I²C Guide

I²C

Texas Instruments

Texas Instruments

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

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3Q 2009

Contents and Overview

Texas Instruments (TI) has supported the highly efficient I²C bus interface for many years. This overview provides an updated look at I²C applications and how TI's I/O expanders, multiplexers, buffers and repeaters can help system designers achieve effective subsystem communications using proven I²C devices.

History

During the 1980s, Philips (Koninklijke Philips Electronics N.V.) developed the two-wire inter-integrated circuit (I²C) 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 general-purpose input and output (GPIO) usage on the microprocessor, the I²C bus met this requirement.

Operation

The I²C bus is used in a wide range of applications because it is simple and quick to use. It consists of a two-wire 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 backward-compatible, mixed-speed communication is possible with the bus speed controlled by the processor or I²C master.

Typical I²C Features

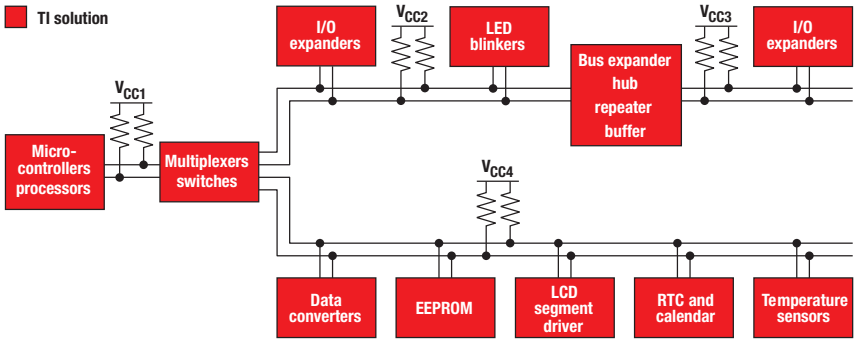
- Requires one master (processor) and one or more slave devices
- Each device on the bus has a unique address
- Bus capacitive load: 400 pF max
- Rise time: 1000 ns (standard mode) and 300 ns (fast mode)

I²C Applications

The I²C 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
- Consumer
- Industrial
- Mobile
- PC/server
- Radio/TV
- Telephony
- Notebooks
- Battery-powered portable applications
- Telecom/networking

Many of the I²C bus products are designed to operate in the SMBus environment. The SMBus is similar to the I²C bus but has lower current and operates at a lower speed.



Block diagram of generic system using I²C devices.

I/O Expanders

The I²C 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.

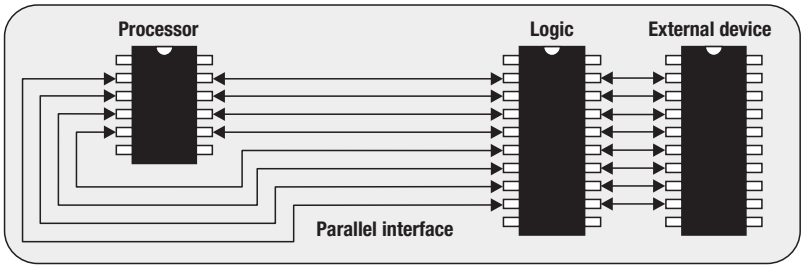
Advantages

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

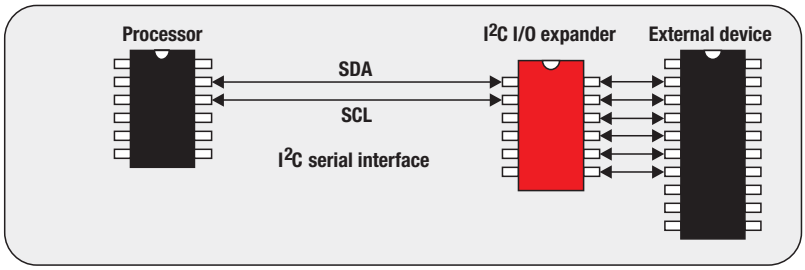
Applications

- Complements processors with limited I/Os
- Feature enhancements
- Keypad control

System without I²C I/O expanders



System with I²C I/O expanders



I/O expanders can simplify board layout.

Low-Voltage I/O Expanders Selection Guide

Device	Max frequency (kHz)	I²C address	V_{CC} range (V)	No. of I/Os	Additional features					I/O type	
					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	✔	✔	✔	✔	✔	✔	
TCA6416A	400	0100 00x	1.65 to 5.5	16-bit	✔	✔		✔	✔	✔	
TCA6424	400	0100 00x	1.65 to 5.5	24-bit	✔	✔	✔	✔	✔	✔	

I/O Expanders Selection Guide

Device	Max frequency (kHz)	I²C address	V_{CC} range (V)	No. of I/Os	Additional features					I/O type	
					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				✔	✔	✔	
PCA6107	400	0011 xxx	2.3 to 5.5	8-bit	✔	✔	✔	✔	✔	✔	✔
PCA9534	400	0100 xxx	2.3 to 5.5	8-bit	✔	✔		✔	✔	✔	
PCA9534A	400	0111 xxx	2.3 to 5.5	8-bit	✔	✔		✔	✔	✔	
PCA9538	400	1110 0xx	2.3 to 5.5	8-bit	✔	✔	✔	✔	✔	✔	
PCA9554A	400	0111 xxx	2.3 to 5.5	8-bit		✔		✔	✔	✔	
PCA9554	400	0100 xxx	2.3 to 5.5	8-bit		✔		✔	✔	✔	
PCA9557	400	0011 xxx	2.3 to 5.5	8-bit	✔		✔	✔	✔	✔	✔
PCA9535	400	0100 xxx	2.3 to 5.5	16-bit	✔	✔		✔	✔	✔	
PCA9539	400	1110 1xx	2.3 to 5.5	16-bit	✔	✔	✔	✔	✔	✔	
PCA9555	400	0100 xxx	2.3 to 5.5	16-bit		✔		✔	✔	✔	
PCF8574	100	0100 xxx	2.5 to 6.0	8-bit		✔				✔	
PCF8574A	100	0111 xxx	2.5 to 6.0	8-bit		✔				✔	
PCF8575	400	0100 xxx	2.5 to 5.5	16-bit		✔				✔	
PCF8575C	400	0100 xxx	4.5 to 5.5	16-bit		✔					✔

Multiplexers and Switches

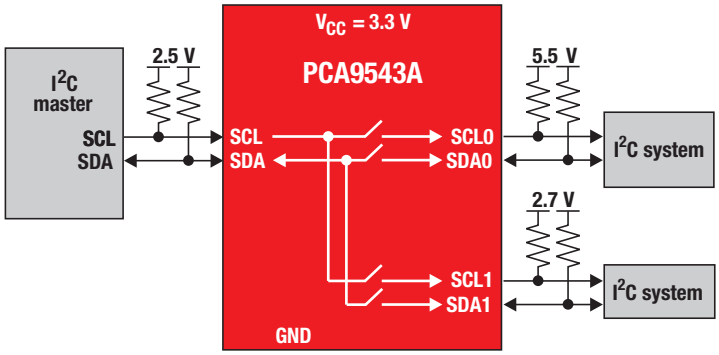
The I²C multiplexer/switch shown in this diagram allows further expansion of I²C systems while maintaining the simple two-wire bus. It can also perform voltage translation and segment isolation.

Advantages

- Pin savings on the I²C master, as each switch is activated or isolated through the I²C software
- Supports voltage-level translation between 1.8-, 2.5-, 3.3- and 5-V buses, which is essential in mixed-voltage I²C systems

Applications

- Resolves I²C address conflicts
- I²C bus isolation
- I²C bus expansion



Dual bidirectional translating switch controlled via I²C bus.

Multiplexers and Switches Selection Guide

Device	Max frequency (kHz)	I²C address	V_{CC} range (V)	Channel width	Additional features				I/O type	
					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	✔	✔	1 to 2	✔		✔
PCA9544A	400	1110 xxx	2.3 to 5.5	4-channel	✔		1	✔		✔
PCA9545A	400	1110 0xx	2.3 to 5.5	4-channel	✔	✔	1 to 4	✔		✔
PCA9546A	400	1110 xxx	2.3 to 5.5	4-channel		✔	1 to 4	✔		✔
PCA9548A	400	1110 xxx	2.3 to 5.5	8-channel		✔	1 to 8	✔		✔

Hubs, Buffers and Repeaters

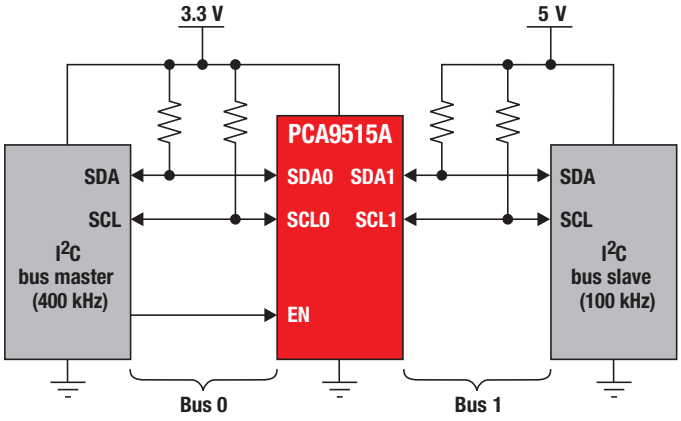
I²C hubs, buffers and repeaters permit bus expansion, sectional bus isolation, address conflict resolution and voltage-level translation, as shown in this diagram.

Advantages

- Can isolate a section on the I²C bus through enable (EN) pin
- Supports voltage-level translation between 1.8-, 2.5-, 3.3- and 5-V buses, which is essential in mixed-voltage I²C systems

Applications

- I²C-bus expansion through buffering of I²C signals
- Resolving address conflicts



Two-channel bidirectional repeater.

Hubs, Buffers and Repeaters (cont.)

Hubs, Buffers and Repeaters Selection Guide

Device	Max frequency (kHz)	I²C address	V_{CC} range (V)	Channel width	Enable pin	EXP pin	I²C bus capacitance supported		5-V-tolerant I/O	I/O type	
							Master side (pF)	Each slave side (pF)		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	✔		✔
P8131715	1,000	None	3.0 to 12.0	2-channel							
P82B96	400	None	2.0 to 15.0	2-channel			400	400	✔		✔
PCA9548A	400	None	2.3 to 5.5	8-channel			400	400	✔		✔
TCA4311	400	None	2.7 to 5.5	2-channel	✔		400	400			✔

Special Functions

LED Driver

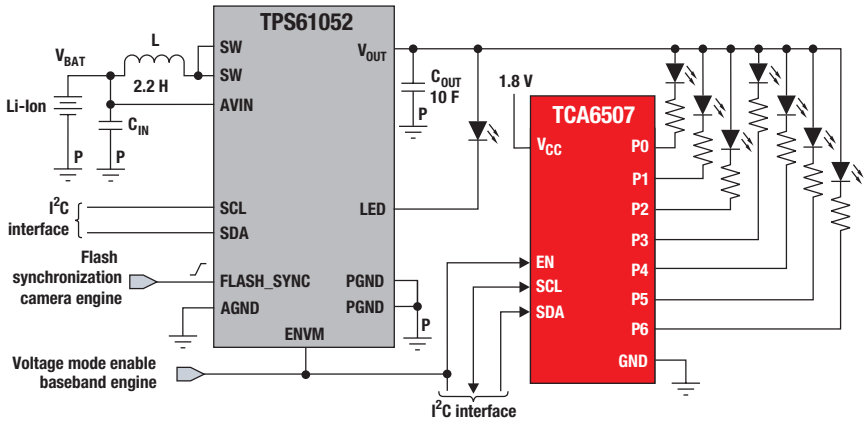
The LED driver frees the processer from having to manage the LEDs. It will manage turning the LEDs on and off (per the required dimming rate). This will free up valuable processor time, thus helping to create a more efficient system.

Advantages

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

Applications

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



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

I²C Special Functions Selection Guide

Device	Function	Max frequency (kHz)	I²C address	V_{CC} 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	✔	✔	✔		✔
TCA8418	Keypad controller	400	0110 100	1.65 to 3.6	✔	✔	✔		✔
PCA9306	Voltage translator	400	None	0 to 5.5		✔	✔		

I²C Translators

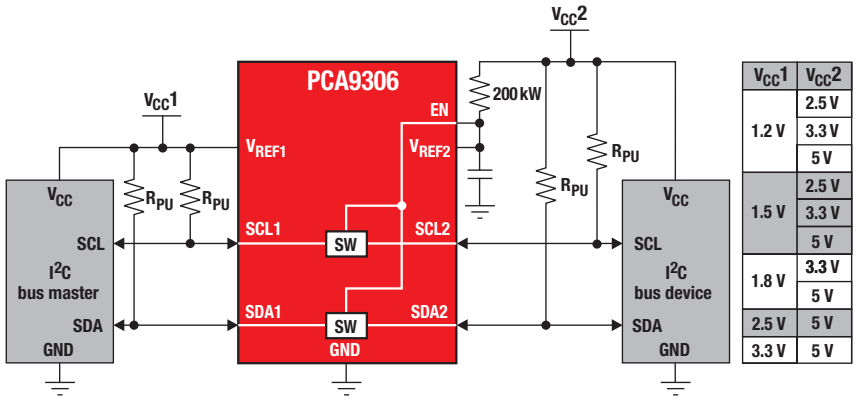
Bidirectional voltage-level translators enable voltage translation where interconnection between voltage levels is required.

Advantages

- Can interface between processors operating at 1.8 V and I²C slave devices operating at V_{CC} of 2.5 V and higher
- Provides bidirectional voltage translation without a direction pin
- Accommodates standard- and fast-mode I²C devices and multiple masters

Applications

- I²C bus voltage translation



PCA9306 bidirectional voltage-level translator.

Keypad Controller

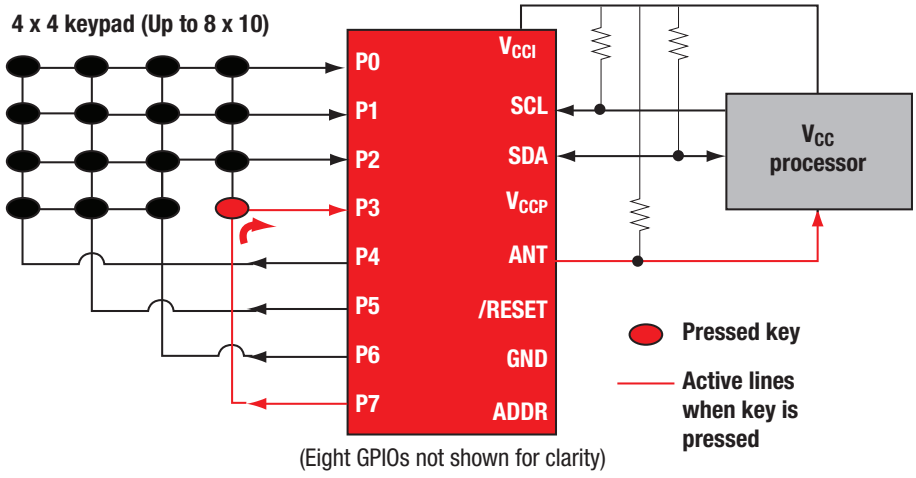
The keypad controller frees the processor from having to scan the keypad for presses and releases. It is a keypad scan device with 18 GPIOs that can be configured into 8 inputs and 10 outputs to support up to an 8 x 10 keypad array (80 buttons).

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



TCA8418 application to support a 4 x 4 keypad.

Frequently Asked Questions

Q. Why doesn't the slave device respond to the master after an I²C call is made from the master?

A.
- If the device is not responding properly, there may be an I²C protocol violation.
  - To begin, a proper I²C 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 I²C 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 power-on reset holds the device in a reset condition until V_{CC} reaches Vpor (~1.4 V).
- Once V_{CC} reaches Vpor, the internal registers and I²C/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_{CCP}).
- 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?

A.
- The /INT is an open-drain output in the I²C slave. It is used to inform the I²C 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_{CC} 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?

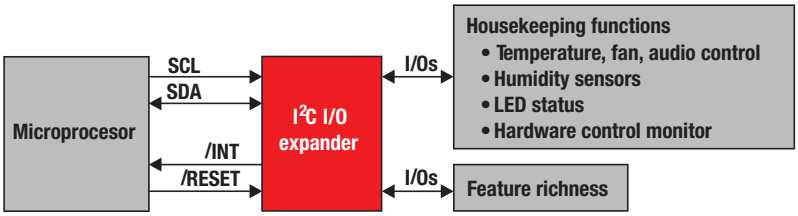
A. High.

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 I²C 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_{CC} 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 I²C I/O expander applications.

Frequently Asked Questions

Q. What is the power-on default for the P port (I/O port) in an I²C 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.

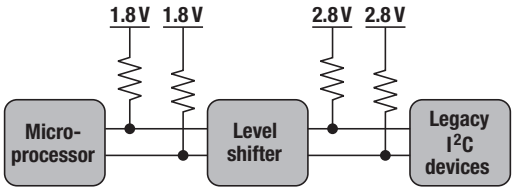
Q. What is a fun light and what is its purpose?

A. 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).

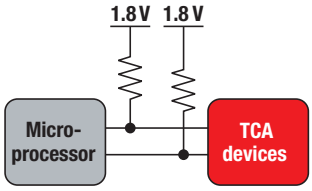
Fun lights are mostly found on battery-powered portable applications:
- Notebooks
- Handsets
- Consumer portables
- Portable media players

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.”

Solution No. 1: Using legacy I²C devices



Solution No. 2: Using TCA devices



Q. How should an unused I/O pin in an I²C I/O expander be terminated?

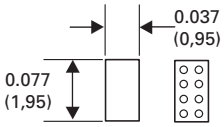
A. For devices with internal resistors between V_{CC} and the I/O, such as PCA9555, PCA9536 and PCA9554/A, the I/O can be connected directly to V_{CC} or GND.

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

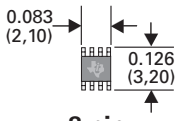
Q. What are the benefits of using TCA-series devices? (See figure above.)

A.
- Low-voltage operation. TCA-series 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.

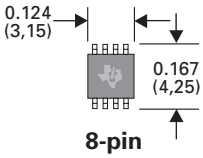
Packages



8-ball WCSP NanoFree™ package (YZP)
Ball pitch = 0.020 (0,50)
Height = 0.020 (0,50)
Area = 0.003 (1,85)

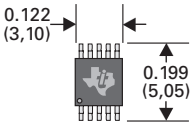


8-pin US8/VSSOP (DCU)
Lead pitch = 0.020 (0,50)
Height = 0.035 (0,90)
Area = 0.010 (6,72)

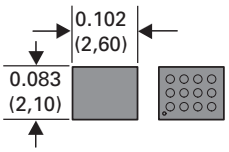


8-pin SM8/SSOP (DCT)
Lead pitch = 0.026 (0,65)
Height = 0.051 (1,30)
Area = 0.010 (6,72)

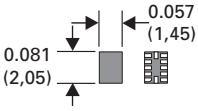
Dimensions are in inches (millimeters)



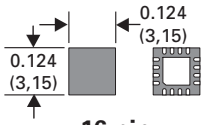
10-pin MSOP (DGS)
Lead pitch = 0.020 (0,50)
Height = 0.043 (1,10)
Area = 0.024 (15,7)



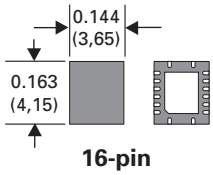
12-ball UFBGA (ZXU)
Ball pitch = 0.020 (0,50)
Height = 0.016 (0,41)
Area = 0.008 (5,46)



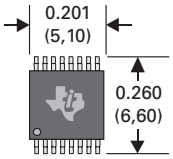
12-pin QFN (RUE)
Lead pitch = 0.016 (0,40)
Height = 0.016 (0,40)
Area = 0.005 (2,97)



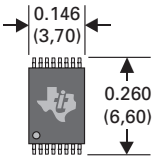
16-pin QFN (RGT)
Lead pitch = 0.020 (0,50)
Height = 0.039 (1,00)
Area = 0.015 (9,9)



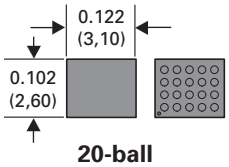
16-pin QFN (RGY)
Lead pitch = 0.020 (0,50)
Height = 0.039 (1,00)
Area = 0.023 (15,1)



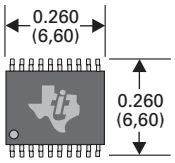
16-pin TSSOP (PW)
Lead pitch = 0.026 (0,65)
Height = 0.047 (1,20)
Area = 0.052 (33,7)



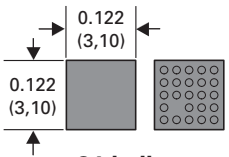
16-pin TVSOP (DGV)
Lead pitch = 0.016 (0,40)
Height = 0.047 (1,20)
Area = 0.038 (24,4)



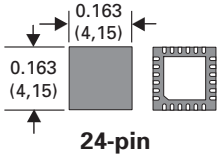
20-ball VFBGA (ZXY)
Ball pitch = 0.020 (0,50)
Height = 0.016 (0,41)
Area = 0.012 (8,1)



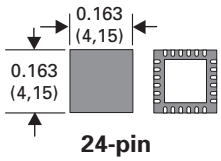
20-pin TSSOP (PW)
Lead pitch = 0.026 (0,65)
Height = 0.047 (1,20)
Area = 0.068 (44)



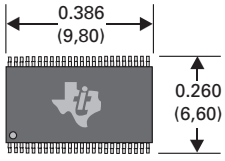
24-ball VFBGA (ZQS)
Ball pitch = 0.020 (0,50)
Height = 0.030 (0,77)
Area = 0.015 (9,61)



24-pin QFN (RGE)
Lead pitch = 0.020 (0,50)
Height = 0.039 (1,00)
Area = 0.027 (17,2)



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



48-pin widebus TVSOP (DGV)
Lead pitch = 0.016 (0,40)
Height = 0.047 (1,20)
Area = 0.100 (63)

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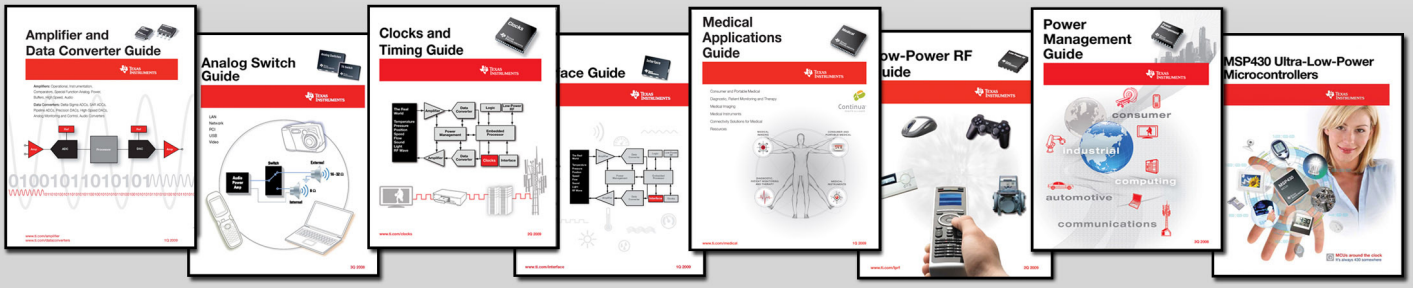

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