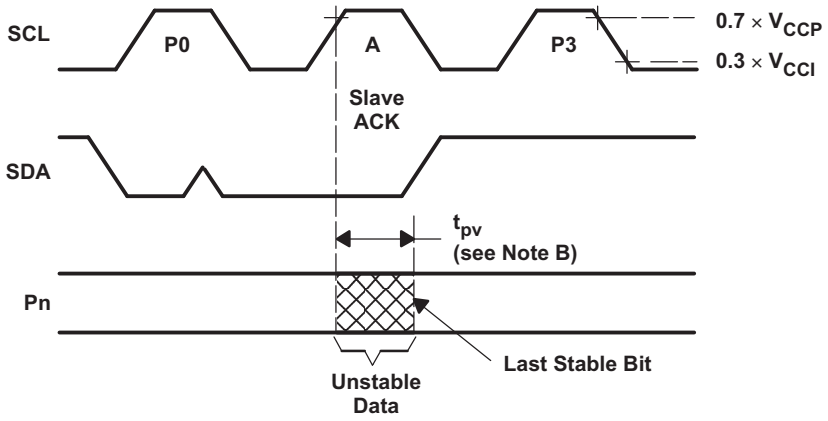
C. All parameters and waveforms are not applicable to all devices.

Figure 11. Interrupt Load Circuit and Voltage Waveforms

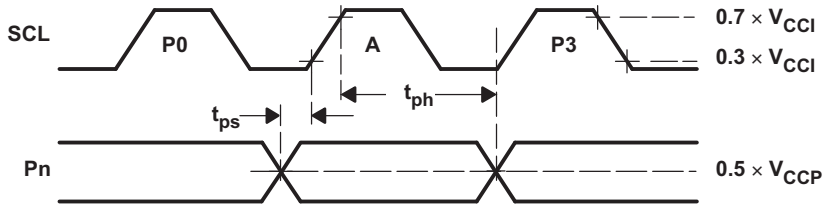
PARAMETER MEASUREMENT INFORMATION (continued)



P-PORT LOAD CONFIGURATION



WRITE MODE (R/$\overline{W}$ = 0)

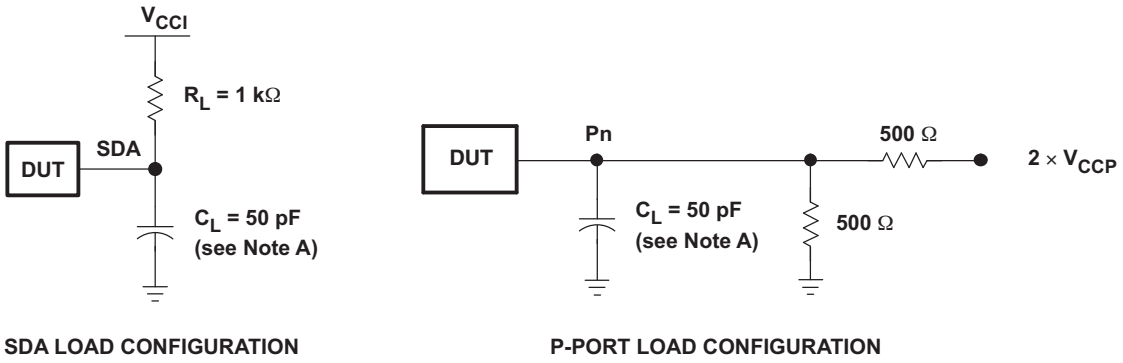


READ MODE (R/$\overline{W}$ = 1)

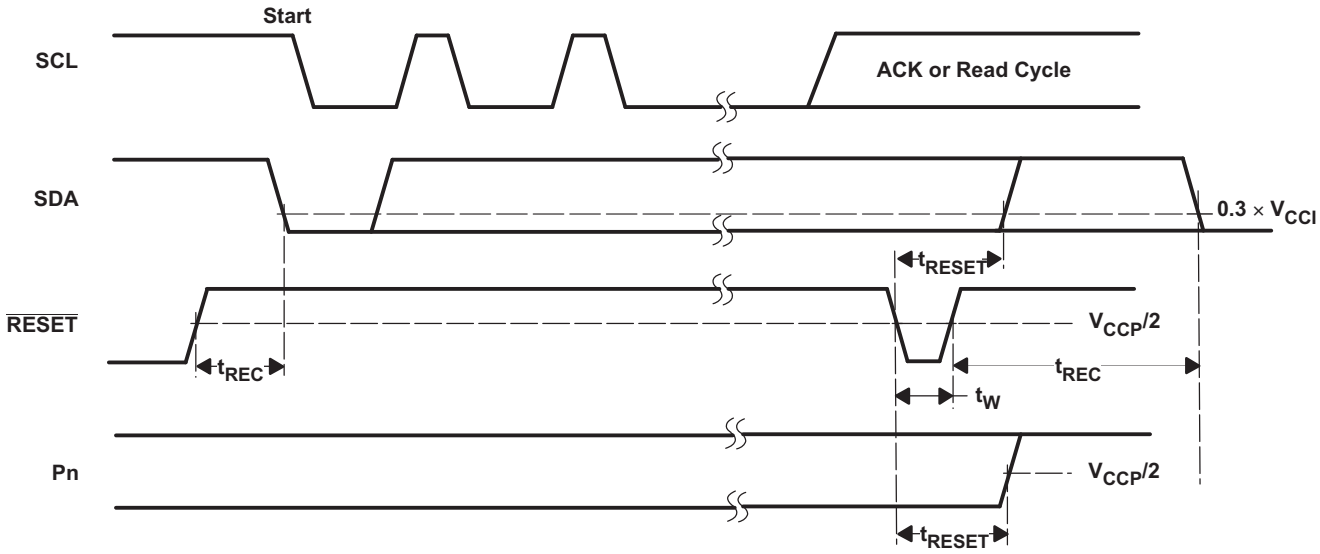
A. C_L includes probe and jig capacitance.
B. t_{pv} is measured from 0.7 × V_{CC} on SCL to 50% I/O (Pn) output.
C. All inputs are supplied by generators having the following characteristics: PRR ≤ 10 MHz, Z_O = 50 Ω, t_r/t_f ≤ 30 ns.
D. The outputs are measured one at a time, with one transition per measurement.
E. All parameters and waveforms are not applicable to all devices.

Figure 12. P Port Load Circuit and Timing Waveforms

PARAMETER MEASUREMENT INFORMATION (continued)



SDA LOAD CONFIGURATION P-PORT LOAD CONFIGURATION



A. C_L includes probe and jig capacitance.

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

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

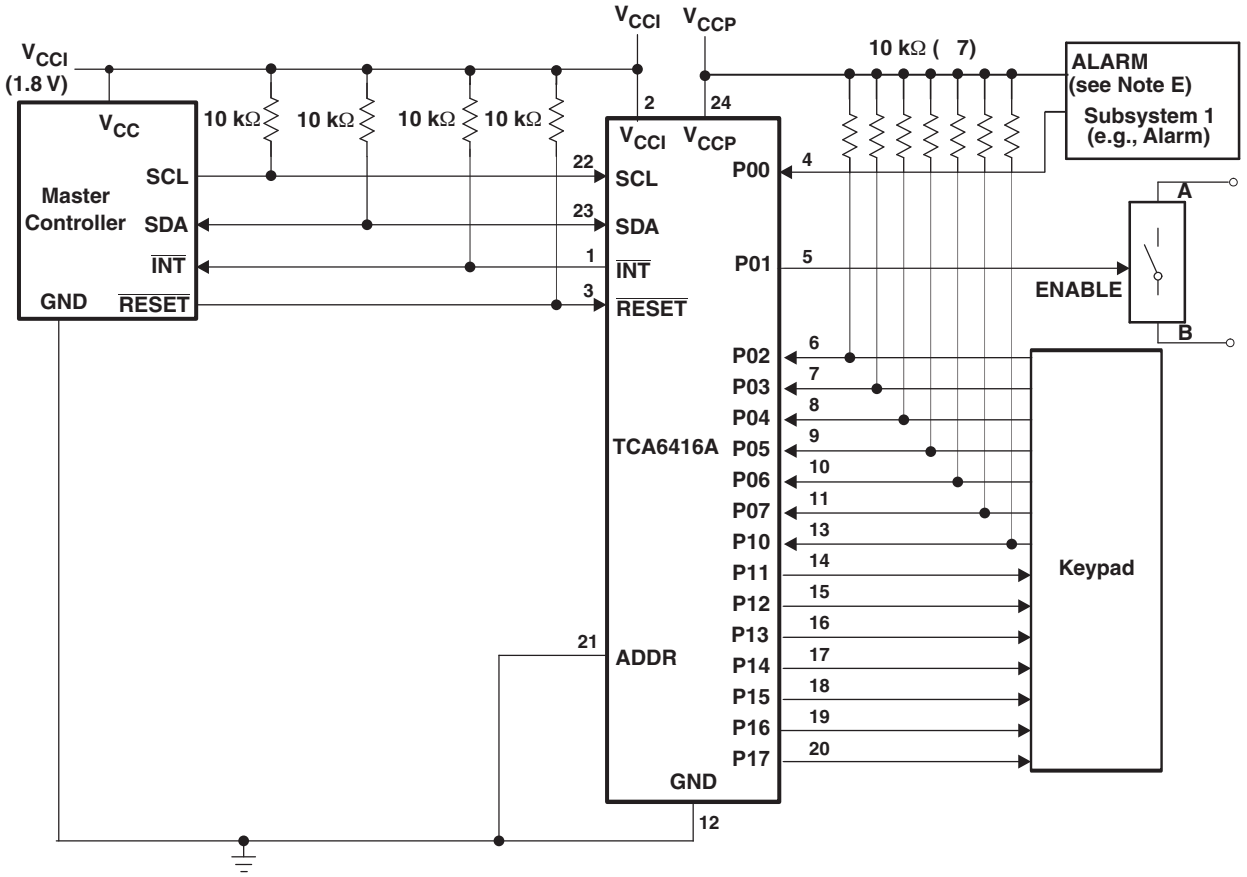
D. I/Os are configured as inputs.

E. All parameters and waveforms are not applicable to all devices.

Figure 13. Reset Load Circuits and Voltage Waveforms

APPLICATION INFORMATION

Figure 14 shows an application in which the TCA6416A can be used.



A. Device address configured as 0100000 for this example.

B. P00 and P02–P10 are configured as inputs.

C. P01 and P11–P17 are configured as outputs.

D. Pin numbers shown are for the PW package.

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

Figure 14. Typical Application

Minimizing I_{CC} When I/Os Control LEDs

When the I/Os are used to control LEDs, normally they are connected to V_{CC} through a resistor as shown in Figure 14. The LED acts as a diode so, when the LED is off, the I/O V_{IN} is about 1.2 V less than V_{CC}. The ΔI_{CC} parameter in Electrical Characteristics shows how I_{CC} increases as V_{IN} becomes lower than V_{CC}. Designs that must minimize current consumption, such as battery power applications, should consider maintaining the I/O pins greater than or equal to V_{CC} when the LED is off.

Figure 15 shows a high-value resistor in parallel with the LED. Figure 16 shows V_{CC} less than the LED supply voltage by at least 1.2 V. Both of these methods maintain the I/O V_{IN} at or above V_{CC} and prevent additional supply current consumption when the LED is off.

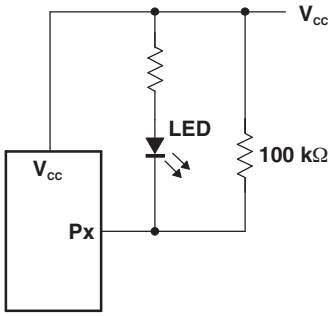


Figure 15. High-Value Resistor in Parallel With the LED

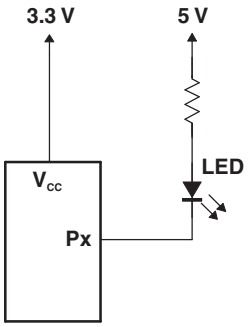


Figure 16. Device Supplied by a Low Voltage

Power-On Reset Requirements

In the event of a glitch or data corruption, TCA6416A can be reset to its default conditions by using the power-on reset feature. Power-on reset requires that the device go through a power cycle to be completely reset. This reset also happens when the device is powered on for the first time in an application.

The two types of power-on reset are shown in Figure 17 and Figure 18.

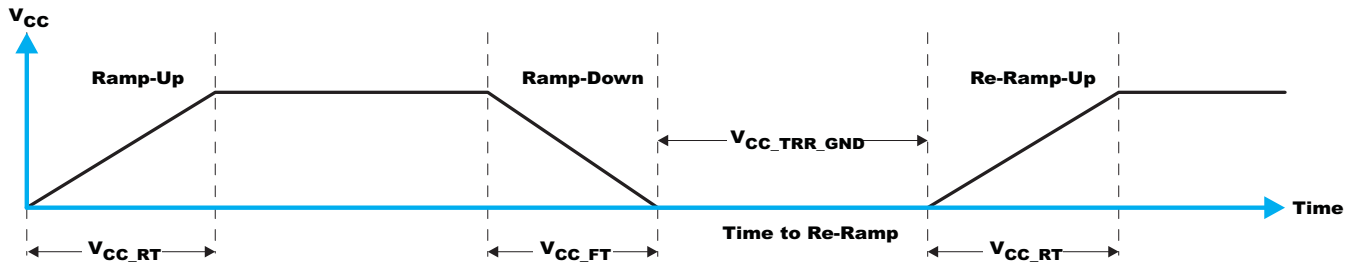


Figure 17. V_{CC} is Lowered Below 0.2 V or 0 V and Then Ramped Up to V_{CC}

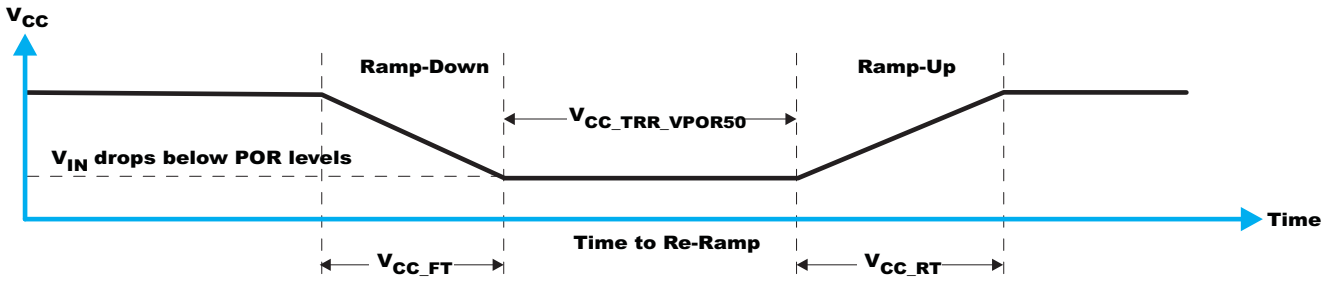


Figure 18. V_{CC} is Lowered Below the POR Threshold, Then Ramped Back Up to V_{CC}

Table 11 specifies the performance of the power-on reset feature for TCA6416A for both types of power-on reset.

Table 11. RECOMMENDED SUPPLY SEQUENCING AND RAMP RATES(1) (2)

PARAMETER			MIN	TYP	MAX	UNIT
t_{FT}	Fall rate	See Figure 17	0.1		2000	ms
t_{RT}	Rise rate	See Figure 17	0.1		2000	ms
t_{TRR_GND}	Time to re-ramp (when V_{CC} drops to GND)	See Figure 17	1			µs
t_{TRR_POR50}	Time to re-ramp (when V_{CC} drops to V_{POR_MIN} – 50 mV)	See Figure 18	1			µs
V_{CC_GH}	Level that V_{CCP} can glitch down to, but not cause a functional disruption when V_{CCX_GW} = 1 µs	See Figure 19			1.2	V
t_{GW}	Glitch width that will not cause a functional disruption when V_{CCX_GH} = 0.5 × V_{CCx}	See Figure 19			10	µs
V_{PORF}	Voltage trip point of POR on falling V_{CC}		0.7			V
V_{PORR}	Voltage trip point of POR on fising V_{CC}				1.4	V

(1) T_A = 25°C (unless otherwise noted).
(2) Not tested. Specified by design.

Glitches in the power supply can also affect the power-on reset performance of this device. The glitch width (V_{CC_GW}) and height (V_{CC_GH}) are dependent on each other. The bypass capacitance, source impedance, and device impedance are factors that affect power-on reset performance. Figure 19 and Table 11 provide more information on how to measure these specifications.

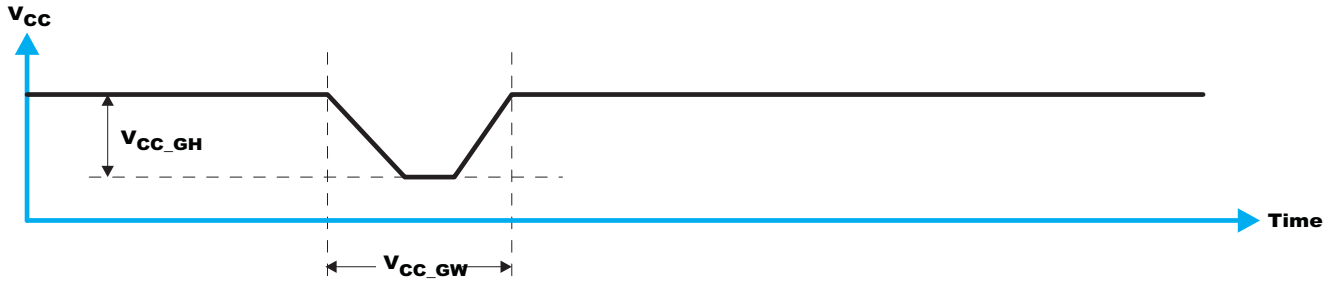


Figure 19. Glitch Width and Glitch Height

V_{POR} is critical to the power-on reset. V_{POR} is the voltage level at which the reset condition is released and all the registers and the I^2C/SMBus state machine are initialized to their default states. The value of V_{POR} differs based on the V_{CC} being lowered to or from 0. Figure 20 and Table 11 provide more details on this specification.

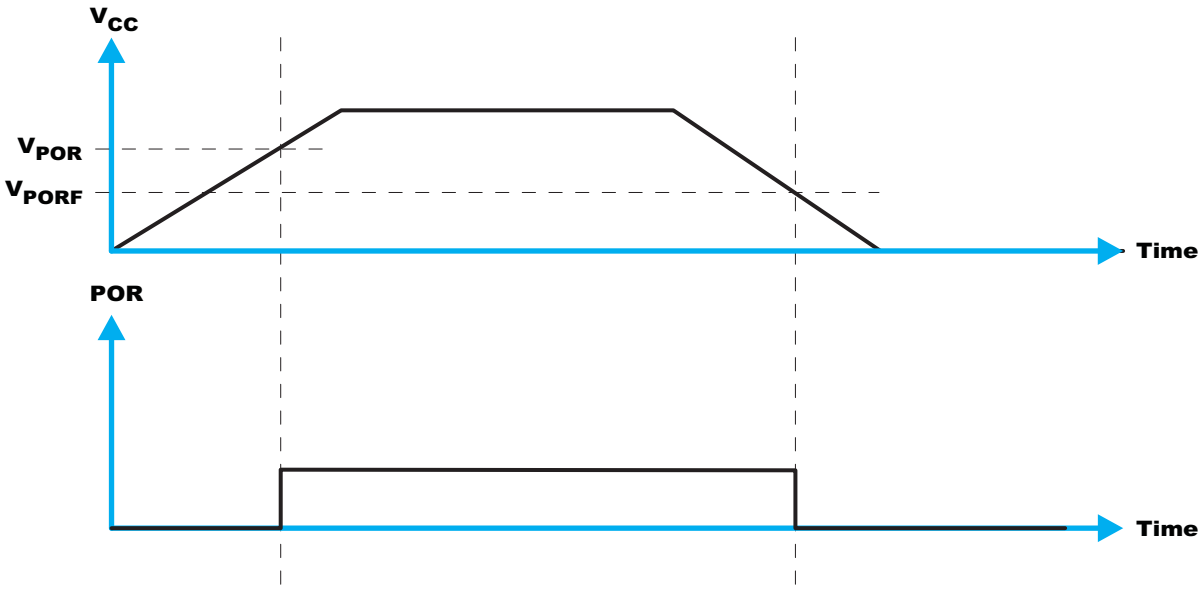


Figure 20. V_{POR}

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
TCA6416APWR	ACTIVE	TSSOP	PW	24	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TCA6416ARTWR	ACTIVE	QFN	RTW	24	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TCA6416AZQSR	ACTIVE	BGA MICROSTAR JUNIOR	ZQS	24	2500	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM

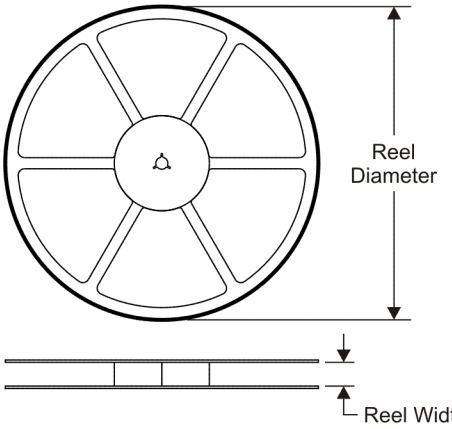
(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

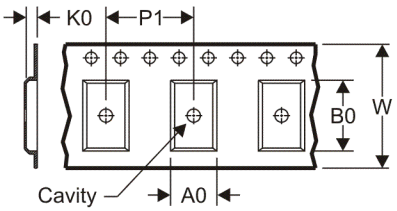
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

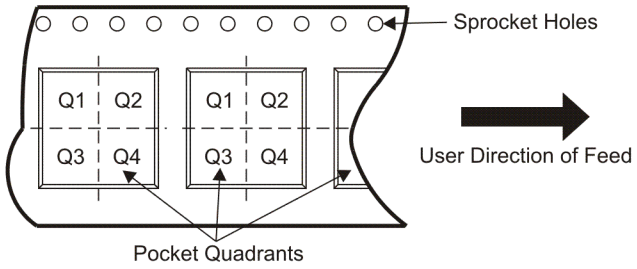


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

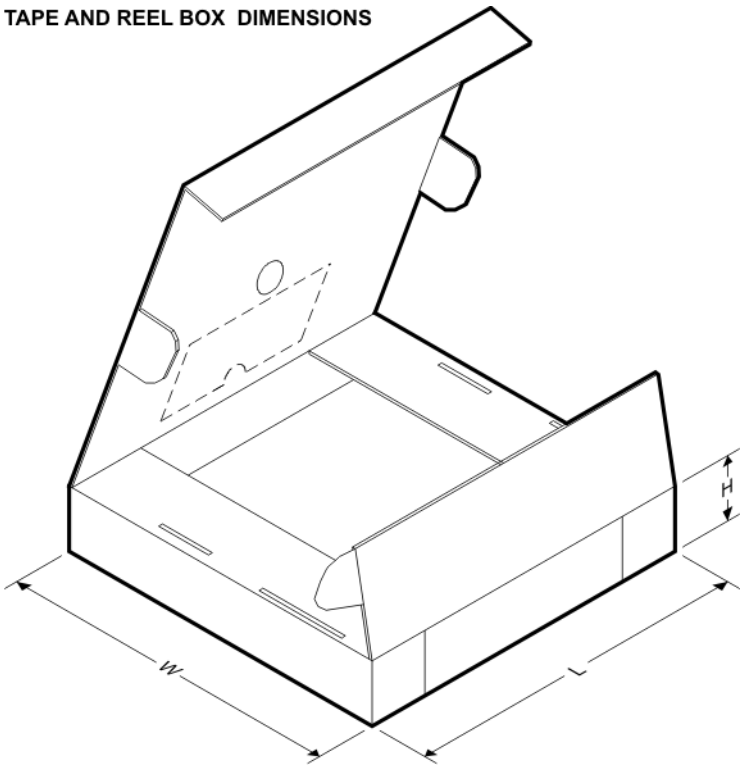
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TCA6416APWR	TSSOP	PW	24	2000	330.0	16.4	6.95	8.3	1.6	8.0	16.0	Q1
TCA6416ARTWR	QFN	RTW	24	3000	330.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
TCA6416AZQSR	BGA MICROSTAR JUNIOR	ZQS	24	2500	330.0	12.4	3.3	3.3	1.6	8.0	12.0	Q1

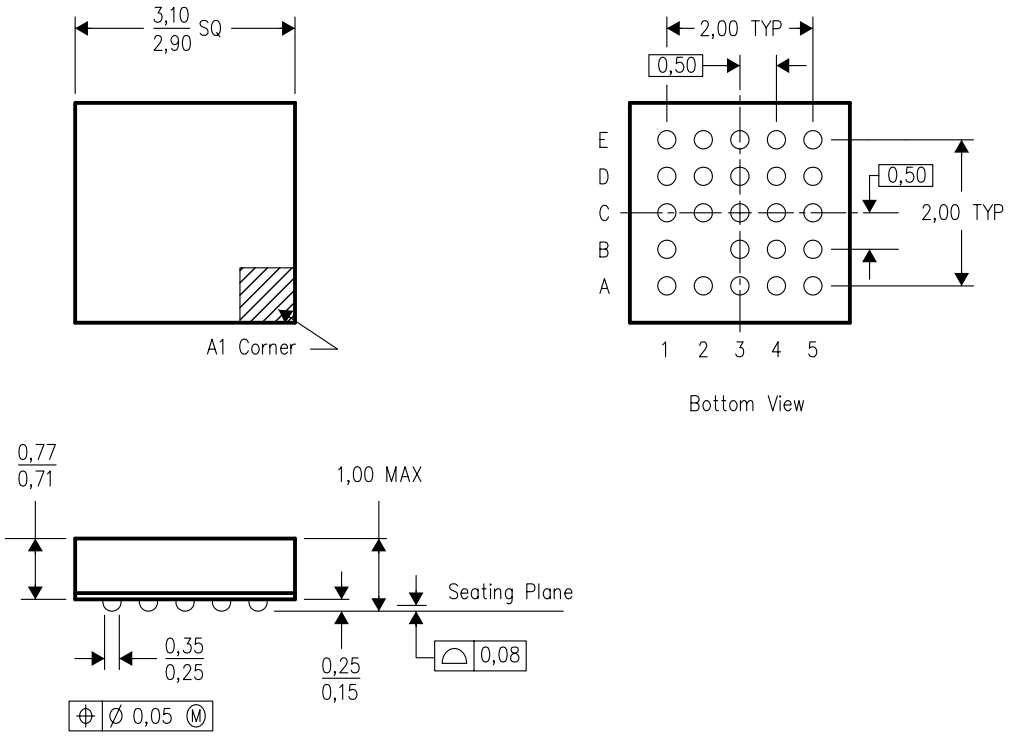
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TCA6416APWR	TSSOP	PW	24	2000	346.0	346.0	33.0
TCA6416ARTWR	QFN	RTW	24	3000	346.0	346.0	29.0
TCA6416AZQSR	BGA MICROSTAR JUNIOR	ZQS	24	2500	340.5	338.1	20.6

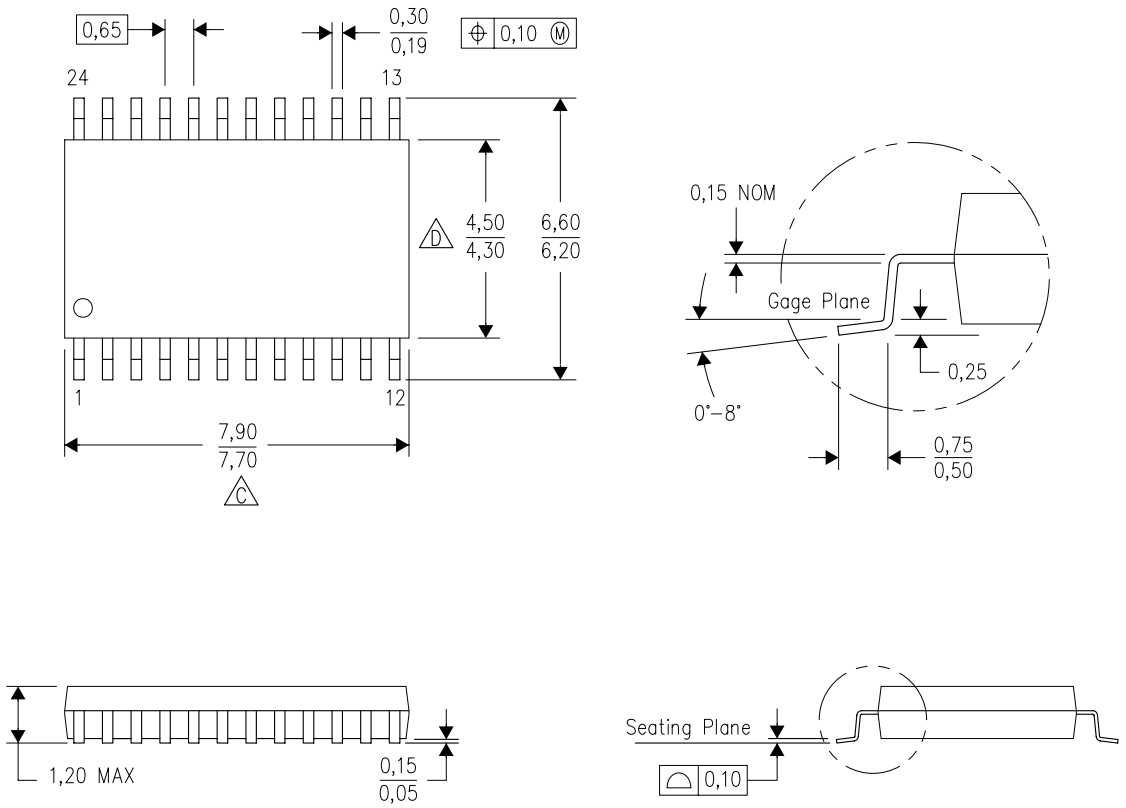
ZQS (S–PBGA–N24) PLASTIC BALL GRID ARRAY



4206374/A 09/04

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Falls within JEDEC MO–225
D. This package is lead–free.

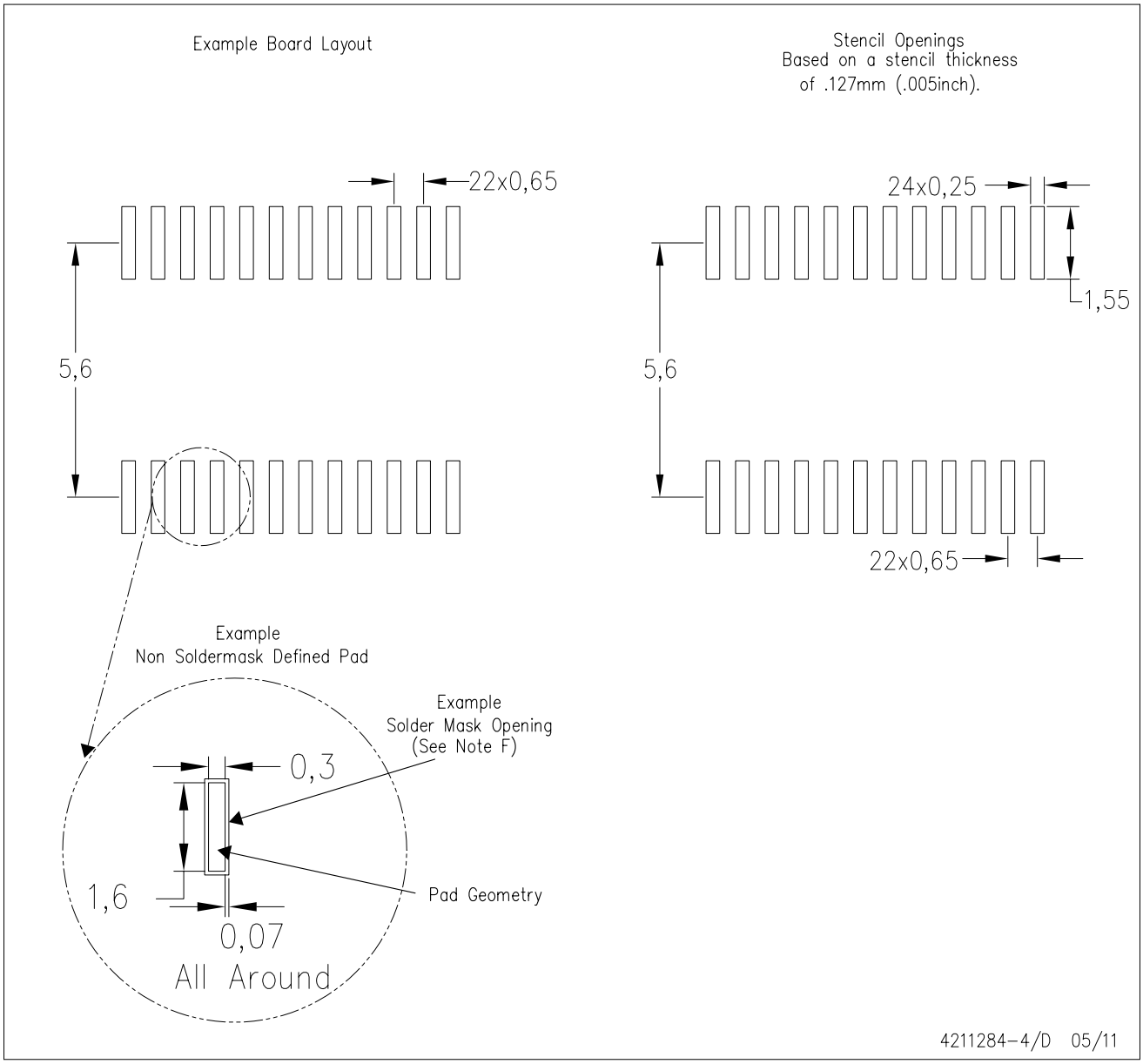
PW (R–PDSO–G24) PLASTIC SMALL OUTLINE



4040064–6/G 02/11

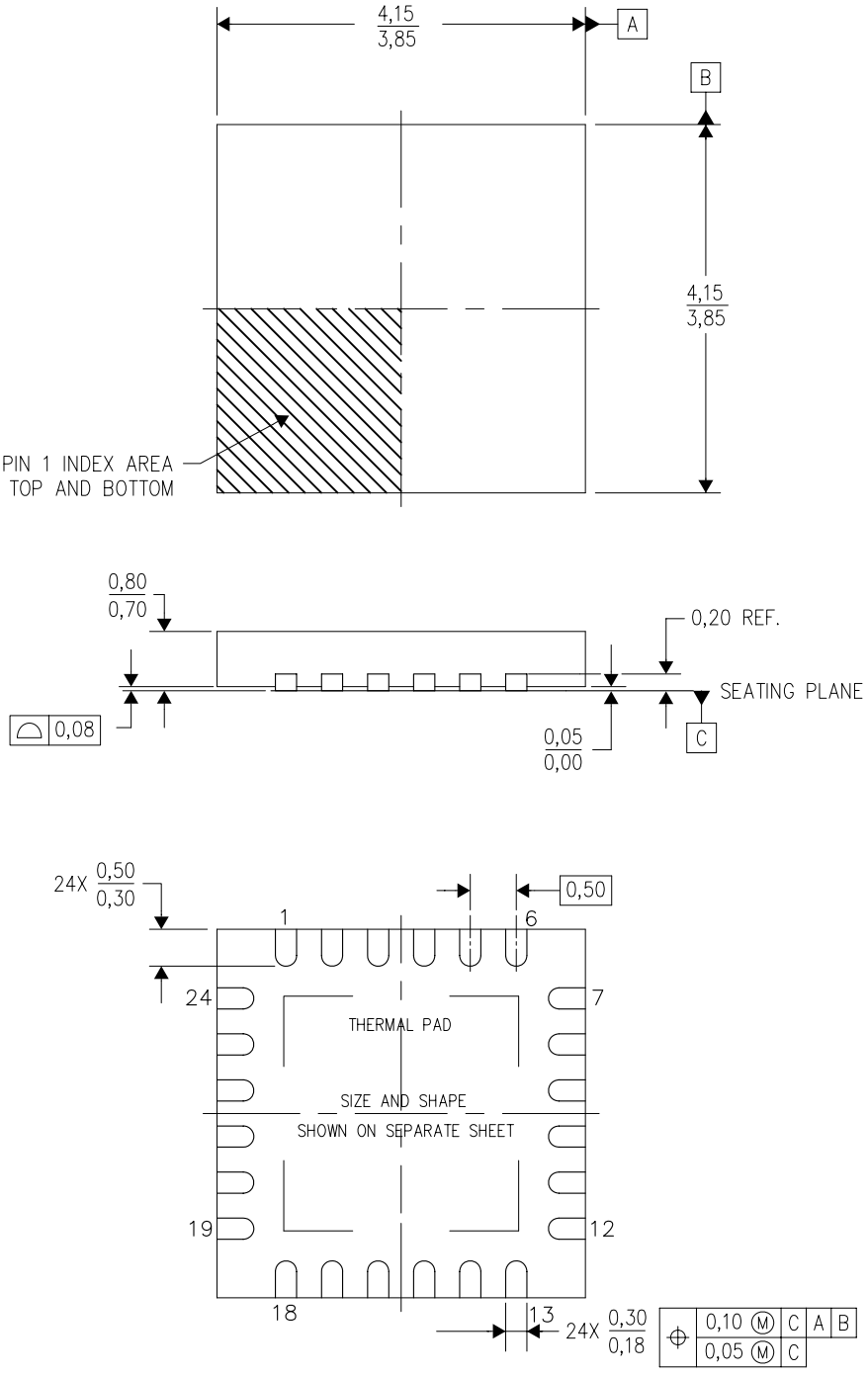
NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
E. Falls within JEDEC MO–153

PW (R–PDSO–G24) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate design.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

RTW (S–PWQFN–N24) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Quad Flatpack, No–Leads (QFN) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Falls within JEDEC MO–220.

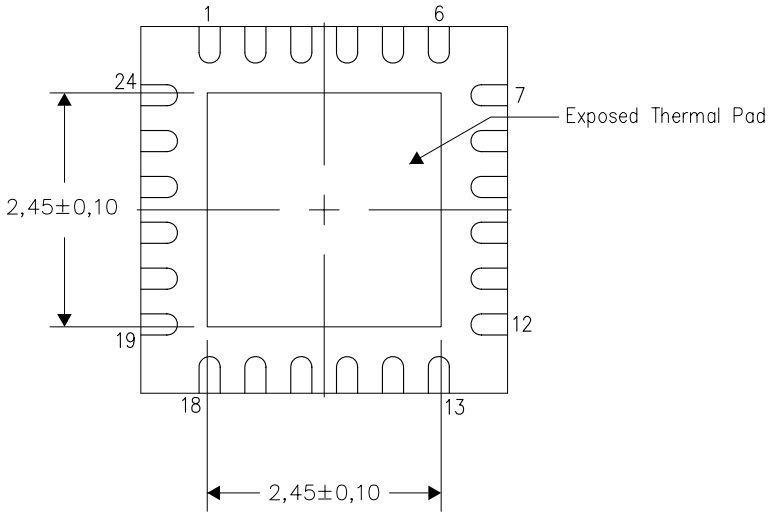
RTW (S–PWQFN–N24) PLASTIC QUAD FLATPACK NO–LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



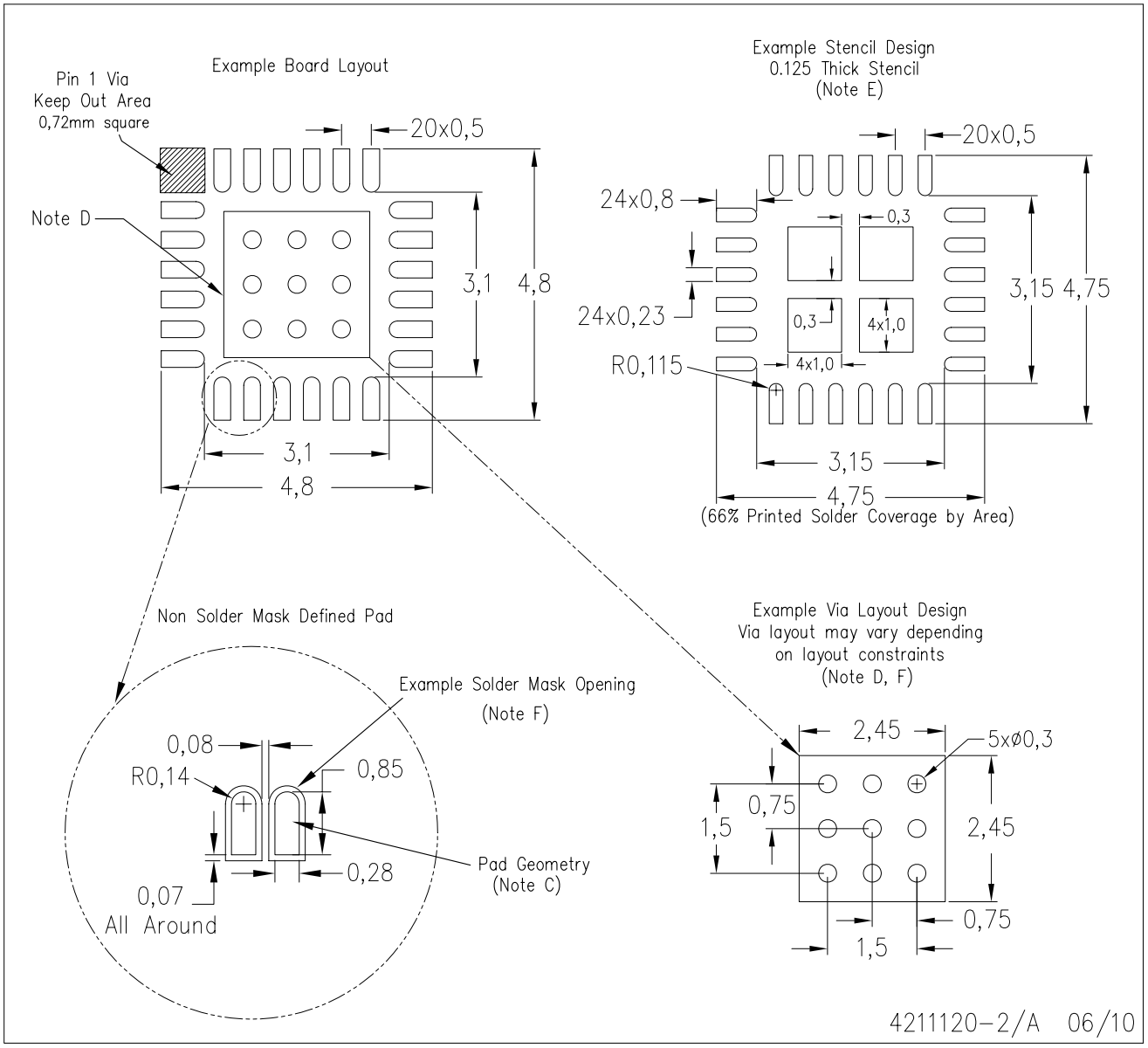
Bottom View

Exposed Thermal Pad Dimensions

4206249–3/K 01/11

NOTES: A. All linear dimensions are in millimeters

RTW (S–PWQFN–N24) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http: //www.ti.com>.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad.

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