CapSense® Sigma-Delta Datasheet CSD V 1.90

Resources	PSoC® Blocks				API Memory		Pins (per External I/O)
	Decimator	I^2C/SPI	Digital	Analog	Flash	RAM	
CY8C28x45, CY8C28x52, CY8C28x13, CY8C28x33, CY8CLED04							
First Order Modulator with IDAC	1	-	0...2	2	-	-	1
Second Order Modulator with IDAC	1	-	0...2	2	-	-	1

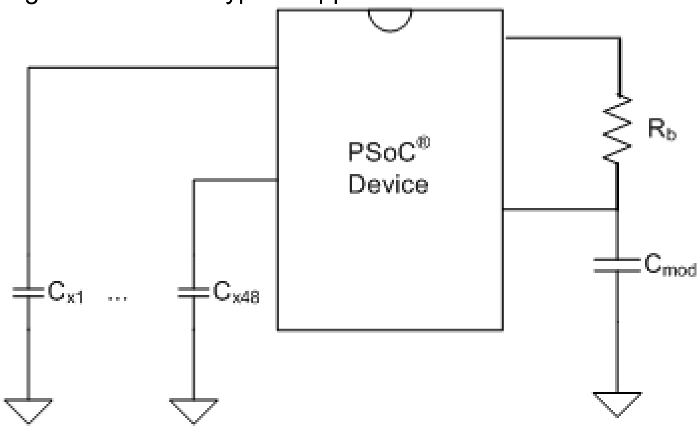
For one or more fully configured, functional example projects that use this user module go to www.cypress.com/psocexampleprojects.

Features and Overview

- Scan up to 41 capacitive sensors (depending on the device pin count).
- Sensing is possible with up to a 15 mm glass overlay.
- Proximity detection to 20 cm with a wire-based sensor.
- High immunity to AC mains noise, EMC noise, and power supply voltage changes.
- Supports different combinations of independent and slide capacitive sensors.
- Double slide sensor physical resolution using diplexing.
- Increase slide sensor resolution using interpolation.
- Touchpad support with two slide sensors.
- Sensing support through high resistive conductive materials (for example, indium tin oxide (ITO) films).
- Shield electrode support for reliable operation in the presence of water film or droplets.
- Guided sensor and pin assignments using the CSD Wizard.
- Integrated baseline update algorithm for handling temperature, humidity, and electrostatic discharge (ESD) events.
- Easily adjustable operational parameters.
- PC GUI application support for raw data monitoring and parameter optimization in real time.

The Capacitive Sensing using a Sigma-Delta Modulator (CSD) User Module provides capacitance sensing using the switched capacitor technique with a sigma-delta modulator to convert the sensing switched capacitor current to digital code. The CSD User Module can support single-channel CapSense scanning with a First and Second order Sigma Delta Modulator.

Figure 1. CSD Typical Application



Quick Start

1. Select and place the user modules that require dedicated pins (for example, I2C and LCD). Assign ports and pins as required.
2. Select and place the CSD User Module.
3. Right-click the CSD User Module in the Workspace Explorer to access the CSD Wizard (the wizard is explained later in the datasheet).
4. Set the number of sensors, sliders, or rotary sliders that you want.
5. Set the sensor settings for each sensor.
6. Set pins and global parameters. Read all parameter descriptions and follow requirements and guidelines.
7. Generate the application and switch to the Application Editor.
8. Adapt the sample code as required to implement independent sensors, sliding sensors, or a touchpad.
9. Connect the I^2C-USB bridge to the target board, and observe the signals.
10. Change the CSD parameters to optimize your settings and rebuild the application.
11. Program the PSoC device and verify module operation.Tune the CSD parameters to achieve a 5:1 SNR requirement as discussed in the CY8C21x34/B CapSense Design Guide.

See the *Troubleshooting* section in the *Appendix* if you encounter any problems.

Functional Description

A capacitive sensor array consists of combinations of independent sensors, sliding sensors, and touchpads implemented as a pair of orthogonal sliders. High level decision logic provides compensation for environmental factors, such as temperature, humidity, and power supply voltage change. A separate shield electrode can be used for shielding the sensor array to reduce stray capacitance. This provides more reliable operation in the presence of a water film or droplets.

The high level software functions accommodate slider diplexing so that a single electrical sensor may be used in two physical locations for resolution enhancement. The functions also provide further interpolation of resolved sensor position between physical sensor locations.

The capacitive sensor consists of physical, electrical, and software components:

- **Physical**: The physical sensor itself, typically a conductive pattern constructed on a PCB connected to the PSoC with an insulating cover, a flexible membrane, or a transparent overlay over a display.
- **Electrical**: A method to convert the sensor capacitance to digital format. The conversion system consists of a sensing switched capacitor, a sigma-delta modulator, and a counter-based digital filter to convert the modulator output bit stream to a readable digital format.
- **Software**: Detection and compensation software algorithms convert the count value into a sensor detection decision. In the case of consecutive, dependent sensors (such as sliders and touchpads) APIs are provided to interpolate a position with greater resolution than the physical pitch of the sensors. For example, you can create a volume slider with 10 sensors and use the provided firmware to expand the number of volume levels to 100. Alternatively, using the same APIs, you can use two capacitive sensors that taper into each other and determine the position of a conductive object (such as a finger) between them.

While there are a number of methods to measure capacitance, the one used in this user module is combination switching capacitor with delta-sigma modulator.

The following documents are recommended reading before you use the CSD User Module for the first time.

- *CY8C28X45 and CY8C21345 PSoC Programmable System-on-Chip Technical Reference Manual*, sections - CapSense System

The following design guides are recommended after reading the CSD User Module datasheet. These documents are available on the Cypress Semiconductor website at www.cypress.com:

- Getting Started with CapSense
- CY8C20xx6A/H CapSense Design Guide
- CY8C21x34/B CapSense Design Guide
- CY8C20x34 CapSense Design Guide
- CY8CMBR2044 CapSense Design Guide

Capacitance Measurement Operation

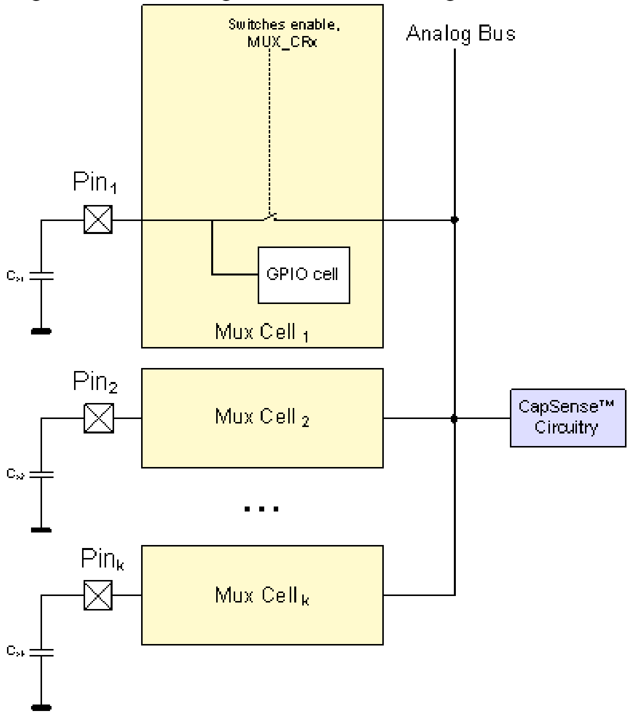
The decision logic is implemented in firmware. The firmware analyzes capacitance measurement, tracks the slow capacitance change due to environmental factors, and runs decision logic to detect button touches and calculate slider position.

Scanning an Array of Sensors

The CY8C28x45 family of devices have a built in analog bus. It allows capacitive sensor connections to any PSoC pin. The CSD User Module uses internal precharge switches to charge active sensors at clock signal phase Ph_1 and connects the Analog Bus to the sensor at phase Ph_2. The sigma-delta modulator modulation capacitor and comparator inputs are connected to the analog bus permanently.

The firmware performs sensor scanning in series by setting corresponding bits in the MUX_CRx registers.

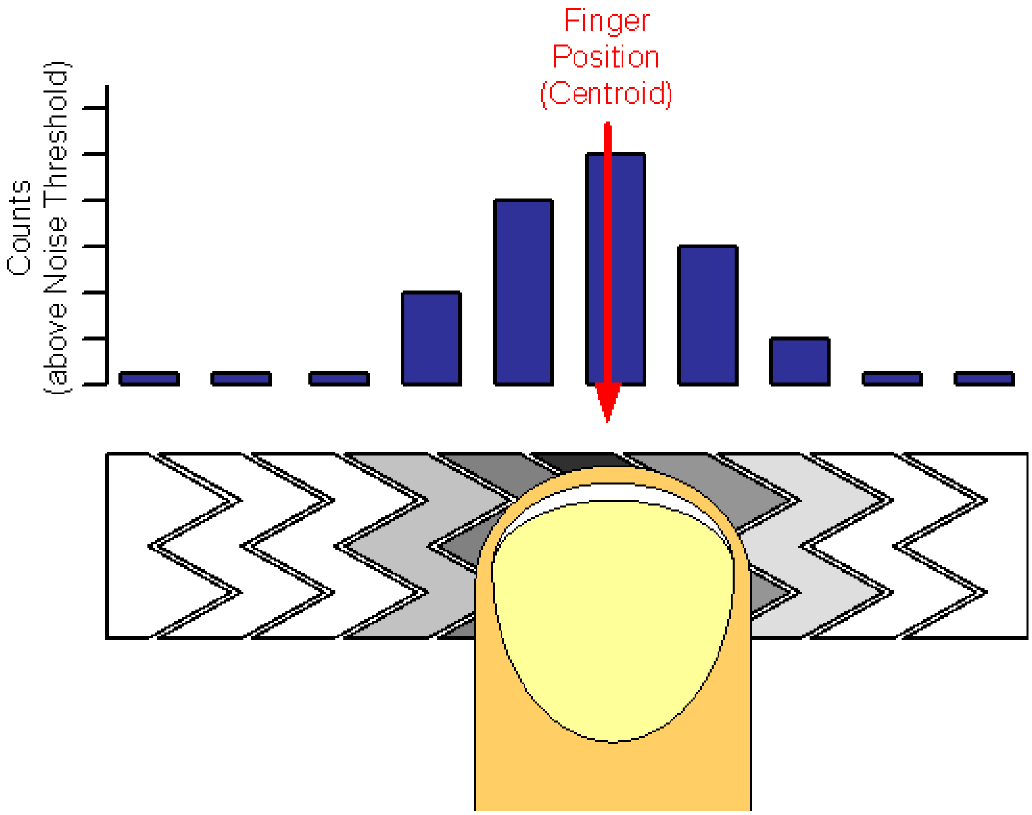
Figure 2. Analog Bus with Precharge Switches



Sliders

Sliders are used for controls requiring gradual adjustments. Examples include a lighting control (dimmer), volume control, graphic equalizer, and speed control. These sensors are mechanically adjacent to one another. Actuation of one sensor results in partial actuation of physically adjacent sensors. The actual position in the slider is found by computing the centroid location of the set of activated sensors. Sliders are accommodated in the CSD Wizard, by establishing groups in which each group of sliders has a specific order. The practical lower limit number for sensors slider is five, the upper limit is simply the number of sensor positions available on the PSoC device selected.

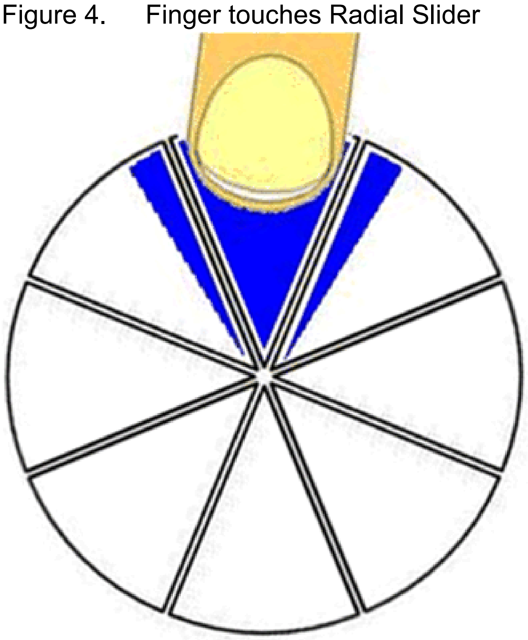
Figure 3. Ordering Physical Sensor Locations



The close proximity of strong signals in one half of the slider results in the same levels aliased into the upper half, but the results are scattered. The sensing algorithms search for strong adjacent sets of signals to declare the resolved slider position.

Radial Sliders

Figure 4. Finger touches Radial Slider



The CSD User Module has two slider types: linear and radial. Radial sliders are similar to linear ones. While linear sliders have a beginning and an end, radial sliders do not. When a touch happens, the centroid calculation algorithm takes into account sensor counts of the switches to the right and left of the current switch. Radial sliders are not diplexed.

The CSD User Module two API functions that support radial sliders. The first function CSD_wGetRadiaPos() returns centroid location and the second CSD_wGetRadialInc() returns finger shift in resolution units. When the finger moves in a clockwise direction it is a positive offset.

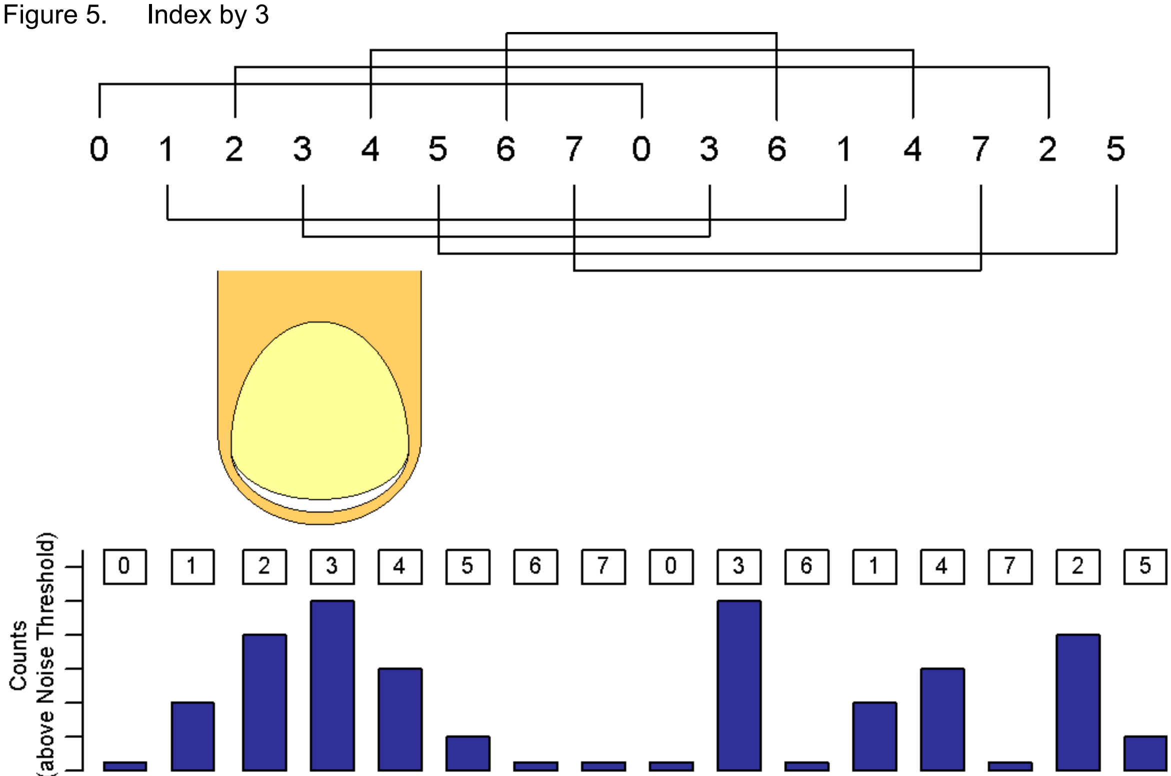
The reference point(0) is located in the middle of the first sensor. The Resolution for both linear and radial sliders is limited and is (number of pins used for sensors – 1) x 2^8 – 1 or (2 x pins used for sensors – 1) x 2^8 -1 for diplexed sliders.

Diplexing

Each PSoC sensor connection in a slider is mapped to two physical locations in the array of slider sensors. The first (or numerically lower) half of the physical locations is mapped sequentially to the base assigned sensors, with the port pin assigned by the designer using the CSD Wizard. The second (or upper) half of the physical sensor locations is automatically mapped by an algorithm in the Wizard and listed in an include file. The order is established so that adjacent sensor actuation in one half does not result in adjacent sensor actuation in the other half. Take care to determine this order and map it onto the printed circuit board.

There are many methods to order the second half of the physical sensor locations. The simplest is to index the sensors in the upper half, all of the even sensors, followed by all of the odd sensors. Other methods include indexing by other values. The method selected for this user module is to index by three.

Figure 5. Index by 3



Balance sensor capacitance in the slider. Depending on sensor or PCB layouts, there may be longer routes for some of the sensor pairs. The diplex sensor index table is automatically generated by the CSD

Wizard when you select diplexing. The following table illustrates the diplexing sequences for different slider segments count.

Table 1. Diplexing Sequence for Different Slider Segment Counts

Total Slider Segment Count	Segment Sequence
10	0,1,2,3,4,0,3,1,4,2
12	0,1,2,3,4,5,0,3,1,4,2,5
14	0,1,2,3,4,5,6,0,3,6,1,4,2,5
16	0,1,2,3,4,5,6,7,0,3,6,1,4,7,2,5
18	0,1,2,3,4,5,6,7,8,0,3,6,1,4,7,2,5,8
20	0,1,2,3,4,5,6,7,8,9,0,3,6,9,1,4,7,2,5,8
22	0,1,2,3,4,5,6,7,8,9,10,0,3,6,9,1,4,7,10,2,5,8
24	0,1,2,3,4,5,6,7,8,9,10,11,0,3,6,9,1,4,7,10,2,5,8,11
26	0,1,2,3,4,5,6,7,8,9,10,11,12,0,3,6,9,12,1,4,7,10,2,5,8,11
28	0,1,2,3,4,5,6,7,8,9,10,11,12,13,0,3,6,9,12,1,4,7,10,13,2,5,8,11
30	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,0,3,6,9,12,1,4,7,10,13,2,5,8,11,14
32	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,0,3,6,9,12,15,1,4,7,10,13,2,5,8,11,14
34	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,0,3,6,9,12,15,1,4,7,10,13,16,2,5,8,11,14
36	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,0,3,6,9,12,15,1,4,7,10,13,16,2,5,8,11,14,17
38	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,0,3,6,9,12,15,18,1,4,7,10,13,16,2,5,8,11,14,17
40	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,0,3,6,9,12,15,18,1,4,7,10,13,16,19,2,5,8,11,14,17
42	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,0,3,6,9,12,15,18,1,4,7,10,13,16,19,2,5,8,11,14,17,20
44	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,0,3,6,9,12,15,18,21,1,4,7,10,13,16,19,2,5,8,11,14,17,20
46	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,0,3,6,9,12,15,18,21,1,4,7,10,13,16,19,22,2,5,8,11,14,17,20
48	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,0,3,6,9,12,15,18,21,1,4,7,10,13,16,19,22,2,5,8,11,14,17,20,23

Total Slider Segment Count	Segment Sequence
50	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,0,3,6,9,12,15,18,21,24,1,4,7,10,13,16,19,22,2,5,8,11,14,17,20,23
52	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,0,3,6,9,12,15,18,21,24,1,4,7,10,13,16,19,22,25,2,5,8,11,14,17,20,23
54	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,0,3,6,9,12,15,18,21,24,1,4,7,10,13,16,19,22,25,2,5,8,11,14,17,20,23,26
56	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,0,3,6,9,12,15,18,21,24,27,1,4,7,10,13,16,19,22,25,2,5,8,11,14,17,20,23,26

Slider Segment Selection Guidelines for the Diplex Slider

Selecting the number of segments needed for a slider mainly depends on the physical length of the slider. However, special care must be taken when you decide the number of segments for a diplexing slider.

In a diplexing slider design, one sensor is used as two different physical slider segments to increase the physical length of slider. The number of segments that are completely covered by a finger touch must be less than the number of sensors between two segments derived from the same sensor. This ensures the proper working of the diplex slider.

For example, in the case of a 10-segment slider (5 sensors), two slider segments derived from sensor 3 are separated by only two sensors (sensor 4 and 0). In this case, a finger touch must not completely cover more than two sensor segments to ensure the proper working of the slider.

For a 12-segment slider, one finger touch must not cover more than 3 segments. Similarly, for a 18-segment slider, one finger touch must not completely cover more than 4 segments.

Interpolation and Scaling

In applications for sliding sensors and touchpads it is often necessary to determine finger (or other capacitive object) position to more resolution than the native pitch of the individual sensors. The contact area of a finger on a sliding sensor or a touchpad is often larger than any single sensor.

To calculate the interpolated position using a centroid, the array is first scanned to verify that a given sensor location is valid. The requirement is for some number of adjacent sensor signals to be above a noise threshold. When the strongest signal is found, this signal and those contiguous signals larger than the noise threshold are used to compute a centroid. As few as two and as many as (typically) eight sensors are used to calculate the centroid in the form of:

Equation 1

$$N_{Cent} = \frac{n_{i-1}(i-1) + n_i i + n_{i+1}(i+1)}{n_{i-1} + n_i + n_{i+1}}$$

The calculated value is typically fractional. To report the centroid to a specific resolution, for example a range of 0 to 100 for 12 sensors, the centroid value is multiplied by a calculated scalar. It is more efficient to combine the interpolation and scaling operations into a single calculation and report this result directly in the desired scale. This is handled in the high level APIs.

Slider sensor count and resolution are set in the CSD Wizard. A scaling value is calculated by the wizard and stored as fractional values.

The multiplier for the centroid resolution is contained in three bytes with these bit definitions:

Resolution Multiplier MSB								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Multiplier	2^{15}	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}	2^{8}
Resolution Multiplier ISB								
Multiplier	128	64	32	18	16	8	4	2
Resolution Multiplier LSB								
Multiplier	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256

The resolution is found by using this equation:

Resolution = (Number of Sensors – 1) x Multiplier

The centroid is held in a 24-bit unsigned integer and its resolution is a function of the number of sensors and the multiplier.

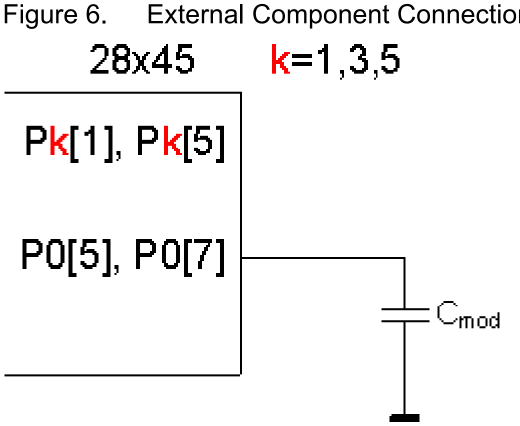
Feedback Components Selection Guidelines

The user module requires an external modulation capacitor C_{mod}. It also supports an optional shielding electrode. This section explains how to select external components.

Modulation Capacitor

The capacitor can be connected to the P0[5], P0[7] port pins and Vss ground. The pins are selected with the user module parameter setting. Do not use pins selected for modulator component connection for any other purposes.

Figure 6. External Component Connections



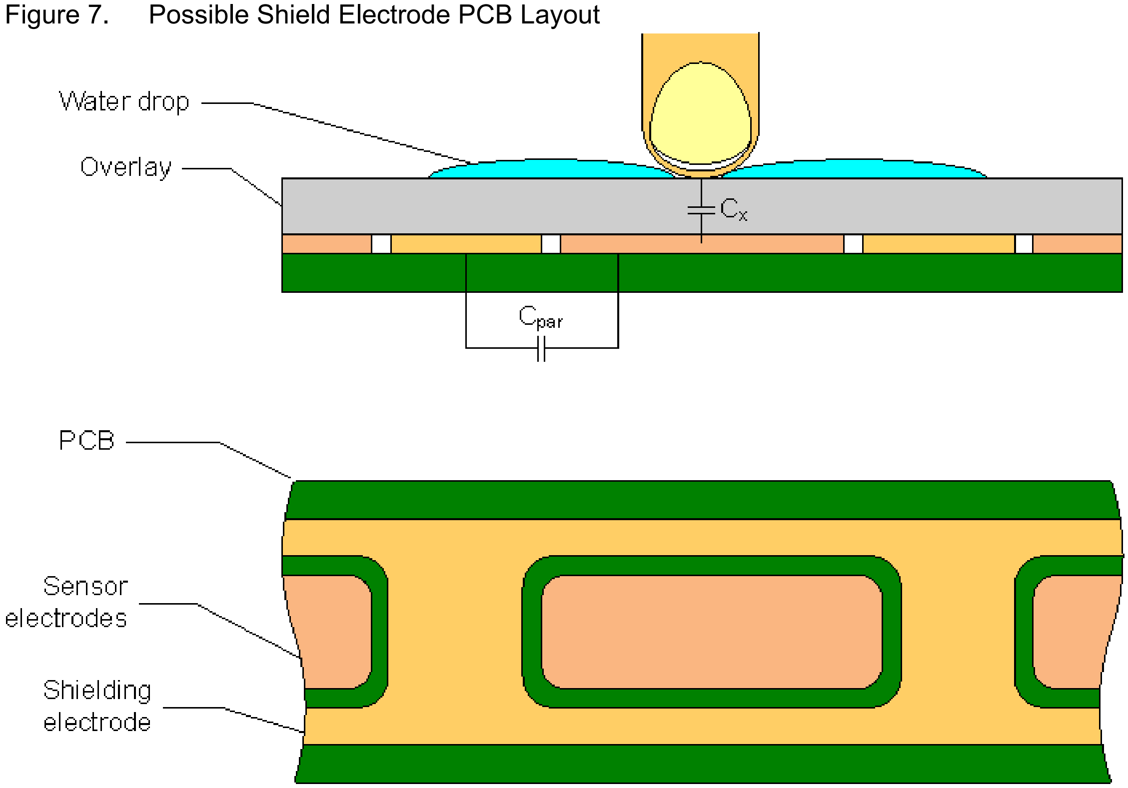
The recommended value for the modulation capacitor is 4.7 – 47 nF. The optimal capacitance can be selected by experiment to get maximum SNR. A value of 5.6 – 10 nF gives good results in the most cases. You can experiment with several capacitor values to get the best SNR after selecting the feedback resistor. A ceramic capacitor should be used. The temperature capacitance coefficient is not important.

Shielding Electrode

Some applications require reliable operation in the presence of water films or droplets. White goods, automotive applications, various industrial applications, and others need capacitive sensors that do not provide false triggering because of water, ice, and humidity changes. In this case a separate shielding electrode can be used. This electrode is located behind or outside the sensing electrode. When water films are located on the device insulation overlay surface, the coupling between the shielding and sensing electrodes is increased. The shielding electrode allows you to reduce the influence of parasitic capacitance, which gives you more dynamic range for processing sense capacitance changes.

In some applications, it is useful to select the shielding electrode signal and its placement relative to the sensing electrode so that increasing the coupling between these electrodes causes the opposite of the touch change of the sensing electrode capacitance measurement. This simplifies the high level software API work. The CSD User Module supports separate output for the shielding electrode.

Figure 7. Possible Shield Electrode PCB Layout



The previous figure illustrates one possible layout configuration for the button's shield electrode. The shield electrode is especially useful for transparent ITO touchpad devices, where it blocks the LCD drive electrode's noise influence and reduces stray capacitance at the same time.

In this example, the button is covered by a shielding electrode plane. As an alternative, the shielding electrode can be located on the opposite PCB layer, including the plane under the button. A hatch pattern is recommended in this case, with a fill ratio of about 30 to 40%. No additional ground plane is required in this case.

When water drops are located between the shielding and sensing electrodes, the C_{par} is increased and modulator current can be reduced. In practical tests, the modulator reference voltage can be increased by the API so that the raw count increase from water drops should be close to zero or be slightly negative. You can achieve this by selecting the appropriate modulator reference.

In this user module, the same signal used for the precharge clock is supplied to the shielding electrode. The shield electrode can be connected to any free row output bus. The drive mode can be set to **Strong Slow** to reduce ground noise and radiated emissions. Also, a slew limiting resistor can be connected between the PSoC device and the shielding electrode. For the row LUT function you should select **A**.

Clock Source

The clock source is used to control the switches on the sensing capacitor. The user module supports four selection options as the clock source for the precharge switches:

- The 16-bit pseudo-random sequence generator (PRS16)
- The 8-bit PRS source
- The 8-bit PRS source with prescaler
- VC2

The required configuration should be selected when you first select the user module. To change this selection later, right click the CSD User Module icon in Interconnect View and select **User Module Selection Options**.

The PRS16 configuration uses the PRS16 module as a clock source. The PRS16 source provides spread-spectrum operation and ensures good immunity from external noise sources. In addition, designs with the spread spectrum clock have lower electromagnetic emission levels. When your application is targeted to pass EMC/EMI tests or must provide reliable operation in harsh environments, the PRS16 configuration is recommended. The following table compares the four configurations:

Configuration	Operation Frequency	Digital Blocks Used	EMC Noise Immunity
PRS16	Spread spectrum, average is $F_{IMO}/4$, peak is $F_{IMO}/2$	3	High. Sensitive points are multiples of the PRS sequence repeat period and PRS fundamental frequency F_{IMO}.
PRS8	Spread spectrum, average is $F_{IMO}/4$, peak is $F_{IMO}/2$	2	Moderate. Sensitive at more points due to the shorter PRS repeat period.
PRS8 with prescaler	Adjustable spread spectrum, average is $F_{IMO}/8 – F_{IMO}/1024$, peak is $F_{IMO}/4 – F_{IMO}/512$	1	Moderate. Sensitive at more points due to the shorter PRS repeat period.
VC2	fixed, $IMO/(VC_1 x VC_2)$	0	Sensitive for EMC signals at operation frequency and its harmonics. Recommended only when no certification EMC/EMI tests are planned.

Comparator Reference Source

The comparator reference source used to form the comparator reference voltage. The reference voltage value determines the sensitivity.

The user module uses different references for first order and second order configurations.

For the first order configuration, the user module supports multiple selections for a reference source:

- Bandgap reference
- Analog modulator, driven by a PRSPWM or a prescaler-PWM signal
- External resistive voltage divider
- External RC filter for a PRSPWM or a prescaler-PWM signal

The following table summarizes the reference selection options:

External Components	UM Selection	When to Use
None	VBG	Readings are proportional to the power supply voltage. Use only when power supply is well regulated
None	ASE11	Recommended for most applications. Try starting testing from this option.
2	AnalogColumn Input Select	Readings are less dependent on power supply. Recommended R1 = 10k; R2 = 3.6k
2	AnalogColumn Input Select	If other reference selections have too much noise.

You may use only the reference selection bandgap (VBG) or analog modulator (ASE11).

For the second order configuration, the modulator reference is formed using a resistive divider located inside a Continuous Time Block. The reference value can be changed with a user module parameter or with an API call.

DC and AC Electrical Characteristics

Table 2. Power Supply Voltage

Parameter	Min	Typical	Max	Unit	Test Conditions and Comments
Value	2.7	5.0	5.25	V	

Table 3. Noise

Parameter[a]	Min	Typical	Max	Unit	Test Conditions (Vdd = 3.3V, SysClk = 24 MHz,CPU Clock = 6 MHz,Baseline >= 70% of Resolution Max Count)
Noise Counts, peak-peak		0.2		% (noise counts)/ (baseline counts)	Resolution = 16
Noise Counts, peak-peak		1		% (noise counts)/ (baseline counts)	Resolution = 14
Noise Counts, peak-peak		10		% (noise counts)/ (baseline counts)	Resolution = 10

a. SNR increases as the Scan Speed slows and the Baseline counts increase.

Table 4. Power Consumption

Supply Voltage	Min	Typ	Max	Unit	Test Conditions and Comments
Active Current		10		mA	Average current during scan, 8 sensors
Standby Current		250		µA	Scanning Speed = Fast, Resolution = 9 100 ms report rate, 8 sensors
		1.6		mA	Scanning Speed = Fast, Resolution = 12 100 ms report rate, 8 sensors
Sleep/Wake Current		10		µA	1s report rate, 1 sensor

Table 5. Power Consumption

Supply Voltage	Min	Typ	Max	Unit	Test Conditions and Comments
Active Current		10		mA	Average current during scan, 8 sensors
Standby Current		250		µA	Scanning Speed = Fast, Resolution = 9 100 ms report rate, 8 sensors
		1.6		mA	Scanning Speed = Fast, Resolution = 12 100 ms report rate, 8 sensors
Sleep/Wake Current		10		µA	1s report rate, 1 sensor

Table 6. 5.0 V PGA DC Electrical Characteristics

Parameter	Typical	Limit	Units	Conditions and Notes
Gain Deviation from Nominal				
G=48.00	3.0	--	%	
G=24.00	2.2	--	%	
G=16.00	1.5	--	%	
G=4.00	0.7	--	%	
G=1.0	0.5	--	%	
Input				
Input Offset Voltage	4.5	--	mV	
Input Voltage Range	--	Vss to Vdd	V	
Leakage[1]	1	--	nA	
Input Capacitance[1]	3	--	pF	
Output Swing	0.05 to Vdd-0.05	--	V	
PSRR	73	--	dB	

Table 7. 5.0 V PGA AC Electrical Characteristics

Parameter	Typical	Limit	Units	Conditions and Notes
Slew Rate(20% to 80%)[2]				
Low Power	0.6	--	V/µs	
Med Power	2.5	--	V/µs	
High Power	9.5	--	V/µs	
Settling Time				
Low Power	13	--	µs	
Med Power	4	--	µs	
High Power	1	--	µs	
Noise[2]				Referred to input
Med Power	110		nV/√Hz	OpAmp bias low except at High Power. Reference input set to AGND
High Power	100		nV/√Hz	

Table 8. 3.3 V PGA DC Electrical Characteristics

Parameter	Typical	Limit	Units	Conditions and Notes
Gain Deviation from Nominal				
G=48.00	4.0	--	%	
G=24.00	2.2	--	%	
G=16.00	1.2	--	%	
G=4.00	0.6	--	%	
G=1.0	0.3	--	%	
Input				
Input Offset Voltage	3.5	--	mV	
Input Voltage Range	--	Vss to Vdd	V	
Leakage[1]	1	--	nA	
Input Capacitance[1]	3	--	pF	
Output Swing	0.05 to Vdd-0.05	--	V	
PSRR	68	--	dB	
Operating Current				
Low Power	130	--	µA	
Med Power	520	--	µA	
High Power	2000	--	µA	

Table 9. 5.0 V ADC Modulator DC and AC Electrical Characteristics

Parameter	Typical	Limit	Units	Conditions and Notes
Input				
Input Voltage Range	---	Vss to Vdd	V	Ref Mux = Vdd/2 ± Vdd/2
Input Capacitance	3	---	pF	Includes I/O pin.
Input Impedance	1/(C*clk)	---	W	
Effective Resolution Decimate by 64 Decimate by 128 Decimate by 256	---	10 12 14	Bits	
Sample Rate Decimate by 64 Decimate by 128 Decimate by 256	---	31,250 15625 7812	sps	Data Clock 8 MHz
DC Accuracy				

Parameter	Typical	Limit	Units	Conditions and Notes
DNL Decimate by 64 Decimate by 128 Decimate by 256	<1 <1 <1 0.6	---	LSB	Source Clock 1.5 MHz
Offset Error	13	---	mV	
Gain Error	2		% FSR	Including Reference Gain Error
Data Clock	---	0.032 to 8.0	MHz	Input to digital blocks and analog column clock

Table 10. 3.3 V ADC Modulator DC and AC Electrical Characteristics

Parameter	Typical	Limit	Units	Conditions and Notes
Input				
Input Voltage Range	---	Vss to Vdd	V	Ref Mux = Vdd/2 ± Vdd/2
Input Capacitance	3	---	pF	Includes I/O pin.
Input Impedance	1/(C*clk)	---	W	
Effective Resolution Decimate by 64 Decimate by 128 Decimate by 256	---	10 12 14	Bits	
Sample Rate Decimate by 64 Decimate by 128 Decimate by 256	---	31,250 15625 7812	sps	Data Clock 8 MHz
DC Accuracy				
DNL Decimate by 64 Decimate by 128 Decimate by 256	<1 <1 0.5	---	LSB	Data Clock 1.5 MHz
Offset Error	13	---	mV	
Gain Error	2		% FSR	Including Reference Gain Error
Data Clock	---	0.032 to 8.0	MHz	Input to digital blocks and analog column clock

Placement

The blocks for the user module are automatically placed when the user module is instantiated, alternate placements are not available. All configurations use ACC and ASC/ ASD or ACE/ASE analog blocks. Different user module configurations use 0-2 digital blocks. User modules (such as AMuxN) that occupy the same analog mux bus may have a conflict with the CSD2X User Module when they are used at the same time. If a simultaneous operation is needed, then the user modules should use the pins that belong to different analog mux buses.

The following table summarizes the digital resources used.

Configuration	Used Digital Blocks
PRS16	Two digital blocks
PRS8	One digital block
PRS8 with prescaler	Two digital blocks
VC2	No digital blocks are used

The unused analog and digital blocks are available for your own purposes. All user module configurations use the hardware decimator.

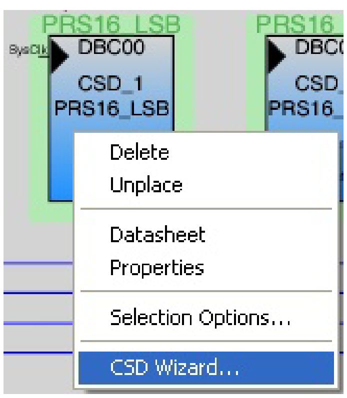
User modules that consume specific pin resources, including the LCD and I2CHW, must be placed before establishing port pin connections for the CSD User Module. The configuration selections are reflected in the Wizard when it is opened.

Avoid P1[0] and P1[1] when placing capacitive sensor connections. These pins are used for programming the part and may have excess routing capacitance affecting sensor sensitivity and noise.

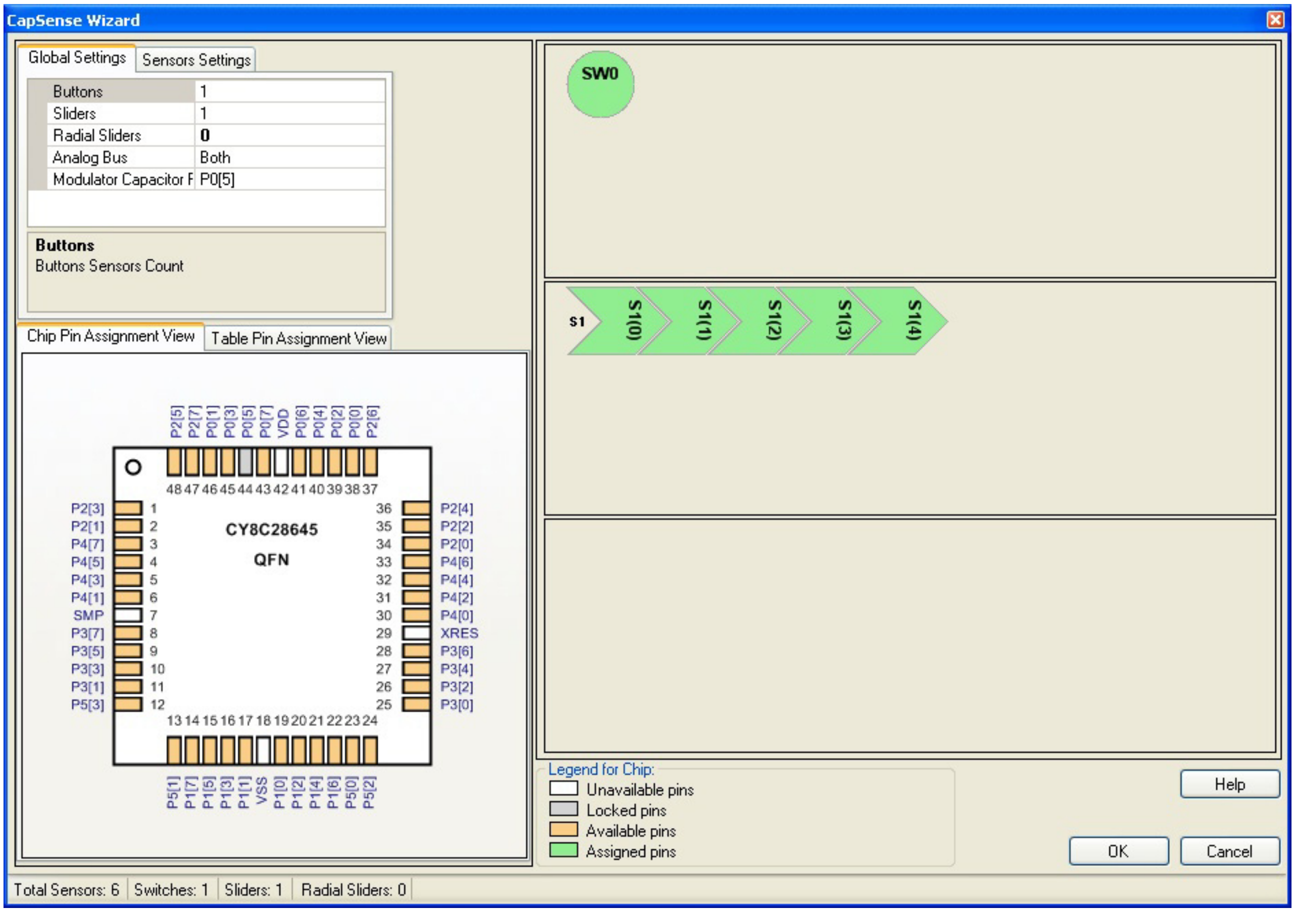
Wizard

The CSD Wizard is used to set up the pinout for your CapSense buttons and sliders. You choose the configuration you want and assign the buttons and segments using a drag and drop interface.

1. To access the Wizard, right click any block of the CSD in the Device Editor Interconnect View, then select the CSD Wizard with a left mouse click.



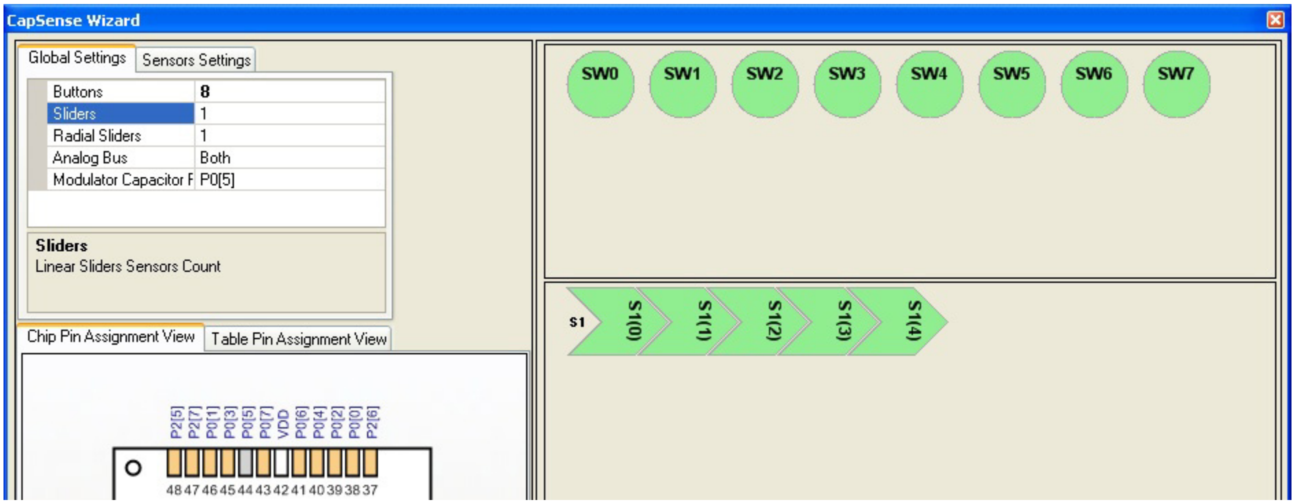
2. The Wizard opens showing the numeric entry boxes for the number of sensors and the number of slider sensors.



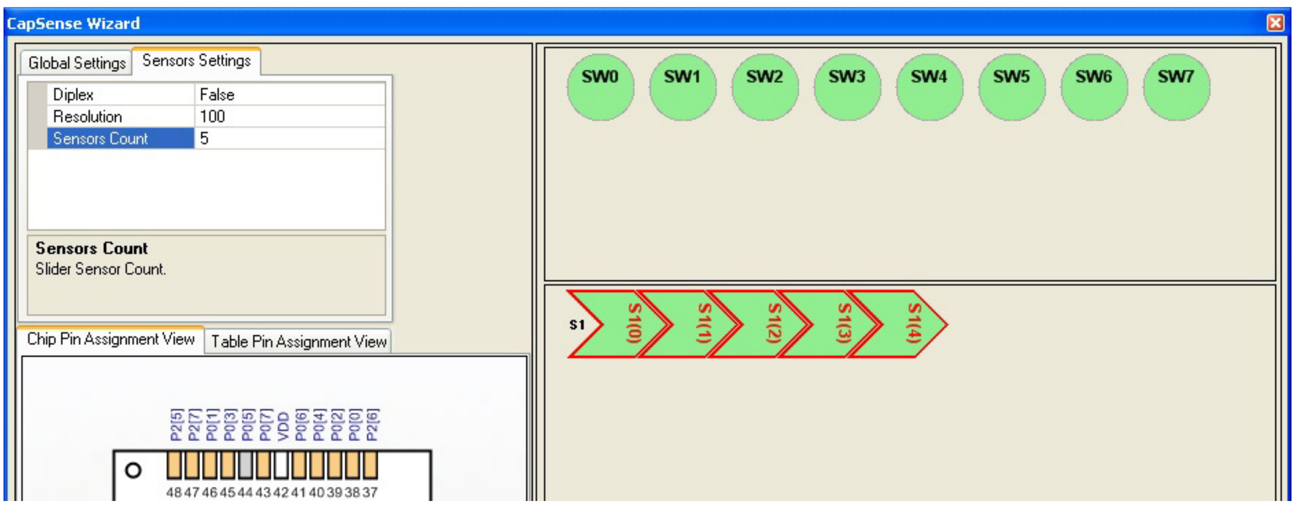
Wizard Pin Legend

- White – The pin cannot be used as a CapSense input.
- Gray – The pin is locked. There are two possible causes for this. The first possibility is that another user module such as the LCD or I^2C has claimed the pin. The second possibility is that the name of the pin has been changed from its default.To return the pin name to its default, in the Pinout view expand the pin, from the **Select** menu, select **Default**. The pin is now available for assignment in the wizard.
- Orange – The pin is available for assignment.
- Green – The pin has been assigned as a CapSense input.

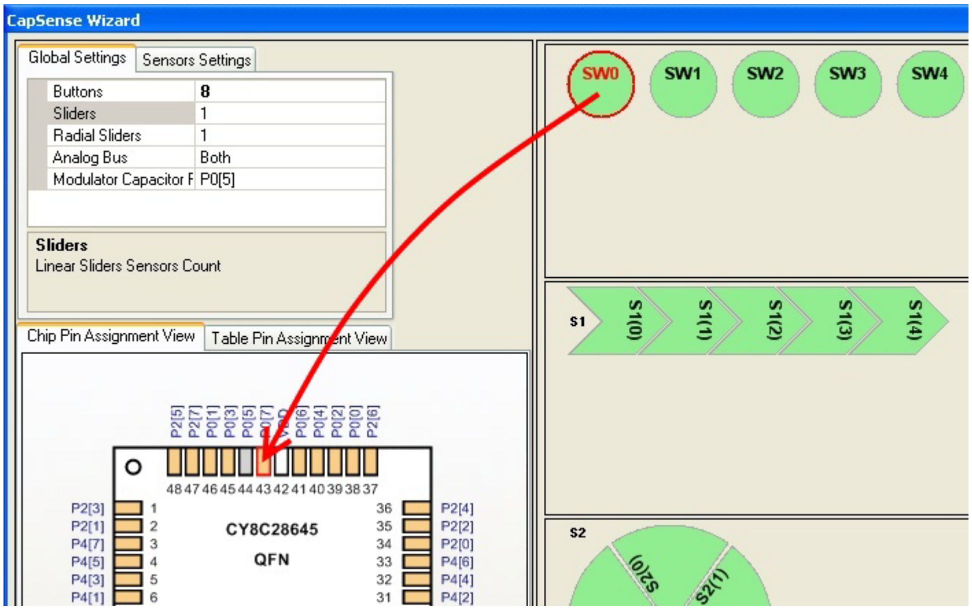
3. Type the number of independent sensors. The number of sensors is limited to the number of pins available.
4. Type the number of sliders.



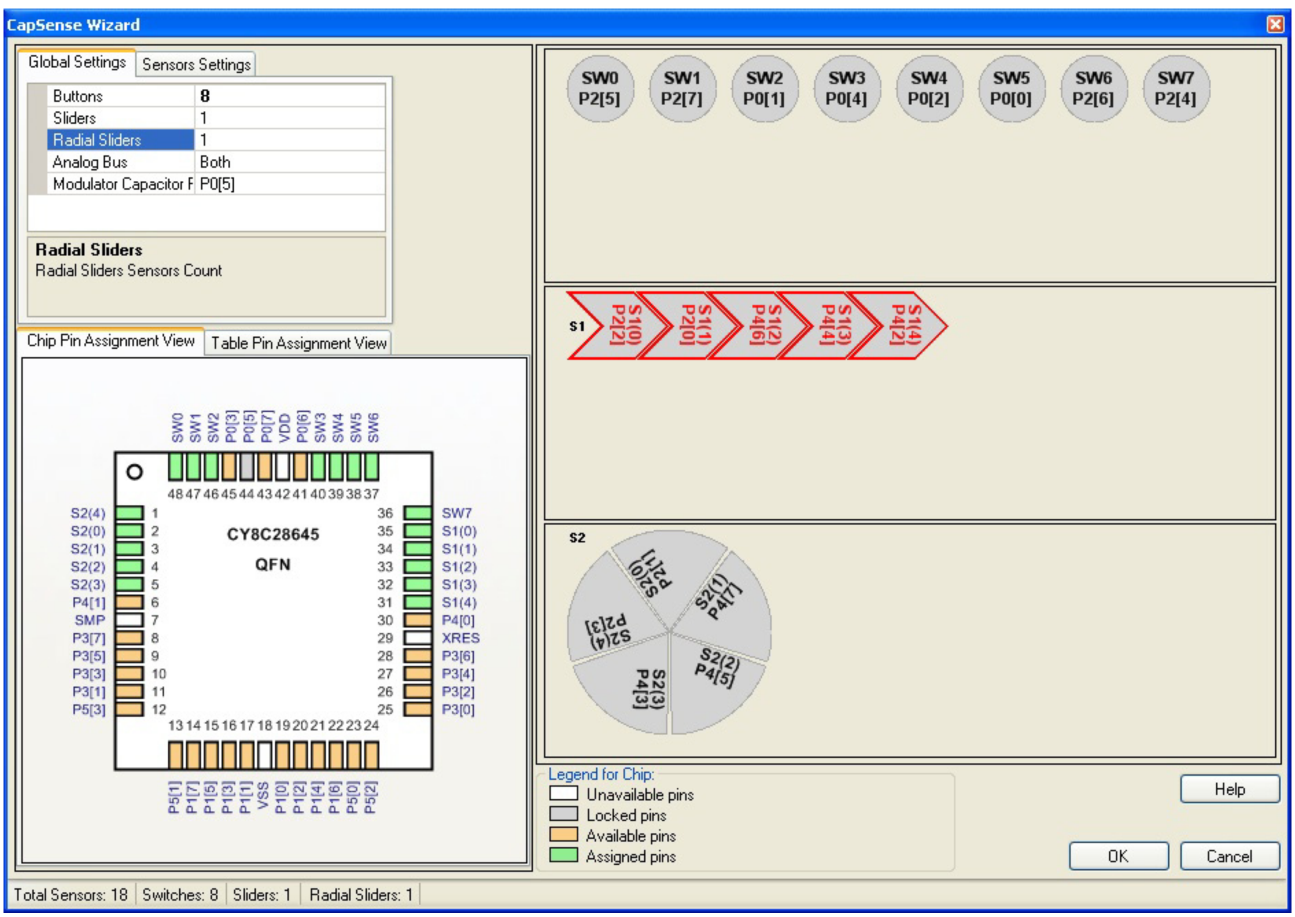
5. Click the slider to enable the Sensor Settings. Select the **Sensor Settings** tab. Type the number of sensor elements in the slider. The practical minimum number of sensors in a slider sensor is five, the maximum is limited by pin count.



6. Type the output resolution. The minimum value is five. The maximum value is (number of pins used for sensors – 1) x 2^8 – 1 or (2 x pins used for sensors – 1) x 2^8 -1 for diplexed sliders.
7. Select Diplex, if desired. This maps the number of pins selected for sensors to twice as many sensor locations on the board. Only the first half of the diplex sensors is shown; the second half is automatically mapped as outlined in the previous section on Diplexing. See the Diplexing section to find Diplexing tables for pin connections.
8. Left click a sensor and drag it onto any available pin. The port pin green after selection and is no longer available. Change sensor assignments by dragging the sensor off of the port pin.



9. Repeat for the remainder of independent sensors.
10. Mapping of individual slider sensors onto physical port pins is the same as for individual sensors.
11. Click **OK** to accept data and return to PSoC Designer.



Sensor placement is now complete. Right click in the Device Editor window and select **Refresh** to update the pin connections.

Set user module parameters and generate application. You can adapt a sample project now, if you wish.

When entering the numerical values in the CSD Wizard, delete the old value first, then enter the new value. The cursor is not shown in the edit box.

If you want change pin assignment, place your cursor on the assigned pin, click the pin, and drag and drop it outside the switches box. The pin is unassigned and you can then reassign it.

Wizard Slider Settings

Diplex

For Sliders only. Allows you to use a single pin to monitor two electrical sensors for resolution enhancement. See the section on diplexing for more information.

Slider Resolution

For sliders and rotary sliders, this value sets the range of values returned by the CSD_wGetCentroidPos API. If any slider sensor is active, the function returns values from zero to the Resolution value set in the CSD Wizard. The CapSense algorithm interpolates the centroid position to this resolution based on readings from adjacent sensors.

Tables Produced by the Wizard

After completing the Wizard, click Generate Application. Based on your entries for sensor count, pin assignment, diplexing, and resolution, a set of tables is generated. The tables are located in CSD_Table.asm.

Sensor Table

The Sensor Table consists of a 2-byte entry for each sensor. The first byte is the port number and the second byte is the bit mask for the bit (not the bit number). There are two tables for left and right channel each. The table includes all independent sensors, then each sensor in order. An example for a table with six sensors is:

```
CSD_Sensor_Table_Right:
_CSD_Sensor_Table_Right:
      dw    0x0140  //  Port 1 Bit 6
      dw    0x0301  //  Port 3 Bit 0
      dw    0x0304  //  Port 3 Bit 2

CSD_Sensor_Table_Left:
_CSD_Sensor_Table_Left:
      dw    0x0308  //  Port 3 Bit 3
      dw    0x0302  //  Port 3 Bit 1
      dw    0x0108  //  Port 1 Bit 3
```

This table is used by CSD_wGetPortPin() routine.

Group Table

The Group Table defines each of the groups of button sensors or sliders. There is one entry for each slider plus one for the free button sensors. The first entry is always the free sensors. Each entry is six bytes. The first byte is the index in the Sensor Table where the group starts. The second byte is how many sensors are in that group. The third byte signifies whether the slider is diplexed or not (4 is diplexed, 0 is not

diplexed). The fourth, fifth, and sixth bytes are the fixed point multiplier that the slider's calculated centroid is multiplied by to achieve the resolution desired in the CSD wizard.

```
CSD_Group_Table:
_CSD_Group_Table:
; Group Table:
;     Origin     Count     Diplex?     DivBtwSw(wholeMSB, wholeLSB, fractByte)
 db    0x0,      0x3,      0x00,       0x00,     0x00,     0x00 ; Buttons
 db    0x3,      0x8,      0x4,        0x0,      0x0,      0x44 ; Slider 1
```

Diplex Table

Diplex table scan order data is produced for a group when it is a slider and is also diplexed. Otherwise a label is created but no data is placed. The table consists of two parts: sensor mapping for each slider, and a reference for each separate slider to its table. A typical example for an eight sensor slider is:

```
DiplexTable_0:
; This group is not a diplexed slider
DiplexTable_1:
db0,1,2,3,4,5,6,7,0,3,6,1,4,7,2,5// 8 switch slider


 CSD_Diplex_Table:
_CSD_Diplex_Table:
db >DiplexTable_0, <DiplexTable_0
db >DiplexTable_1, <DiplexTable_1
```

Parameters and Resources

PGA Gain

Parameter available in Second Order Modulator configurations only. Sets the PGA gain for the ADC. Gain ranges are 1 to 48.00, using PSoC Designer or the CSD_SetGain routine provided in the API. Gain settings less than 1 are not supported. This parameter is only available with the second order sigma delta modulator. The default value is 4.00.

Finger Threshold

This threshold is used to determine the state of each button sensor. If any sensor is active, the bIsAnySensorActive() function returns a 1. If all sensors are off, the bIsAnySensorActive() function returns a 0.

The finger detection threshold values apply to all sensors and sliders. For individual sensors (not contained in a slider group), these thresholds are variable and provided in the baBtnFThreshold[] array. The SetDefaultFingerThresholds() function may be used to set the thresholds to the default value set in the Device Editor. To adjust the sensitivity for individual sensors, change the baBtnFThreshold[] value for each sensor. (The size of this byte array is equal to the count of implemented individual sensors.)

Possible values range from 5 to 255; the default value is 40.

Noise Threshold

For individual sensors, count values above this threshold do not update the baseline. For slider sensors, count values below this threshold are not counted in the calculation of the centroid. Possible values are 5 to 255; the default value is 20.

BaselineUpdate Threshold

When the new raw count value is above the current baseline and the difference is below the noise threshold (with the Sensors Autoreset parameter set to Disabled), the difference between the current baseline and the raw count is accumulated into what could be thought of as a bucket. When the bucket fills, the baseline is incremented by some value and the bucket is emptied. This parameter sets the threshold that the bucket must reach for the baseline to increment. Possible values are 0 to 255. Larger parameter values yield slower baseline update speeds. If you need more frequent baseline updates, decrease this parameter. The default setting is 200.

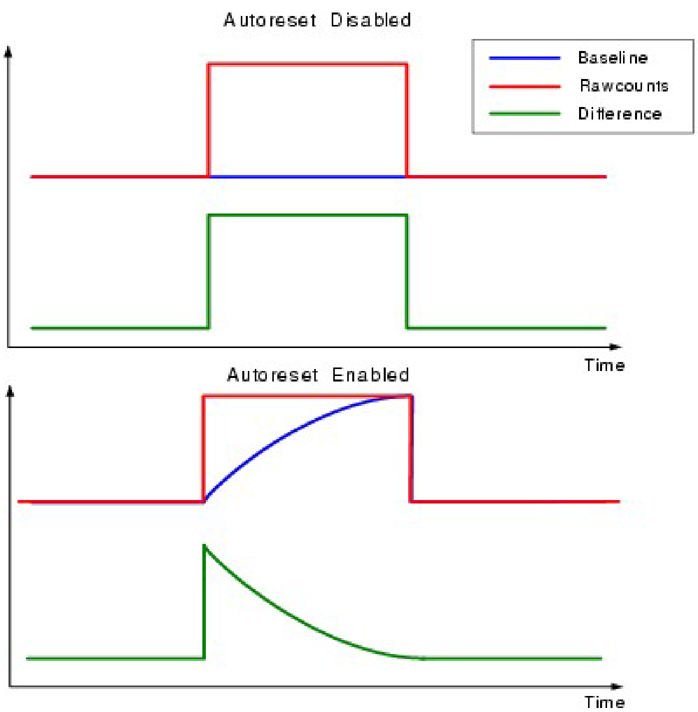
Sensors Autoreset

This parameter determines whether the baseline is updated at all times or only when the signal difference is below the Noise Threshold. When set to **Enabled** the baseline is updated constantly. This setting limits the maximum time duration of the sensor (typical values are 5 – 10s), but it prevents the sensors from permanently turning on when the raw count suddenly rises without anything touching the sensor. This sudden rise can be caused by a large power supply voltage fluctuation, a high energy RF noise source, or a very quick temperature change.

When the parameter is set to **Disabled** the baseline is updated only when raw count and baseline difference is below the Noise Threshold parameter. You should leave this parameter Disabled unless you have problems with sensors permanently turning on when the raw count suddenly rises without anything touching the sensor. The default setting is Disabled.

The following figure illustrates this parameter’s influence on the baseline update.

Figure 8. Sensor Autoreset Parameter



Hysteresis

The Hysteresis parameter adds or subtracts from the finger threshold depending on whether the sensor is currently active or inactive. If the sensor is inactive, the difference count must overcome the finger threshold plus hysteresis. If the sensor is active, the difference count must go below the finger threshold minus hysteresis. It is used to add debouncing and stickiness to the finger detection algo-

rithm. The threshold with hysteresis is evaluated when bIsSensorActive() or bIsAnySensorActive() is called. The sensor state can be monitored with the return value of bIsSensorActive() or the baSnsOnMask[] array. Possible values are 0 to 255, but must be lower than the Finger Threshold parameter setting.

Proper selection of high level decision logic parameters allows you to effectively compensate for environmental factors (temperature, humidity changes, and so on), suppress noisy signals (ESD, power supply spikes), and provide reliable touch detection under various conditions. The default setting is 10.

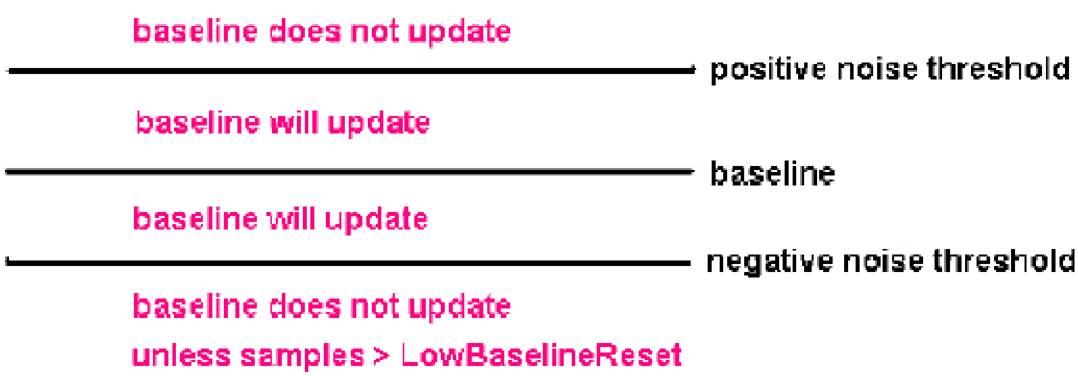
Debounce

The Debounce parameter adds a debounce counter to the sensor active transition. For the sensor to transition from inactive to active the difference count value must stay above the finger threshold plus hysteresis for the number of samples specified. The debounce counter is incremented by the bIsSensorActive or bIsAnySensorActive API functions.

Possible values are 1 to 255. A setting of 1 provides no debouncing. The default setting is 3.

NegativeNoiseThreshold

The NegativeNoiseThreshold parameter adds a negative difference count threshold. If the current raw count is below the baseline and the difference between them is greater than this threshold, the baseline is not updated. However, if the current raw count stays in the low state (difference greater than threshold) for the number of samples specified by the LowBaselineReset parameter, the baseline is reset. The default setting is 20.



LowBaselineReset

The LowBaselineReset parameter works together with the NegativeNoiseThreshold parameter. If the sample count values are below the baseline minus the NegativeNoiseTreshold for the specified number of samples, the baseline is set to the new raw count value. It essentially counts the number of abnormally low samples required to reset the baseline. It is generally used to correct for the finger-on-at-startup condition. The default setting is 50.

Scanning Speed

This parameter affects the sensors' scanning speed. The available selections are **Fast**, **Normal**, and **Slow**. The default setting is Normal. Slower scanning speeds provide these advantages:

- Improved SNR
- Better immunity to power supply and temperature changes
- Less demand for system interrupt latency; you can handle longer interrupts

The scanning speed and resolution affect the VC1 divider in the following ways:

Scanning Speed	VC1	
	Second Order Delta-Sigma Modulator ACC+ASD Blocks	First Order Delta-Sigma Modulator ACE+ASE Blocks
Fast	3	2
Normal	4	4
Slow	8	8

Resolution (First Order Modulator)

This parameter determines the scanning resolution in bits. Possible selections are 8, 10, and 12 bits. The maximum raw count for scanning resolution for N bits is 2^N-1.

Increasing the resolution improves sensitivity and the SNR of touch detection. The default setting is 12.

Table 11. Scanning Time in µs vs. Scanning Speed and Resolution for 24 MHz IMO Operation

Resolution, bits	Scanning speed		
	Fast	Normal	Slow
8	85	130	260
10	130	260	510
12	260	510	1020

Note The scanning time was measured as the time interval between 2 sensor scans. This time includes the sensor setup time, modulator stabilization delay, sample conversion interval and data preprocessing time.

Resolution (Second Order Modulator)

This parameter determines the scanning resolution in bits. Possible selections are 10, 12, and 14 bits. If you need higher resolution with these configurations, use oversampling and average several samples. The maximum raw count for scanning resolution for N bits is 2^N-1. Increasing the resolution improves sensitivity and the SNR of touch detection. The default setting is 12.

Table 12. Scanning Time in µs vs. Scanning Speed and Resolution for 24 MHz IMO Operation

Resolution, bits	Scanning speed		
	Fast	Normal	Slow
10	124	136	296
12	220	220	548
14	428	552	1060

Note The scanning time was measured as the time interval between 2 sensor scans. This time includes the sensor setup time, modulator stabilization delay, sample conversion interval and data preprocessing time.

Analog Bus

This parameter defines one or two Analog MUX Buses are used. If AnalogMUXbus_0 selected then only those sensors will be scanned that are connected to the odd pins (with the exception of P0[7]). The default setting is to use both analog buses.

Modulator Capacitor Pin

This parameter sets the pin to connect the external modulator capacitor (C_{mod}). Choose from the available pins. The default setting is P0[5].

Compensation IDAC

Parameter available in IDAC configurations only. 0-255 (Default: 0). 0 disables the compensation IDAC.

IDAC

Parameter available in IDAC configurations only. The capacitance measurement range depends on this parameter. Higher value corresponds to wider range. Adjust the IDAC value to get raw counts about 50-70% of full range. This parameter can be changed at run time using the CSD_SetIDACValue API function.

Possible values are 1 to 255; the default setting is 200.

IDAC Range

Parameter available in IDAC configurations only. Sets the IDAC current multiplier. The result of the setting is different for dual channel configurations. The results in dual channel configurations are shown:

Setting	Effect
1X	Maximum IDAC current is 19.92 µA
4X	Maximum IDAC current is 91.03 µA
16X	Maximum IDAC current is 318.75 µA
32X	Maximum IDAC current is 637.50 µA

Connect sensors that have large capacitance to the left channel in two channel configurations. The default setting is x32.

Prescaler Period

Parameter available in the Prescaler + PRS8 configurations only. This parameter sets the prescaler period register and determines the precharge switch output frequency. This parameter is available for configuration with prescaler only. The prescaler period values can range from 1 to 255.

The recommended values are 2n – 1 to obtain the maximum signal to noise ratio (SNR).

- 1
- 3
- 7

- 15
- 31
- 63
- 127
- 255

Other values can result in more noise, especially at low resolution and high scan speed. The default setting is 7.

Shield Electrode Out

This parameter is not available when the Precharge Source Type Selection is VC2. The shielding electrode signal source can be selected from one of the free digital row buses (Row_0_Output_0 to Row_0_Output_3). The chosen route has signal to any of three pins. Set the selected Row LUT Function to A. The default setting is None.

PRS Polynomial

This parameter is not available when the Precharge Source Type Selection is VC2. This parameter sets the PRS polynomial in the PRS-based configurations. There are two selection options:

- Short – The short polynomial setting yields better SNR, but due to the shorter repeat period, the end device can be more susceptible to external noise sources.
- Long – The long polynomial setting yields worse SNR, but the device is more robust against noise signals.

The default setting is Short.

Auto Calibration

Parameter available in IDAC configurations only. Enable or disable auto calibration API functions. The default setting is Disabled.

Autocalibration automatically selects possible IDAC values to get raw counts in half of the resolution range. This reduces the overall sensitivity of the CapSense algorithm, but it allows you to quickly get raw counts in a readable range when you begin the tuning process. The autocalibration consumes ROM and RAM resources and increases the start time. If the raw count value after calibration is less than half of the resolution range then you should increase the IDAC range or reduce the precharge frequency. Autocalibration works to improve marginally functional configurations.

Reference

Parameter available in First Order Modulator configurations only. This parameter sets the comparator reference value. The reference comes from the internal resistive voltage divider. The default setting is ASE10.

Ref Value

Parameter available in First Order Modulator configurations only. This parameter sets the comparator reference value. The reference comes from the internal resistive voltage divider. Zero corresponds to the minimum reference (1/4 Vdd). Eight corresponds to the maximum value (3/4 Vdd). Reference voltage is increased in linearly as the parameter increases. When reference increases the sensitivity decreases, but the influence on the shielding electrode is increased.

If the design has sensors with noticeable capacitance differences (for example, sensors with different sized squares), you can balance raw counts by setting a higher reference for the sensors with larger capacitance using an API function.

Valid values are 0-15 when Vref = ASExx; the default setting is 4.

Feedback Resistor Pin

Parameter available in External Bleed Resistor (Rb) configurations only. This parameter sets the pin to connect the external feedback resistor (R_b). Choose from the available pins. Using P1[1] for the feedback resistor connection is not recommended due to possible problems with ISSP programming.

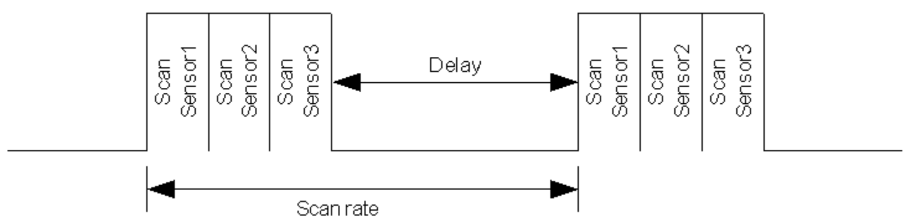
Tip: If some of these pins are used for other purposes (for example, allocated for sensor connection), they are not available for selection in the user module parameter list.

This parameter depends on comparator placement. The default P1[1].

Sensor Scan Rate Selection Guidelines

Scan rate is defined as the rate at which sensors are scanned. An example of a 3-button design is shown in the following figure. All sensors in the design are scanned sequentially and there is a delay before the next sensor scan is initiated.

Figure 9. Typical Sensor Scan



To ensure proper working of the baseline, it is recommended to maintain a scan rate of 15 mS or more in a design. This indicates that a design with less number of sensors needs to add a delay to make the sensor scan rate equal to or greater than 15 ms. A design with more number of sensors may not need any delay as scanning all sensors itself may consume 15 mS. A good design may put the CapSense controller in sleep mode, instead of firmware delay routine, to create low power design.

Application Programming Interface

The Application Programming Interface (API) functions are provided as part of the user module to allow you to deal with the module at a higher level. This section specifies the interface to each function together with related constants provided by the include files.

Only one instance of this user module can be placed in project and this also applies to loadable configurations. Each time a user module is placed, it is assigned an instance name. By default, PSoC Designer assigns the CSD_1 to the first instance of this user module in a given project. It can be changed to any unique value that follows the syntactic rules for identifiers. The assigned instance name becomes the prefix of every global function name, variable and constant symbol. In the following descriptions the instance name has been shortened to CSD for simplicity.

Note ** In this, as in all user module APIs, the values of the A and X register may be altered by calling an API function. It is the responsibility of the calling function to preserve the values of A and X before the call if those values are required after the call. This "registers are volatile" policy was selected for efficiency reasons and has been in force since version 1.0 of PSoC Designer. The C compiler automatically takes care of this requirement. Assembly language programmers must also ensure their code observes the policy. Though some user module API functions may leave A and X unchanged, there is no guarantee they may do so in the future.

For Large Memory Model devices, it is also the caller's responsibility to preserve any value in the CUR_PP, IDX_PP, MVR_PP, and MVW_PP registers. Even though some of these registers may not be modified now, there is no guarantee that will remain the case in future releases.

Entry Points are supplied to initialize the CSD, start it sampling, and stop the CSD. In all cases the instance name of the module replaces the CSD prefix shown in the following entry points. Failure to use the correct instance name is a common cause of syntax errors.

API functions use different global arrays. You should not alter these arrays manually. You can inspect these values for debugging purposes, however. For example, you can use a charting tool to display the contents of the arrays. There several global arrays:

- CSD_waSnsBaseline[]
- CSD_waSnsResult[]
- CSD_waSnsDiff[]
- CSD_baSnsOnMask[]

CSD_waSnsBaseline[] – This is an integer array that contains the baseline data of each sensor. The array size is equal to the sensor count. The CSD_waSnsBaseline[] array is updated by these functions:

- CSD_UpdateAllBaselines();
- CSD_UpdateSensorBaseline();
- CSD_InitializeBaselines().

CSD_waSnsResult[] – This is an integer array that contains the raw data of each sensor. The array size is equal to the sensor count. The CSD_waSnsResult[] data is updated by these functions:

- CSD_ScanSensor();
- CSD_ScanAllSensors().

CSD_waSnsDiff [] – This is an integer array that contains the difference between the raw data and the baseline data of each sensor. The array size is equal to the sensor count.

CSD_baSnsOnMask[] – This is a byte array that holds the sensor on or off state (for buttons or sliders). CSD_baSnsOnMask[0] contains the masked bits for sensors 0 through 7 (sensor 0 is bit 0, sensor 1 is bit 1). CSD_baSnsOnMask[1] contains the masked bits for sensors 8 through 15 (if they are needed), and so on. This byte array contains as many elements as are necessary to contain all the placed sensors. The value of a bit is 1 if the button is on and 0 if the button is off. The CSD_baSnsOnMask[] data is updated by CSD_bIsSensorActive(BYTE bSensor) function or CSD_bIsAnySensorActive() routines.

Table 13. API Vs User Module Configuration

	IBCNT	IBPRS	IBPRS8	IBVC2	IECNT	IEPRS	IEPRS8	IEVC2	RBCNT	RBPRS	RBPRS8	RBVC2	RECNT	REPRS	REPRS8	REVC2
CSD_Start()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_Stop()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_ScanSensor()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_ScanAllSensors()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

	IBCNT	IBPRS	IBPRS8	IBVC2	IECNT	IEPRS	IEPRS8	IEVC2	RBCNT	RBPRS	RBPRS8	RBVC2	RECNT	REPRS	REPRS8	REVC2
CSD_ClearSensors()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_wReadSensor()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_wGetPortPin()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_EnableSensor()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_DisableSensor()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_SetScanMode()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_SetPGAGain()	*	*	*	*					*	*	*	*				
CSD_Calibrate()	*	*	*	*	*	*	*	*								
CSD_SetIdacValue()	*	*	*	*	*	*	*	*								
CSD_SetRefValue()					*	*	*						*	*	*	
CSD_UpdateSensorBaseline()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_bIsSensorActive()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_bIsAnySensorActive()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_SetDefaultFingerThresholds()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_InitializeSensorBaseline()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_InitializeBaselines()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_UpdateAllBaselines()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_wGetCentroidPos()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_wGetRadialPos()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
CSD_wGetRadialInc()	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

CSD_Start

Description:

Initializes registers and starts the user module. This function should be called before calling any other user module functions.

C Prototype:

```
void  CSD_Start()
```

Assembly:

```
lcall  CSD_Start
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_Stop

Description:

Stops the sensor scanner, disables internal interrupts, and calls CSD_ClearSensors() to reset all sensors to an inactive state.

C Prototype:

```
void  CSD_Stop()
```

Assembly:

```
lcall  CSD_Stop
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_Resume

Description:

Resumes the user module operation after CSD_Stop call.

C Prototype:

```
void  CSD_Resume()
```

Assembly:

```
lcall  CSD_Resume
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_SetPGAGain

Description:

Sets the gain for the PGA block, overwriting value set in the Device Editor.

C Prototype:

```
void  CSD_SetPGAGain(byte bGainSetting)
```

Assembly:

```
mov   A, bGainSetting
lcall  CSD_SetPGAGain
```

Parameters:

bGainSetting: Symbolic names provided in C and assembly include files, and their associated values, are given in the following table. PGA gain can be set from 1 to 48, settings below 1 are not supported. This function is common for ADC and CSD modes. In the first case it sets a ADC preamplifier gain, in the second it sets a modulator gain.

Symbolic Name	Value
PGA_G48_0	0x0C
PGA_G24_0	0x1C
PGA_G16_0	0x08
PGA_G8_00	0x18
PGA_G5_33	0x28
PGA_G4_00	0x38
PGA_G3_20	0x48
PGA_G2_67	0x58
PGA_G2_27	0x68
PGA_G2_00	0x78
PGA_G1_78	0x88
PGA_G1_60	0x98
PGA_G1_46	0xA8
PGA_G1_33	0xB8
PGA_G1_23	0xC8
PGA_G1_14	0xD8
PGA_G1_06	0xE8
PGA_G1_00	0xF8

For second Order configuration only.

Return Value:

None

Side Effects:

**

CSD_ScanSensor

Description:

Scans the selected sensor. Each sensor has a unique number within the sensor array. This number is assigned by the CSD Wizard in sequence. Sw0 is sensor 0, Sw1 is sensor 1, and so on. For double channel configurations sensor number is value from 0 to Maximum Channel SenSor Number. 0xFF means skip this channel scanning.

In Singe Channel Configuration:

C Prototype:

```
void CSD_ScanSensor(BYTE bSensor)
```

Assembly:

```
mov A,  bSensor
lcall CSD_ScanSensor
```

Parameters:

A => Sensor Number

Return Value:

None

Side Effects

**

In Double Channel Configuration:

C Prototype:

```
void CSD_ScanSensor(BYTE bSensorLeft, byte bSensorRight)
```

Assembly:

```
mov A,  bSensorLeft
mov X,  bSensorRight
lcall CSD_ScanSensor
```

Parameters:

A => Sensor Number Left

X => Sensor Number Right

Return Value:

None

Side Effects

**

CSD_ScanAllSensors

Description:

Scans all of the configured sensors by calling CSD_ScanSensor() for each sensor index.

C Prototype:

```
void CSD_ScanAllSensors()
```

Assembly:

```
lcall CSD_ScanAllSensors
```

Parameters:

None

Return Value:

None

Side Effects

**

CSD_UpdateSensorBaseline

Description:

The historical count value, calculated independently for each sensor, is called the sensor's baseline. This baseline is updated using the Bucket Method.

The Bucket Method uses the following algorithm.

1.Each time CSD_UpdateSensorBaseline() is called, a difference count is calculated by subtracting the previous baseline from the raw count value. This difference is stored in the CSD_waSnsDiff[] array and is provided to you.

2.If Sensors Autoreset is disabled, each time CSD_UpdateSensorBaseline() is called the difference count is compared to the noise threshold. If the difference is below the noise threshold, it is accumulated into a virtual bucket. If the difference is above the noise threshold, the bucket is not updated. If Sensors Autoreset is enabled, the difference is accumulated into a virtual bucket regardless of the noise threshold parameter.

3.Once the accumulated difference counts in the virtual bucket has reached the BaselineUpdateThreshold, the baseline is incremented by one and the bucket is reset to 0.

4.If the difference count is below the noise threshold, the value held in the waSnsDiff[] array is reset to 0. Therefore, this array does not contain elements with values greater than 0 but below the NoiseThreshold.

C Prototype:

```
void CSD_UpdateSensorBaseline(BYTE bSensor)
```

Assembly:

```
mov   A,   bSensor
lcall  CSD_UpdateSensorBaseline
```

Parameter:

A => Sensor Number

Return Value:

None

Side Effects:

**

CSD_UpdateAllBaselines

Description:

Uses the CSD_bUpdateSensorBaseline() function to update the baselines for all sensors

C Prototype:

```
void  CSD_UpdateAllBaselines()
```

Assembly:

```
lcall CSD_UpdateAllBaselines
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_bIsSensorActive

Description:

Checks the difference count array for the given sensor compared to its finger threshold. Hysteresis is taken into account. The Hysteresis value is added or subtracted from the finger threshold based on whether the sensor is currently on. If it is active, the threshold is lowered. If it is inactive, the threshold is raised. This function also updates the sensor's bit in the CSD_baSnsOnMask[] array.

C Prototype:

```
BYTE  CSD_bIsSensorActive(BYTE bSensor)
```

Assembly:

```
mov  A,  bSensor
lcall CSD_bIsSensorActive
```

Parameters:

bSensor A => Sensor Number

Return Value:

Return value of 1 if active, 0 if not active

A => 1 – Selected sensor is active, 0 – Selected sensor is not active.

Side Effects:

**

CSD_bIsAnySensorActive

Description:

Checks the difference count array for all sensors compared to their finger threshold. Calls CSD_bIsSensorActive() for each sensor so the CSD_baSnsOnMask[] array is up to date after calling this function.

C Prototype:

```
BYTE  CSD_bIsAnySensorActive()
```

Assembly:

```
lcall CSD_bIsAnySensorActive
```

Parameters:

None

Return Value:

Return value of 1 if active, 0 if not active

A => 1 – One or more sensors are active, 0 – No sensors are active.

Side Effects:

**

CSD_wGetCentroidPos

Description:

Checks a difference array for a centroid. If one exists, the offset and length are stored in temporary variables and the centroid position is calculated to the resolution specified in the CSD Wizard. This function is available only if slider is defined by the CSD Wizard.

C Prototype:

```
WORD  CSD_wGetCentroidPos(BYTE bSnsGroup)
```

Assembly:

```
mov  A,  bSnsGroup
lcall CSD_wGetCentroidPos
```

Parameters:

bSnsGroup A => Group Number

This parameter is a reference to a specific group of sensors used as a slider. Group 0 is for buttons. Sliders are contained in group 1 and higher.

Return Value:

Position value of the slider, LSB in A and MSB in X.

Side Effects:

This routine modifies the difference counts by subtracting the noise threshold value. The routine should be called only once after each scan to avoid getting negative difference values. If your application monitors difference count signals, call this routine after difference count data transmission.

If any slider sensor is active, the function returns values from zero to the Resolution value set in the CSD Wizard. If no sensors are active, the function returns –1 (FFFFh). If an error occurs during execution of the centroid/diplexing algorithm, the function returns –1 (FFFFh). You can use the CSD_bIsSensorActive() routine to determine which slider segments are touched, if required.

Note If noise counts on the slider segments are greater than the noise threshold, this subroutine may generate a false centroid result. The noise threshold should be set carefully (high enough above the noise level) so that noise does not generate a false centroid.

CSD_wGetRadialPos

Description:

Checks a difference array for a centroid. If one exists, the centroid position is calculated to the resolution specified in the CSD Wizard. This function is available only for radial slider that is defined by the CSD Wizard.

C Prototype:

```
WORD  CSD_wGetRadialPos(BYTE bSnsGroup)
```

Assembly:

```
mov  A,  bSnsGroup
call CSD_wGetRadialPos
```

Parameters:

bSnsGroup A => Group Number

This parameter is a number of radial slider you are working with. You can get its number through CSD User Module wizard on the left hand of radial slider representation (for example, s2, the radial slider number is 2).

Return Value:

Position value of the radial slider, LSB in A and MSB in X.

Side Effects:

The routine should be called only once after each scan to avoid getting negative difference values and baseline update. If your application monitors difference count signals, call this routine after difference count data transmission.

If any slider sensor is active, the function returns values from zero to the Resolution value set in the CSD Wizard. If no sensors are active, the function returns -1 (FFFFh).

Note If noise counts on the slider segments are greater than the noise threshold, this subroutine may generate a false centroid result. The noise threshold should be set carefully (high enough above the noise level) so that noise does not generate a false centroid.

CSD_wGetRadialInc

Description:

Returns actual finger shift, the difference between current and previous finger positions. This function works in pair with CSD_wGetRadialPos() and takes data generated by the latter (data is saved in internal variables).

C Prototype:

```
WORD  CSD_wGetRadialInc(BYTE bSnsGroup)
```

Assembly:

```
mov  A,  bSnsGroup
call CSD_wGetRadialInc
```

Parameters:

bSnsGroup A => Group Number

This parameter is a number of radial slider you are working with. You can get its number through CSD User Module wizard on the left hand of radial slider representation (for example, s2, the radial slider number is 2).

Return Value:

Finger shift value, positive if clockwise and negative if anti-clockwise, LSB in A and MSB in X.

Finger shift value is the difference between current and previous finger positions. If there was no touch during previous scan (the last but one time CSD_wGetRadialPos() returned -1 (FFFFh)) or there is no touch at the moment (this time CSD_wGetRadialPos() returned -1 (FFFFh))

Side Effects:

The routine should be called only after CSD_wGetRadialPos() API. Because it uses internal data CSD_waSliderPrevPos and CSD_waSliderCurrPos that are set by the CSD_wGetRadialPos().

CSD_InitializeSensorBaseline

Description:

Loads the CSD_waSnsBaseline[bSensor] array element with an initial value by scanning the selected sensor. The raw count value is copied in to the baseline array element for the selected sensor. This function can be used for resetting the baseline of an individual sensor.

C Prototype:

```
void CSD_InitializeSensorBaseline(BYTE bSensor)
```

Assembly:

```
mov A, bSensor
lcall CSD_InitializeSensorBaseline
```

Parameters:

A => Sensor Number

Return Value:

None

Side Effects:

**

CSD_InitializeBaselines

Description:

Loads the CSD_waSnsBaseline[] array with initial values by scanning each sensor. The raw count values are copied in to baseline array for each sensor.

C Prototype:

```
void CSD_InitializeBaselines()
```

Assembly:

```
lcall CSD_InitializeBaselines
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_SetDefaultFingerThresholds

Description:

Loads the CSD_baBtnFThreshold[] array with the FingerThreshold parameter value. This function must be called before scanning if the CSD_baBtnFThreshold[] array is not manually loaded with custom values.

C Prototype:

```
void CSD_SetDefaultFingerThresholds()
```

Assembly:

```
lcall CSD_SetDefaultFingerThresholds
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_SetIDACValue

Description:

This function overwrites the user module parameter settings for the iDAC Value. Use it if some sensors need to be scanned with a different iDAC setting. This function can be used in conjunction with CSD_ScanSensor(). This function is not available in Rb configurations.

C Prototype:

```
void CSD_SetIdacValue(BYTE bCompensationIdacValue, BYTE bIdacValue)
```

Assembly:

```
mov A, bCompensationIdacValuemov X, bIdacValue
lcall    CSD_SetIDACValue
```

Parameters:

bCompensationIdacValue - Sets the Compensation IDAC value. Accepted values are 1..255.

bIdacValue - Sets the iDAC value. Accepted values are 1.. 255.

Return Value:

None

Side Effects:

**

CSD_SetScanMode

Description:

Sets scanning speed and resolution. This function can be called at runtime to change the scanning speed and resolution. The function overwrites the user module parameter settings. This function is effective when some sensors need to be scanned with different scanning speed and resolution, for example, regular buttons and a proximity detector. The regular buttons can be scanned with 9-bit resolution and 300 µs scan time. The proximity detector can be scanned less often with 16-bit resolution and scanning time of more than 12 ms for long range detection. This function can be used in conjunction with CSD_ScanSensor() function.

C Prototype:

```
void CSD_SetScanMode(BYTE bSpeed, BYTE bResolution)
```

Assembly:

```
mov      A, bSpeed
mov      X, bResolution
lcall     CSD_SetScanMode
```

Parameters:

bSpeed: Scanning Speed

The following constants are given for the bSpeed parameter:

Constant	Value
CSD_FAST_SPEED	0x01
CSD_NORMAL_SPEED	0x02
CSD_SLOW_SPEED	0x03

bResolution: Scanning Resolution. Set this value to the required number of bits of resolution. The value range depends on the user module configuration.

The following possible constants are given for the bResolution parameter for First Order Modulator:

Constant	Value
CSD_8_BIT_RESOLUTION	8
CSD_10_BIT_RESOLUTION	10
CSD_12_BIT_RESOLUTION	12

The following possible constants are given for the bResolution parameter for Second Order Modulator:

Constant	Value
CSD_10_BIT_RESOLUTION	10
CSD_12_BIT_RESOLUTION	12
CSD_14_BIT_RESOLUTION	14

Return Value:

None

Side Effects:

**

CSD_SetRefValue

Description:

Sets scanning reference value. Valid only when reference is supplied from the analog modulator (ASE11 in the Reference parameter) or from externally filtered PWM/PRSPWM signals. Accepted values are 0..8. Value 0 corresponds to the minimum reference voltage that provides the maximum sensitivity. The value 8 sets the maximum reference voltage and results in lower sensitivity. This function can be used in conjunction with CSD_ScanSensor().

C Prototype:

```
void CSD_SetRefValue(BYTE bRefValue)
```

Assembly:

```
mov      A, bRefValue
lcall     CSD_SetRefValue
```

Parameters:

bRefValue - sets the scanning reference vale. Accepted values are 0..8.

Return Value:

None

Side Effects:

**

CSD_Calibrate

Description:

This function overwrites the user module parameter settings for the DAC values for getting raw counts on half of the range. This function should be run before baseline initialization.

C Prototype:

```
void CSD_Calibrate(void)
```

Assembly:

```
lcall     CSD_Calibrate
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_ClearSensors

Description:

Clears all sensors to the nonsampling state by sequentially calling CSD_wGetPortPin() and CSD_DisableSensor() for each of the sensors.

C Prototype:

```
void  CSD_ClearSensors()
```

Assembly:

```
lcall  CSD_ClearSensors
```

Parameters:

None

Return Value:

None

Side Effects:

**

CSD_wReadSensor

Description:

Returns the key Raw scan value in A (LSB) and X (MSB).

C Prototype:

```
WORD  CSD_wReadSensor(BYTE bSensor)
```

Assembly:

```
mov A, bSensor
lcall CSD_wReadSensor
```

Parameters:

A => Sensor Number

Return Value:

Scan value of sensor, LSB in A and MSB in X.

Side Effects:

**

CSD_wGetPortPin

Description:

Returns the port number and pin mask for a given sensor. The passed parameter indexes and selects the data from the CSD_Sensor_Table[]. The return value can be passed to the CSD_EnableSensor(), CSD_DisableSensor(). This function is available in single channel configurations only.

C Prototype:

```
WORD  CSD_wGetPortPin(BYTE bSensorNum)
```

Assembly:

```
mov   A,   bSensorNumber
lcall     CSD_wGetPortPin
```

Parameters:

bSensorNumber – The range is 0 to (n – 1) where n is the total of the number of sensors set in the CSD Wizard plus the number of sensors included in sliders. The sensor number is used by CSD_wGetPortPin() to determine port and bit mask for the selected active sensor.

Return Value:

A => Sensor Bitmap

X => Port Number

Side Effects:

**

CSD_EnableSensor

Description:

Configures the selected sensor to measure during the next measurement cycle. The port and sensor can be selected using the CSD_wGetPortPin() function, with the port number and sensor bitmask loaded into X and A, respectively. Drive modes are modified to place the selected port and pin into Analog High Z mode and to enable the correct Analog Mux Bus input. This also enables the comparator function.

C Prototype:

```
void  CSD_EnableSensor(BYTE bMask, BYTE bPort)
```

Assembly:

```
mov   X,   bPort
mov   A,   bMask
lcall   CSD_EnableSensor
```

Parameters:

A => Sensor Bitmap

X => Port Number

Return Value:

None

Side Effects:

**

CSD_DisableSensor

Description:

Disables the sensor selected by the CSD_wGetPortPin() function. The drive mode is changed to Strong (001). This effectively grounds the sensor. The connection from the port pin to the Analog-MuxBus is turned off. The function parameters are returned by CSD_wGetPortPin() function.

C Prototype:

```
void  CSD_DisableSensor(BYTE bMask, BYTE bPort)
```

Assembly:

```
mov   X,   bPort
mov   A,   bMask
lcall  CSD_DisableSensor
```

Parameters:

A => Sensor Bitmap

X => Port Number

Return Value:

None

Side Effects:

**

Sample Firmware Source Code

Example 1. This code starts the user module and continuously scans the sensors. The communication section can be used to communicate values to a PC charting tool.

```
//--------------------------------------------------------------------------
// Sample C code for the CSD module
// Scanning all sensors continuously
//--------------------------------------------------------------------------

#include <m8c.h>        // part specific constants and macros
#include "PSoCAPI.h"    // PSoC API definitions for all user modules

void main(void)
{
  M8C_EnableGInt;
  CSD_Start();
CSD_InitializeBaselines() ; //scan all sensors first time, init baseline
  CSD_SetDefaultFingerThresholds() ;
//
// Loop Forever
//
while (1) {
CSD_ScanAllSensors(); //scan all sensors in array (buttons and sliders)
    CSD_UpdateAllBaselines(); //Update all baseline levels;

//detect if any sensor is pressed
if(CSD_bIsAnySensorActive()){
```

```
// Add user code here to proceed the sensor touching
}

    // now we are ready to send all status variables to chart program
    // communication here
//
// OUTPUT CSD_waSnsResult[x] <- Raw Counts
// OUTPUT CSD_waSnsDiff[x] <- Difference
// OUTPUT CSD_waSnsBaseline[x] <- Baseline
// OUTPUT CSD_baSnsOnMask[x] <- Sensor On/Off
}
}
```

Example 2.The following code demonstrates the example of one sensor usage when a couple of sensors configured in the UM Wizard.

```
//-------------------------------------------------------------------------
// Sample C code for the CSD module
//-------------------------------------------------------------------------

#include <m8c.h>        // part specific constants and macros
#include "PSoCAPI.h"    // PSoC API definitions for all user modules

void main(void)
{
     M8C_EnableGInt;
CSD_Start(); // Start CSD UM
     CSD_SetDefaultFingerThresholds();  // Set default thresholds for buttons
     // Initialize baseline for sensor number "3"
     CSD_InitializeSensorBaseline(3);

     while (1)
{
          // Scan continuously sensor number "3" which is connected
CSD_ScanSensor(3);
         CSD_UpdateSensorBaseline(3); // Update Baseline for sensor 3
         if(CSD_bIsSensorActive(3)) // check if sensor 3 is touched
         {
               // Add user code here to proceed the buttons pressing
         }
     }
}
```

Example 3. The following example demonstrates the ability to set the different Finger Threshold levels for each sensor. Useful when different sensors are placed on different locations and some sensors are more sensitive than others.

```
//-------------------------------------------------------------------------
// Sample C code for the CSD module
// Set individual finger threshold parameter for each sensor
//-------------------------------------------------------------------------

#include <m8c.h>        // part specific constants and macros
#include "PSoCAPI.h"    // PSoC API definitions for all user modules
```

```
void main(void)
{
M8C_EnableGInt;

CSD_Start();
CSD_InitializeBaselines();

// set finger threshold for sensor "0"
CSD_baBtnFThreshold[0] = 10;
// set finger threshold for sensor "1"
CSD_baBtnFThreshold[1] = 20;
// set finger threshold for sensor "2"
CSD_baBtnFThreshold[2] = 30;
// set finger threshold for sensor "3"
CSD_baBtnFThreshold[3] = 40;
// set finger threshold for sensor "4"
CSD_baBtnFThreshold[4] = 50;
// set finger threshold for sensor "5"
CSD_baBtnFThreshold[5] = 255;
// set finger threshold for sensor "6"
CSD_baBtnFThreshold[6] = 200;

while (1) {
// Scan continuously all sensors
CSD_ScanAllSensors();
CSD_UpdateAllBaselines();
//detect if any sensor is pressed
if(CSD_bIsAnySensorActive()){
// Add user code here to proceed the buttons pressing
}
}
}
```

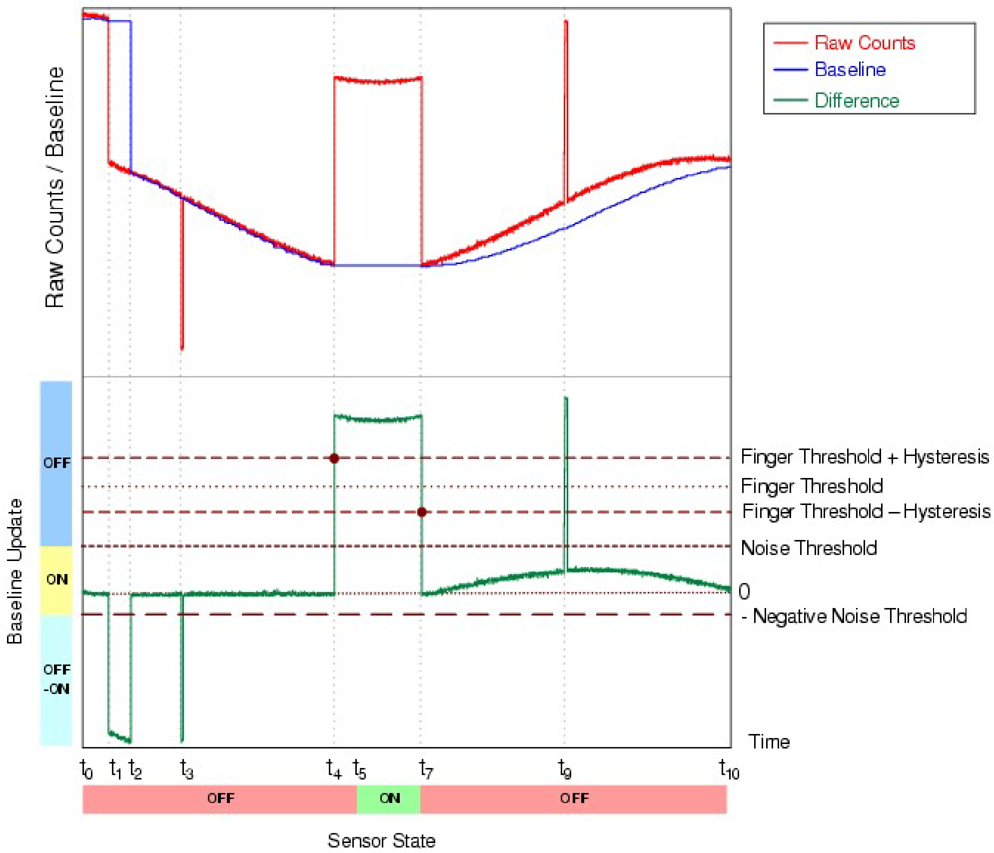
Appendices

The following sections contain information beyond what is usually included in user module datasheets. The detailed information was developed by Cypress engineers to help you successfully design CapSense applications. Some of this information may be moved into application notes in the future.

Interaction of CSD Parameters

The following figures illustrate the baseline update and decision logic operation and can be useful for better understanding how to set user module parameters for optimum performance. The first figure illustrates system operation when the Sensors Autoreset parameter is set to **Disabled**. The second illustrates the Sensors Autoreset parameter **Enabled**. The Finger Threshold, Noise Threshold, Hysteresis, and Negative Noise Threshold are shown together with Difference signal (Raw Count – Baseline). Data was collected during some artificial tests that demonstrate system operation at both slow and rapid rawcount changes.The slow changes can be caused by temperature or humidity variations and the rapid changes can be triggered by a sensor touch, an ESD event, or the influence of a strong RF field.

Figure 10. Example of Raw Counts, Baseline, Difference Signals Change With Sensors Autoreset Set to Disabled



At t_0 the raw counts are close to the baseline level and start to drop slowly because of humidity or temperature changes. Because the raw count change between two successive conversions does not exceed the NegativeNoiseThreshold parameter (by absolute value), the baseline is updated by tracking the Raw Count minimum value, holding the lower value of raw count signal.

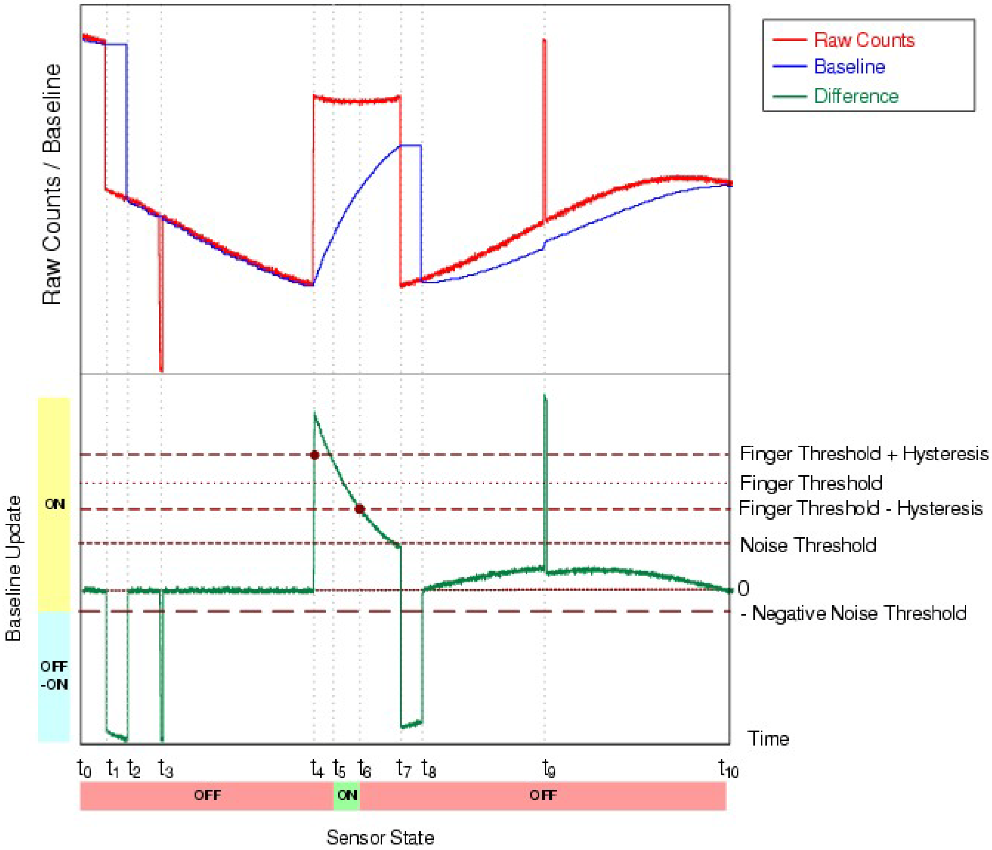
At t_1 the raw count drops sharply and the negative difference exceeds the NegativeNoiseThreshold. This situation can happen if the device is powered on when a finger is on the sensor and then the finger is removed after a period of time. At this time the baseline update mechanism is frozen and an internal timeout counter is activated. The baseline is reset when the difference signal is below the NegativeNoiseThreshold for LowBaselineReset samples. This happens at t_2.

The second large negative difference signal spike happens at t_3, this spike may have been triggered by an ESD event for example. Because the spike duration in the sample count is less than the LowBaselineReset parameter, the baseline is kept on hold and the spike is filtered. This prevents a false baseline reset and the resulting false touch detection.

The sensor is touched at t_4. When the difference signal exceeds the FingerThreshold + Hysteresis value, the internal debounce counter is activated. If the signal exceeds this value for more than Debounce samples, the sensor state is set to on. This happens at t_5. The sensor state reverts back to the off state immediately when the difference signal drops below the FingerThreshold – Hysteresis level at t_7. The short positive spike at t_9 is filtered by the debounce counter because the spike duration in sample units does not exceed the Debounce value.

The raw count drifts up slowly between t_7 and t_{10}. The baseline is updated using the bucket algorithm when the difference signal is below the NoiseThreshold (SensorsAutoreset is set to Disabled), the difference signal is proportional to the drift rate. It is possible to control the baseline update speed using the BaselineUpdate Threshold parameter. Lower parameter values provide faster baseline update speeds.

Figure 11. Example of Raw Counts, Baseline, Difference Signals Change With SensorsAutoreset Set to Enabled



The system operation in the previous figure is similar to the operation in the previous case, except for the following differences:

- The touch duration is decreased because of the active baseline update algorithm while the sensor is touched, t_6.
- After the finger is removed, the baseline is reset after LowBaselineReset samples (t_8), which blocks touch detection for a short time. This serves as an additional debouce mechanism.

CSD Step-By-Step Tuning Guide

The success of capacitive sensing depends on setting the parameters optimally for the given sensing electrodes. Variables that affect these settings include:

- Geometric dimensions of the electrodes
- Overlay thickness and dielectric constant
- Electrode connection resistance to the PSoC device
- The end application conditions such as:

- Presence of a power supply
- Temperature
- Humidity
- Presence of moisture
- ESD, EMC, or EMI requirements

The best practices for different tasks (waterproof operation, sensing using high resistance materials, proximity detection, and operation through thick overlays and recommendations for passing certification tests) are described in separate application notes.

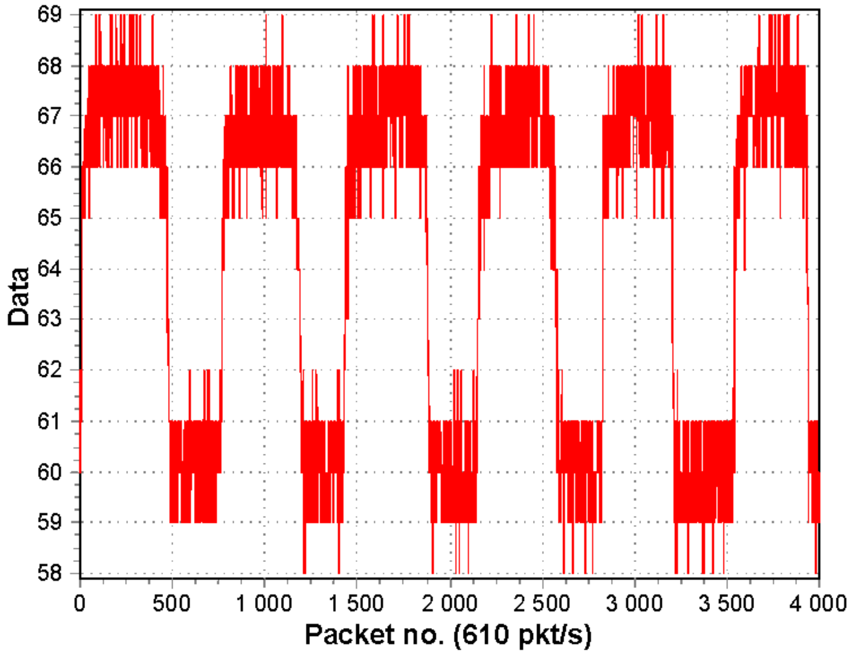
Here are basic guidelines for configuring the user module in a typical CapSense application using the CY3214 board as a test example. The sense zone is covered with a 2 mm plastic overlay. Configure the CSD User Module parameters in the following steps:

1. Prepare the target board. Assemble the target application PCB and fix the overlay on it. Use glue or special adhesive tape for this purpose. Avoid air gaps between the PCB and the overlay as it can reduce sensitivity substantially and cause multiple false button triggers because of the arguable shifting under your touch.
2. Set up a real time monitoring tool to monitor data. During CSD configuration use a PC charting tool that allows you to observe one or more data series in real time. The raw count, baseline, and signal differences must be observed during the user module tuning procedures. You can use an I^2C-USB bridge for this. One was used to monitor raw count data during our tests. Another good alternative is to use the USBUART User Module to send debug information through an emulated serial port. Do not use the LCD or any other numerical displays to monitor counts because they are slow and do not allow you to visualize the data dynamics.
3. Set the initial configuration. This configuration uses the 16-bit PRS. The following parameters were set in the PSoC Designer before starting the tests:

User Module Parameters	Value
FingerThreshold	40
NoiseThreshold	20
BaselineUpdateThreshold	200
Sensors Autoreset	Enabled
Hysteresis	10
Debounce	3
NegativeNoiseThreshold	20
LowBaselineReset	50
Scanning Speed	Fast
Resolution	9
Modulator Capacitor Pin	P0[5]
Feedback Resistor Pin	P3[1]
Ref Value	2
ShieldElectrodeOut	None

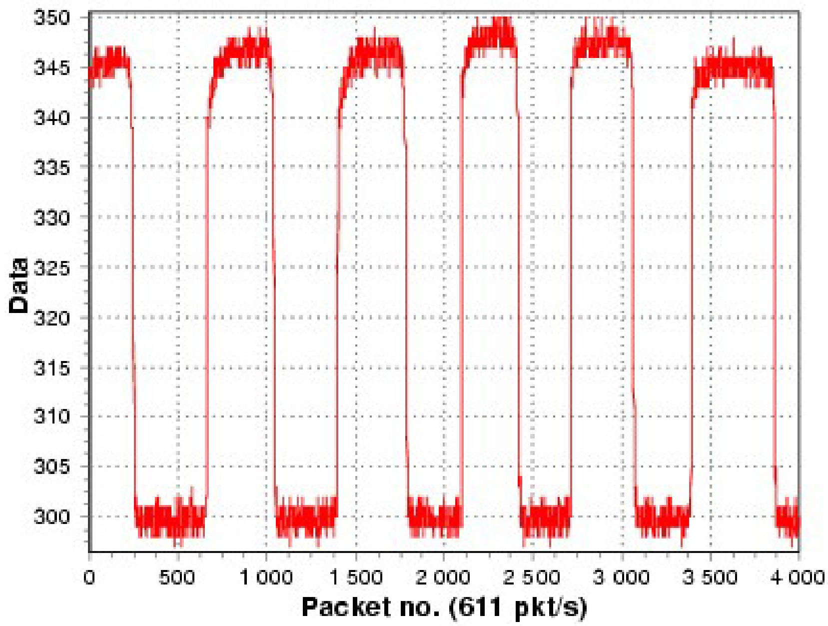
4. Assign the sensor pins in the CSD wizard (assign sensors P5[7], P3[7], and P3[6] for scanning).
5. Generate the application and sample code.

6. Monitor the sensor raw count data using a charting tool to confirm that the user module is operational. Touching the sensor should result in a raw count (CSD_waSnsResult variable) change from 59 to 68.

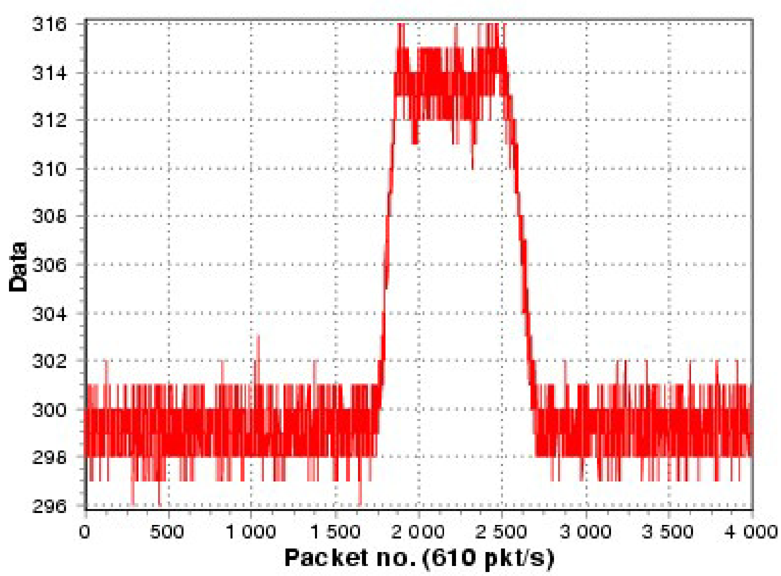


7. Tune the external components. Cypress used a 5.6 nF modulator capacitor (C_{mod}) and 1.2 kΩ feedback resistor R_b initially. After observing raw count values from different sensors under touch conditions, Cypress found the sensor that produced the largest raw count value. The signal from this sensor is shown in the previous figure. The lower signal value corresponds to no finger touch, the upper corresponds to touch conditions. By analyzing the signal values from this sensor, you can see that the system is using only eight percent of the capacitance-to-code converter's dynamic range. The full range for 9-bit resolution is Nm = 512 and the maximum raw count about 85. This means that the dynamic range utilization can be increased to the recommended 60-70% by increasing the feedback resistor value to 5.1 kΩ. You can use different resistor values for this work, depending your raw count observations. The following fin-

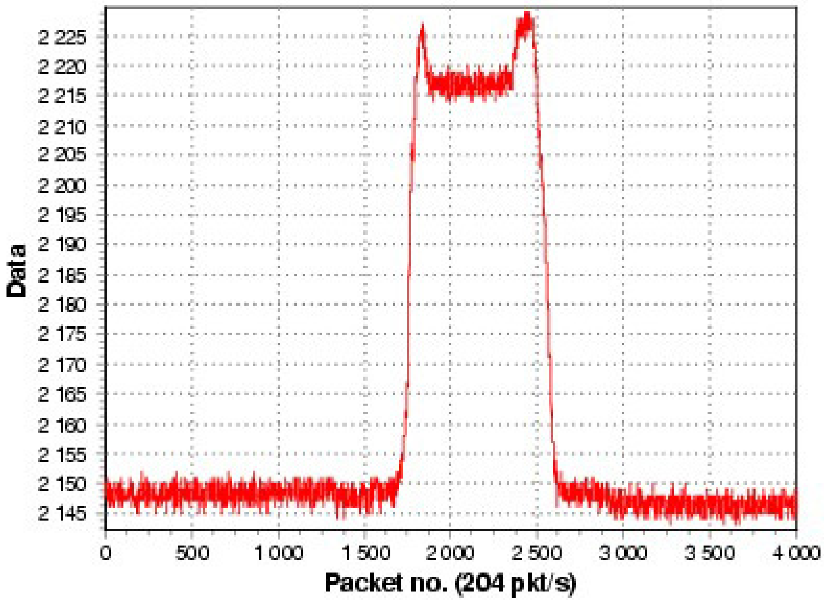
ger response is the result after the resistor was replaced. Response from a finger touch is increased.



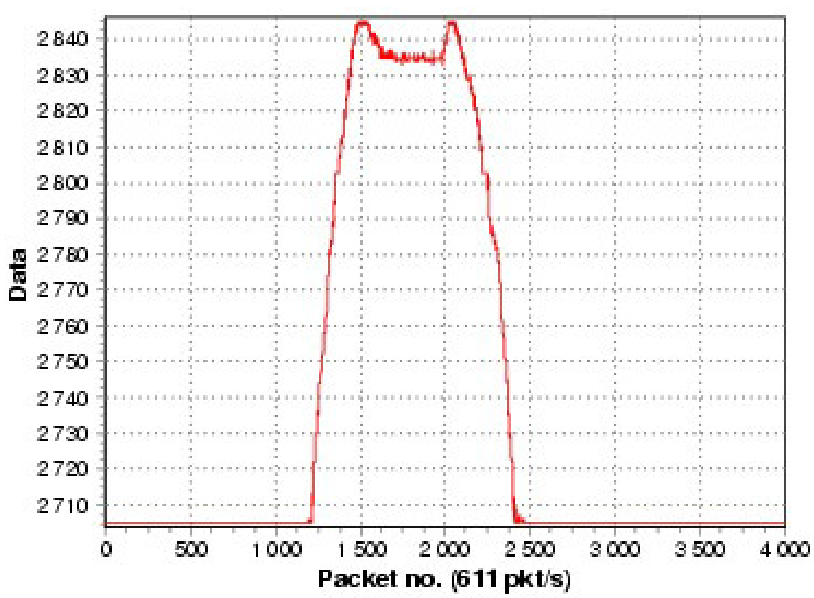
8. Adjust for worst case. Use a finger simulator to be sure that the device works reliably in different conditions, for example, for very slight touch. A 10 mm unconnected coil placed on the overlay simulates a worst case. Move the coil is across the button using a dielectric object such as a match or a toothpick. The following figure shows the results. You can run this test if your board uses a ground plane around sensors. If the board is covered by a shielding electrode instead of a ground plane, you can simulate the worst case response by running a very slight touch with a finger.



9. The signal from the coil is identified, but the SNR is too small for reliable detection. The difference is only about 9 dB. To increase the sensitivity, select higher scanning resolutions. In the test, the resolution was increased from 9 bits to 12 bits. Here is the signal from the coil at these settings.



10. Increasing the scanning resolution from 9 to 12 bits improved the SNR to 25 dB, which is good for most practical applications. Signal from a human finger is much larger. The cost of this is an increase in the scanning time. If scanning time is important for your application, you can switch to the PRS8 configuration. Here is coil response from PRS8 configuration at same user module parameters (PRS Poly was set to Short):

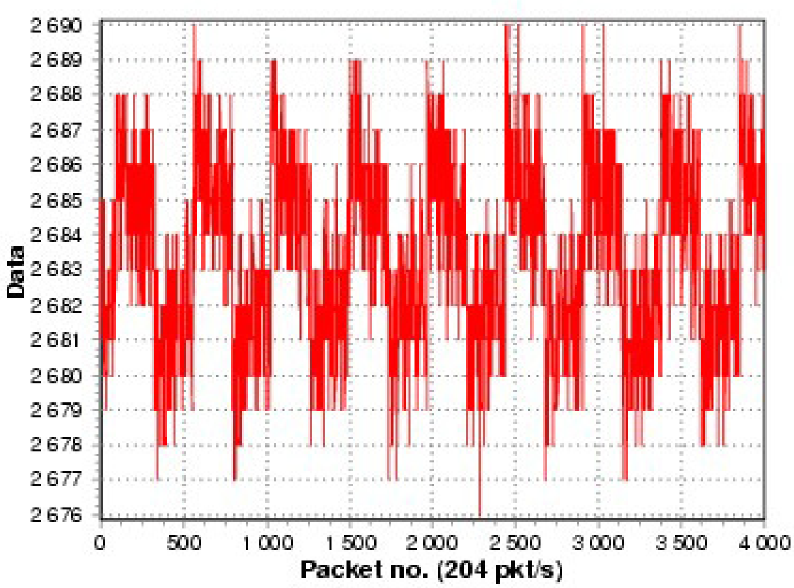


11. This configuration provides even better SNR than the PRS8 configuration at short PRS poly. But the shorter pseudorandom sequence can cause worse external electrical noise immunity.

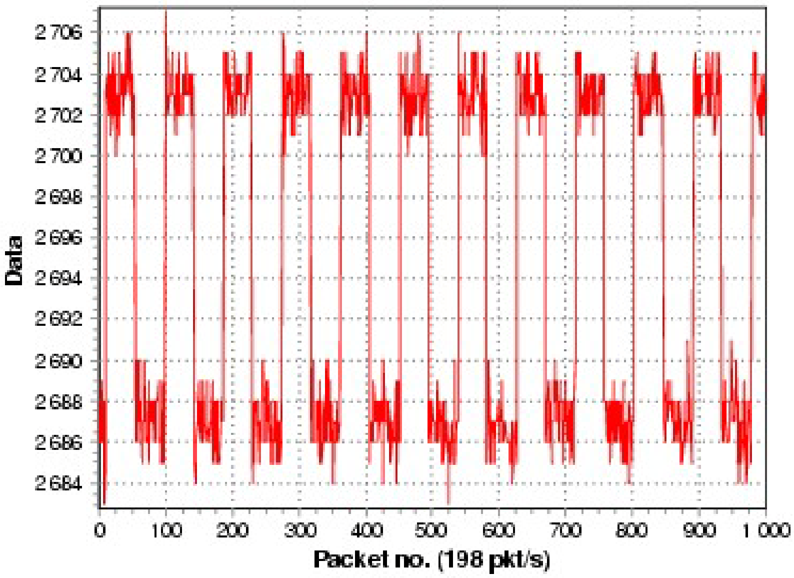
12. Set the thresholds. Make the following changes to the user module parameters:

User Module Parameters	Value
FingerThreshold	40
NoiseThreshold	20
BaselineUpdateThreshold	200
Sensors Autoreset	Enabled
Hysteresis	10
Debounce	3
NegativeNoiseThreshold	20
LowBaselineReset	50
Scanning Speed	Fast
Resolution	12
Modulator Capacitor Pin	P0[5]
Feedback Resistor Pin	P3[1]
Ref Value	2
ShieldElectrodeOut	None

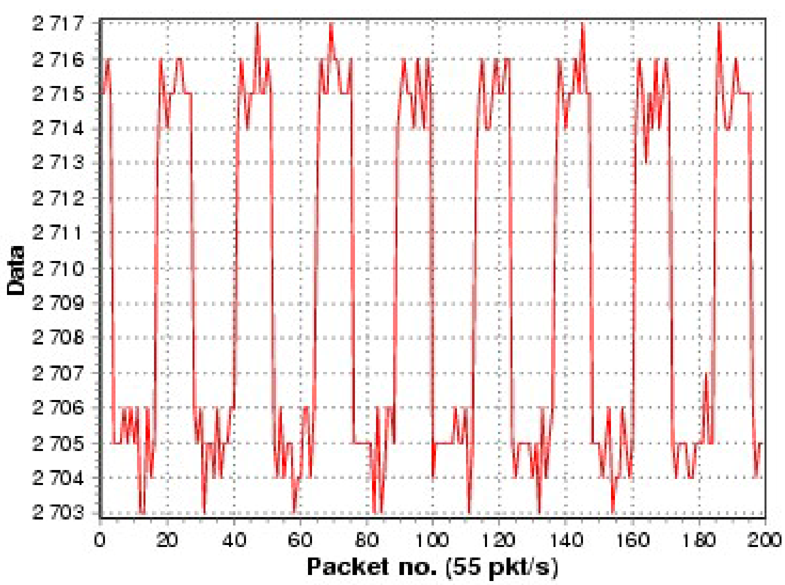
13. Set the optimal scanning speed. Suppose the test application power supply voltage is not well regulated and ± 5% sharp power supply fluctuations are possible due to the operation of other parts of the target device. Also, suppose the PSoC device drives several 10 mA LEDs together with its CapSense functions. The current drop on the internal die resistance can cause the internal power supply voltage to fluctuate. The CapSense system should continue to operate with this voltage transient. Test what changes result in the raw count due to these fluctuations. The LEDs must be turned on and off at same time. The sleep timer interrupt is ideal for this job. Alternatively, an external pulse source can be used to simulate the external loads turning on and off. The following figure shows raw counts when LEDs are toggled while scanning is active.



14. As can be seen from this graph, the LED on/off while scanning is active has no visible influence on the raw count value. Test the CapSense stability for sharp power supply changes. Very slow power supply changes are handled by baseline update algorithms and do not create a problems in most cases. The LM1117-ADJ voltage regulator was used for this test. The output voltage was modulated by a feedback resistor network changing using a MOSFET, driven by external signal source. The following figure shows the raw count difference for a sensor when the power supply is oscillating between 4.75V to 5.25V.



15. As can be seen in this graph, the power supply transient raw count change (18) is close to the threshold values (35..45) and cannot cause a false touch detection. It can cause the multiple touch triggering detection from a very light touch. The solution for this is to increase Hysteresis in the user module parameters. Also, it is possible to reduce the power supply fluctuations influence by using a slower scanning speed. The following figure shows the raw count data collected at Slow scanning speed:



16. As this graph shows, reducing the scan speed decreased the influence of the power supply voltage change on the raw count. The transient difference is now about 10 counts. This is well below threshold values and has no undesirable influence on the CapSense module operation. The cost of this is a four times increase the scanning speed, which can be undesirable in some situations.
17. Tune the BaselineUpdateThreshold parameter. The application requires a maximum touch time detection of less than 1sec. Set the SensorsAutoreset parameter to Enabled. Check whether the BaselineUpdateThreshold provides a baseline update speed that adequately compensates for environment changes. For example, if the application is a kitchen application where quick temperature changes are possible due to cold air flowing over the board, the raw count drops due to the temperature change. The baseline tracks this by resetting the baseline to the raw count value automatically. Therefore, dropping raw counts due to environmental factors should not be problem inmost cases. If the raw count is increased due to the temperature variations, it is possible to trigger a false touch by interpreting this change as a touch. The baseline update speed must be adjusted so that the influence of temperature (or other environmental factors) on the raw count-baseline difference is well below the Finger Threshold value. The raw count-baseline difference was monitored during these tests. The monitored value was 0, making the difference below the Noise Threshold parameter. This parameter was set to the minimum value of five during these tests. This means that the preset BaselineUpdate Threshold parameter provides sufficient baseline tracking speed and temperature fluctuations should be no problem for our application.
18. With all parameters set you can run ESD tests. Your application should be able pass these tests without problems, even with ESD Debounce parameter set to Disabled. If required, you can enable the ESD Debounce parameter if there are problems with ESD tests. The cost of enabling this parameter is an increase in the size of the RAM buffer.
19. Many CapSense applications are required to pass various EMC/EMI compatibility tests. If your application has some problems with EMC/EMI, see the design guide Getting Started with CapSense. Other possible ways to address the problem are to use the slower PRS clock to reduce sensor path radiation. You can try the configuration with prescaler or use slower IMO mode (for example, run SYSCLK at 6 MHz instead 24 MHz). Any changes in PRS clock frequency or prescaler period settings require you to also adjust the feedback resistor to maximize use of the dynamic range to reach maximum sensitivity.
20. If your application fails EMC tests, try a reduced scanning speed and a higher resolution. This results in longer PRS polynomial sequences, yielding better noise immunity. The cost of this is increased sensor scanning time.

Troubleshooting

- You can use the precharge prescaler as a UART baud rate clock source. The recommended UART speed must be not less than 115,200 baud. The prescaler period should be set to 25 for 24 MHz IMO operation. Because this value is not a multiple of 2^N, a slower scanning speed is recommended for better SNR. Test this by experiment.
- If you see large, periodic noise at your reference setting, try increasing the CSD_DELAY constant in the **CSD.asm** file. This delay sets the modulator startup time before the measurement is started. Reducing the modulator capacitor C_{mod} reduction can help as well. The reason for this noise is that the modulator capacitor was charged to a different voltage during the previous measurement cycle due to a low time constant on the internal analog modulator low-pass filter.
- The scanning speed and resolution affect the signal-to-noise ratio (SNR). Slower scanning speeds and higher resolution give better SNR in some cases.
- When the electrode overlay is thick, higher resolution and slower scanning speed may be required.
- The PRS polynomial is automatically adjusted depending on the scanning speed and resolution so that the PRS sequence repeat period is close to the sample conversion cycle count. Slower scanning rates and higher resolutions provide better noise immunity during EMC tests because it produces longer PRS sequences.
- Slower scanning speeds results in lower modulator operation frequency, making readings less dependent on the comparator dynamic characteristics. When you need good raw count stability despite power supply fluctuations or when the PSoC device controls high current loads, use the analog modulator to form the comparator reference internally. The recommended scanning speed in this situation is Normal or Slow.
- The Sigma-Delta conversion method belongs to the class of integrating methods. It demonstrates the best performance at higher resolutions. Use the longest scanning time possible. Use 1 ms for sensor scanning for best results.
- The shield electrode can be used effectively to reduce the stray capacitance influence even in applications that do not need to be water resistant. In this case the shield electrode can be located on the bottom layer of the PCB under the capacitive sensor zone. A hatch filling pattern is recommended in this case to decrease the capacitance of the shielding electrode.

Eliminate Possible Resource Use Conflicts

Be careful not to alter the hardware configurations used by this user module. This includes:

- The GlobalOutEven_1 or GlobalOutEven_5 (depending on your modulator feedback resistor pin selection) buses are used internally to pass comparator output signal to the output bus. Do not connect any sources to these buses.
- Do not change the Comparator Bus 1 LUT functions. The Comparator Bus_1 should be set to **~A**.
- The analog column one clock source should be set to **VC1**.
- The VC1 are set internally by the user module. The value entered in the Global Resources are overwritten at runtime.
- When using a shield electrode, set the row LUT function to **A**.

Interrupt Duration Management

Manage your Interrupt Service Routine (ISR) duration when sensor scanning is active for the PRS16 configuration. The 8-bit timer is clocked from VC2. The worse-case overflow interval for timer is:

Equation 2

$$T_{owf} = VC_2 \cdot VC_1 \frac{256}{F_{IMO}}$$

F_{IMO} – IMO frequency, VC1 = 2, 4,or 8 for Fast, Normal, or Slow scanning speeds respectively

VC_2 – This value is set to four at all times.

This interval does not cause problems in the most cases. In some cases it needs to be checked.

ISSP Pins Possible Conflicts

Permanent connection of a low-resistance feedback resistor to the P1[1] pin can cause ISSP programming faults. Use another pin for this.

Clock Speed

The CPU speed for CY8C24x94 devices should be SysClk/32 or faster for proper functionality.

Version History

Version	Originator	Description
1.4	DHA	1. The Resolution maximum is (number of pins used for sensors – 1) x 2^8 – 1 or (2 x pins used for sensors – 1) x 2^8 -1 for diplexed sliders. Removed 0.5 shift and added compensation for negative values. 2. Fixed pin list in wizard. 3. Added API Vs User Module Configuration table. 4. Corrected error in assignment of P0(7) in the CY8C28xxx family.
1.50	DHA	Added support for CY8C21x12 devices.
1.50.b	DHA	1. Changed max resolution of sensors in slider 2. Added help file to wizard 3. The following updates were done to this user module datasheet: a. Added description of analog bus for CY8C28xxx. b. Updated images.
1.60	DHA	1. Transferred the DiplexTable from "AREA UserModules" to "AREA lit". 2. Set the default "DiplexTable" parameter value to 0x0112. 3. Added the "DiplexUsed" parameter to improve code compression. 4. Added CSD_ScanAllSensors API call at the end of the Start API.

Version	Originator	Description
1.70	DHA	1. Updated area declarations to support Imagecraft optimization. 2. Added symbolic names for the Resolution parameter in this user module datasheet. 3. Addressed issues with CSD and DelSig User Modules coexistence. 4. Added the precharge function to precharge the Cmod capacitor to reference voltage. 5. Added support for Rb pins P1[0], P1[4] and P3[0] on CY8C21x34 devices. 6. Added Design Rule Check when the wrong Feedback resistor parameter is set. 7. Added support for Rb pins P1[0],P3[0],P5[0],P1[4],P3[4], and P5[4] on CY8C24x94 devices. 8. Added max value limitation on the Resolution parameter for Slider and RadialSlider. 9. Updated the following sections in this user module datasheet: SetScanMode() API Function description Feedback Resistor Pin section ISSP Pins Possible Conflicts section Rb Pin Reference 10. Updated the resolution range calculation for Slider and Radial Slider in the user module wizard. 11. Updated the user module wizard help. Added a description of the slider resolution parameter min/max values.
1.70.b	DHA	1. Changed peak frequency from FIMO/4 to FIMO/2 for PRS8 and prescaler configurations 2. Moved setting of CSD_MODE bit from ScanSensor API to Start API for CY8C20xx7/S only. 3. Changed calibration resolution from 9 bits to 12 bits in CSD_Start API for CY8C20xx7/S only.
1.80	DHA	1. Changed default "Reference" value from VBG to ASE11. 2. Updated user module block diagram. 3. Updated RAM and ROM usage values in user module datasheet. 4. Deleted redundant register writing and corrected shield signal connection for PRS16 configuration. 5. Added CYRF89x35 device support. 6. Removed redundant comparator bus usage for CY8C24x94 chip architecture. 7. Analog mux resource freed when CSD is unplaced.

Version	Originator	Description
1.90	MYKZ	1. Added Resume() function to User Module API. 2. Fixed problem with saving information for sliders. 3. Updated baseline algorithm to check for negative difference counts. 4. Added build error message when user attempts to build project without first calling the user module wizard. 5. Updated UM Wizard sliders setting algorithm to take into account free pins. 6. Optimized Start User Module function code. 7. Removed default value for feedback resistor pin. 8. Updated Precharge() function to correct Cmod connection to GND. 9. Updated ScanSensor() function to reset PRS.

Note PSoC Designer 5.1 introduces a Version History in all user module datasheets. This section documents high level descriptions of the differences between the current and previous user module versions.