

Touch Screen Control and Calibration -- Four-Wire, Resistive

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Associated Projects: Yes

Associated Part Family: CY8C27443, CY8C24423

PSoC Designer Version: 4.1

Summary

This Application Note describes two control methods and a calibration algorithm for a four-wire, resistive touch screen using the PSoC device.

Introduction

Resistive-type touch screens are widely used in many types of designs. Their construction is simple, their cost is low, and their operation is well understood by users. Despite simple read operations, touch screen devices almost always require a calibration algorithm to convert touch screen coordinates to true screen coordinates (LCD or otherwise).

Touch Screen Construction

Four-wire touch screens are constructed as shown in Figure 1. They consist of two transparent layers, the interior surfaces of which have been coated with a conductive material. When a finger or stylus presses against the surface, the upper material bends just enough to contact the lower sheet, making a connection between resistive layers.

First Measurement Method

Touch can be defined by three parameters. The first and second parameters are X- and Y-position. The third parameter relates to “touch pressure” and allows the touch screen to differentiate between finger and stylus contacts. Equivalent circuits for touched and untouched touch screens are shown in Figure 2.

All measurement cycles need voltage applied in various combinations. In this project, V_{CC} is put on the touch screen connector by switching the connected PSoC port in the strong drive and setting a logic high value. Connecting to ground means setting the port to the strong drive and setting the logic to a low value. The PSoC output stage drain resistance is low and its influence is also low. The calibration algorithm compensates for this discrepancy.

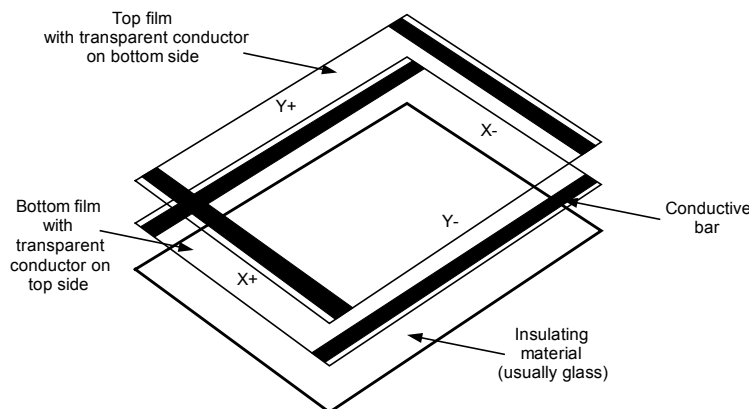


Figure 1. Four-Wire Touch Screen Construction

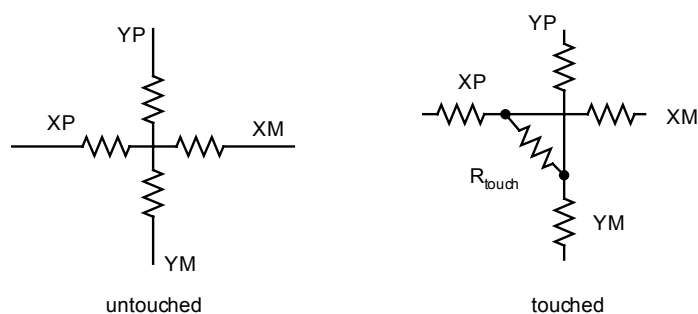


Figure 2. Touch Screen Equivalent Circuits

All measurements are performed by an incremental analog-to-digital converter (ADC) through a programmable gain amplifier (PGA). Measurements are made in radiometric mode. The touch screen is powered by the same source that powers the PSoC. The ADC is configured to measure in the $GND-V_{CC}$ range. Hence, measurement does not depend on power supply voltage.

Various configurations for the touch screen measurement cycle are shown in Figure 3. X-position is measured as voltage is applied over the X-plane by connecting XP to V_{CC} and XM to ground. Voltage measured from YP or YM touch screen connector is proportional to the touch X-coordinate.

Y-position is measured as voltage is applied over the Y-plane by connecting YP to V_{CC} and YM to ground. Voltage measured from XP or XM touch screen connector is proportional to the touch Y-coordinate.

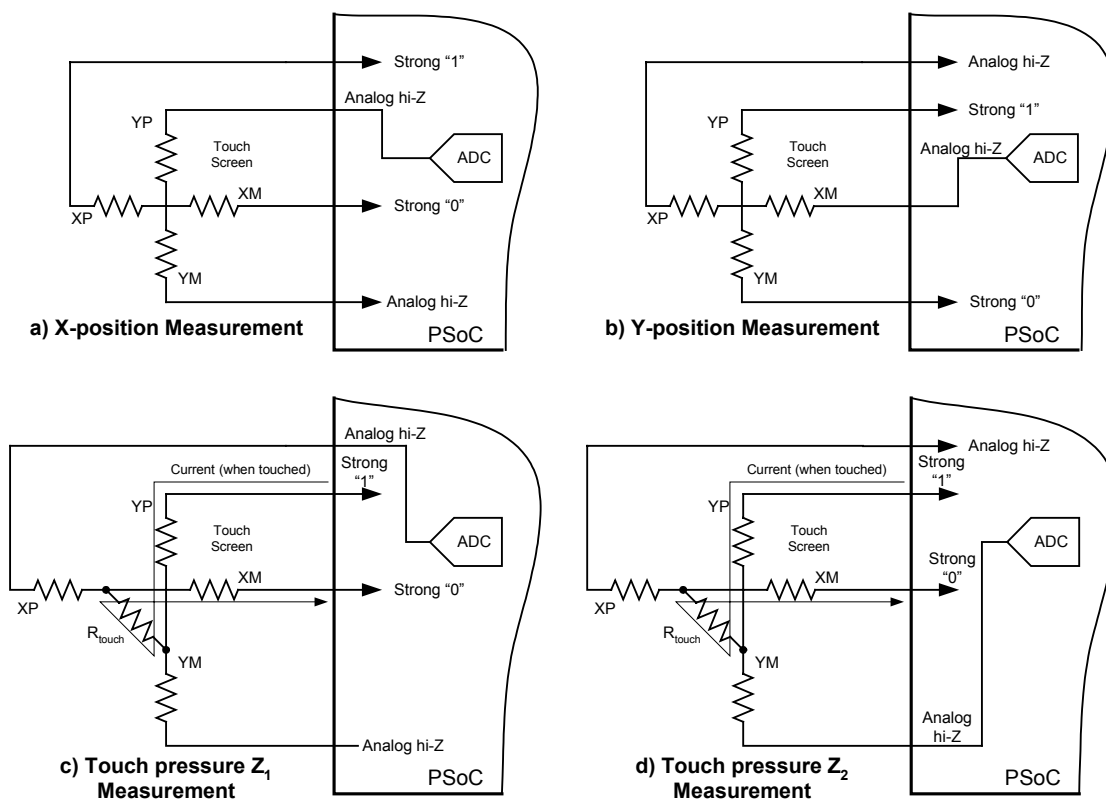


Figure 3. Various Parameter Measurements

To measure touch pressure, it is necessary to relate pressure to resistance.

Since touch pressure is most often used to determine the presence of a finger or pen touch and not the intensity of the contact, it is not necessary to have high accuracy pressure measurement. The resolution used in this project for pressure measurement is 8-bit ADC instead of the 12-bit resolution used for X- and Y-positional measurements.

There are several different methods for touch pressure measurement. Two methods are discussed in this Application Note.

The first method requires a known X-plate resistance, measurements of X-position (X) and two additional cross-panel measurements (Z_1 and Z_2) of the touch screen. Voltage is applied to YP (V_{CC}) and XM (ground) and measures both XP (Z_1) and YM (Z_2) values. Equation 1 defines the touch resistance.

The second method requires known X- and Y-plate resistance values but only allows measurement of Z_1 . Equation 2 defines the touch resistance for the second method.

The associated project uses the first method and Equation 1 since the arithmetic is much simpler.

$$R_{touch} = R_{x_plate} \frac{X}{2^{ADC_resolution}} \left(\frac{Z_1}{Z_2} - 1 \right) \quad (1)$$

$$R_{touch} = (X) \frac{R_{x_plate}}{2^{ADC_resolution}} \left(\frac{2^{ADC_resolution}}{Z_1} - 1 \right) - R_{y_plate} \left(1 - \frac{Y}{2^{ADC_resolution}} \right) \quad (2)$$

Pen Interrupt and Power Consumption

If the user does not touch the screen for a long period of time, there is no need for operation or measurement. The touch screen is then put in sleep mode and waits for a pen interrupt. Upon user touch, an interrupt occurs and the touch screen controller wakes up and measures touch parameters.

Voltage is applied to the touch screen XP connector through resistors that have four (or more) times the maximal cross-powered touch screen resistance in touched mode. In the proposed design, cross-powered touch screen resistance values are greater than 1 k Ω . Therefore, an internal pull-up resistor with a resistance of 5.6K can be used. The port pin that is connected to the touch screen XP connector is configured to pull-up mode and set to a logic state of high. The port pin connected to the XM connector is configured as a digital input and the interrupt is enabled by falling edge. If the lower touch screen is still untouched, XM holds the logic in high state. If the user touches the screen, the voltage of XM falls to a low logic level and initiates an interrupt that wakes up the PSoC.

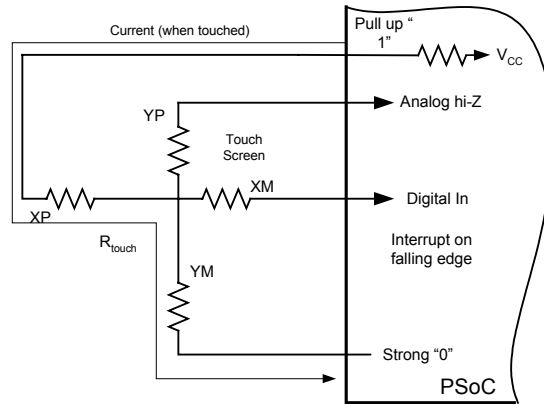


Figure 4. Touch Screen Configured for a Waiting Pen Interrupt

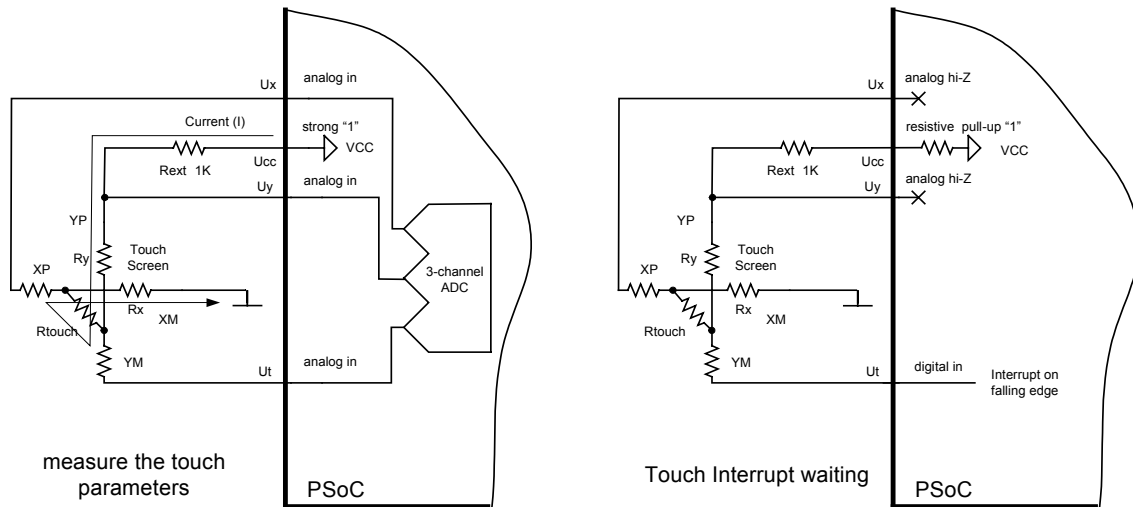


Figure 5. Second Method of Touch Screen Parameter Measurement

Second Measuring Method

The second method also measures all three parameters. The X-position, Y-position, and touch pressure are measured at the same time. This method allows elimination of touch screen power-scheme switching characteristics due to a greater sample rate but requires a three-channel ADC. Touch screen connections and port pin configuration are shown in Figure 5.

By the simple network theory, the current in the circuit is calculated as:

$$I = \frac{U_{cc} - U_y}{R_{ext}}; \quad (3)$$

Therefore, resistances R_x , R_t and R_y are given by:

$$\begin{aligned} R_x &= \frac{U_x}{I} = \frac{R_{ext} \cdot U_x}{U_{cc} - U_y}; \\ R_t &= \frac{R_{ext} \cdot (U_t - U_x)}{U_{cc} - U_y}; \\ R_y &= \frac{R_{ext} \cdot (U_y - U_t)}{U_{cc} - U_y}; \end{aligned} \quad (4)$$

Because R_{ext} is constant and because further calibration is used to relate touch screen and display coordinates, R_{ext} may be ignored and X, Y and T calculated by Equation 5.

$$\begin{aligned}
 X &= \frac{U_x}{U_{cc} - U_y} \\
 Y &= \frac{U_y - U_t}{U_{cc} - U_y} \\
 T &= \frac{U_t - U_x}{U_{cc} - U_y}
 \end{aligned} \quad (5)$$

Pen Interrupt with the Second Measurement Scheme

Benefits and requirements of pen-interrupt sleep mode and wake-up are described above. To wait for pen interrupts, the designer must switch the powering port pin into pull-up high mode and allow an interrupt on the falling edge of the pin connected to YM.

Touch Screen Calibration

In many cases the touch screen is mounted over an LCD or another display. In these cases, data measured by the touch screen must be translated into true screen coordinates.

A calibration algorithm proposed in this note permits the elimination of scaling factors and mechanical misalignment of the touch screen.

The challenge for the calibration algorithm is to translate the set of coordinates reported by the touch screen into a set of coordinates that accurately represent a point on the display.

$$[X_D, Y_D] = \bar{f}([X_T, Y_T]) \quad (6)$$

Figure 6 shows some misalignment touch screen and display coordinates. This figure also shows that it is possible to describe each point on the display as $P_D = [X_D, Y_D]$ and each point on the touch screen as $P_T = [X_T, Y_T]$. Three factors of error are presented:

- Rotation of touch screen coordinates relatively to display coordinates.
- Linear shift of coordinates.
- A scaling factor.

The following expression considers all three error factors.

$$\begin{aligned}
 X_D &= A(X_T) + B(T_T) + C \\
 Y_D &= D(X_T) + E(T_T) + F
 \end{aligned} \quad (7)$$

These relationships present six calibration coefficients. Therefore, three sample points are required to solve the system of linear equations, Equation (8), and get calibration coefficient values.

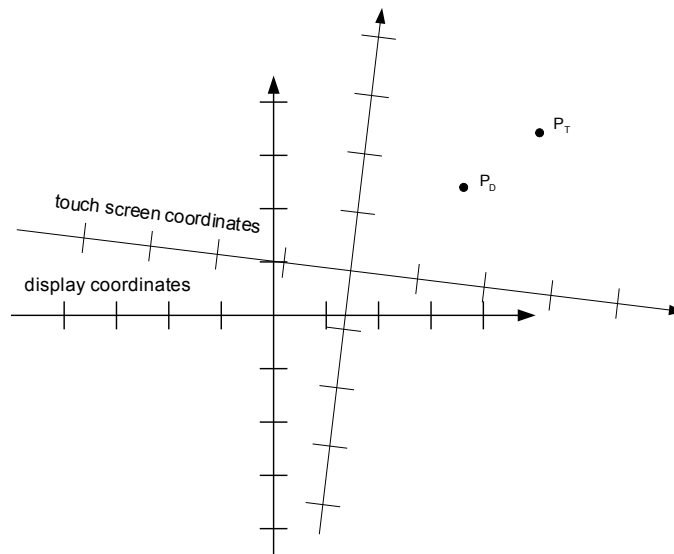


Figure 6. Misalignment of Display and Touch Screen. Touch Screen and Display Coordinates

$$\begin{aligned}
X_{D0} &= A(X_{T0}) + B(T_{T0}) + C \\
X_{D1} &= A(X_{T1}) + B(T_{T1}) + C \\
X_{D2} &= A(X_{T2}) + B(T_{T2}) + C \\
Y_{D0} &= D(X_{T0}) + E(T_{T0}) + F \\
Y_{D1} &= D(X_{T1}) + E(T_{T1}) + F \\
Y_{D2} &= D(X_{T2}) + E(T_{T2}) + F
\end{aligned} \tag{8}$$

The unknowns are resolved in Equation (9):

$$\begin{aligned}
A &= \frac{(X_{D0} - X_{D2})(Y_{T1} - Y_{T2}) - (X_{D1} - X_{D2})(Y_{T0} - Y_{T2})}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})} \\
B &= \frac{(X_{T0} - X_{T2})(Y_{D1} - Y_{D2}) - (X_{D1} - X_{D2})(Y_{T0} - Y_{T2})}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})} \\
C &= \frac{Y_{T0}[X_{T2}(X_{D1}) - X_{T1}(X_{D2})] + Y_{T1}[X_{T0}(X_{D2}) - X_{T2}(X_{D0})] + Y_{T2}[X_{T1}(X_{D0}) - X_{T0}(X_{D1})]}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})} \\
D &= \frac{(Y_{D0} - Y_{D2})(Y_{T1} - Y_{T2}) - (Y_{D1} - Y_{D2})(Y_{T0} - Y_{T2})}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})} \\
E &= \frac{(X_{T0} - X_{T2})(Y_{D1} - Y_{D2}) - (Y_{D0} - Y_{D2})(X_{T1} - X_{T2})}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})} \\
F &= \frac{Y_{T0}[X_{T2}(Y_{D1}) - X_{T1}(Y_{D2})] + Y_{T1}[X_{T0}(Y_{D2}) - X_{T2}(Y_{D0})] + Y_{T2}[X_{T1}(Y_{D0}) - X_{T0}(Y_{D1})]}{(X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2})}
\end{aligned} \tag{9}$$

The right sides of all the expressions contain the same denominator. This can be very useful for integer arithmetic. Isolating the denominator and marking it as K, yields Equation (10). Rewriting Equation (8) using K produces Equation (11).

All operations required by Equation (8) are performed by integer arithmetic.

$$\begin{aligned}
K &= (X_{T0} - X_{T2})(Y_{T1} - Y_{T2}) - (X_{T1} - X_{T2})(Y_{T0} - Y_{T2}) \\
A' &= (X_{D0} - X_{D2})(Y_{T1} - Y_{T2}) - (X_{D1} - X_{D2})(Y_{T0} - Y_{T2}) \\
B' &= (X_{T0} - X_{T2})(X_{D1} - X_{D2}) - (X_{D0} - X_{D2})(X_{T1} - X_{T2}) \\
C' &= Y_{T0}((X_{T2})(X_{D1}) - (X_{T1})(X_{D2})) + Y_{T1}((X_{T0})(X_{D2}) - (X_{T2})(X_{D0})) + Y_{T2}((X_{T1})(X_{D0}) - (X_{T0})(X_{D1})) \\
D' &= (Y_{D0} - Y_{D2})(Y_{T1} - Y_{T2}) - (Y_{D1} - Y_{D2})(Y_{T0} - Y_{T2}) \\
E' &= (X_{T0} - X_{T2})(Y_{D1} - Y_{D2}) - (Y_{D0} - Y_{D2})(X_{T1} - X_{T2}) \\
F' &= Y_{T0}((X_{T2})(Y_{D1}) - (X_{T1})(Y_{D2})) + Y_{T1}((X_{T0})(Y_{D2}) - (X_{T2})(Y_{D0})) + Y_{T2}((X_{T1})(Y_{D0}) - (X_{T0})(Y_{D1}))
\end{aligned} \tag{10}$$

$$X_D = \frac{A'(X_T) + B'(T_T) + C'}{K}$$

$$Y_D = \frac{D'(Y_T) + E'(T_T) + F'}{K}$$
(11)

For best results, the first sample point must be roughly 10% of the top left edge of screen. The second and third points are roughly 10% of the center and 10% of the side, respectively (see Figure 7). For the calibration process, points 1, 2, and 3 must be touched in ascending order.

Calibration must be performed for each device that contains a touch screen before use. There is no need to perform calibration every time the device is powered on. However, it is prudent to save the calibration parameters in energy-independent memory. Every time the device is used after calibration it reads these coefficients and uses them to calculate true screen coordinates.

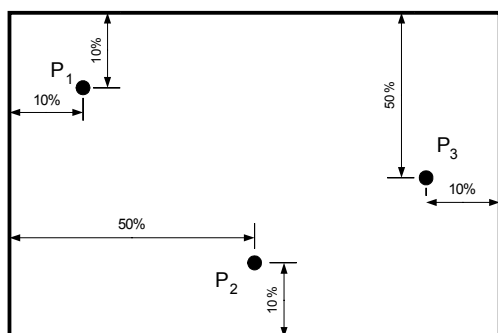


Figure 7. Calibration Point's Placement on Screen

CY8C24423 Implementation of the First Measurement Method

The first measurement method is realized on the CY8C24423 device. A schematic of this is shown in Figure 8. A resistive touch screen with an X-plane resistance of 800Ω and a Y-plane resistance of 600Ω is used.

The touch screen controller on a PSoC reads touch screen parameters as “X-,” “Y-position,” and “Touch Pressure” then sends them via the serial interface. Because the interface is not the main focus of this Application Note, a serial interface similar to a UART is used. Real applications may use a different interface such as an SPI or I²C bus.

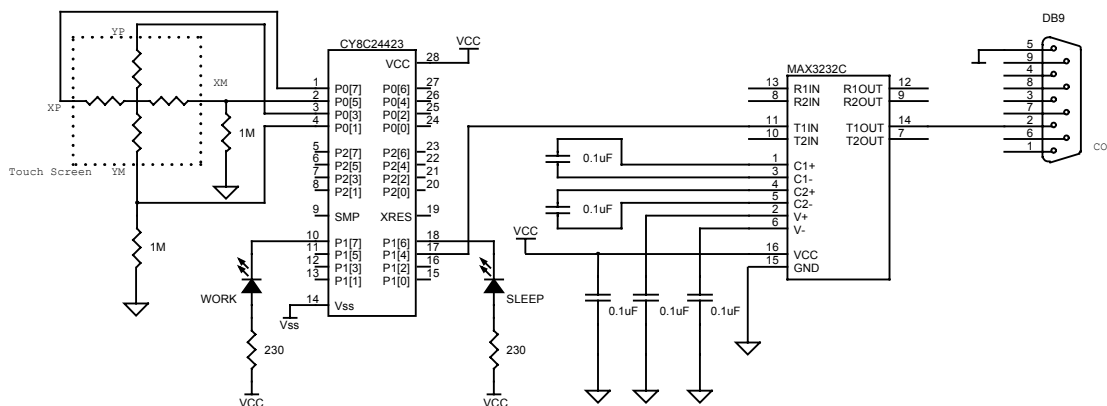


Figure 8. Touch Screen Controller on a Base of CY8C24423

Two light diodes are used to show the present state of the touch screen controller (sleep or work). If the user does not touch the screen within 2 seconds, the device goes into sleep mode.

A flowchart for the touch screen parameter measurement routine is shown in Figure 9.

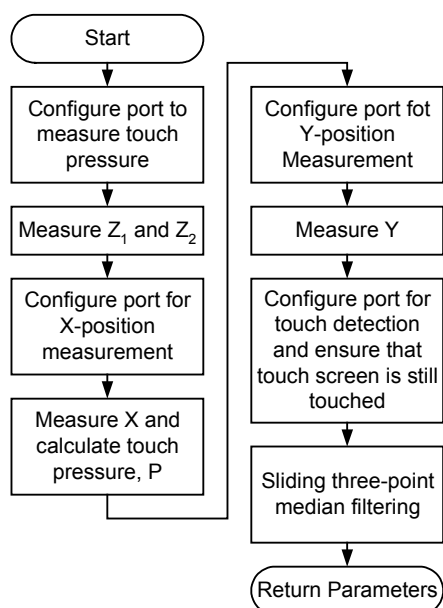


Figure 9. Touch Screen Parameters Measurement Routine Flowchart

The measured values are accepted if touch pressure is not greater than a fixed value. Otherwise, the decision is made that the screen was not touched. To avoid distortion caused by a touch that is too brief, three-point sliding median filtering is applied. A state machine with two states controls all measurements.

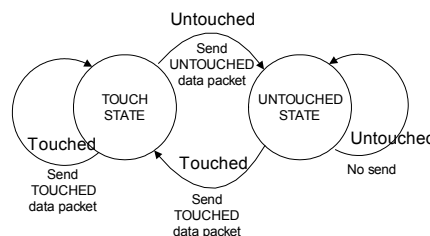


Figure 10. State Machine used for Control

The device can send one of two data packets through the serial interface. The TOUCHED data packet contains touch parameters and the UNTOUCHED data packet indicates an end of a touch only. If the user touches the touch screen, a TOUCHED data packet is sent until the user releases the touch screen. An UNTOUCHED data packet is then sent to the interface. An UNTOUCHED data packet is sent only one time after the user releases the screen.

The TOUCHED data packet shown is in Figure 11 and consists of start marker 'T', two bytes that contain the X-position, two bytes that contain the Y-position, one byte the contains touch pressure, and an end marker 'E'. The UNTOUCHED data packet contains only the marker 'U'.

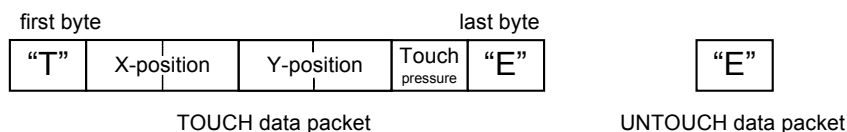


Figure 11. Data Packets used by Touch Screen Controller

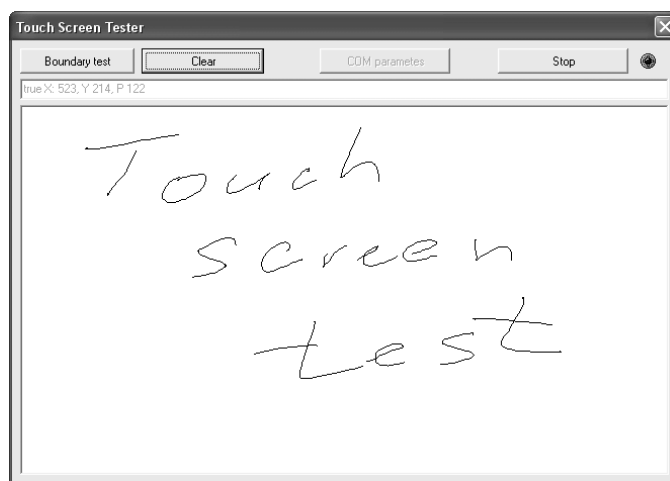


Figure 12. Touch Screen Controller Test Application

For evaluation and testing, a PC application that reads the COM port and visualizes the data was developed. Figure 12 shows a screenshot of this application.

CY8C27443 Implementation of the Second Measurement Method

The second measurement method uses the CY8C27443 device. This method requires the triple input ADC. In this design, a BP320240C LCD with built-in touch panel is used. The reader can find the BP320240C data sheet at the Bolymin web site^[1].

A calibration algorithm is also implemented. This algorithm allows conversion of an LCD point to a touch screen point.

A brief flowchart for the touch screen controller function is shown in Figure 14.

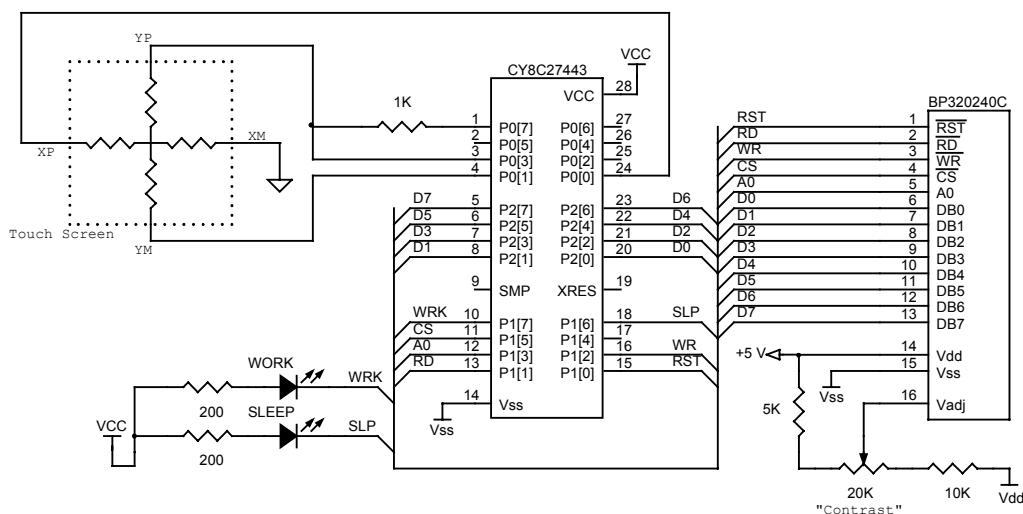


Figure 13. LCD and Touch Screen Controller on a Base of CY8C27443

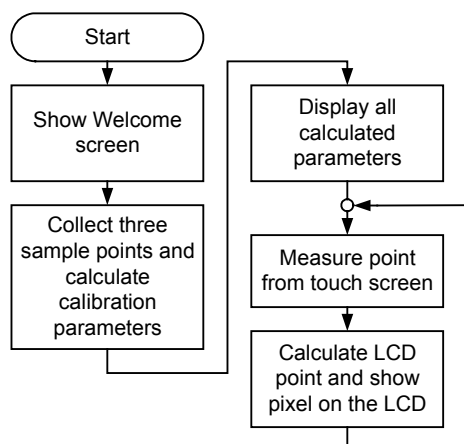
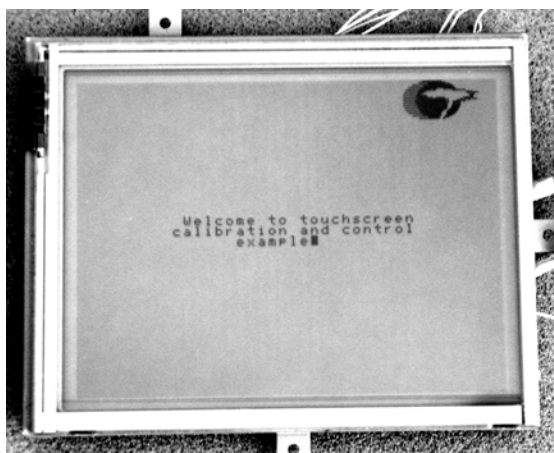


Figure 14. Brief Algorithm of CY8C27443-Based Touch Screen Controller Work Flow

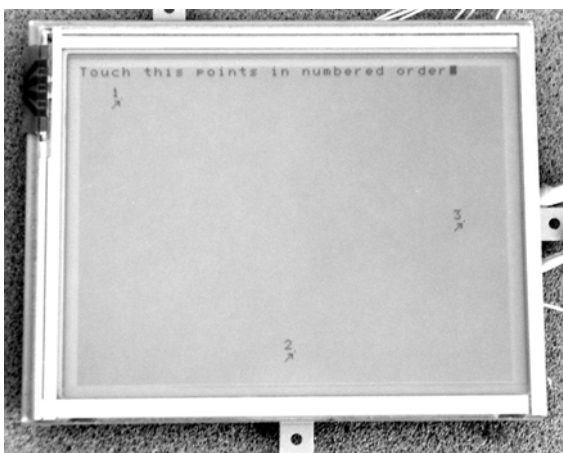
Because this application is written as an example using the touch screen, calibration is performed every time the device is powered on. In real applications, calibration is performed at the manufacturing or service stage and coefficients are written into the nonvolatile memory and stored until the next time they are needed.

Figure 15 contains some photos of an LCD with a touch screen under CY8C27443 control.

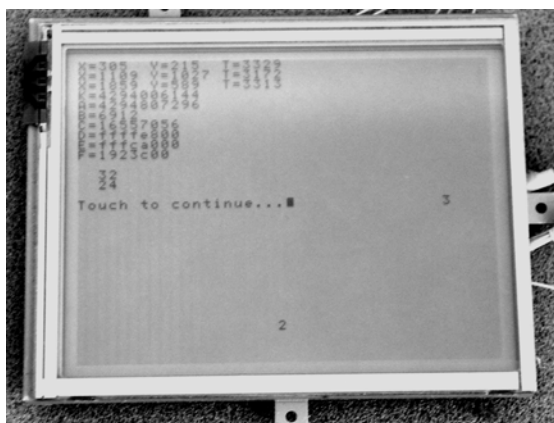
The first photo illustrates the Welcome screen. Figure 15b shows the screen used for calibration with three sample points that must be touched for calculation of the calibration parameters. Figure 15c shows the calculated parameters' output. The last photo shows the painting mode. Every point that was touched in this mode is displayed on the LCD.



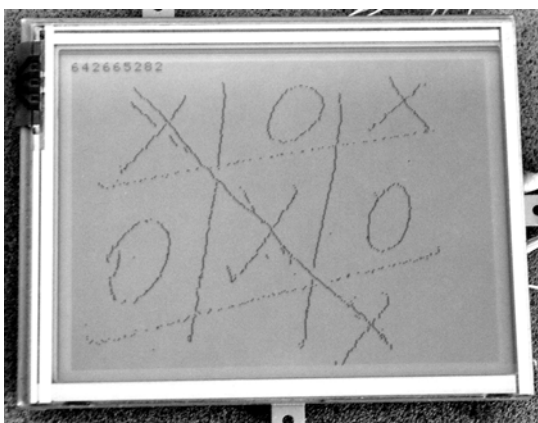
a) Welcome Screen



b) Calibration Screen



c) Calculated Parameters Output



d) Painting Mode

Figure 15. LCD Snapshots

Some Words About LCD

The LCD used in this design is built on the S1D3305 controller. The data sheet for this controller can be found at the Epson Electronic America web site^[2]. Because this controller may be used for different LCD resolutions, it requires initialization with specific LCD parameters.

Typical initialization sequences are shown in the controller data sheet. Flowcharts for the command and data write are shown in Figure 16.

The LCD controller functions are configured into two layers. The first layer is a text plane using a built-in 8x8 font generator and the second layer is graphical plane. Configuring the display in the specified mode is described in the S1D3305 data sheet.

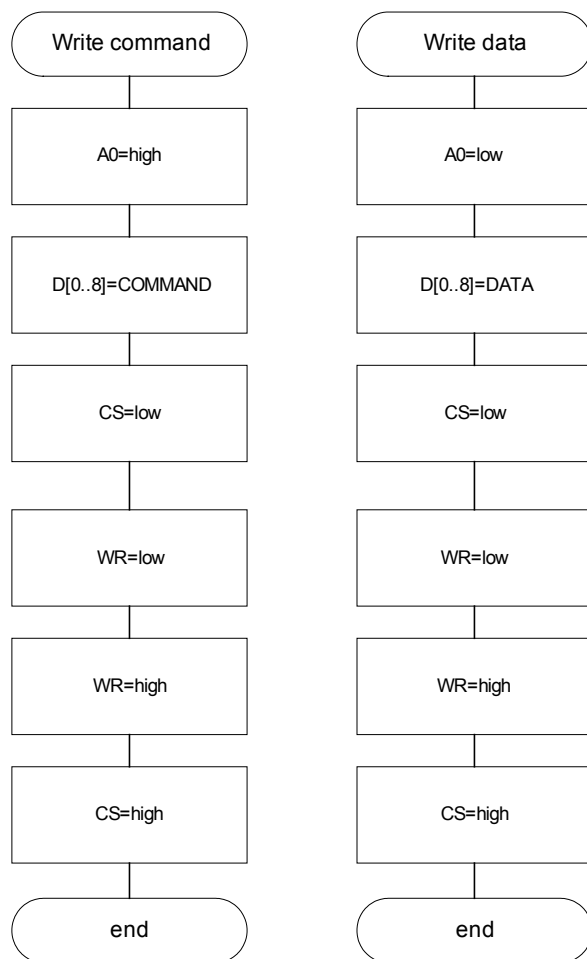


Figure 16. Command and Data Write Flowcharts

Summary

This Application Note describes two touch screen control methods, a calibration algorithm, and examples of touch screens controlled by a PSoC.

An attached file contains two projects for two different control methods on the CY8C27443 and the CY8C24423 and a PC application that allows users to test the touch screen controller.

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References

[1] Data sheet for BP320240C can be downloaded at <http://www.bolymin.com.tw/product/data/BP320240C.pdf>.

[2] Data sheet for S1D3305 can be downloaded at http://www.eea.epson.com/go/Prod_Admin/Categories/EEA/IC/ASSP/Display_IC/LCD Controllers/go/Resources/Manuals/s1d1335tm.

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