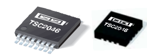


Low Voltage I/O TOUCH SCREEN CONTROLLER

FEATURES

- SAME PINOUT AS ADS7846
- 2.2V TO 5.25V OPERATION
- 1.5V TO 5.25V DIGITAL I/O
- INTERNAL 2.5V REFERENCE
- DIRECT BATTERY MEASUREMENT (0V TO 6V)
- ON-CHIP TEMPERATURE MEASUREMENT
- TOUCH-PRESSURE MEASUREMENT
- QSPI™ AND SPI™ 3-WIRE INTERFACE
- AUTO POWER-DOWN
- AVAILABLE IN TSSOP-16, QFN-16, AND VFBGA-48 PACKAGES

APPLICATIONS

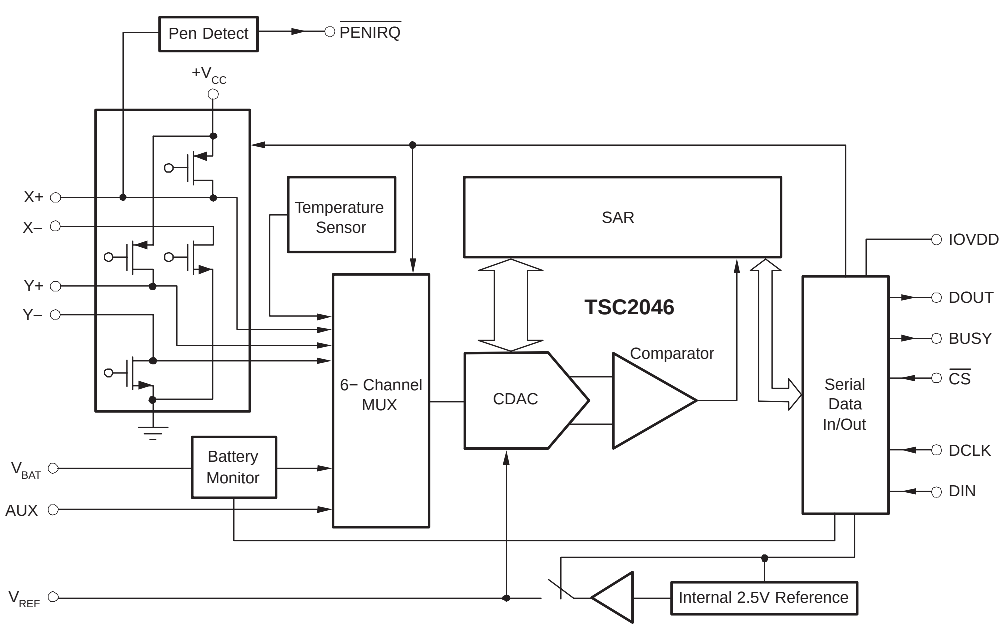
- PERSONAL DIGITAL ASSISTANTS
- PORTABLE INSTRUMENTS
- POINT-OF-SALE TERMINALS
- PAGERS
- TOUCH SCREEN MONITORS
- CELLULAR PHONES

US Patent No. 6246394
QSPI and SPI are registered trademarks of Motorola.

DESCRIPTION

The TSC2046 is a next-generation version to the ADS7846 4-wire touch screen controller which supports a low-voltage I/O interface from 1.5V to 5.25V. The TSC2046 is 100% pin-compatible with the existing ADS7846, and will drop into the same socket. This allows for easy upgrade of current applications to the new version. The TSC2046 also has an on-chip 2.5V reference that can be used for the auxiliary input, battery monitor, and temperature measurement modes. The reference can also be powered down when not used to conserve power. The internal reference operates down to 2.7V supply voltage, while monitoring the battery voltage from 0V to 6V.

The low-power consumption of < 0.75mW typ at 2.7V (reference off), high-speed (up to 125kHz sample rate), and on-chip drivers make the TSC2046 an ideal choice for battery-operated systems such as personal digital assistants (PDAs) with resistive touch screens, pagers, cellular phones, and other portable equipment. The TSC2046 is available in TSSOP-16, QFN-16, and VFBGA-48 packages and is specified over the –40°C to +85°C temperature range.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

ABSOLUTE MAXIMUM RATINGS(1)

$+V_{CC}$ and IOVDD to GND	−0.3V to +6V
Analog Inputs to GND	−0.3V to $+V_{CC}$ + 0.3V
Digital Inputs to GND	−0.3V to IOVDD + 0.3V
Power Dissipation	250mW
Maximum Junction Temperature	+150°C
Operating Temperature Range	−40°C to +85°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (soldering, 10s)	+300°C

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not implied.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION(1)

PRODUCT	NOMINAL PENIRQ PULLUP RESISTOR VALUES	MAXIMUM INTEGRAL LINEARITY ERROR (LSB)	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
TSC2046I	50kΩ	±2	TSSOP-16	PW	−40°C to +85°C	TSC2046I	TSC2046IPW	Rails, 100
							TSC2046IPWR	Tape and Reel, 2500
			4x4, 1mm QFN-16	RGV	−40°C to +85°C	TSC2046	TSC2046IRGVT	Tape and Reel, 250
							TSC2046IRGVR	Tape and Reel, 2500
							TSC2046IRGVRG4	Tape and Reel, 2500
			4x4 VFBGA-48	GQC	−40°C to +85°C	AZ2046	TSC2046IGQCR	Tape and Reel, 2500
				ZQC	−40°C to +85°C	BC2046	TSC2046IZQCT	Tape and Reel, 250
							TSC2046IZQCR	Tape and Reel, 2500
TSC2046I(2)	90kΩ	±2	4x4 VFBGA-48	GQC	−40°C to +85°C	AZ2046A	TSC2046IGQCR-90	Tape and Reel, 2500
				ZQC	−40°C to +85°C	BC2046A	TSC2046IZQCR-90	Tape and Reel, 2500

(1) For the most current package and ordering information, see the Package Option Addendum located at the end of this data sheet, or see the TI web site at www.ti.com.

(2) High-impedance version.

ELECTRICAL CHARACTERISTICS: V_S = +2.7V to +5.5V

At T_A = −40°C to +85°C, $+V_{CC}$ = +2.7V, V_{REF} = 2.5V internal voltage, f_{SAMPLE} = 125kHz, f_{CLK} = 16 • f_{SAMPLE} = 2MHz, 12-bit mode, digital inputs = GND or IOVDD, and $+V_{CC}$ must be • IOVDD, unless otherwise noted.

PARAMETER	CONDITION	TSC2046 MIN	TSC2046 TYP	TSC2046 MAX	UNITS
ANALOG INPUT					
Full-Scale Input Span	Positive Input−Negative Input	0		V_{REF}	V
Absolute Input Range	Positive Input	−0.2		$+V_{CC}$ + 0.2	V
	Negative Input	−0.2		+0.2	V
Capacitance			25		pF
Leakage Current			0.1		μA
SYSTEM PERFORMANCE					
Resolution			12		Bits
No Missing Codes		11			Bits
Integral Linearity Error				±2	LSB(1)
Offset Error				±6	LSB
Gain Error	External V_{REF}			±4	LSB
Noise	Including Internal V_{REF}		70		μVrms
Power-Supply Rejection			70		dB
SAMPLING DYNAMICS					
Conversion Time				12	CLK Cycles
Acquisition Time		3			CLK Cycles
Throughput Rate				125	kHz
Multiplexer Settling Time			500		ns
Aperture Delay			30		ns
Aperture Jitter			100		ps
Channel-to-Channel Isolation	V_{IN} = 2.5V_{PP} at 50kHz		100		dB
SWITCH DRIVERS					
On-Resistance					
Y+, X+			5		Ω
Y−, X−			6		Ω
Drive Current(2)	Duration 100ms			50	mA
REFERENCE OUTPUT					
Internal Reference Voltage		2.45	2.50	2.55	V
Internal Reference Drift			15		ppm/°C
Quiescent Current			500		μA
REFERENCE INPUT					
Range		1.0		$+V_{CC}$	V
Input Impedance	SER/$\overline{\text{DFR}}$ = 0, PD1 = 0		1		GΩ
	Internal Reference Off				
	Internal Reference On		250		Ω
BATTERY MONITOR					
Input Voltage Range		0.5		6.0	V
Input Impedance					
Sampling Battery			10		kΩ
Battery Monitor Off			1		GΩ
Accuracy	V_{BAT} = 0.5V to 5.5V, External V_{REF} = 2.5V	−2		+2	%
	V_{BAT} = 0.5V to 5.5V, Internal Reference	−3		+3	%
TEMPERATURE MEASUREMENT					
Temperature Range		−40		+85	°C
Resolution	Differential Method(3)		1.6		°C
	TEMP0(4)		0.3		°C
Accuracy	Differential Method(3)		±2		°C
	TEMP0(4)		±3		°C

(1) LSB means *Least Significant Bit*. With V_{REF} = +2.5V, one LSB is 610μV.
(2) Assured by design, but not tested. Exceeding 50mA source current may result in device degradation.
(3) Difference between TEMP0 and TEMP1 measurement, no calibration necessary.
(4) Temperature drift is −2.1mV/°C.
(5) TSC2046 operates down to 2.2V.
(6) IOVDD must be − ($+V_{CC}$).
(7) Combined supply current from $+V_{CC}$ and IOVDD. Typical values obtained from conversions on AUX input with PD0 = 0.

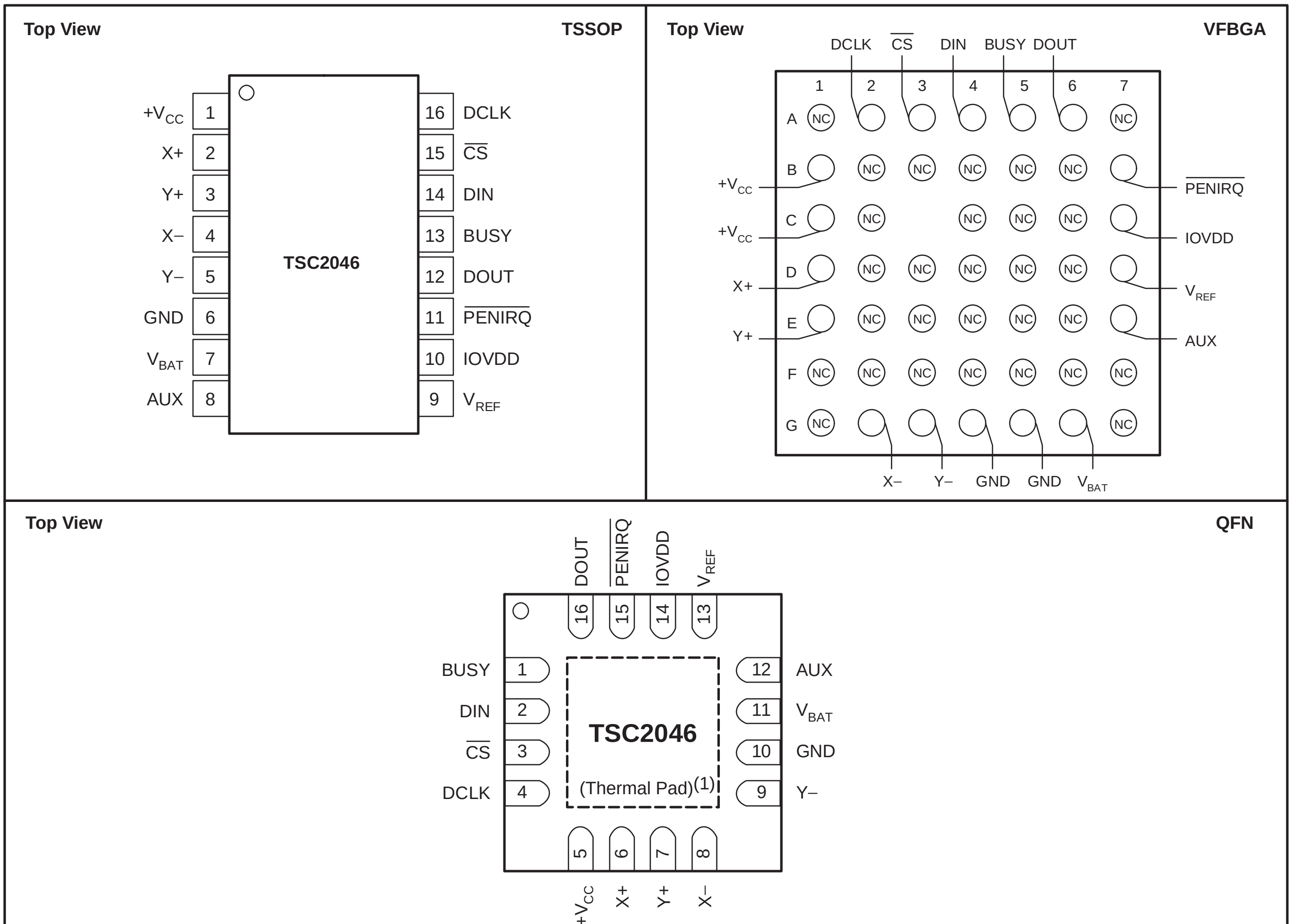
ELECTRICAL CHARACTERISTICS: V_S = +2.7V to +5.5V (continued)

At T_A = −40°C to +85°C, $+V_{CC}$ = +2.7V, V_{REF} = 2.5V internal voltage, f_{SAMPLE} = 125kHz, f_{CLK} = 16 • f_{SAMPLE} = 2MHz, 12-bit mode, digital inputs = GND or IOVDD, and $+V_{CC}$ must be • IOVDD, unless otherwise noted.

PARAMETER	CONDITION	TSC2046			UNITS
		MIN	TYP	MAX	
DIGITAL INPUT/OUTPUT					
Logic Family			CMOS		
Capacitance	All Digital Control Input Pins		5	15	pF
V_{IH}	$\vert I_{IH} \vert \leq +5\mu A$	IOVDD • 0.7		IOVDD + 0.3	V
V_{IL}	$\vert I_{IL} \vert \leq +5\mu A$	−0.3		0.3 • IOVDD	V
V_{OH}	$I_{OH} = -250\mu A$	IOVDD • 0.8			V
V_{OL}	$I_{OL} = 250\mu A$			0.4	V
Data Format			Straight Binary		
POWER-SUPPLY REQUIREMENTS					
$+V_{CC}$(5)	Specified Performance	2.7		3.6	V
	Operating Range	2.2		5.25	V
IOVDD(6)		1.5		$+V_{CC}$	V
Quiescent Current(7)	Internal Reference Off		280	650	µA
	Internal Reference On		780		µA
	f_{SAMPLE} = 12.5kHz		220		µA
	Power-Down Mode with $\overline{CS}$ = DCLK = DIN = IOVDD			3	µA
Power Dissipation	$+V_{CC}$ = +2.7V			1.8	mW
TEMPERATURE RANGE					
Specified Performance		−40		+85	°C

(1) LSB means *Least Significant Bit*. With V_{REF} = +2.5V, one LSB is 610µV.
(2) Assured by design, but not tested. Exceeding 50mA source current may result in device degradation.
(3) Difference between TEMP0 and TEMP1 measurement, no calibration necessary.
(4) Temperature drift is −2.1mV/°C.
(5) TSC2046 operates down to 2.2V.
(6) IOVDD must be − ($+V_{CC}$).
(7) Combined supply current from $+V_{CC}$ and IOVDD. Typical values obtained from conversions on AUX input with PD0 = 0.

PIN CONFIGURATION



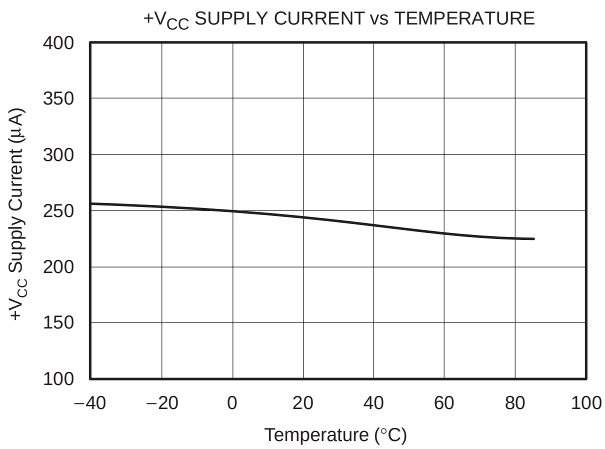
(1) The thermal pad is internally connected to the substrate. This pad can be connected to the analog ground or left floating. Keep the thermal pad separate from the digital ground, if possible.

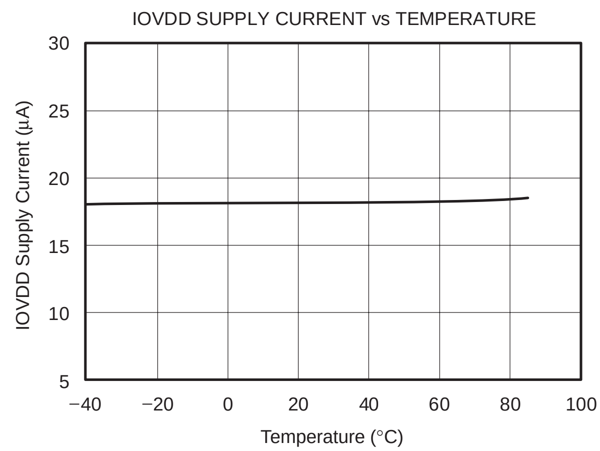
PIN DESCRIPTION

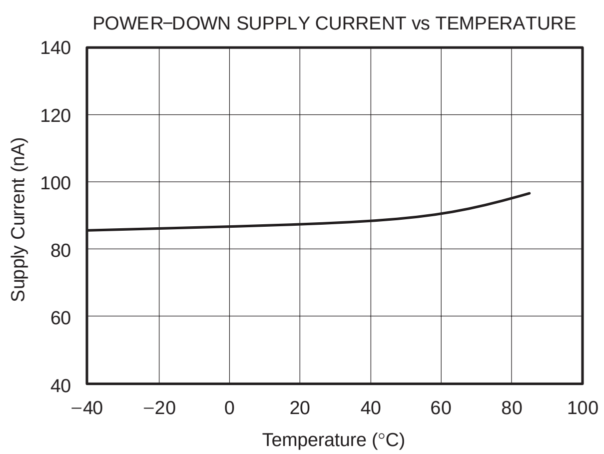
TSSOP PIN #	VFBGA PIN #	QFN PIN #	NAME	DESCRIPTION
1	B1 and C1	5	$+V_{CC}$	Power Supply
2	D1	6	X+	X+ Position Input
3	E1	7	Y+	Y+ Position Input
4	G2	8	X−	X− Position Input
5	G3	9	Y−	Y− Position Input
6	G4 and G5	10	GND	Ground
7	G6	11	V_{BAT}	Battery Monitor Input
8	E7	12	AUX	Auxiliary Input to ADC
9	D7	13	V_{REF}	Voltage Reference Input/Output
10	C7	14	IOVDD	Digital I/O Power Supply
11	B7	15	$\overline{PENIRQ}$	Pen Interrupt
12	A6	16	DOUT	Serial Data Output. Data is shifted on the falling edge of DCLK. This output is high impedance when $\overline{CS}$ is high.
13	A5	1	BUSY	Busy Output. This output is high impedance when $\overline{CS}$ is high.
14	A4	2	DIN	Serial Data Input. If $\overline{CS}$ is low, data is latched on the rising edge of DCLK.
15	A3	3	$\overline{CS}$	Chip Select Input. Controls conversion timing and enables the serial input/output register. $\overline{CS}$ high = power-down mode (ADC only).
16	A2	4	DCLK	External Clock Input. This clock runs the SAR conversion process and synchronizes serial data I/O.

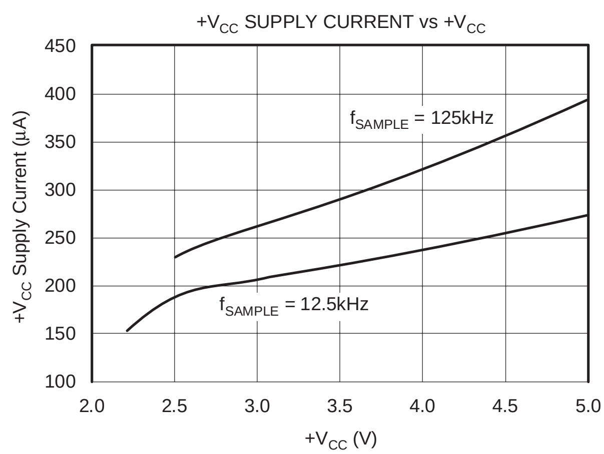
TYPICAL CHARACTERISTICS

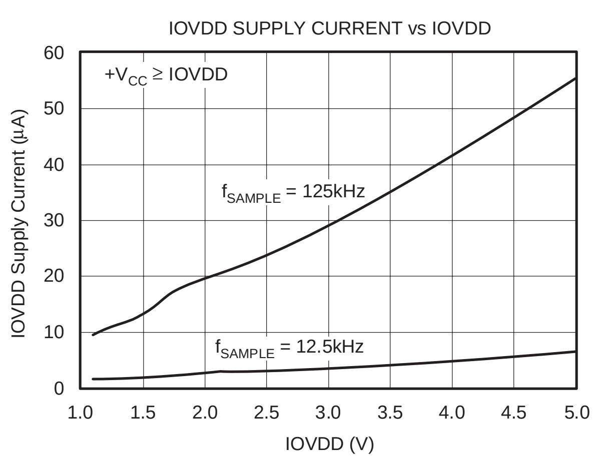
At T_A = +25°C, $+V_{CC}$ = +2.7V, IOVDD = +1.8V, V_{REF} = External +2.5V, 12-bit mode, PD0 = 0, f_{SAMPLE} = 125kHz, and f_{CLK} = 16 • f_{SAMPLE} = 2MHz, unless otherwise noted.

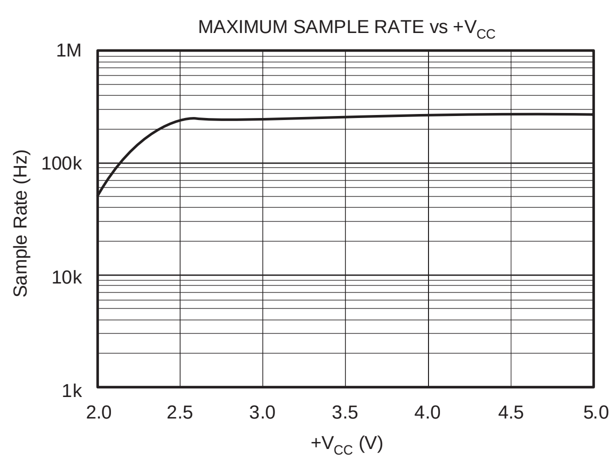






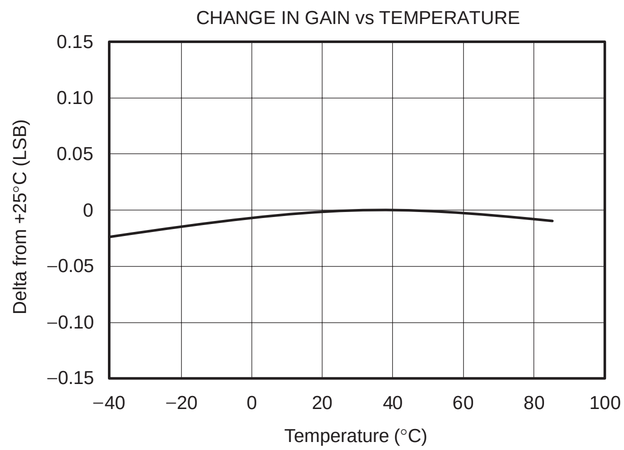


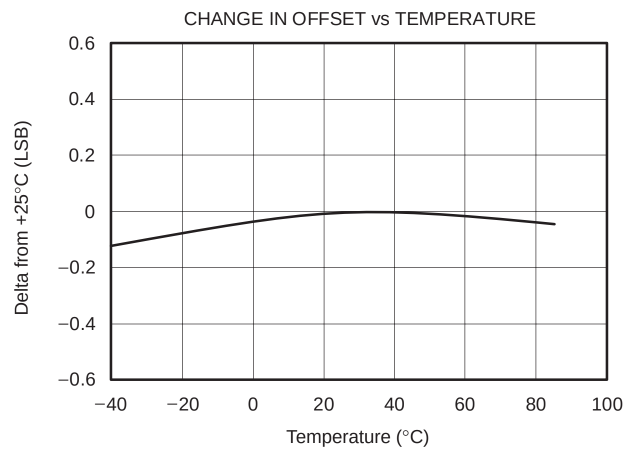


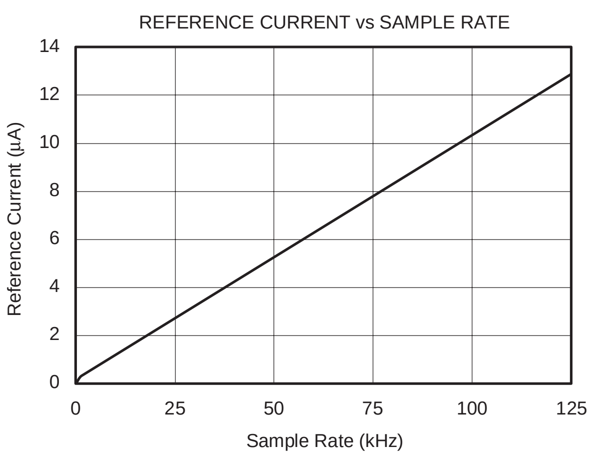


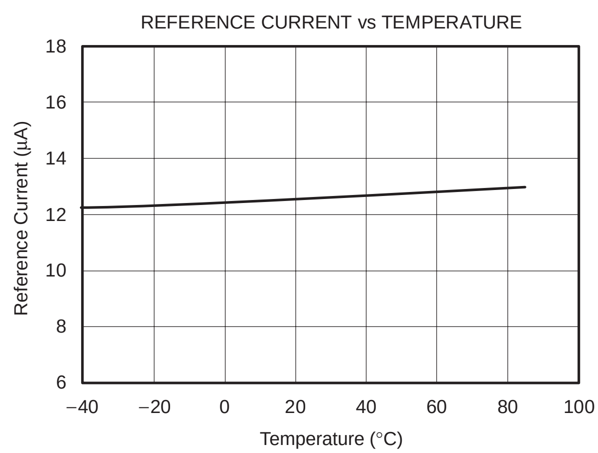
TYPICAL CHARACTERISTICS (continued)

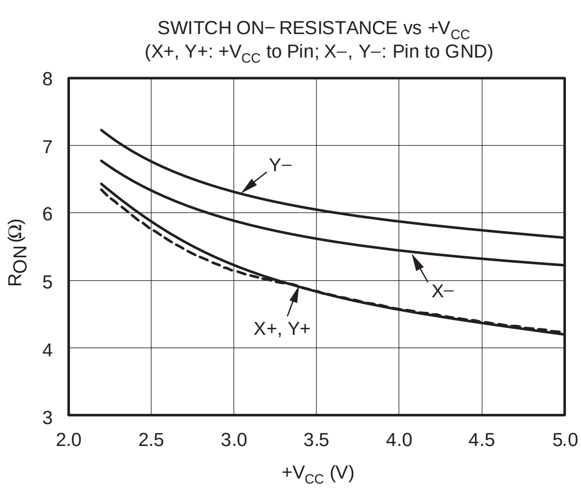
At T_A = +25°C, $+V_{CC}$ = +2.7V, IOVDD = +1.8V, V_{REF} = External +2.5V, 12-bit mode, PD0 = 0, f_{SAMPLE} = 125kHz, and f_{CLK} = 16 • f_{SAMPLE} = 2MHz, unless otherwise noted.

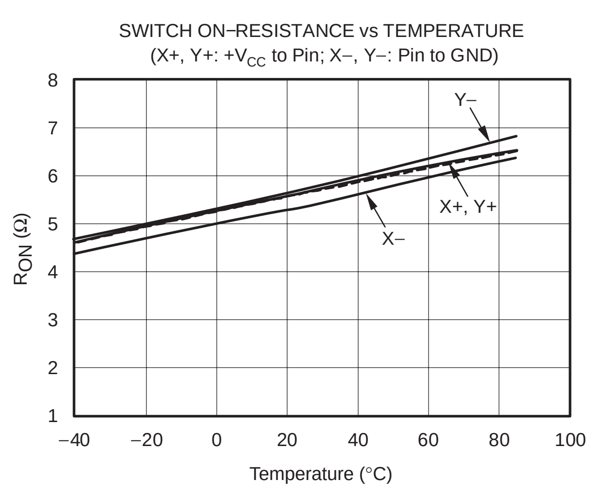






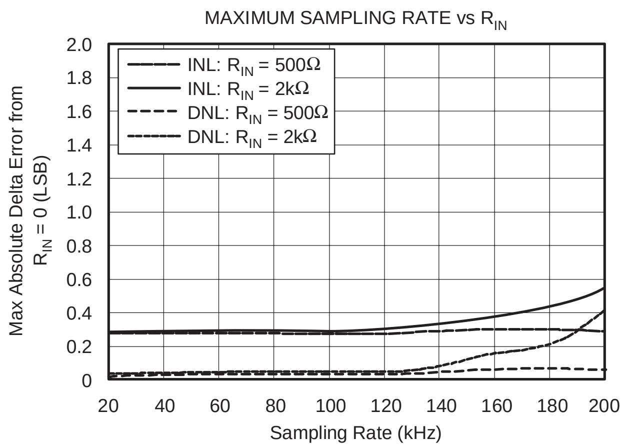


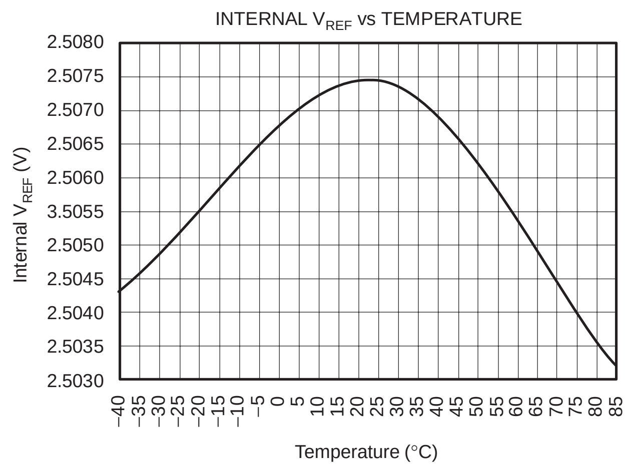


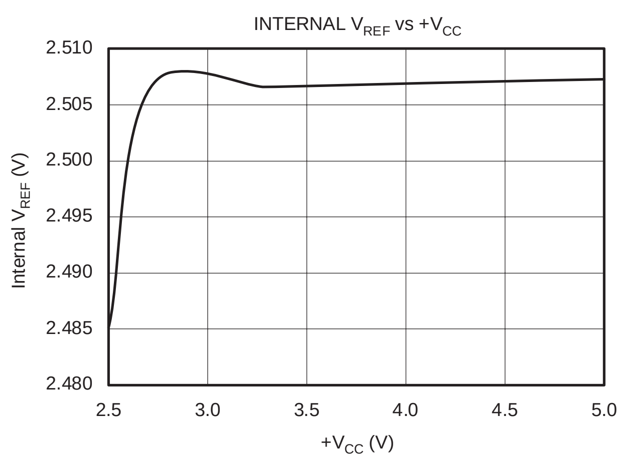


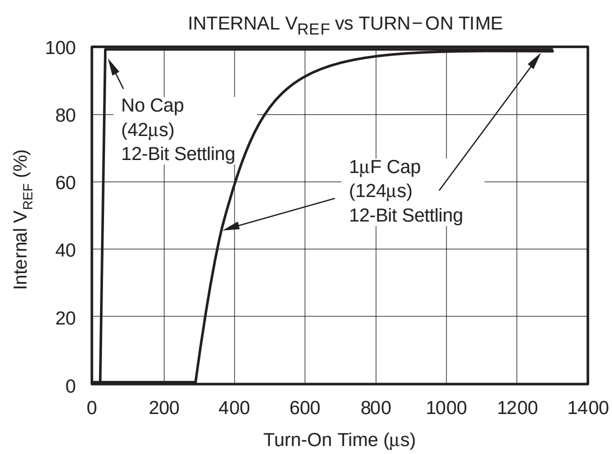
TYPICAL CHARACTERISTICS (continued)

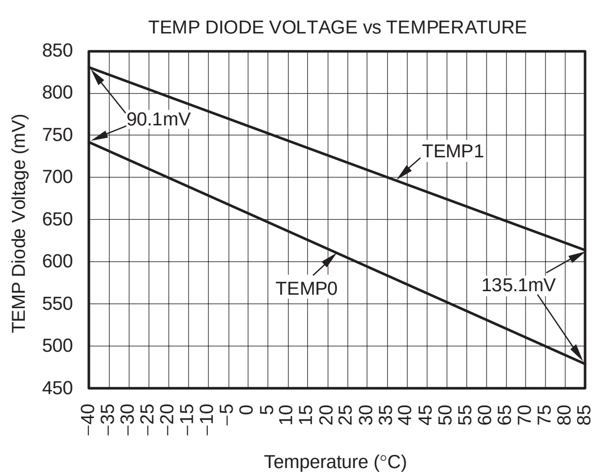
At T_A = +25°C, $+V_{CC}$ = +2.7V, IOVDD = +1.8V, V_{REF} = External +2.5V, 12-bit mode, PD0 = 0, f_{SAMPLE} = 125kHz, and f_{CLK} = 16 • f_{SAMPLE} = 2MHz, unless otherwise noted.

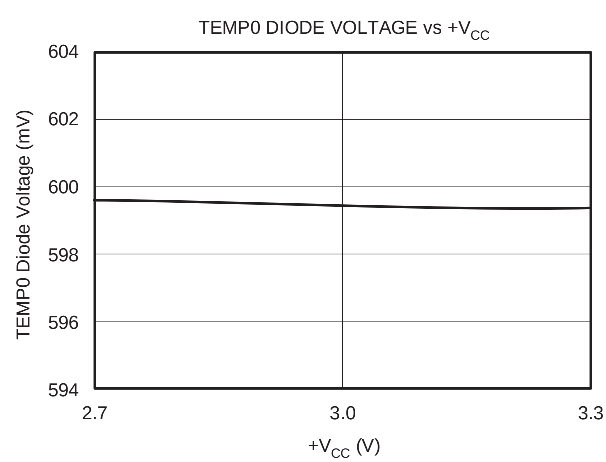






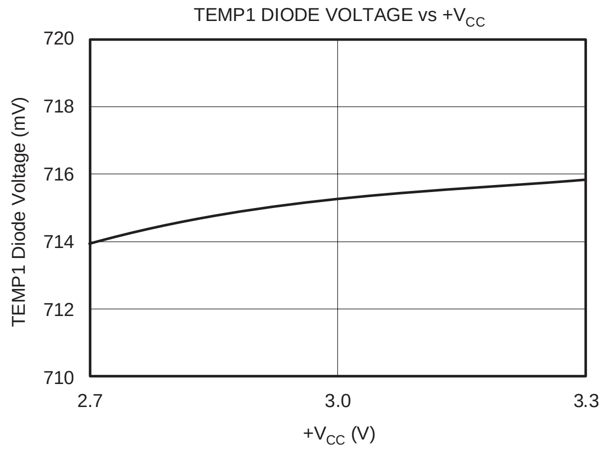






TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, $+V_{CC}$ = +2.7V, IOVDD = +1.8V, V_{REF} = External +2.5V, 12-bit mode, PD0 = 0, f_{SAMPLE} = 125kHz, and f_{CLK} = 16 • f_{SAMPLE} = 2MHz, unless otherwise noted.



THEORY OF OPERATION

The TSC2046 is a classic successive approximation register (SAR) analog-to-digital converter (ADC). The architecture is based on capacitive redistribution, which inherently includes a sample-and-hold function. The converter is fabricated on a 0.6µm CMOS process.

The basic operation of the TSC2046 is shown in Figure 1. The device features an internal 2.5V reference and uses an external clock. Operation is maintained from a single supply of 2.7V to 5.25V. The internal reference can be overdriven with an external, low-impedance source between 1V and $+V_{CC}$. The value of the reference voltage directly sets the input range of the converter.

The analog input (X-, Y-, and Z-Position coordinates, auxiliary input, battery voltage, and chip temperature) to the converter is provided via a multiplexer. A unique configuration of low on-resistance touch panel driver switches allows an unselected ADC input channel to provide power and the accompanying pin to provide ground for an external device, such as a touch screen. By maintaining a differential input to the converter and a differential reference architecture, it is possible to negate the error from each touch panel driver switch's on-resistance (if this is a source of error for the particular measurement).

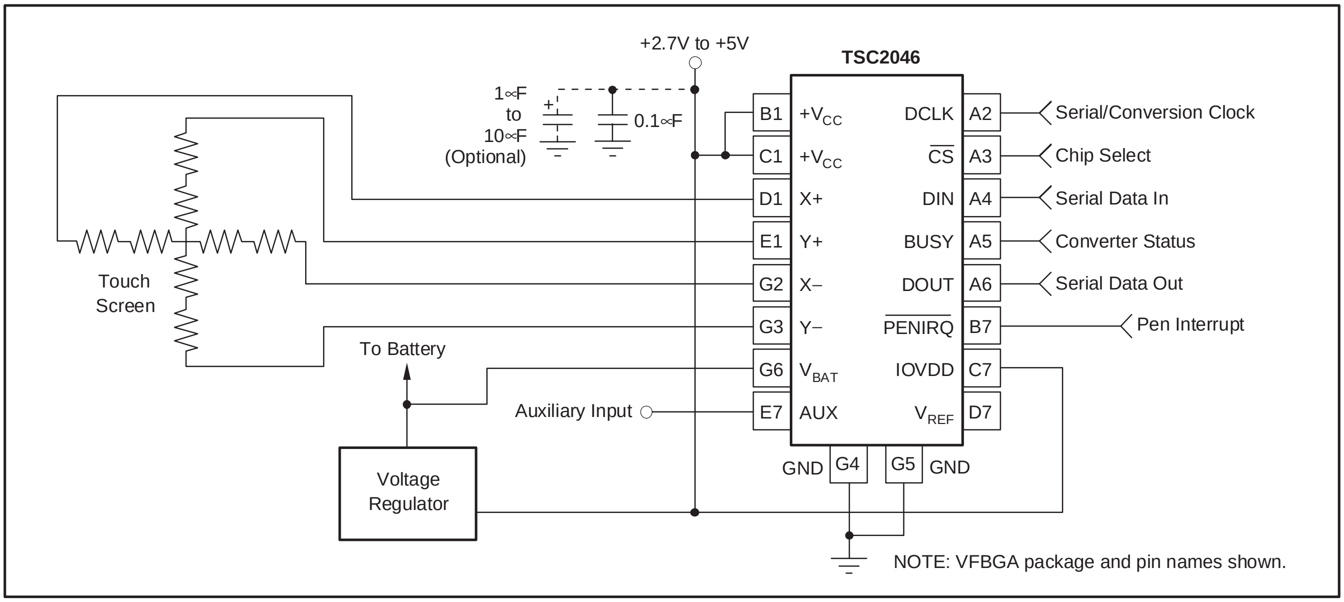


Figure 1. Basic Operation of the TSC2046

ANALOG INPUT

Figure 2 shows a block diagram of the input multiplexer on the TSC2046, the differential input of the ADC, and the differential reference of the converter. Table 1 and Table 2 show the relationship between the A2, A1, A0, and SER/$\overline{\text{DFR}}$ control bits and the configuration of the TSC2046. The control bits are provided serially via the DIN pin—see the *Digital Interface* section of this data sheet for more details.

When the converter enters the hold mode, the voltage difference between the +IN and –IN inputs (shown in Figure 2) is captured on the internal capacitor array. The input current into the analog inputs depends on the conversion rate of the device. During the sample period, the source must charge the internal sampling capacitor (typically 25pF). After the capacitor is fully charged, there is no further input current. The rate of charge transfer from the analog source to the converter is a function of conversion rate.

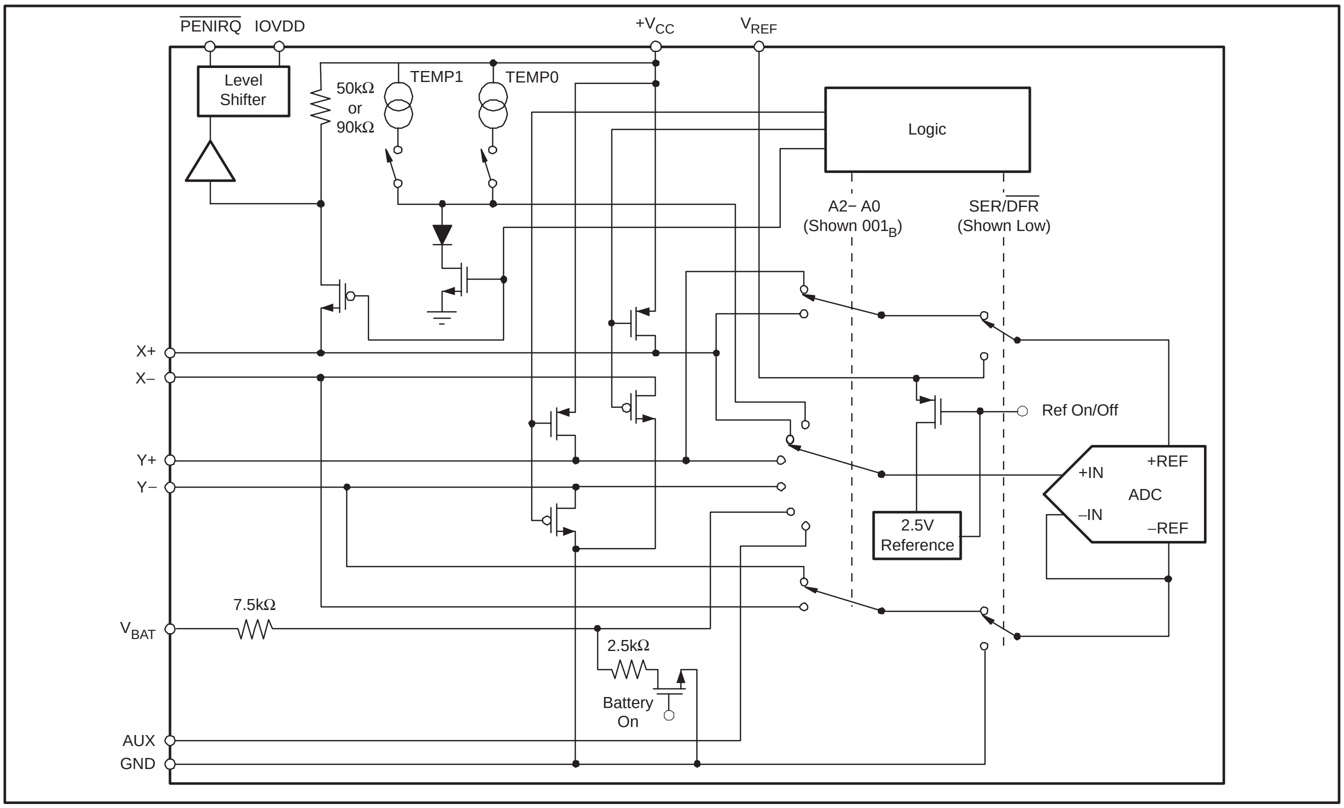


Figure 2. Simplified Diagram of Analog Input

A2	A1	A0	V_{BAT}	AUX_{IN}	TEMP	Y−	X+	Y+	Y-POSITION	X-POSITION	Z_1-POSITION	Z_2-POSITION	X-DRIVERS	Y-DRIVERS
0	0	0			+IN (TEMP0)								Off	Off
0	0	1					+IN		Measure				Off	On
0	1	0	+IN										Off	Off
0	1	1					+IN				Measure		X−, On	Y+, On
1	0	0				+IN						Measure	X−, On	Y+, On
1	0	1						+IN		Measure			On	Off
1	1	0		+IN									Off	Off
1	1	1			+IN (TEMP1)								Off	Off

Table 1. Input Configuration (DIN), Single-Ended Reference Mode (SER/$\overline{\text{DFR}}$ high)

A2	A1	A0	+REF	−REF	Y−	X+	Y+	Y-POSITION	X-POSITION	Z_1-POSITION	Z_2-POSITION	DRIVERS
0	0	1	Y+	Y−		+IN		Measure				Y+, Y−
0	1	1	Y+	X−		+IN				Measure		Y+, X−
1	0	0	Y+	X−	+IN						Measure	Y+, X−
1	0	1	X+	X−			+IN		Measure			X+, X−

Table 2. Input Configuration (DIN), Differential Reference Mode (SER/$\overline{\text{DFR}}$ low)

INTERNAL REFERENCE

The TSC2046 has an internal 2.5V voltage reference that can be turned on or off with the control bit, PD1 (see Table 5 and Figure 3). Typically, the internal reference voltage is only used in the single-ended mode for battery monitoring, temperature measurement, and for using the auxiliary input. Optimal touch screen performance is achieved when using the differential mode. The internal reference voltage of the TSC2046 must be commanded to be off to maintain compatibility with the ADS7843. Therefore, after power-up, a write of PD1 = 0 is required to insure the reference is off (see the Typical Characteristics for power-up time of the reference from power-down).

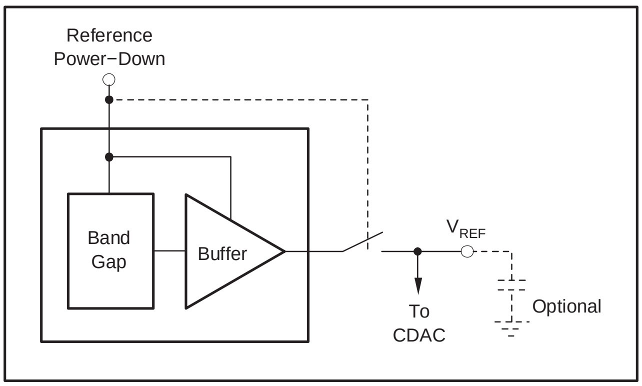


Figure 3. Simplified Diagram of the Internal Reference

REFERENCE INPUT

The voltage difference between +REF and –REF (see Figure 2) sets the analog input range. The TSC2046 operates with a reference in the range of 1V to $+V_{CC}$. There are several critical items concerning the reference input and its wide voltage range. As the reference voltage is reduced, the analog voltage weight of each digital output code is also reduced. This is often referred to as the LSB (least significant bit) size and is equal to the reference voltage divided by 4096 in 12-bit mode. Any offset or gain error inherent in the ADC appears to increase, in terms of LSB size, as the reference voltage is reduced. For example, if the offset of a given converter is 2LSBs with a 2.5V reference, it is typically 5LSBs with a 1V reference. In each case, the actual offset of the device is the same, 1.22mV. With a lower reference voltage, more care must be taken to provide a clean layout including adequate bypassing, a clean (low-noise, low-ripple) power supply, a low-noise reference (if an external reference is used), and a low-noise input signal.

The voltage into the V_{REF} input directly drives the capacitor digital-to-analog converter (CDAC) portion of the TSC2046. Therefore, the input current is very low (typically < 13µA).

There is also a critical item regarding the reference when making measurements while the switch drivers are ON. For this discussion, it is useful to consider the basic operation of the TSC2046 (see Figure 1). This particular application shows the device being used to digitize a resistive touch screen. A measurement of the current Y-Position of the pointing device is made by connecting the X+ input to the ADC, turning on the Y+ and Y– drivers, and digitizing the voltage on X+ (Figure 4 shows a block diagram). For this measurement, the resistance in the X+ lead does not affect the conversion (it does affect the settling time, but the resistance is usually small enough that this is not a concern). However, since the resistance between Y+ and Y– is fairly low, the on-resistance of the Y drivers does make a small difference. Under the situation outlined so far, it is not possible to achieve a 0V input or a full-scale input regardless of where the pointing device is on the touch screen because some voltage is lost across the internal switches. In addition, the internal switch resistance is unlikely to track the resistance of the touch screen, providing an additional source of error.

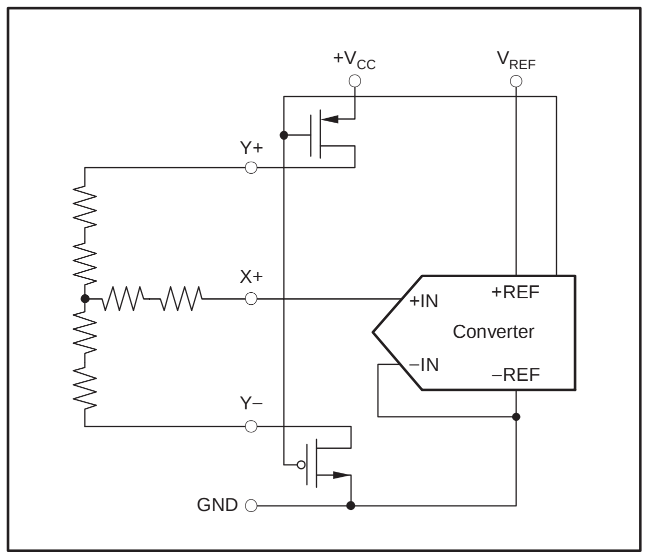


Figure 4. Simplified Diagram of Single-Ended Reference (SER/$\overline{DFR}$ high, Y switches enabled, X+ is analog input)

This situation can be remedied as shown in Figure 5. By setting the SER/$\overline{DFR}$ bit low, the +REF and –REF inputs are connected directly to Y+ and Y–, respectively, which makes the analog-to-digital conversion ratiometric. The result of the conversion is always a percentage of the external resistance, regardless of how it changes in relation to the on-resistance of the internal switches. Note that there is an important consideration regarding power dissipation when using the ratiometric mode of operation (see the *Power Dissipation* section for more details).

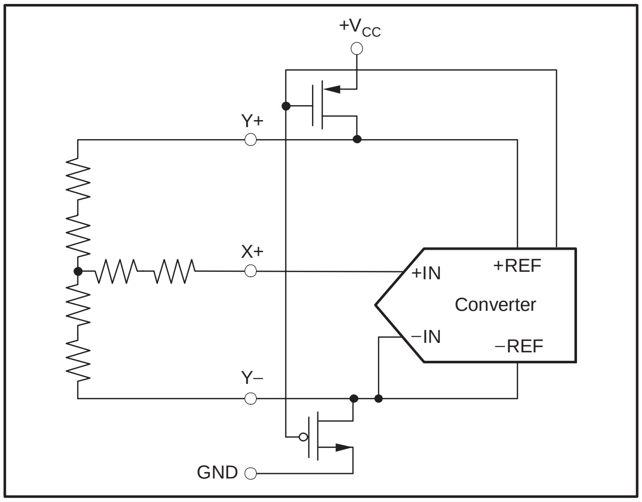


Figure 5. Simplified Diagram of Differential Reference (SER/DFR low, Y switches enabled, X+ is analog input)

As a final note about the differential reference mode, it must be used with $+V_{CC}$ as the source of the +REF voltage and cannot be used with V_{REF}. It is possible to use a high-precision reference on V_{REF} and single-ended reference mode for measurements which do not need to be ratiometric. In some cases, it is possible to power the converter directly from a precision reference. Most references can provide enough power for the TSC2046, but might not be able to supply enough current for the external load (such as a resistive touch screen).

TOUCH SCREEN SETTLING

In some applications, external capacitors may be required across the touch screen for filtering noise picked up by the touch screen (e.g., noise generated by the LCD panel or backlight circuitry). These capacitors provide a low-pass filter to reduce the noise, but cause a settling time requirement when the panel is touched that typically shows up as a gain error. There are several methods for minimizing or eliminating this issue. The problem is that the input and/or reference has not settled to the final steady-state value prior to the ADC sampling the input(s) and providing the digital output. Additionally, the reference voltage may still be changing during the measurement cycle. Option 1 is to stop or slow down the TSC2046 DCLK for the required touch screen settling time. This allows the input and reference to have stable values for the Acquire period (3 clock cycles of the TSC2046; see Figure 9). This works for both the single-ended and the differential modes. Option 2 is to operate the TSC2046 in the differential mode only for the touch screen measurements and command the TSC2046 to remain on (touch screen drivers ON) and not go into power-down (PD0 = 1). Several conversions are made depending on the settling time required and the TSC2046 data rate. Once the required number of conversions have been made, the processor commands the TSC2046 to go into its power-down state on the last measurement. This process is required for X-Position, Y-Position, and Z-Position measurements. Option 3 is to operate in the 15 Clock-per-Conversion mode, which overlaps the analog-to-digital conversions and maintains the touch screen drivers on until commanded to stop by the processor (see Figure 13).

TEMPERATURE MEASUREMENT

In some applications, such as battery recharging, a measurement of ambient temperature is required. The temperature measurement technique used in the TSC2046 relies on the characteristics of a semiconductor junction operating at a fixed current level. The forward diode voltage (V_{BE}) has a well-defined characteristic versus temperature. The ambient temperature can be predicted in applications by knowing the +25°C value of the V_{BE} voltage and then monitoring the delta of that voltage as the temperature changes. The TSC2046 offers two modes of operation. The first mode requires calibration at a known temperature, but only requires a single reading to predict the ambient temperature. A diode is used (turned on) during this measurement cycle. The voltage across the diode is connected through the MUX for digitizing the forward bias voltage by the ADC with an address of A2 = 0, A1 = 0, and A0 = 0 (see Table 1 and Figure 6 for details). This voltage is typically 600mV at +25°C with a 20µA current through the diode. The absolute value of this diode voltage can vary a few millivolts. However, the TC of this voltage is very consistent at –2.1mV/°C. During the final test of the end product, the diode voltage would be stored at a known room temperature, in memory, for calibration purposes by the user. The result is an equivalent temperature measurement resolution of 0.3°C/LSB (in 12-bit mode).

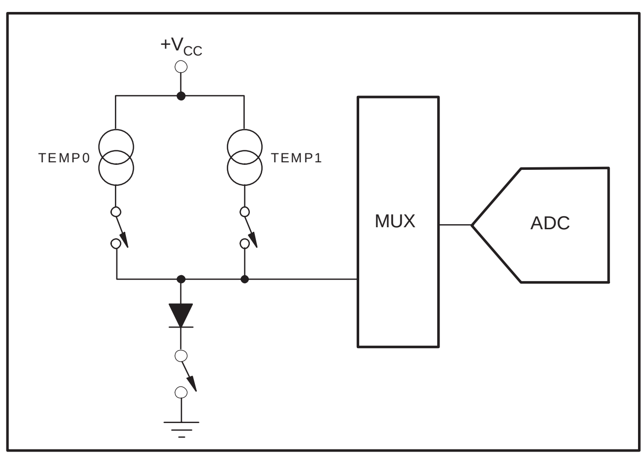


Figure 6. Functional Block Diagram of Temperature Measurement

The second mode does not require a test temperature calibration, but uses a two-measurement method to eliminate the need for absolute temperature calibration and for achieving 2°C accuracy. This mode requires a second conversion with an address of A2 = 1, A1 = 1, and A0 = 1, with a 91 times larger current. The voltage difference between the first and second conversion using 91 times the bias current is represented by Equation (1):

$$\frac{kT}{q} \cdot \ln(N) \tag{1}$$

where:

N is the current ratio = 91.

k = Boltzmann's constant ($1.38054 \bullet 10^{-23}$ electron volts/ degrees Kelvin).

q = the electron charge ($1.602189 \bullet 10^{-19}$ C).

T = the temperature in degrees Kelvin.

This method can provide improved absolute temperature measurement over the first mode at the cost of less resolution (1.6°C/LSB). The equation for solving for °K is:

$$^{\circ}K = q \cdot \frac{\Delta V}{(k \cdot \ln(N))} \tag{2}$$

where:

$\Delta V = V(I_{91}) - V(I_1)$ (in mV)

$\therefore\ ^{\circ}K = 2.573\ ^{\circ}K/mV \bullet \Delta V$

$^{\circ}C = 2.573 \bullet \Delta V(mV) - 273^{\circ}K$

NOTE: The bias current for each diode temperature measurement is only on for 3 clock cycles (during the acquisition mode) and, therefore, does not add any noticeable increase in power, especially if the temperature measurement only occurs occasionally.

BATTERY MEASUREMENT

An added feature of the TSC2046 is the ability to monitor the battery voltage on the other side of the voltage regulator (DC/DC converter), as shown in Figure 7. The battery voltage can vary from 0V to 6V, while maintaining the voltage to the TSC2046 at 2.7V, 3.3V, etc. The input voltage (V_{BAT}) is divided down by 4 so that a 5.5V battery voltage is represented as 1.375V to the ADC. This simplifies the multiplexer and control logic. In order to minimize the power consumption, the divider is only on during the sampling period when A2 = 0, A1 = 1, and A0 = 0 (see Table 1 for the relationship between the control bits and configuration of the TSC2046).

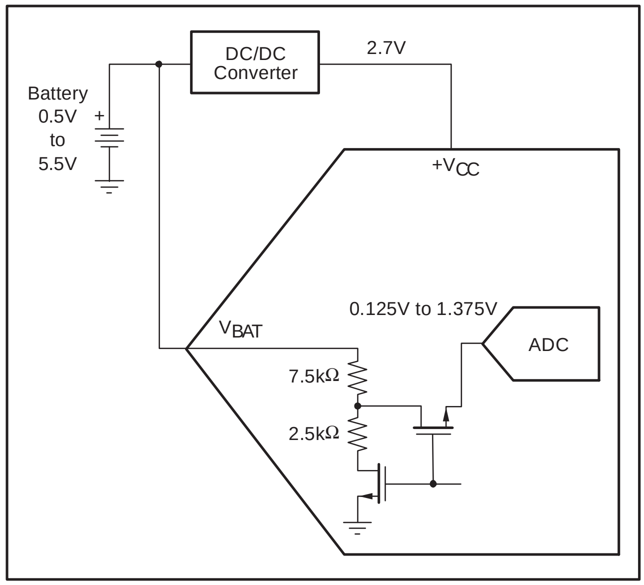


Figure 7. Battery Measurement Functional Block Diagram

PRESSURE MEASUREMENT

Measuring touch pressure can also be done with the TSC2046. To determine pen or finger touch, the pressure of the touch needs to be determined. Generally, it is not necessary to have very high performance for this test; therefore, the 8-bit resolution mode is recommended (however, calculations will be shown here in the 12-bit resolution mode). There are several different ways of performing this measurement. The TSC2046 supports two methods. The first method requires knowing the X-plate resistance, measurement of the X-Position, and two additional cross panel measurements (Z_1 and Z_2) of the touch screen, as shown in Figure 8. Using Equation (3) calculates the touch resistance:

$$R_{TOUCH} = R_{X-Plate} \cdot \frac{X-Position}{4096}\left(\frac{Z_2}{Z_1} - 1\right) \quad (3)$$

The second method requires knowing both the X-plate and Y-plate resistance, measurement of X-Position and Y-Position, and Z_1. Using Equation (4) also calculates the touch resistance:

$$R_{TOUCH} = \frac{R_{X-Plate} \cdot X-Position}{4096}\left(\frac{4096}{Z_1} - 1\right) - R_{Y-Plate}\left(1 - \frac{Y-Position}{4096}\right) \quad (4)$$

DIGITAL INTERFACE

See Figure 9 for the typical operation of the TSC2046 digital interface. This diagram assumes that the source of the digital signals is a microcontroller or digital signal processor with a basic serial interface. Each communication between the processor and the converter, such as SPI, SSI, or Microwire™ synchronous serial interface, consists of eight clock cycles. One complete conversion can be accomplished with three serial communications for a total of 24 clock cycles on the DCLK input.

The first eight clock cycles are used to provide the control byte via the DIN pin. When the converter has enough information about the following conversion to set the input multiplexer and reference inputs appropriately, the converter enters the acquisition (sample) mode and, if needed, the touch panel drivers are turned on. After three more clock cycles, the control byte is complete and the converter enters the conversion mode. At this point, the input sample-and-hold goes into the hold mode and the touch panel drivers turn off (in single-ended mode). The next 12 clock cycles accomplish the actual analog-to-digital conversion. If the conversion is ratiometric (SER/$\overline{DFR}$ = 0), the drivers are on during the conversion and a 13th clock cycle is needed for the last bit of the conversion result. Three more clock cycles are needed to complete the last byte (DOUT will be low), which are ignored by the converter.

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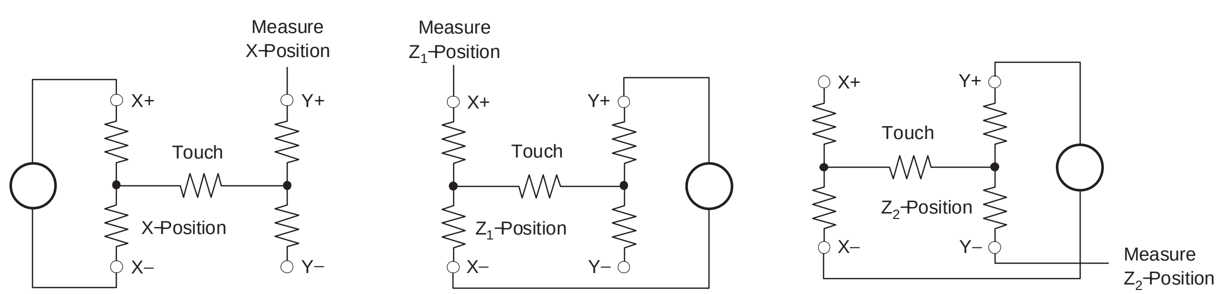


Figure 8. Pressure Measurement Block Diagrams

Control Byte

The control byte (on DIN), as shown in Table 3, provides the start conversion, addressing, ADC resolution, configuration, and power-down of the TSC2046. Figure 9, Table 3 and Table 4 give detailed information regarding the order and description of these control bits within the control byte.

Initiate START—The first bit, the S bit, must always be high and initiates the start of the control byte. The TSC2046 ignores inputs on the DIN pin until the start bit is detected.

Addressing—The next three bits (A2, A1, and A0) select the active input channel(s) of the input multiplexer (see Table 1, Table 2, and Figure 2), touch screen drivers, and the reference inputs.

MODE—The mode bit sets the resolution of the ADC. With this bit low, the next conversion has 12 bits of resolution, whereas with this bit high, the next conversion has eight bits of resolution.

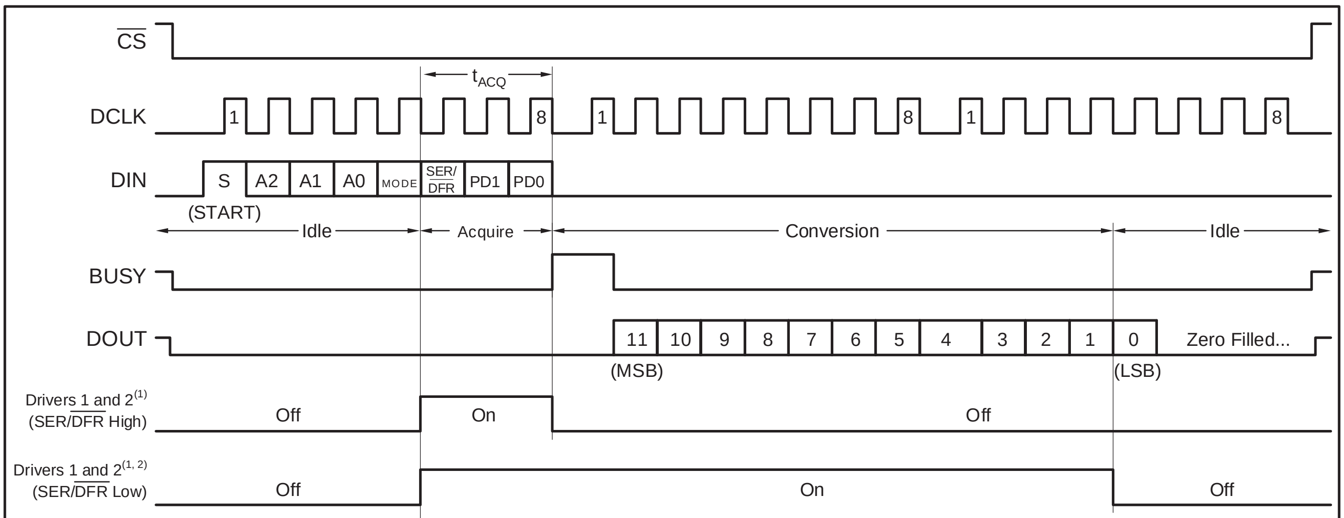
SER/$\overline{\text{DFR}}$—The SER/$\overline{\text{DFR}}$ bit controls the reference mode, either single-ended (high) or differential (low). The differential mode is also referred to as the ratiometric conversion mode and is preferred for X-Position, Y-Position, and Pressure-Touch measurements for optimum performance. The reference is derived from the voltage at the switch drivers, which is almost the same as the voltage to the touch screen. In this case, a reference voltage is not needed as the reference voltage to the ADC is the voltage across the touch screen. In the single-ended mode, the converter reference voltage is always the difference between the V_{REF} and GND pins (see Table 1 and Table 2, and Figure 2 through Figure 5, for further information).

BIT 7 (MSB)	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0 (LSB)
S	A2	A1	A0	MODE	SER/$\overline{\text{DFR}}$	PD1	PD0

Table 3. Order of the Control Bits in the Control Byte

BIT	NAME	DESCRIPTION
7	S	Start bit. Control byte starts with first high bit on DIN. A new control byte can start every 15th clock cycle in 12-bit conversion mode or every 11th clock cycle in 8-bit conversion mode (see Figure 13).
6-4	A2-A0	Channel Select bits. Along with the SER/$\overline{\text{DFR}}$ bit, these bits control the setting of the multiplexer input, touch driver switches, and reference inputs (see Table 1 and Figure 13).
3	MODE	12-Bit/8-Bit Conversion Select bit. This bit controls the number of bits for the next conversion: 12-bits (low) or 8-bits (high).
2	SER/$\overline{\text{DFR}}$	Single-Ended/Differential Reference Select bit. Along with bits A2-A0, this bit controls the setting of the multiplexer input, touch driver switches, and reference inputs (see Table 1 and Table 2).
1-0	PD1-PD0	Power-Down Mode Select bits. Refer to Table 5 for details.

Table 4. Descriptions of the Control Bits within the Control Byte



NOTES: (1) For Y−Position, Driver 1 is on X+ is selected, and Driver 2 is off. For X−Position, Driver 1 is off, Y+ is selected, and Driver 2 is on. Y− will turn on when power−down mode is entered and PD0 = 0.
(2) Drivers will remain on if PD0 = 1 (no power down) until selected input channel, reference mode, or power−down mode is changed, or $\overline{\text{CS}}$ is high.

Figure 9. Conversion Timing, 24 Clocks-per-Conversion, 8-Bit Bus Interface. No DCLK delay required with dedicated serial port

If X-Position, Y-Position, and Pressure-Touch are measured in the single-ended mode, an external reference voltage is needed. The TSC2046 must also be powered from the external reference. Caution should be observed when using the single-ended mode such that the input voltage to the ADC does not exceed the internal reference voltage, especially if the supply voltage is greater than 2.7V.

NOTE: The differential mode can only be used for X-Position, Y-Position, and Pressure-Touch measurements. All other measurements require the single-ended mode.

PD0 and PD1—Table 5 describes the power-down and the internal reference voltage configurations. The internal reference voltage can be turned on or off independently of the ADC. This can allow extra time for the internal reference voltage to settle to the final value prior to making a conversion. Make sure to also allow this extra wake-up time if the internal reference is powered down. The ADC requires no wake-up time and can be instantaneously used. Also note that the status of the internal reference power-down is latched into the part (internally) with BUSY going high. In order to turn the reference off, an additional write to the TSC2046 is required after the channel has been converted.

PD1	PD0	$\overline{\text{PENIRQ}}$	DESCRIPTION
0	0	Enabled	Power-Down Between Conversions. When each conversion is finished, the converter enters a low-power mode. At the start of the next conversion, the device instantly powers up to full power. There is no need for additional delays to ensure full operation, and the very first conversion is valid. The Y− switch is on when in power-down.
0	1	Disabled	Reference is off and ADC is on.
1	0	Enabled	Reference is on and ADC is off.
1	1	Disabled	Device is always powered. Reference is on and ADC is on.

Table 5. Power-Down and Internal Reference Selection

$\overline{\text{PENIRQ}}$ OUTPUT

The pen-interrupt output function is shown in Figure 10. While in power-down mode with PD0 = 0, the Y-driver is on and connects the Y-plane of the touch screen to GND. The $\overline{\text{PENIRQ}}$ output is connected to the X+ input through two transmission gates. When the screen is touched, the X+ input is pulled to ground through the touch screen.

In most of the TSC2046 models, the internal pullup resistor value is nominally 50kΩ, but this may vary between 36kΩ and 67kΩ given process and temperature variations. In order to assure a logic low of 0.35 • (+V_{CC}) is presented to the $\overline{\text{PENIRQ}}$ circuitry, the total resistance between the X+ and Y− terminals must be less than 21kΩ.

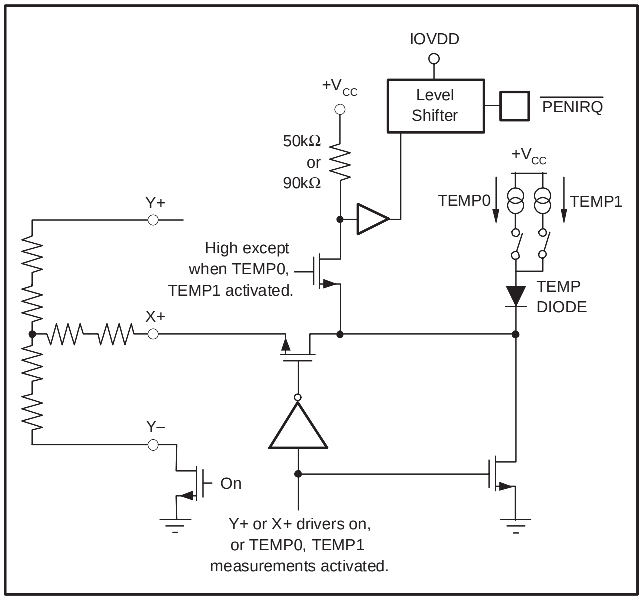


Figure 10. $\overline{\text{PENIRQ}}$ Functional Block Diagram

The −90 version of the TSC2046 uses a nominal 90kΩ pullup resistor, which allows the total resistance between the X+ and Y− terminals to be as high as 30kΩ. Note that the higher pullup resistance will cause a slower response time of the $\overline{\text{PENIRQ}}$ to a screen touch, so user software should take this into account.

The $\overline{\text{PENIRQ}}$ output goes low due to the current path through the touch screen to ground, which initiates an interrupt to the processor. During the measurement cycle for X-, Y-, and Z-Position, the X+ input is disconnected from the $\overline{\text{PENIRQ}}$ internal pull-up resistor. This is done to eliminate any leakage current from the internal pull-up resistor through the touch screen, thus causing no errors.

Furthermore, the $\overline{\text{PENIRQ}}$ output is disabled and low during the measurement cycle for X-, Y-, and Z-Position. The $\overline{\text{PENIRQ}}$ output is disabled and high during the measurement cycle for battery monitor, auxiliary input, and chip temperature. If the last control byte written to the TSC2046 contains PD0 = 1, the pen-interrupt output function is disabled and is not able to detect when the screen is touched. In order to re-enable the pen-interrupt output function under these circumstances, a control byte needs to be written to the TSC2046 with PD0 = 0. If the last control byte written to the TSC2046 contains PD0 = 0, the pen-interrupt output function is enabled at the end of the conversion. The end of the conversion occurs on the falling edge of DCLK after bit 1 of the converted data is clocked out of the TSC2046.

It is recommended that the processor mask the interrupt $\overline{\text{PENIRQ}}$ is associated with whenever the processor sends a control byte to the TSC2046. This prevents false triggering of interrupts when the $\overline{\text{PENIRQ}}$ output is disabled in the cases discussed in this section.