





Expanders, Multiplexers and Switches; Hubs, Translator Buffers and Repeaters





## Contents and Overview

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Texas Instruments (TI) has supported the highly efficient I<sup>2</sup>C bus interface for many years. This overview provides an updated look at I<sup>2</sup>C applications and how TI's I/O expanders, multiplexers, buffers and repeaters can help system designers achieve effective subsystem communications using proven I<sup>2</sup>C devices.

#### History

During the 1980s, Philips (Koninklijke Philips Electronics N.V.) developed the two-wire inter-integrated circuit (I<sup>2</sup>C) bus to provide an easy way to connect multiple peripheral circuits to a central processing unit (CPU/MCU) in TV applications.

As circuits became more complex with many peripheral connections, a method was needed to simplify designs and reduce costs. By limiting the number of printed circuit board (PCB) traces and lowering generalpurpose input and output (GPIO) usage on the microprocessor, the I<sup>2</sup>C bus met this requirement.

#### Operation

The I<sup>2</sup>C bus is used in a wide range of applications because it is simple and quick to use. It consists of a twowire communication bus that supports bidirectional data transfer between a master and several slaves. The master or processor controls the bus - in particular, the serial clock (SCL) line. Data is transferred between the master and slave through a serial data (SDA) line. This data can be transferred in four speeds or modes: standard (0 to 100 Kbps), fast (0 to 400 Kbps), fast-mode plus (0 to 1 Mbps) and high-speed (0 to 3.4 Mbps). The most common speeds are the standard and fast modes. See block diagram below for a generic system.

There can be more than one master on a system; the software protocol uses arbitration and synchronization to manage data collisions and loss. Since successive specification enhancements are backwardcompatible, mixed-speed communication is possible with the bus speed controlled by the processor or I<sup>2</sup>C master.

#### Typical I<sup>2</sup>C Features

- Requires one master (processor) and one or more slave devices
- Each device on the bus has a unique address
- Bus capacitive load: 400 pF max
- Rise time: 1000 ns (standard mode) and 300 ns (fast mode)

### I<sup>2</sup>C Applications

The I<sup>2</sup>C bus is useful for many of today's microcontroller- and microprocessor-based systems or other systems linking many I/O devices. These systems may include applications in the following fields:

- Automotive 
   PC/server
- Consumer
   Radio/TV
- Industrial
   Telephony
- Mobile
   Notebooks
- Battery-powered portable applications
- Telecom/networking

Many of the  $I^2C$  bus products are designed to operate in the SMBus environment. The SMBus is similar to the  $I^2C$  bus but has lower current and operates at a lower speed.



Block diagram of generic system using I<sup>2</sup>C devices.



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# I/O Expanders

The  $l^2C$  I/O expanders (as shown in the block diagram) allow system layout to be greatly simplified. The two-wire bus reduces PCB complexity through trace reduction and routing simplification.

### **Advantages**

- Easy board routing
- Board-space savings
- Processor-pin savings
- Low cost
- Industry standard

#### Applications

 Complements processors with limited I/Os

Low-Voltage I/O Expanders Selection Guide

- Feature enhancements
- Keypad control

# Processor Logic



#### System with I<sup>2</sup>C I/O expanders

System without I<sup>2</sup>C I/O expanders



I/O expanders can simplify board layout.

	Мах				Additional features					I/O type		
Device	frequency (kHz)	l <sup>2</sup> C address	V <sub>CC</sub> range (V)	No. of I/Os	Low power	Interrupt	Reset	Configuration registers	5-V-tolerant I/O	Push- pull	Open- drain	
TCA6408A	400	0100 00x	1.65 to 5.5	8-bit	~	~	~	~	<b>v</b>	<b>v</b>		
TCA6416A	400	0100 00x	1.65 to 5.5	16-bit	~	~		~	<b>v</b>	<b>v</b>		
TCA6424A	400	0100 01x	1.65 to 5.5	24-bit	~	~	~	~	~	<b>v</b>		
TCA7408	1000	0100 00x	1.65 to 5.5	8-bit	~	~	~	~	<b>v</b>	<b>v</b>		
TCA9535	400	0100 xxx	1.65 to 5.5	16-bit	~	~		~	<b>v</b>	<b>v</b>		
TCA9539	400	1110 1xx	1.65 to 5.5	16-bit	~	~	~	~	<b>v</b>	<b>v</b>		
TCA9554/A	400	0100 xxx/0111 xxx	1.65 to 5.5	8-bit	~	~		~	<b>v</b>	<b>v</b>		
TCA9555	400	0100 xxx	1.65 to 5.5	16-bit	~	~		~	~	~		

5-V tolerant on the GPIO sides.

New products are listed in **bold red.** Preview products are listed in **bold blue**.

External device

#### I/O Expanders Selection Guide

	Мах					Ac	I/O type				
Device	frequency (kHz)	l <sup>2</sup> C address	V <sub>CC</sub> range (V)	No. of I/Os	Low power	Interrupt	Reset	Configuration registers	5-V-tolerant I/O	Push- pull	Open- drain
PCA9536	400	1000 001	2.3 to 5.5	4-bit				~	✓	<b>v</b>	
PCA6107	400	0011 xxx	2.3 to 5.5	8-bit	<b>v</b>	<b>v</b>	~	~	<ul> <li>✓</li> </ul>	~	<ul> <li>✓</li> </ul>
PCA9534	400	0100 xxx	2.3 to 5.5	8-bit	~	<b>v</b>		~	<b>v</b>	<b>v</b>	
PCA9534A	400	0111 xxx	2.3 to 5.5	8-bit	<b>v</b>	<b>v</b>		~	<b>v</b>	<b>v</b>	
PCA9538	400	1110 Oxx	2.3 to 5.5	8-bit	~	<b>v</b>	~	~	<b>v</b>	<b>v</b>	
PCA9554A	400	0111 xxx	2.3 to 5.5	8-bit		<b>v</b>		~	<b>v</b>	<b>v</b>	
PCA9554	400	0100 xxx	2.3 to 5.5	8-bit		<b>v</b>		~	<b>v</b>	<b>v</b>	
PCA9557	400	0011 xxx	2.3 to 5.5	8-bit	<b>v</b>		~	~	~	~	<ul> <li>✓</li> </ul>
PCA9535	400	0100 xxx	2.3 to 5.5	16-bit	<b>v</b>	<b>v</b>		~	<b>v</b>	<b>v</b>	
PCA9539	400	1110 1xx	2.3 to 5.5	16-bit	<b>v</b>	<b>v</b>	~	~	<b>v</b>	<b>v</b>	
PCA9555	400	0100 xxx	2.3 to 5.5	16-bit		<b>v</b>		~	<b>v</b>	<b>v</b>	
PCF8574	100	0100 xxx	2.5 to 6.0	8-bit		<b>v</b>				~	
PCF8574A	100	0111 xxx	2.5 to 6.0	8-bit		<b>v</b>				<b>v</b>	
PCF8575	400	0100 xxx	2.5 to 5.5	16-bit		V				<b>v</b>	
PCF8575C	400	0100 xxx	4.5 to 5.5	16-bit		~					~



The  $l^2C$  multiplexer/switch shown in this diagram allows further expansion of  $l^2C$  systems while maintaining the simple two-wire bus. It can also perform voltage translation and segment isolation.

#### **Advantages**

- Pin savings on the I<sup>2</sup>C master, as each switch is activated or isolated through the I<sup>2</sup>C software
- Supports voltage-level translation between 1.8-, 2.5-, 3.3- and 5-V buses, which is essential in mixedvoltage I<sup>2</sup>C systems

### **Applications**

- Resolves I<sup>2</sup>C address conflicts
- I<sup>2</sup>C bus isolation
- I<sup>2</sup>C bus expansion

## **Multiplexers and Switches Selection Guide**



Dual bidirectional translating switch controlled via I<sup>2</sup>C bus.

-	Мах				Additional features				I/O type		
Device	frequency (kHz)	l <sup>2</sup> C address	V <sub>CC</sub> range (V)	Channel width	Interrupt	Reset	Simultaneously active channels	5-V-tolerant I/O	Push- pull	Open- drain	
PCA9543A	400	1110 0xx	2.3 to 5.5	2-channel	~	<b>v</b>	1 to 2	~		<ul> <li>✓</li> </ul>	
PCA9544A	400	1110 xxx	2.3 to 5.5	4-channel	~		1	~		v	
PCA9545A	400	1110 0xx	2.3 to 5.5	4-channel	~	<b>v</b>	1 to 4	~		v	
PCA9546A	400	1110 xxx	2.3 to 5.5	4-channel		<b>v</b>	1 to 4	~		v	
PCA9548A	400	1110 xxx	2.3 to 5.5	8-channel		V	1 to 8	~		V	

# Hubs, Translator Buffers and Repeaters

I<sup>2</sup>C hubs, buffers and repeaters permit bus expansion, sectional bus isolation, address conflict resolution and voltage-level translation, as shown in this diagram.

#### **Advantages**

- Can isolate a section on the I<sup>2</sup>C bus through enable (EN) pin
- Supports voltage-level translation between 1.1-, 1.8-, 2.5-, 3.3- and 5-V buses, which is essential in mixedvoltage I<sup>2</sup>C systems

### **Applications**

- I<sup>2</sup>C-bus expansion through buffering of I<sup>2</sup>C signals
- Resolving address conflicts



Two-channel bidirectional repeater.

## Hubs, Translator Buffers and Repeaters (cont.)

Hubs, Translator Buffers, and Repeaters Selection Guide

	Max						I <sup>2</sup> C bus capacita	nce supported		I/O 1	уре
Device	frequency (kHz)	l <sup>2</sup> C address	V <sub>CC</sub> range (V)	Channel width	Enable pin	EXP pin	Master side (pF)	Each slave side (pF)	5-V-tolerant I/O	Push- pull	Open- drain
PCA9515A	400	None	2.3 to 5.5	2-channel	~		400	400	~		~
PCA9517	400	None	0.9 to 5.5	2-channel	~		400	400	~		~
PCA9518	400	None	3.0 to 3.6	5-channel	~	~	400	400	~		~
P82B715	1,000	None	3.0 to 12.0	2-channel							
P82B96	400	None	2.0 to 15.0	2-channel			400	400	~		~
TCA4311A	400	None	2.7 to 5.5	2-channel	~		400	400	~		~
TCA9509	400	None	0.9 to 5.5	2-channel	~		400	400	~		~

New products are listed in **bold red**. Preview products are listed in **bold blue**.

# **Special Functions LED** Driver

The LED driver frees the processer from having to manage the LEDs. It will manage turning the LEDs on and off (per the required dimming rate). This will free up valuable processor time, thus helping to create a more efficient system.

## Advantages

- · Supports brightness control and blink modes at the same time
- 1.8-V compatible for use with nextgeneration processors
- Multiple PWMs for multiple blink modes

#### **Applications**

- Fun light (decoration)
- Enhanced feature set ٠
- Driving RGB LEDs •
- Control function (indicator lights) •

## I<sup>2</sup>C Special Functions Selection Guide

Device	Function	Max frequency (kHz)	l <sup>2</sup> C address	V <sub>CC</sub> range (V)	Low voltage	Enable pin	5-V-tolerant I/O	Push- pull I/O type	Open- drain I/O type
TCA6507	LED driver	400	100 0101	1.65 to 3.6	~	~	<b>v</b>		~
TCA8418	Keypad controller	400	0110 100	1.65 to 3.6	~	~	<b>v</b>		~
TCA8418E	Keypad controller	1 MHz	0110 100	1.65 to 3.6	~				~
PCA9306	Voltage translator	400	None	0 to 5.5		~	~		
TCA9406	Voltage translator	1 MHz	None	1.65 to 5.5	~	~	~	~	~
5-V tolerant on t	the GPIO sides						New c	products are list	ted in <b>bold red</b>

rant on the GPIU si



White-LED flashlight driver and high-brightness LED indicator/backlight power supply.

# 😔 One-Wire Interface

The TCA5405 is a 5-bit output expander controlled using a single wire input. This device is ideal for portable applications as it has a wide VCC range of 1.65V to 3.6 V. The TCA5405 uses a self-timed serial data protocol with a single data input driven by a master device synchronized to an internal clock of that device. During a Setup phase, the bit period is sampled, then the TCA5405 generates its own internal clock synchronized to that of the Master device to sample the input over a five-bit-period Data Transfer phase and writes the bit states on the parallel outputs after the last bit is sampled. The TCA5405 is available in an 8-pin 1.5mm x 1.5mm RUG µQFN package.

## **Advantages**

- Operating power-supply voltage range of 1.65 V to 3.6 V
- Five independent push-pull outputs
- Single input (DIN) controls state of all outputs
- High-current drive outputs 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
  - 1000-V Charged-Device Model

## Applications

- Cell phones
- PDAs
- Portable media players
- MP3 players
- Portable instrumentation



TCA5405 block diagram.



Bidirectional voltage-level translators enable voltage translation where interconnection between voltage levels is required.

## **Advantages**

- Can interface between processors operating at 1.8 V and I<sup>2</sup>C slave devices operating at V<sub>CC</sub> of 2.5 V and higher
- Provides bidirectional voltage translation without a direction pin
- Accommodates standard- and fast-mode I<sup>2</sup>C devices and multiple masters
- Automotive qualified part available
- 8-kV Human Body Model (HBM) ESD
  Protection

## **Applications**

• I<sup>2</sup>C bus voltage translation



TCA9406 bidirectional voltage-level translator.

## Keypad Controller

The keypad controller frees the processor from having to scan the keypad for presses and releases. It is a keypad scan device with 18 GPIOs that can be configured into 8 inputs and 10 outputs to support up to an 8 x 10 keypad array (80 buttons).

## **Advantages**

- Ideal for usage with processors that have limited GPIOs
- Provides power and bandwidth savings
- Includes an oscillator that debounces at 50 us and a 10 byte FIFO to store 10-key presses and releases
- Interrupt output can be configured to alert key presses and releases either as they occur, or at maximum rate

## Applications

- Smart phones
- PDAs
- GPSs
- MP3 players



7

# Frequently Asked Questions

- Q. Why doesn't the slave device respond to the master after an I<sup>2</sup>C call is made from the master?
- If the device is not responding properly, there may be an I<sup>2</sup>C protocol violation.
  - To begin, a proper I<sup>2</sup>C start condition must be issued.
  - After stop condition, the master must reissue the start condition.
  - After every start condition, the master must send the full slave address.
  - During communication, if the master issues a restart condition, the full slave address must be sent.
  - If the device does not respond with an ACK, it did not recognize the address.
  - Partial data cannot be written to the I/O.
    - To write to the I/O, complete 8-bit data must be sent to the slave.
    - If fewer than 8 bits are sent, the slave will not respond with an ACK and will not update the I/O port.
- Q. When using I<sup>2</sup>C I/O expanders, what is the functionality difference between power-on reset and /RESET? (See figure on this page.)
- A. Power-on reset:
  - When power (from 0 V) is applied to the  $V_{CC}$ , the internal poweron reset holds the device in a reset condition until  $V_{CC}$  reaches Vpor (~1.4 V).
  - Once V<sub>CC</sub> reaches Vpor, the internal registers and I<sup>2</sup>C/SMBus state machine are initialized to their default states.
  - After this, the device can be returned to its default reset state if  $V_{CC}$  is lowered to 0 V.

## /RESET:

• Simply asserting a low on the /RESET input returns the device to its default state.

- Creates the same effect as a power-on reset without power cycling the device.
- The /RESET input is 5.5-V tolerant (regardless of voltage level on V<sub>CCP</sub>).
- Partial data cannot be written to the I/O.
  - To write to the I/O, complete 8-bit data must be sent to the slave.
  - If fewer than 8 bits are sent, the slave will not respond with an ACK and will not update the I/O port.

# Q. How should an unused /RESET pin be terminated?

A. /RESET is an input to the master. It requires a pull-up resistor to  $V_{CC}$  if no active connection is used.

# Q. What is the functionality of the interrupt (/INT) control?

- The /INT is an open-drain output in the I<sup>2</sup>C slave. It is used to inform the I<sup>2</sup>C master if any of the inputs in the slave device have changed state.
  - If any of the I/Os configured as inputs change state before the I/O is read (i.e., if a mismatch between the I/O and the contents of the internal input register occurs), /INT will become low.
  - /INT is not affected by I/Os configured as outputs.
  - /INT can be tied to any voltage (or V<sub>CC</sub> pin) up to 5.5 V through a pull-up resistor.

# Q. How should an unused /INT pin be terminated?

- A. /INT is an open-drain output that requires a pull-up resistor for proper operation. If /INT is not used, it can be left open or connected directly to GND.
- Q. What is the power-on default for the interrupt (/INT) pin?
- A. High.
- Q. How can an /INT be cleared (returned back to high state)?
- A. Read (clock) the data on the I/O port that generated the /INT.
  - Change the data on the I/O to the original setting.
  - A stop event will clear the /INT.
- Q. How can a low /INT be avoided at power up in I<sup>2</sup>C I/O expanders?
- A. At power up, the P ports are configured as inputs by default.
  - When power up ends and the device has a valid V<sub>CC</sub> value, the input port (P port) is compared to the internal input register (no clock needed), and /INT goes active (low) unless there is a match.
  - The internal input registers are designed to power up with all ones or high.
  - The /INT should start high at power up if the P port is initially high (all ones) to match the internal input register.



Typical I<sup>2</sup>C I/O expander applications.

# Frequently Asked Questions

- Q. What is the power-on default for the P port (I/O port) in an I<sup>2</sup>C I/O expander?
- A. For the PCF8574/A, PCF8575 and devices with internal pull-up resistors like the PCA9536, PCA9554, PCA9554A and PCA9555, the input default is high.

For the PCF8575C and devices without internal pull-up resistors, the input is 3-state.

# Q. What is a fun light and what is its purpose?

- Fun lights are any set of lights used for less critical tasks such as:
   Decoration.
  - Enhancing the feature set of an application.
  - Control functions (such as indicator lights).

Fun lights are mostly found on battery-powered portable applications:

- Notebooks
- Handsets
- Consumer portables
- Portable media players

Some example fun-light

applications are:

- Predictive key entry for text messages.
- Making a smartphone flash to remind the user of an appointment.
- Providing battery-charging status.
- Enhancing audio experience through supporting a "base."



# Q. How should an unused I/O pin in an I<sup>2</sup>C I/O expander be terminated?

A. For devices with internal resistors between  $V_{CC}$  and the I/O, such as PCA9555, PCA9536 and PCA9554/A, the I/O can be connected directly to  $V_{CC}$  or GND.

For devices without internal resistors, a resistor can be used to terminate unused I/Os to  $V_{CC}$  or GND.

#### Solution No. 2: Using TCA devices



- Q. What are the benefits of using TCAseries devices? (See figure above.)
- Low-voltage operation. TCAseries devices provide a one-chip interface with processors operating at 1.8 V to:
  - Save board costs.
  - Save board space.
  - Provide better inventory management.
  - Wide-voltage operation:
    - Can interface with legacy and next-generation processors.
  - Low power consumption.







0.083

(2,10)

16-pin

µCSP (ZSZ)

Area =  $4.0 \text{ mm}^2$ 

0.167

(4,25)

0.083

(2, 10)

♣

0.260

(6, 60)

╈

QFN (RUG) Lead pitch = 0.020(0,5)Height = 0.015 (0,37) Area = 2.4025 mm<sup>2</sup>



★.

1.55

(1,45)

16-pin QFN (RGT)

Lead pitch = 0.020 (0,50) Height = 0.039 (1,00) Area = 0.015 (9,9)



20-ball VFBGA (ZXY) Ball pitch = 0.020 (0,50) Height = 0.016 (0,41) Area = 0.012 (8,1)



24-pin QFN (RTW) Lead pitch = 0.020 (0,50) Height = 0.032 (0,80)Area = 0.027 (17,2)



**Dimensions are in inches (millimeters)** 



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- TPS920x microcontroller power
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