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Texas Instruments

CapTIvate™ Touchpad

Hardware Design Guide

Beta Release

MSP Applications Team

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Document Revision History

Version 0.1 - Aug 22, 2016

- Initial release

Version 0.2 – Nov 17, 2017

- Updated mechanical section and added routing guidelines

Version 0.3 – Nov 20, 2018

- Added section for ground pours and flex PCBs

Version 0.4 – Dec 18, 2019

- Added section for ground pours and flex PCBs

Overview

Touchpad HMI inputs are very popular for hand held devices, such as entertainment remotes and VR (virtual reality) hand controllers. These type of inputs can create a great user experience by augmenting the device's button or keypad controls with finger gesturing inputs like tap, double-tap, tap-n-hold, swipe up, swipe down, swipe left, and swipe right, etc., as well as XY finger position.

This guide covers the design aspects of a mutual capacitive square, or round Touchpad on FR4, FPC and ITO substrates. This document does not discuss self capacitive Touchpad designs or designs that include curved (concave, convex) surfaces.

MSP430 FR26xx_25xx CapTIvate™ Technology

- Integrated CapTIvate IP
- 5uA typical using **wake on proximity** (great for battery powered applications)
- Supports multiple combinations of sensors in the same design
- CapTIvate Library in ROM allows more user code in FRAM

Touchpad Features

- User programmable resolution (1000 pts default)
- Reports X,Y position
- Gestures (Swipe up, down, left, right, Tap, double-tap, tap and hold)
- Programmable Sensor Scan Rate (10ms default)
- Up to 3mm plastic or glass overlay

Touchpad Variants

This document supports two Touchpad variants, standard and basic. The standard Touchpad design solution provides the performance and features to meet both precision XY finger tracking and gesturing requirements for hand-held applications. The basic Touchpad design provides a cost sensitive solution for gesture applications that rely only on finger gesturing and don't require the higher performance XY finger tracking.

Standard

CapTIvate Touchpad designs offer best in class XY resolution and accuracy, with gesturing.

- Applications requiring precision tracking performance, such as game or VR applications
- XY accuracies to 1mm across touch surface
- MSP430 CapTIvate MCUs with larger pin-count and memory configurations
- Maximum 8x8 sensor configuration (64 measurement pts)

Application	Device	FRAM (bytes)	RAM (bytes)	CAPT IO
TV mouse pointer control or game console, gestures	MSP430FR2633	15.5K	4K	16(2)
	MSP430FR2533	15.5K	2K	
	MSP430FR2676(1)	64K	8K	
	MSP430FR2675(1)	32K	6K	

(1) Larger memory devices could replace application host MCU

(2) Supports sensor configurations from 2x2 to 8x8

Basic

A basic CapTIvate Touchpad is a lower cost solution for applications used primarily for gesturing control.

- Hand-held remote control or wearable devices
- Lower XY resolution and accuracy
- MSP430 CapTIvate MCUs with smaller pin-count, lower memory options
- Smaller touch areas with 2x2, 3x3 and 4x4 configurations (up to 16 measurement pts)

Basic Touchpad recommended MSP430 MCUs.

Application	Device	FRAM (bytes)	RAM (bytes)	CAPT IO
Simple remote or wearable using gestures	MSP430FR2632	8K	2K	8(3) (5)
	MSP430FR2532	8K	1K	
	MSP430FR2522	7.5K	2K	
	MSP430FR2512	7.5K	2K	4(4) (5)

(3) Supports 2x2 to 4x4 sensor configurations

(4) Supports only 2x2 sensor configuration

(5) Custom software modifications are necessary to support certain features.

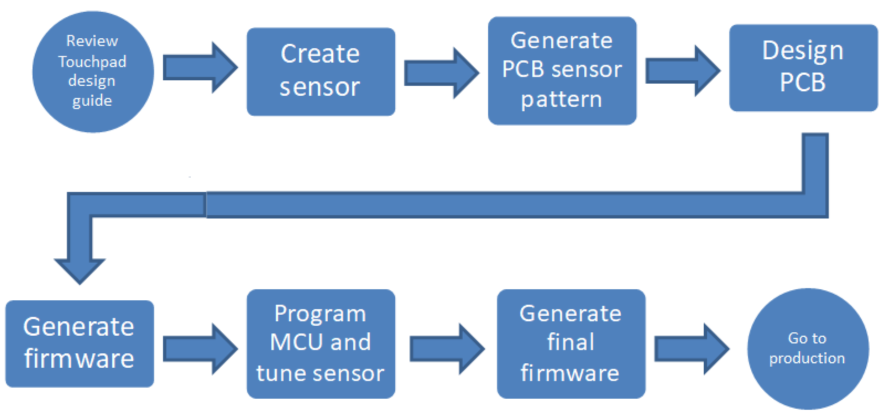
Terms

- RX and TX electrode or channel
    - These are the receive and transmit diamonds connected to MCU's CapTIvate IO pins
- Measurement node
    - Created by the junction of an RX row and TX column
- Projected Capacitance
    - Same as Mutual capacitance

Design Flow

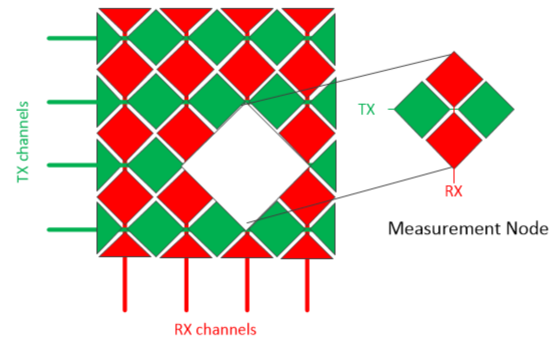
A normal design flow includes the steps listed here.

- Follow this design guide to determine your best solution based on the application requirements
- Generate sensor configurations using CapTIvate Design Center
- Create PCB sensor pattern using OpenScad with Touchpad design scripts created by TI
- Import sensor design onto PCB and Fabricate
- Generate initial firmware using CapTIvate Design Center
- Program MCU, tune Touchpad, generate final code then go to production



Technology

Capacitive Touchpads are commonly made using diamond shaped copper electrodes aligned in rows (TX) and columns (RX). This creates a 2D matrix of measurement nodes at the intersection of each RX and TX electrode. When scanned, all the nodes are processed and the finger position is translated into X and Y coordinates.

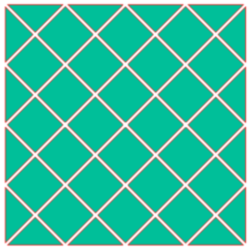


Mechanicals

Shapes

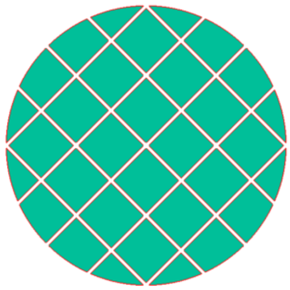
Generally defined by the product requirements, touchpads are commonly square (rectangular) or round. Other shapes are possible, however, in this design guide only square (rectangular) and round shapes are discussed. See the section Create the Touchpad PCB Sensor.

Square



The square or rectangular touchpad is a common shape found on any laptop computer. Many hand-held remotes now feature small square touchpads for controlling a pointer on a TV or gaming console. Shown here is an example 4x4 square configuration. A 4x4 has 4 TX and 4 RX channels and the resulting matrix creates 16 measurement nodes.

Round

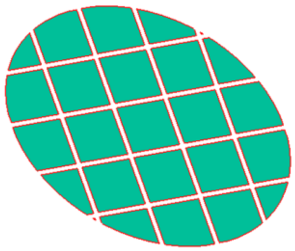


A round shaped touchpad is also common on hand-held devices used as inputs for VR hand controls. Shown here is a 4x4 configuration in a round shape. The round shape has one dis-advantage compared to the square shape. Depending on the sensor configuration and radius of the circle, some measurement nodes will be either partial or phantom nodes because some or all of the copper diamond lie outside of the sensor perimeter, as shown with the yellow dots. This is why choosing the proper configuration based on the size of the round Touchpad shape is important. This is explained in further detail later in the Round Sensor Design section.

1D Slider

Wearable device applications with a Capacitive touch interface are becoming more common in products like headphones, earbuds and eye glasses to control a music device's volume or music selection.

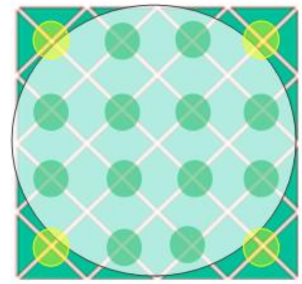
Custom



Some designs require the sensor area to conform to a product's size and shape. In these cases the sensor area can be created using the .dxf output of the desired shape rendered in a CAD program. Here is an example of an ellipse shaped sensor that was drawn in AutoCad.

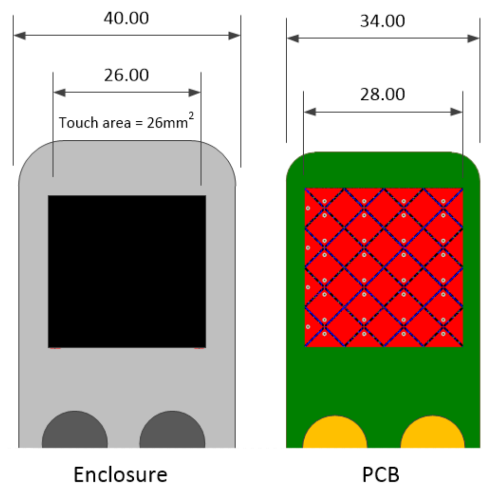
Considerations

Depending on the sensor configuration and radius of the circular touchpad, some measurement nodes will be either partial or phantom nodes because some or all of the copper diamond lie outside of the sensor perimeter, as shown with the yellow dots. This is why choosing the proper configuration based on the size of the round Touchpad shape is important

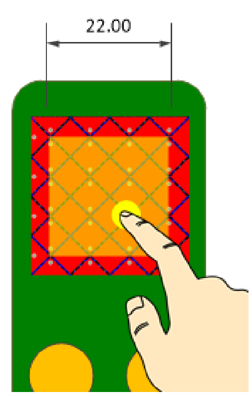


Size

The size of the Touchpad sensor is typically dictated by the available space on the PCB or FPC. For the sake of this example, the remote shown here has a width of 40mm, leaving room for a 34mm wide PCB. Taking into account the PCB design rules and room for a ground pour around the sensor's perimeter, this leaves $28mm^2$ available for the touchpad pattern on the PCB.



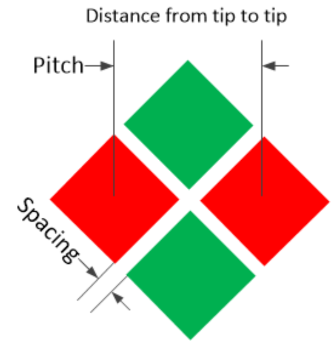
The specification for the product's touch area is only $26mm^2$ so the first thought is to shrink the PCB's pattern size to be the same as the touch area. However, the sensitivity around the perimeter of the sensor pattern is less than the sensitivity in the region highlighted in the illustration here. This is due to the half-diamond shaped electrodes around the perimeter not contributing and therefore the highlighted area is referred to as the "linear" region.



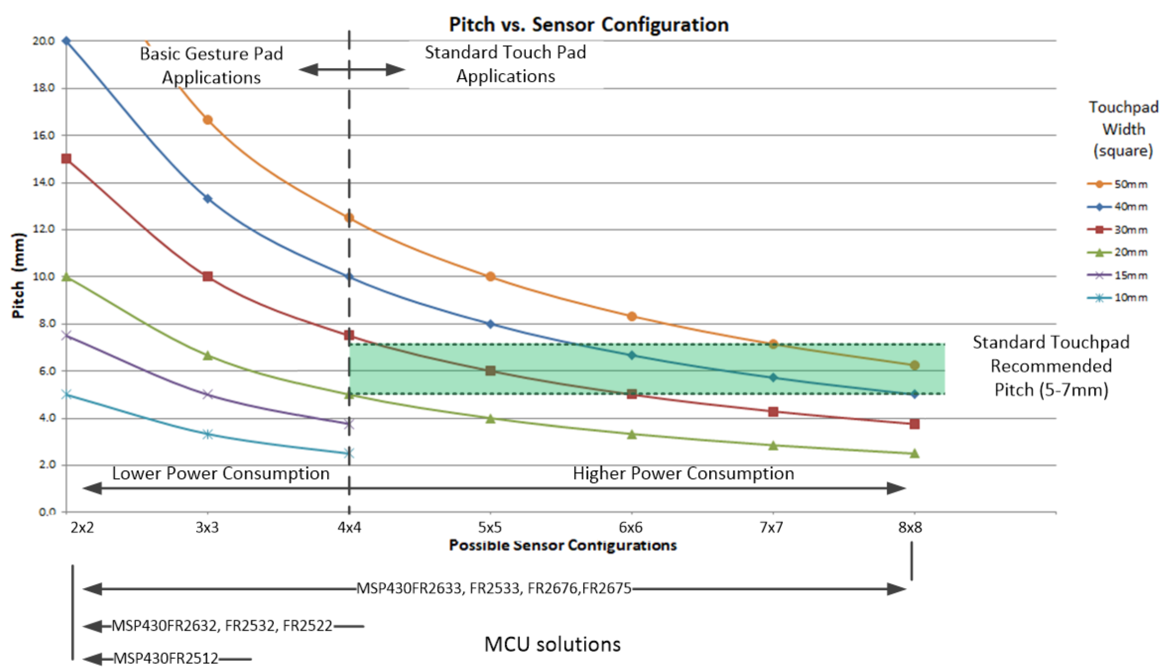
As you might guess, this limits the usable touch region to a smaller area, shown in yellow here. Certain corrections for this are applied in the CapTIvate software library to minimize the effect, but this must be understood as a limitation of the touchpad design. As demonstrated in this example, the resulting $22mm^2$ does not meet the $26mm^2$ specification. The engineer is left with making some design trade-offs to increase the useable touch area. As discussed later, increasing the sensor configuration greater than 4x4 will help by increasing the number of measurement nodes and pushing the non-linear boundary further out towards the perimeter.

Electrode Dimensions

Pitch



A sensor's pitch is the measured distance from the center of one diamond to the center of a neighboring diamond as shown here and is important because it impacts a sensor's resolution. A sensor with smaller pitch will have higher resolution. This makes it possible to detect more than one finger. Selecting the appropriate pitch depends on the application's requirements or use case. The graph below shows three typical sized touchpads and a plot of recommended diamond pitch as a function of the sensor configuration. To the left of the 4x4 line the sensor configurations have less resolution and are therefore recommended for basic, gesture only type applications. Sensor configurations typically associated with finger tracking applications, where higher resolution and accuracy is required fall to the right of the 4x4 line.



The recommendation for electrode pitch ranges from 4mm (min) to 5-7mm (typical) and 8-10mm (max). See chart above for application specific recommendations.

Spacing

The spacing determines the quality of the coupling between an RX and TX diamond. The smaller this spacing the more tightly coupled the e-field between the diamonds, which reduces the e-field propagation through the overlay material and improves the SNR by minimizing the crosstalk between channels. For thicker overlay material the e-field must be sufficient to pass through the ticker material or the spacing should be wider.

- Smaller spacing creates strong coupling with good signal SNR
- Larger spacing reduces the signal SNR and cause cross-talk with neighboring electrodes

Recommended spacing is 0.1mm (min) to 0.3mm (typical), up to 0.5mm (max) with thicker overlays.

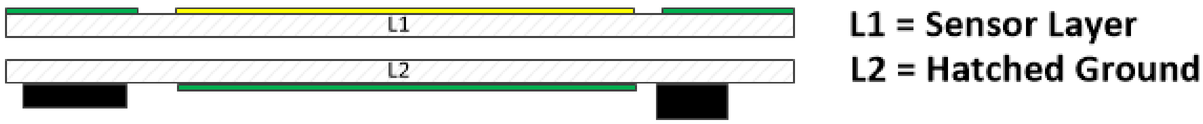
Sensor Accuracy

TBD –

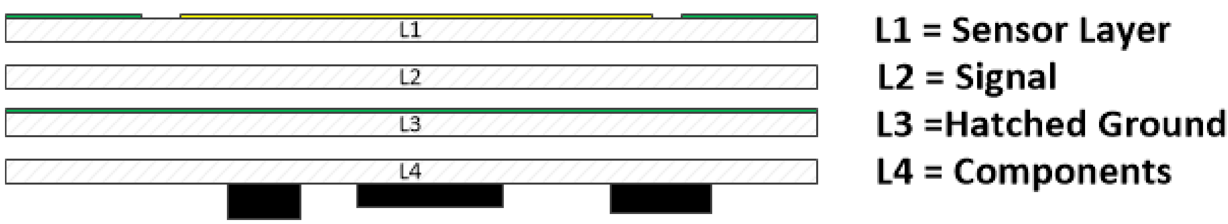
Stack up

Touchpads can be implemented on as few as 2 layers, which is typical with FPC substrates where the MCU is not located directly under the sensor. A 4 layer touchpad allows the MCU and other components to be mounted directly under the sensor because a shielding layer can be used on the layers between the component layer and the sensor layer.

On 2-layer PCB and FPC substrates, avoid placing components on L2 directly under the Touchpad sensor. If components must be placed directly under the Touchpad, consider a multi-layer stack up.



On a multi-layer stack up the MSP430 and other components can be located directly underneath the Touchpad sensor on L4. To shield the Touchpad sensor on L1 from the potential noise sources and uneven distribution of parasitic capacitances on L4, a hatched ground layer is required, typically on layer 3, furthest from the sensor as shown. For a 4 layer FPC the shield must be on L3. On a 4 layer FR4 placing the shield closer to the sensor on L2 will increase the parasitic capacitance seen by the sensor. This of course can be minimized by controlling the %fill of the hatched pour.



The percentage of ground pour fill is typically recommended to be 25% for FR4 PCB designs and 10% for FPC designs, due to the smaller distance between layers.

Overlay

The overlay is a very important part of the capacitive touch design and can impact the overall performance. For example, a thicker overlay will require higher sensitivity, which translates to a higher conversion count target and an increase in power consumption. The overlay material must be non-conductive, such as plastic or glass.

Concave Surface

A flat surface will have the same sensitivity across the linear portion of the Touchpad surface while a concaved surface's sensitivity will vary, with the sensitivity being the greatest in the center. Depending on the selected conversion count and touch thresholds, no software compensation should be required.

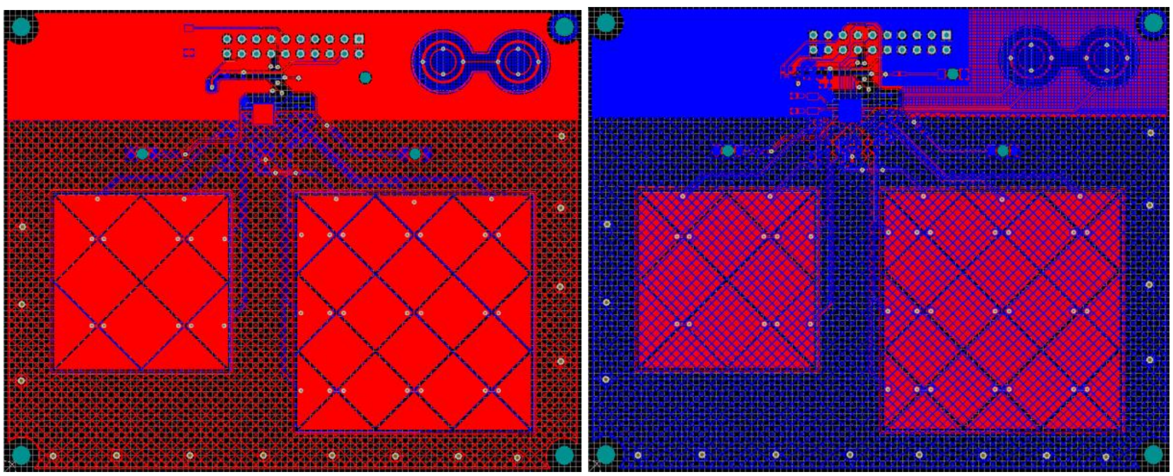
Recommended overlay thickness can range from 1 to 3mm.

Ground Pours

FR4 Substrates

Ground pours are important and help with noise immunity. Where possible, provide a 25% hatched ground on the same layer as the electrodes, keeping a gap between the ground pour and electrodes approximately 1 to 3mm. The entire backside should also be filled with the same 25% hatched ground. Avoid using a solid ground pour because it can increase the parasitic capacitance and decrease the sensitivity of the touchpad.

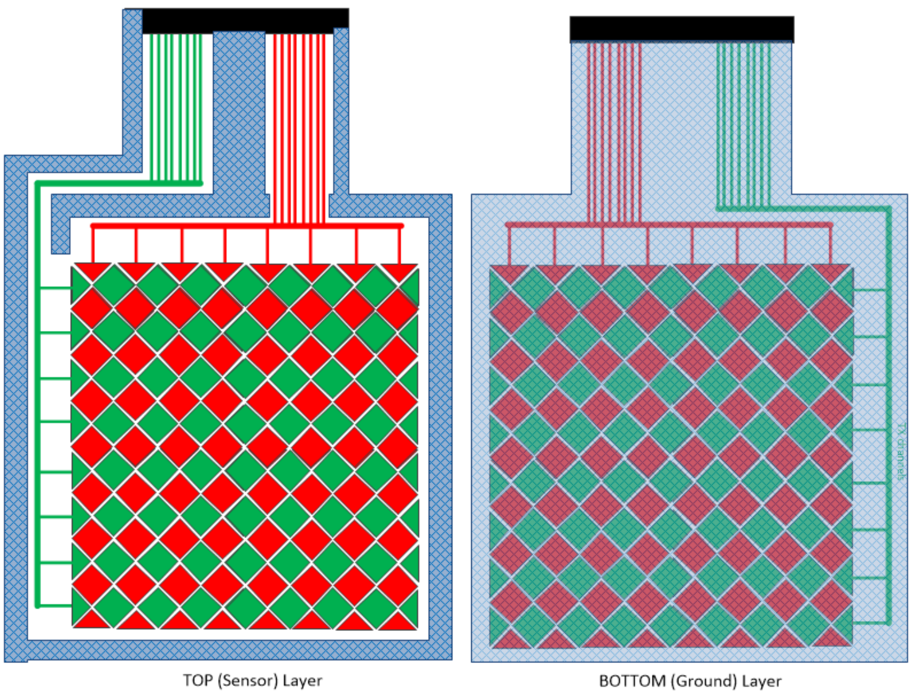
Here is an example layout for a 2-layer PCB with a 2x2 and 3x3 dual touchpad controlled by a single MSP430FR2633 device.



FPC Substrates

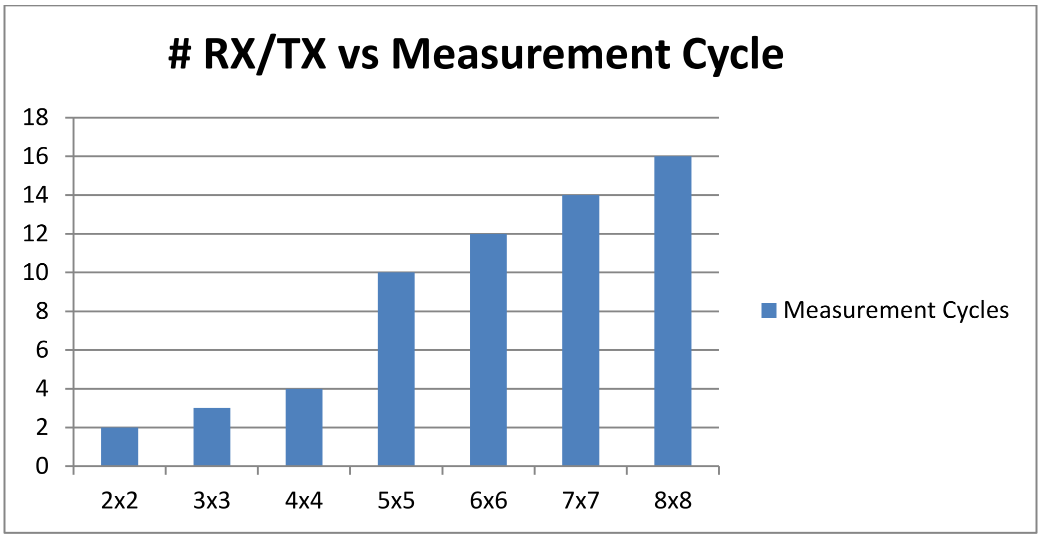
For FPC designs, the touchpad sensor is placed on the top layer, along with an optional hatched ground. The MCU can also be mounted on the FPC and is generally recommended when possible. Else the MCU can reside on the main PCB and connects to the sensor through the FPC tail and connector. When routing the flex circuit from the connector tail to the sensor electrodes it is important to prevent any unwanted interaction between the RX and TX signals. Grouping them apart from each other and providing a large air gap or ground pour between the RX and TX signals is recommended.

Adding a hatched ground is highly recommended, especially on the second layer underneath the traces and touchpad sensor. Note, because of the very small distance between the top and bottom layers on an FPC, the parasitic ground pour capacitance is much higher when compared to an FR4 PCB. For this reason use a 10% to 15% hatching. Optionally, include ground pour on the top layer, leaving a 1-3mm spacing between the sensor electrodes and the hatched ground pour.



Performance

Selecting the appropriate sensor configuration for an application is a balance between quality of measurement, system performance and power consumption. On MCUs with 16 CapTIvate IO pins, the CapTIvate peripheral can measure up to 4 channels in parallel during each measurement cycle. The 4x4 sensor is the optimal configuration because an entire sensor can be scanned in only 4 measurement cycles. For this reason, the 4x4 sensor configuration provides an excellent balance between responsiveness and power consumption, especially for smaller touchpads. For those applications that require higher resolution and accuracy, a larger sensor configuration is needed so be aware of the trade-offs.



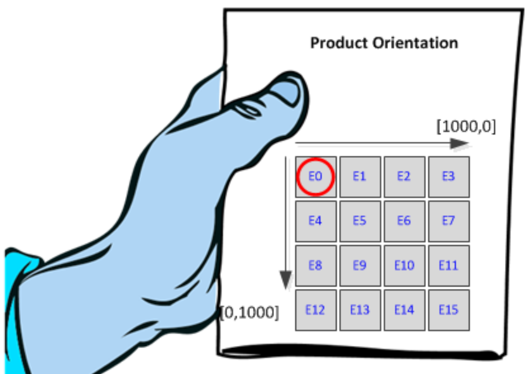
Configuration	#measurement nodes	# CapTIvate IO pins	Measurement Cycles	Measurement Time(1)
2x2	4	4	2	250us
3x3	9	6	3	375us
4x4	16	8	4	500us
5x5	25	10	5 + 5 = 10	1.25ms
6x6	36	12	6 + 6 = 12	1.5ms
7x7	49	14	7 + 7 = 14	1.75ms
8x8	64	16	8 + 8 = 16	2ms

(1) Conversion count = 250, F= 4Mhz, measurement time only (no processing), estimated

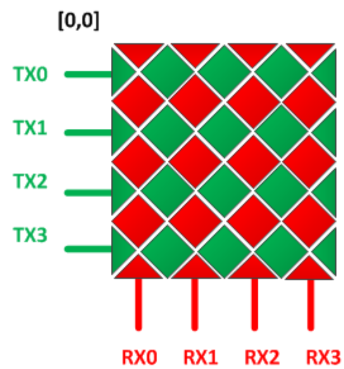
Touchpad Orientation

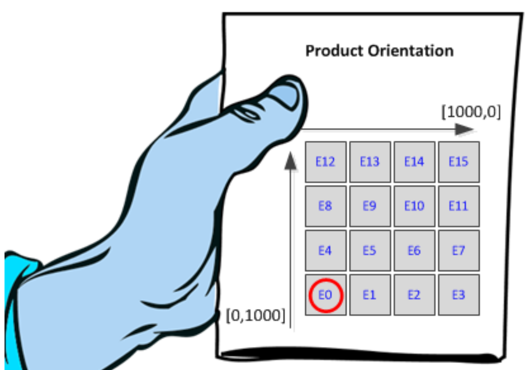
RX / TX Layout

Based on the desired product orientation, the typical touchpad origin is either in the upper left or lower left corners of the touchpad. This can be controlled by how the RX0...RXn and TX0…TXn touchpad PCB layout is assigned to each of the rows and columns of diamonds. The illustration shows how the RX/TX orientation corresponds to the touchpad orientation in the product and how the CapTIvate Software library will report position relative to the origin. The CapTIvate Design Center features a check box can be set to indicate the orientation.

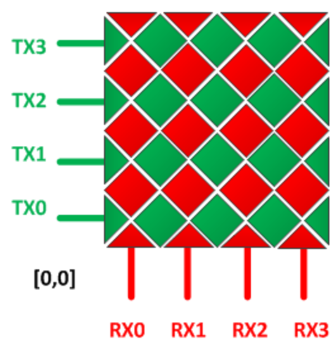


Upper Left Origin





Lower Left Origin



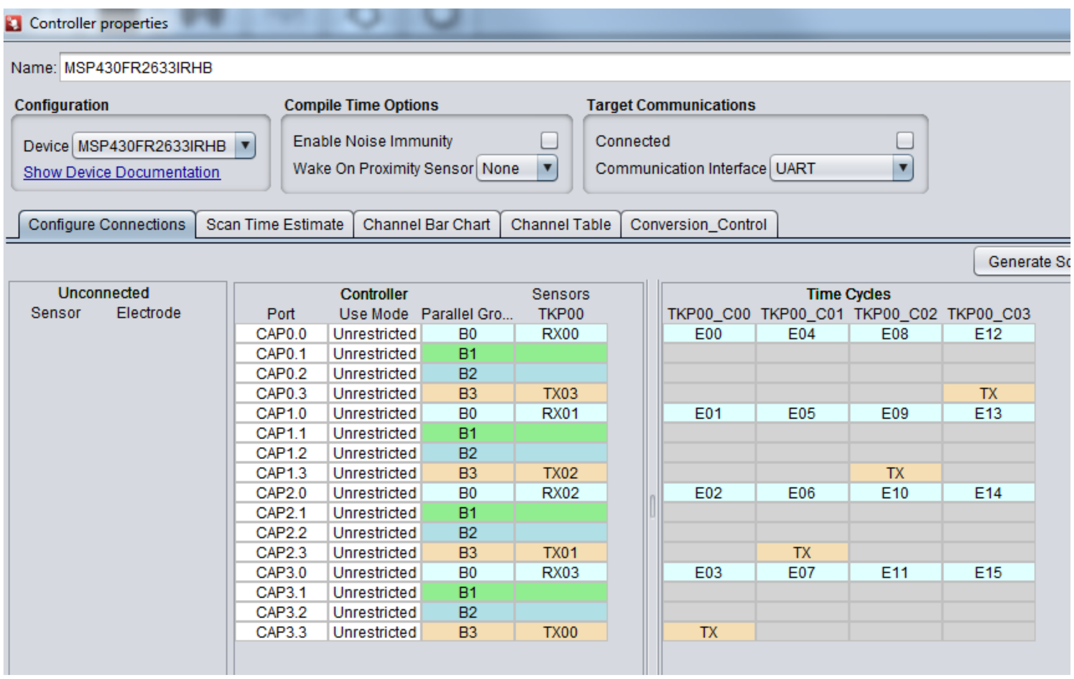
Touchpad Connections to MCU

As mentioned earlier, the MSP430FR2633 is capable of measuring 4 capacitive touch channels in parallel. Measuring channels in parallel improves throughput by minimizing the number of measurement cycles which improves responsiveness and lowers the power consumption.

RX / TX Channel Connections

When using the CapTIvate Design Center to create the initial touchpad sensor, the RX and TX pins will be automatically assigned in the most optimal configuration as illustrated below. You can see that each touchpad RX signal is assigned to the first pin on each of the CapTIvate measurement blocks and the TX pins are randomly assigned.

(For information about the CapTIvate Design Center and how to create a touchpad sensor, refer to the CapTIvate touchpad Quick Start Guide)



However, it is often the case that when performing the PCB layout based on the auto-assigned connections, the RX and TX traces will not be optimal for layout between the MCU and the touchpad sensor.

To work around this situation, the designer can route the RX and TX pins manually with some flexibility while following the same rules used by the CapTIvate Design Center. To help visualize the process, the following example of a 4x4 touchpad will illustrate the proper sequence to assign the RX channel connections between the touchpad and MSP430FR2633.

In this example, limitations on the PCB has forced the designer to configure the RX and TX connections manually as shown, rather than using the auto assigned connections in the CapTIvate Design Center. The designer follows these rules to select the appropriate pin and block combination. When complete, the designer must update the CapTIvate Design Center project to match these pin assignments in order for the software to properly measure the sensor electrodes.

Step #1 - Assign or connect sensor RX0 to any pin on CapTIvate measurement block CAP0.

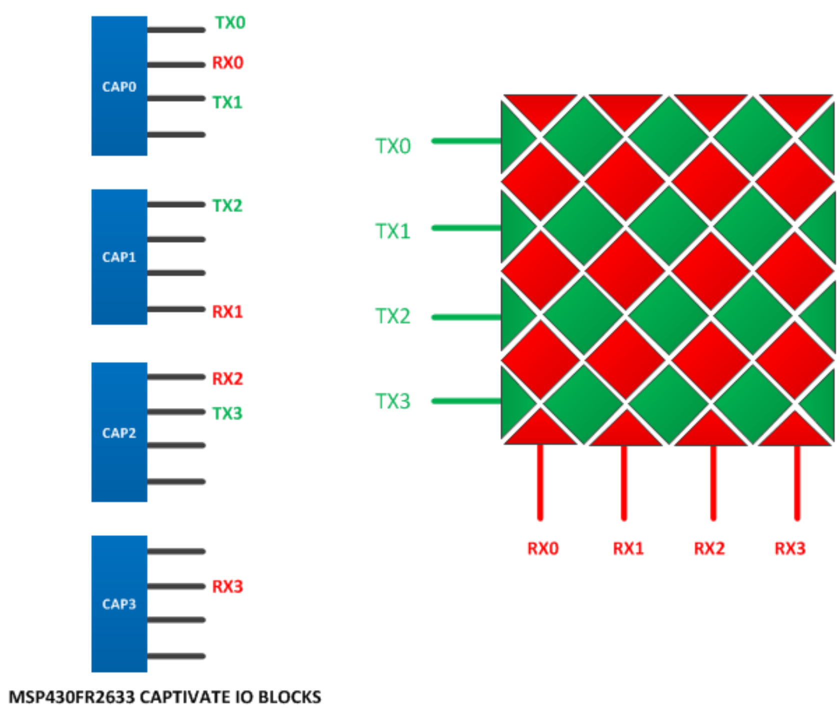
Step #2 – Assign or connect sensor RX1 to any pin on CapTIvate measurement block CAP1.

Step #3 – Assign or connect sensor RX2 to any pin on CapTIvate measurement block CAP2.

Step #4 – Assign or connect sensor RX3 to any pin on CapTIvate measurement block CAP3.

Step #5 – Assign or connect additional RX electrodes by repeating steps 1 – 4.

Step #5 – Assign or connect sensor pins TX0, TX1, TX2 and TX3 to any available pin on any of the measurement blocks.



Step #6 – Update CapTIvate Design Center project.

After the designer has updated the sensor and CapTIvate port assignments as shown here, notice that there are 12 measurement cycles instead of only 4.

	Controller		Sensors
Port	Use Mode	Parallel Gro...	TKP00
CAP0.0	Unrestricted	B0	TX00
CAP0.1	Unrestricted	B1	RX00
CAP0.2	Unrestricted	B2	TX01
CAP0.3	Unrestricted	B3	
CAP1.0	Unrestricted	B0	TX02
CAP1.1	Unrestricted	B1	
CAP1.2	Unrestricted	B2	
CAP1.3	Unrestricted	B3	RX01
CAP2.0	Unrestricted	B0	RX02
CAP2.1	Unrestricted	B1	TX03
CAP2.2	Unrestricted	B2	
CAP2.3	Unrestricted	B3	
CAP3.0	Unrestricted	B0	
CAP3.1	Unrestricted	B1	RX03
CAP3.2	Unrestricted	B2	
CAP3.3	Unrestricted	B3	

Time Cycles											
TKP00_C00	TKP00_C01	TKP00_C02	TKP00_C03	TKP00_C04	TKP00_C05	TKP00_C06	TKP00_C07	TKP00_C08	TKP00_C09	TKP00_C10	TKP00_C11
TX	TX	TX									
	E00			E04			E08			E12	
			TX	TX	TX						
						TX	TX	TX			
		E01			E05			E09			E13
E02			E06			E10			E14		
									TX	TX	TX
	E03			E07			E11			E15	

This is because there is one more step needed to assign the pins to parallel groups. Notice that RX0 and RX3 have the same colored cell and so these will be measured in parallel. RX1 and RX2 are in different colored cells and will be measured in a different measurement cycle. So the goal is to assign RX0-3 channels to same colored cell or parallel group. If using more than four RX electrodes, RX4-7 is assigned to a different color group and so on.

Step #7 – Assign R1 – RX2 to same parallel group (colored cell) as RX0 and RX3 by modifying the CapTIvate Design Center "Parallel Group" column accordingly. RX0 and RX3 are assigned to parallel group B1 (green), so assign RX1 and RX2 to the same. To switch the RX1 parallel group assignment, click on the parallel group cell and a drop down will appear. Select the B1 group. Repeat the same for RX2.

Configure Connections | Scan Time Estimate | Channel Bar Chart | Channel Table | Conv

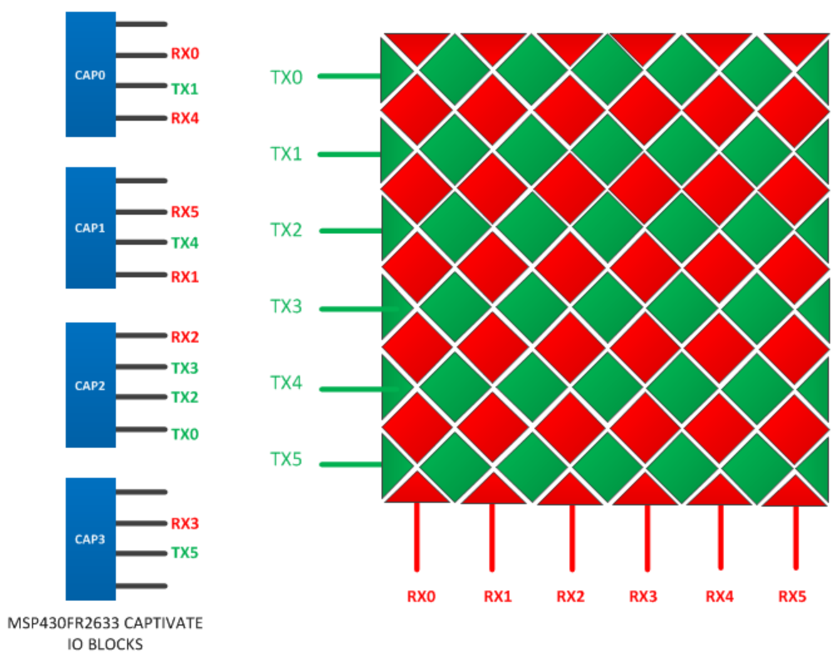
Unconnected
Sensor Electrode

	Controller		Sensors
Port	Use Mode	Parallel Gro...	Trackpad
CAP0.0	Unrestricted	B0	TX00
CAP0.1	Unrestricted	B1	RX00
CAP0.2	Unrestricted	B2	TX01
CAP0.3	Unrestricted	B3	
CAP1.0	Unrestricted	B0	TX02
CAP1.1	Unrestricted	B1	
CAP1.2	Unrestricted	B2	
CAP1.3	Unrestricted	B3 ▼ (B0 / B1 / B2 / B3)	RX01
CAP2.0	Unrestricted		RX02
CAP2.1	Unrestricted		TX03
CAP2.2	Unrestricted		
CAP2.3	Unrestricted		
CAP3.0	Unrestricted		
CAP3.1	Unrestricted	B1	RX03
CAP3.2	Unrestricted	B2	
CAP3.3	Unrestricted	B3	

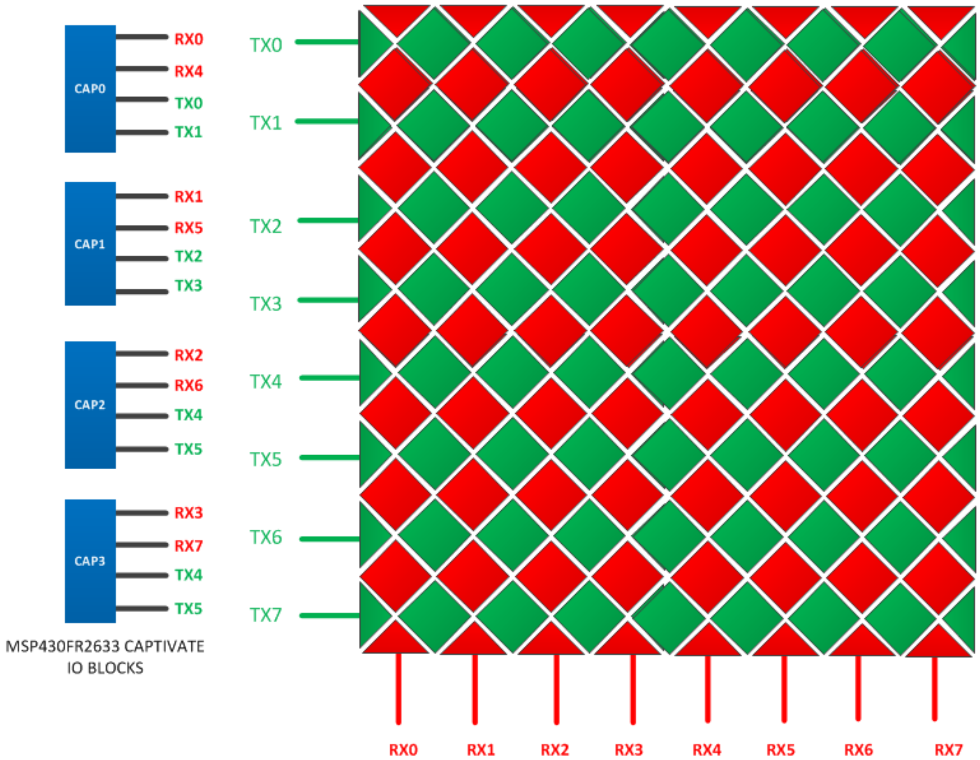
When complete, the number of measurement cycles reduces to 4.

Controller			Sensors	Time Cycles			
Port	Use Mode	Parallel Gro...	TKP00	TKP00_C00	TKP00_C01	TKP00_C02	TKP00_C03
CAP0.0	Unrestricted	B0	TX00	TX			
CAP0.1	Unrestricted	B1	RX00	E00	E04	E08	E12
CAP0.2	Unrestricted	B2	TX01		TX		
CAP0.3	Unrestricted	B3					
CAP1.0	Unrestricted	B0	TX02			TX	
CAP1.1	Unrestricted	B3					
CAP1.2	Unrestricted	B2					
CAP1.3	Unrestricted	B1	RX01	E01	E05	E09	E13
CAP2.0	Unrestricted	B1	RX02	E02	E06	E10	E14
CAP2.1	Unrestricted	B0	TX03				TX
CAP2.2	Unrestricted	B2					
CAP2.3	Unrestricted	B3					
CAP3.0	Unrestricted	B0					
CAP3.1	Unrestricted	B1	RX03	E03	E07	E11	E15
CAP3.2	Unrestricted	B2					
CAP3.3	Unrestricted	B3					

Touchpads with more than 4 RX signals repeat this pattern in Step #7 with RX4 assigned to block CAP0, RX5 assigned to block CAP1, etc.



Note the recommended RX pin assignment sequence for an 8x8 touchpad.



RX / TX layout guidelines

Signal Routing

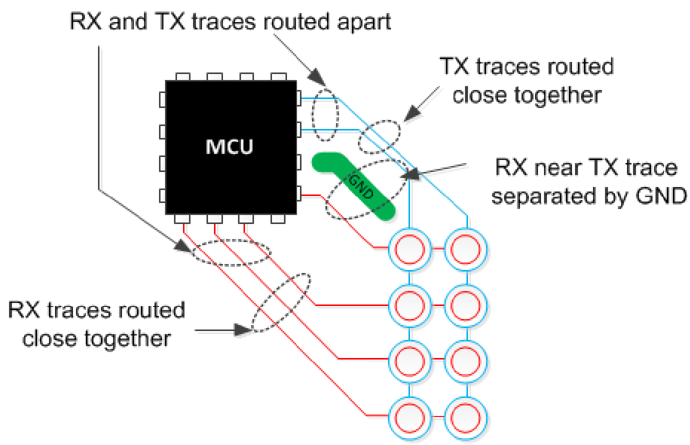
Touchpad electrodes are created by a junction or intersection of an RX and TX signal driven in mutual capacitive mode. Any place an RX signal runs near to a TX signal can create a touch artifact if a finger is placed in this area. To prevent these unwanted detections outside of the touchpad sensor area, it is very important to follow these rules.

Best Case:

- Do not route TX lines near RX lines (keep as far apart as possible)
- Where TX and RX must cross, make the crossing perpendicular on different layers
- Group TX lines together
- Group RX lines together

If no other options to prevent RX near TX:

- In some cases TX and RX must be routed near to each other. If RX and TX are parallel, either place a wide ground pour or grounded trace in between the signals. If this is not possible, a large air gap can also work.



Creating the Touchpad PCB Sensor

To minimize the burden of creating the touchpad diamond patterns, an open source 2D/3D rendering tool named OpenSCAD along with scripts provided by TI can be used to generate the diamond patterns. The output is a DXF file that can be imported into a CAD tool, such as Altium Designer, and converted to regions.

See Application Note SLAA891b - "Automating Capacitive Touch Sensor PCB Design using OpenSCAD Scripts.