Touch Solutions

AT13323: QTouch Smart Scan with Lumped Mode

APPLICATION NOTE

Introduction

The Peripheral Touch Controller features a Lumped Mode configuration which allows users to combine multiple sense channels together. This feature allows the designers to apply innovative strategies to implement user interface, improve response time and reduce power consumption.

This document provides guidelines to utilize the lumped mode feature in various applications. The associated package contains two example projects to demonstrate Smart Scan and Dynamic UI.

Features

This application note features the following topics

- Configuring Lumped Sensors
- Improved Response Time
- Improved Power Efficiency
- Dynamic User Interface

Table of Contents

1. Lumped Mode

In self capacitance method, each Y line is termed as a channel. In mutual capacitance method, combination of an X and a Y line is termed as a channel. To form a sensor key, a single channel is required and to create a rotor or slider three or more channels are required.

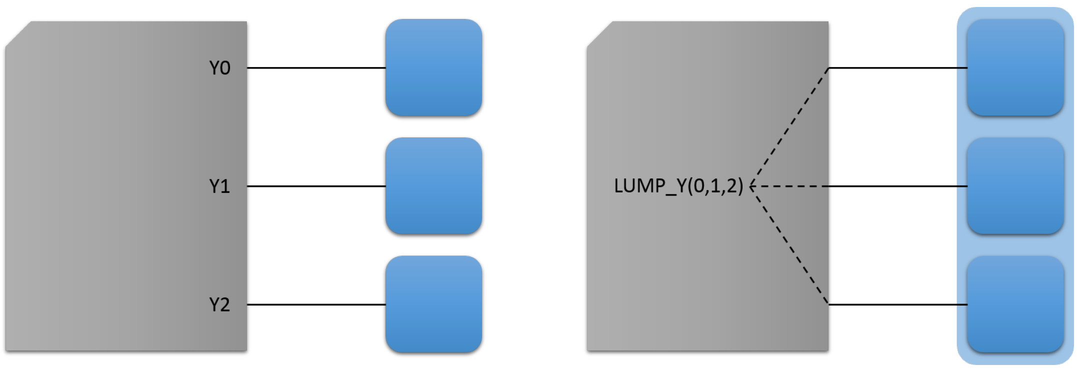
PTC features Lumped mode configuration that allows to combine or lump multiple physical Y lines to form an additional logical Y channel. This creates a new channel for self capacitance method. Similar to Y lines, it is also possible to lump multiple X lines. This allows to create new logical channels for mutual capacitance method as well.

This feature allows to merge multiple physical sensors and configure them as a single sensor. This kind of sensor is termed as Lumped sensor.

1.1. Lumped Sensor in Self Capacitance

In a self capacitance design, user needs to configure the Y lines that are combined together to form a lump sensor. In the following figure, we consider a system with three physical Y lines that are lumped to create an additional lump sensor.

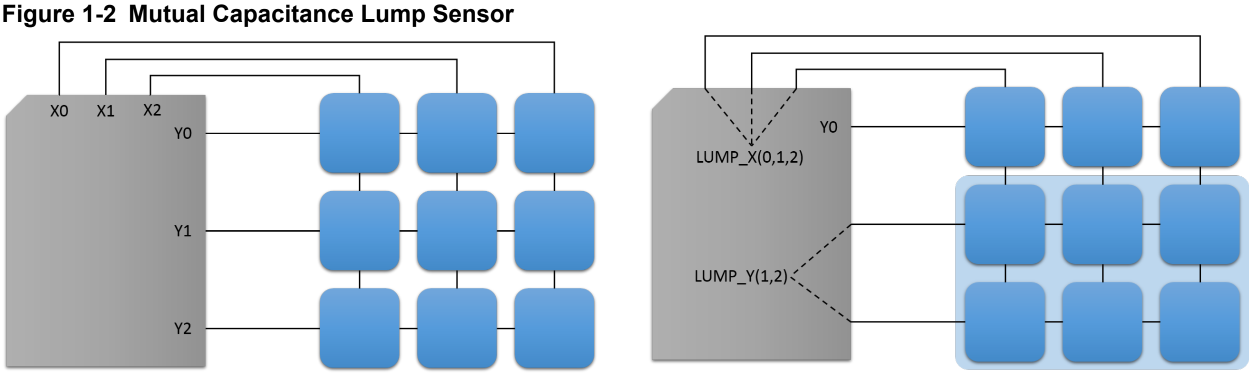
Figure 1-1 Self Capacitance Lump Sensor



1.2. Lumped Sensor in Mutual Capacitance

In a mutual capacitance design, the user needs to configure the X lines and the Y lines that are combined together to form a lumped sensor. In the following figure, we consider a system with three physical X and three physical Y lines, out of which three X and two Y lines are lumped to create and additional lumped sensor.

Figure 1-2 Mutual Capacitance Lump Sensor



2. Considerations before Implementing Lumped Mode

2.1. Compensation Circuit Saturation

The PTC compensation circuit limits the maximum sensor capacitance per channel. For reliable touch operation, it is important that the compensation circuit is not saturated.

Lumping multiple sensors leads to accumulation of sensor capacitance of multiple sensors on a single sensor channel. If capacitance is beyond the limits of the compensation circuit, it will result in calibration error.

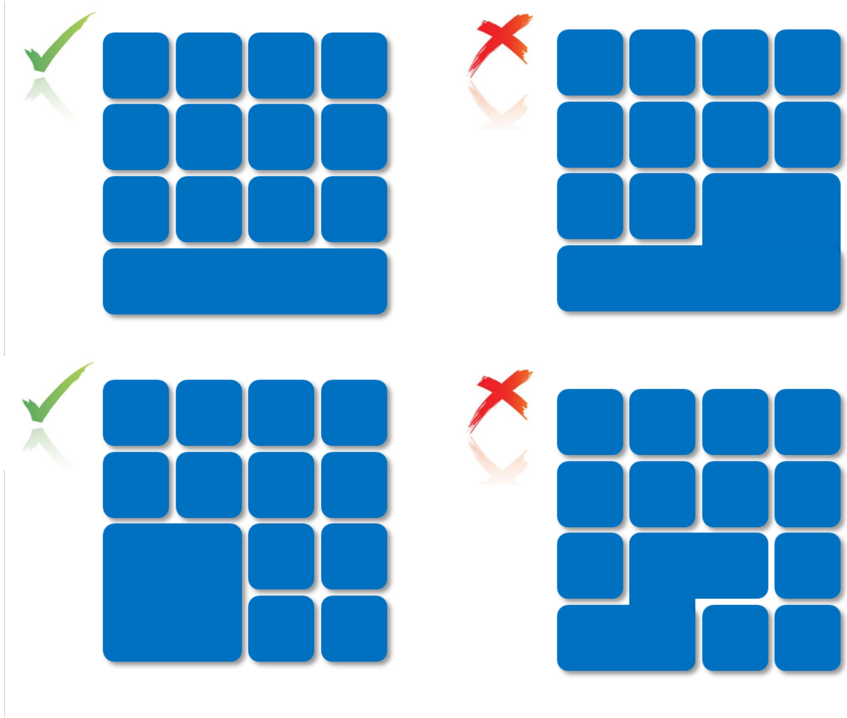
The CC calibration value helps to understand the effect of sensor capacitance of a channel on the compensation circuit. In QTouch® Library the CC calibration value is stored as a 16-bit unsigned integer. The compensation circuit is considered to be saturated if the CC calibration value is equal to 16382.

Important: It is recommended that the CC calibration value of any sensor channel does not exceed 15500.

2.2. Restricted Lump Sensor Configuration in Mutual Capacitance

Lumped mode feature only allows to lump multiple Y lines or multiple X lines. Thus, in mutual capacitance sensors, it is not possible to select any arbitrary group of sensor channels and make a lump sensor for them. The following figure illustrates restrictions on possible lump sensor configurations.

Figure 2-1 Lump Configurations



3. Configuring Lumped Sensors

The lumped sensors can be configured either manually or by using the QTouch Project Builder GUI.

3.1. Configuring Lumped Mode without GUI

The number of ways in which lumped sensors can be configured are only limited by the designer's imagination. The QTouch Project Builder might not be able to generate all possible sensor configurations. In such instances the sensor configuration needs to be done manually.

3.1.1. Self Capacitance Lumped Sensors

In self capacitance sensors, the Y lines for the lumped sensor should be defined as follows

```
LUMP_Y(Channel, Channel,...)
```

```
#define DEF_SELFCAP_LINES Y(0), Y(1), Y(2), LUMP_Y(0,1,2)
```

Lumped sensor has been defined as the 3rd channel, thus it is assigned as `CHANNEL_3`.

The sensor configuration should be done as follows:

```
touch_selfcap_sensor_config(SENSOR_TYPE_LUMP, CHANNEL_3, CHANNEL_3,
NO_AKS_GROUP, 40u, HYST_6_25, RES_8_BIT, &sensor_id);
```

3.1.2. Mutual Capacitance Lumped Sensors

X and Y lines for the lumped sensor should be defined as:

```
LUMP_X(Channel, Channel,...), LUMP_Y(Channel, Channel,...)
```

```
#define DEF_MULTCAP_NODES   X(0),Y(0), X(1),Y(0), X(2),Y(0), \
                            X(0),Y(1), X(1),Y(1), X(2),Y(1), \
                            X(0),Y(2), X(1),Y(2), X(2),Y(2), \
                            LUMP_X(0,1,2),LUMP_Y(1,2)
```

Lumped sensor node has been defined as the 10th channel above, thus it is assigned as `CHANNEL_10`.

The sensor configuration should be done as follows:

```
touch_multcap_sensor_config(SENSOR_TYPE_LUMP, CHANNEL_10, CHANNEL_10,
NO_AKS_GROUP, 40u, HYST_6_25, RES_8_BIT, &sensor_id);
```

3.1.3. Other Settings

Lump sensors are treated as additional sensors by the QTouch Library.

Thus, it is required to update the number of channels and sensors.

```
#define DEF_xxxxCAP_NUM_CHANNELS
#define DEF_xxxxCAP_NUM_SENSORS
```

3.2. Configuring Lumped Mode Using QTouch Project Builder

Lump sensors can be configured using the GUI by the following steps:

1. Sensor Selection.

1.1. Add buttons to represent the number of physical sensor channels.
1.2. Select the group of keys that are to be lumped.
1.3. Click on the Settings button and select Lump Sensor Group.

2. Pin Selection.
   2.1. In the Pin Selection stage, X/Y line Selection are to be done for the physical sensor channels only. No extra X or Y lines should be added for the lump sensors.
   2.2. The Channel Assignment can be only done for the physical sensor channels. Instead of Auto Assigning, it is better to perform the Channel assignment manually.

Tip: To remove a Lump Group, select all the sensors in the **Lump Group** and click the **Settings** button and select **Lump Sensor Group** as `LUMP_NONE`

Figure 3-1 Selecting Individual Sensors for Lump Sensor

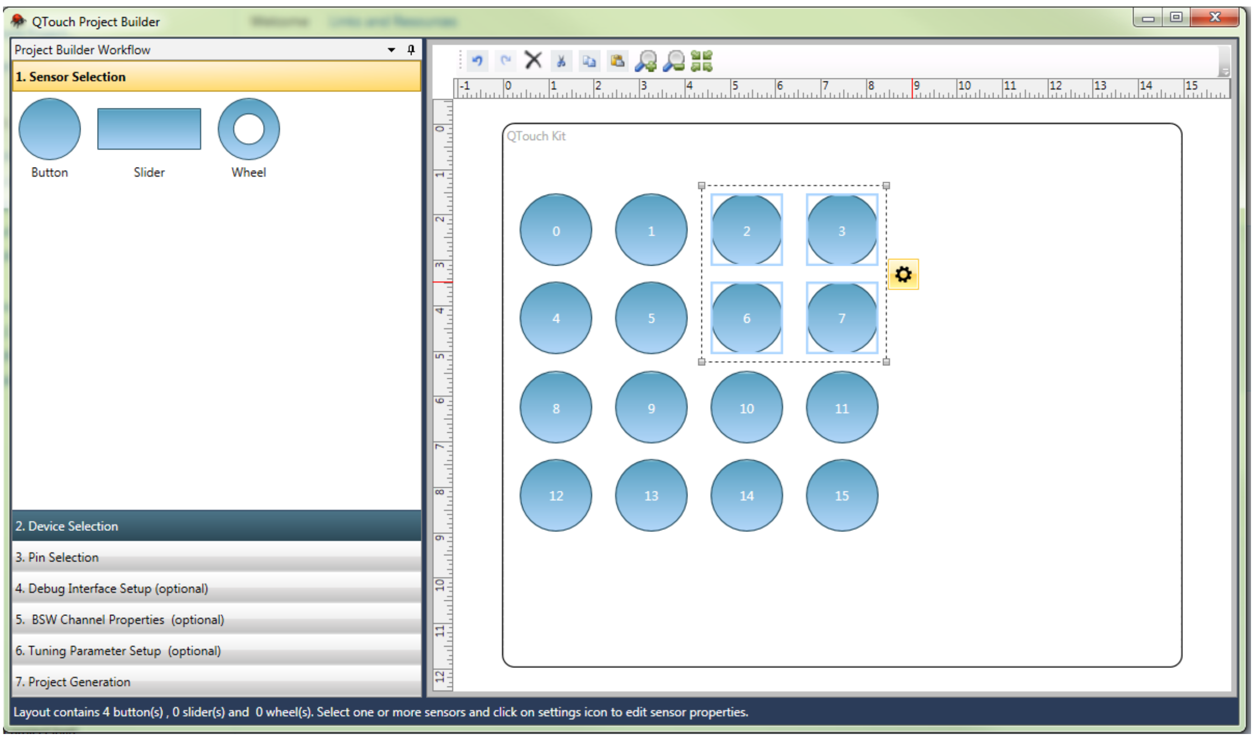


Figure 3-2 Lump Sensor Group Selection

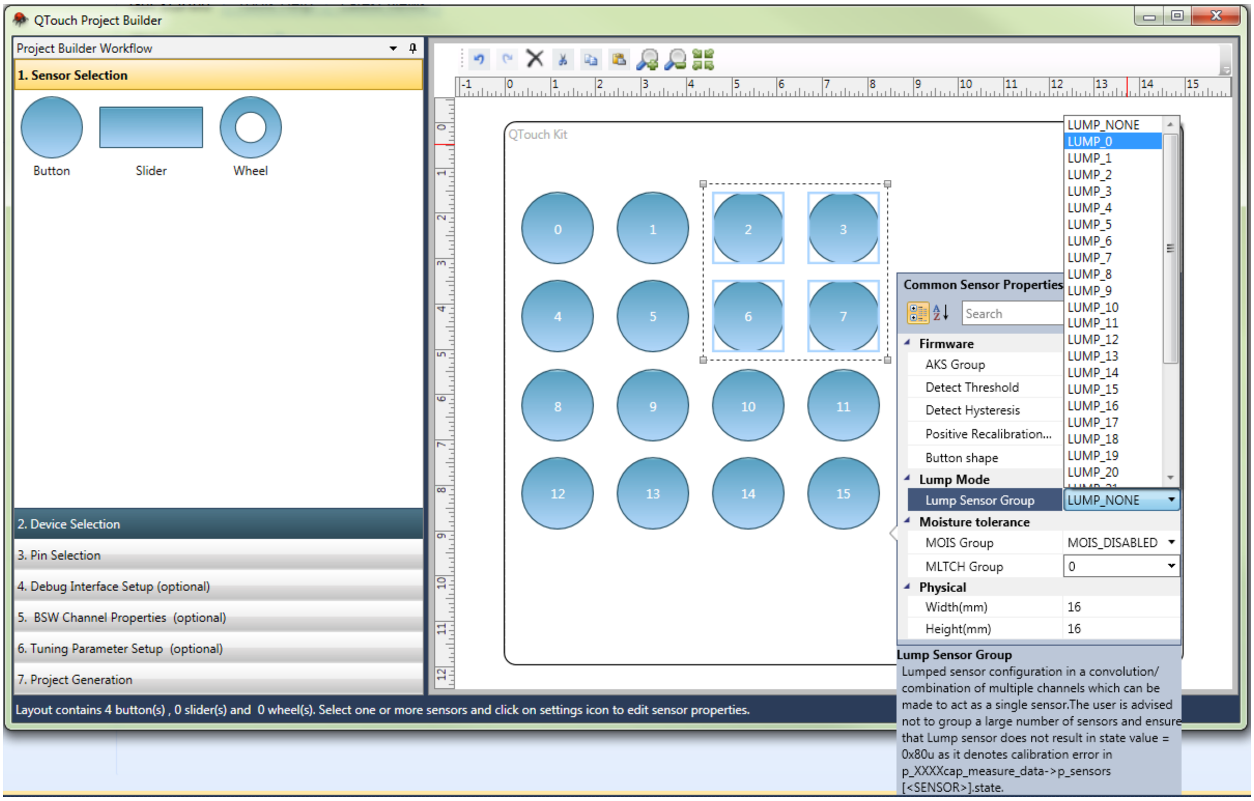
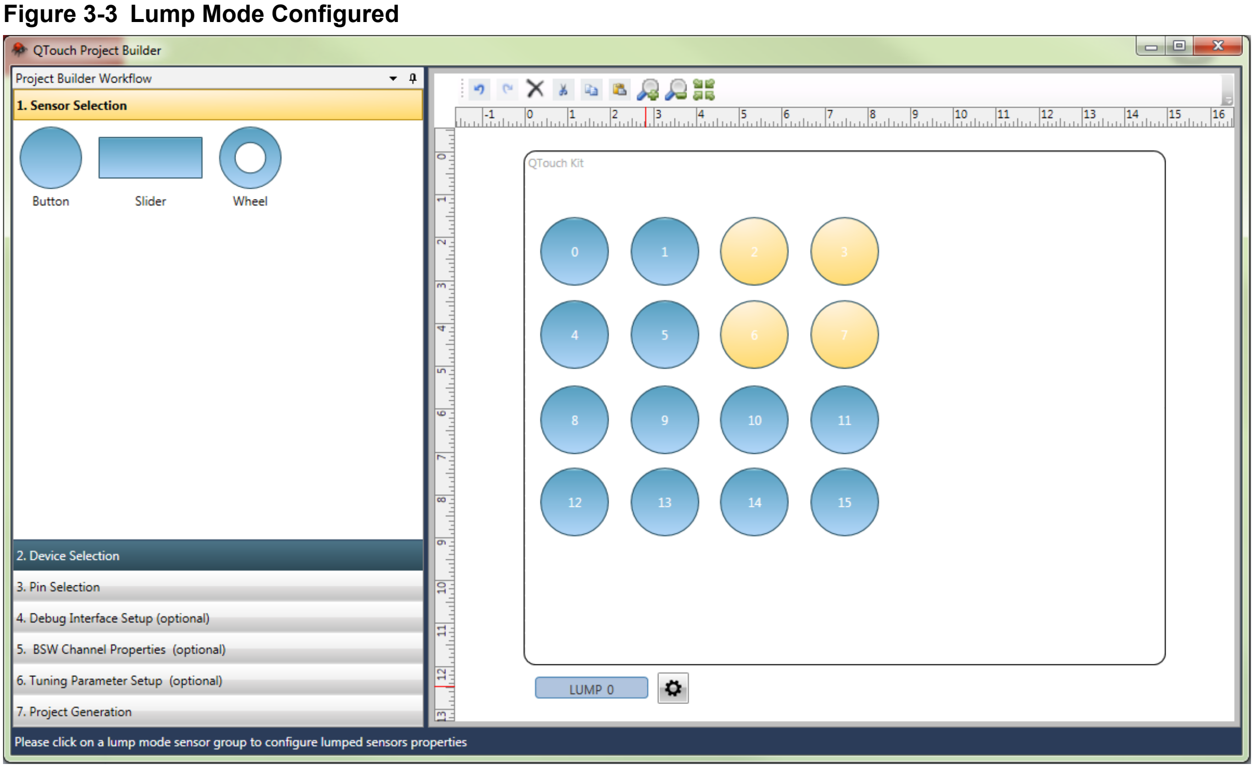


Figure 3-3 Lump Mode Configured



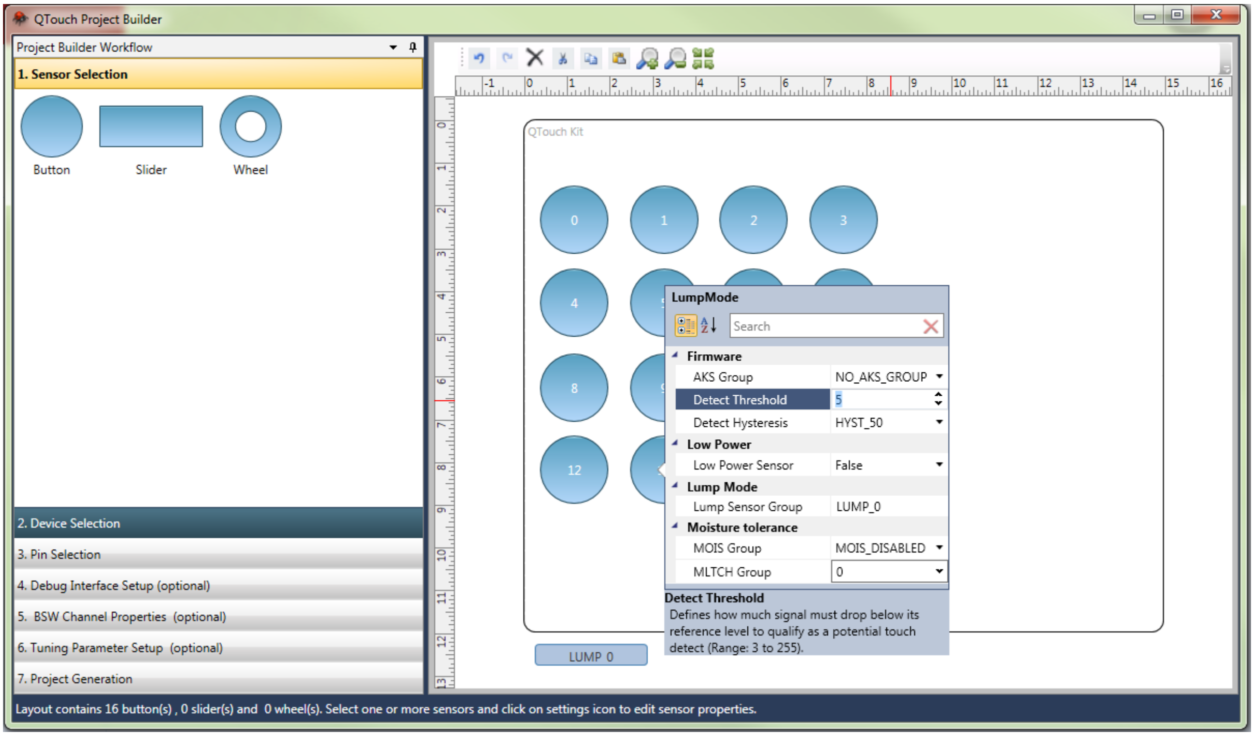
3.3. Tuning Lumped Sensors

Tuning procedure for lump sensor is similar to the tuning process for normal sensors.

3.3.1. Threshold Tuning

Detect Threshold and Detect Hysteresis can be set from the Project Builder GUI. These values are mentioned in the arguments to the `touch_xxxxcap_sensor_config()` function in the *touch.c* file.

Figure 3-4 Tuning Lumped Sensor Using QTouch Project Builder



3.3.2. Acquisition Parameter Tuning

The QTouch Library provides certain sensor specific features to influence the acquisition characteristics of the PTC for each sensor channel. For a well-tuned system, it is essential to have appropriate settings for the same. These parameters are available in the *touch.h* file.

- Gain

```
DEF_MUTLCAP_GAIN_PER_NODE
DEF_SELFCAP_GAIN_PER_NODE
```

- Pre-Scalar

```
DEF_MUTLCAP_CLK_PRESCALE
DEF_SELFCAP_CLK_PRESCALE
```

- Series Resistor

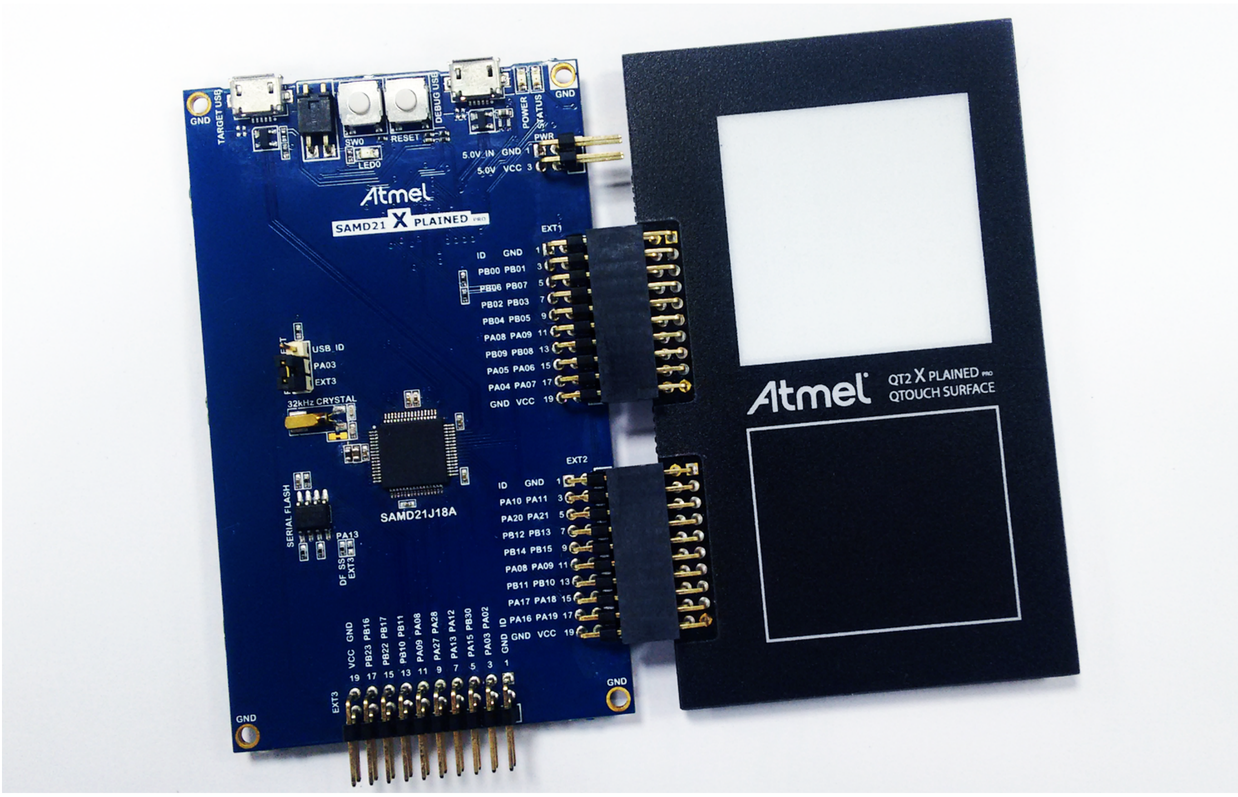
```
DEF_MUTLCAP_SENSE_RESISTOR
DEF_SELFCAP_SENSE_RESISTOR
```

Refer to Atmel® QTouch Library PTC User Guide for details.

4. Hardware Platform for Demo Firmware

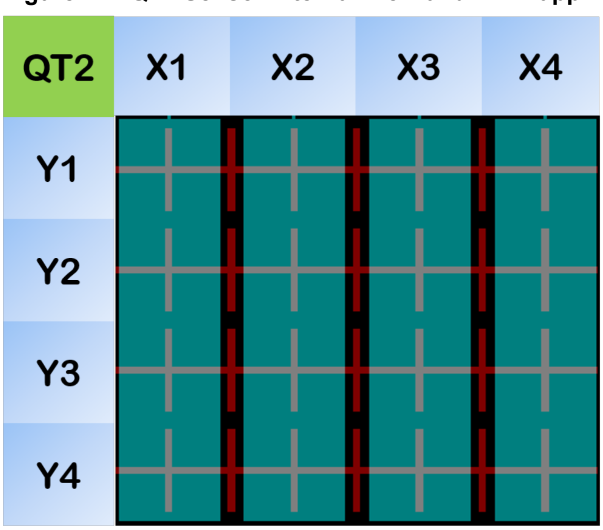
The demo firmware bundled with this application note uses SAM D21 Xplained Pro kit and QT2 Xplained Pro kit as the hardware platform. A detailed user guide for these kits are available at the Atmel website.

Figure 4-1 SAM D21 Xplained Pro connected with QT2 Xplained Pro



QT2 Xplained Pro kit is an extension board that enables the evaluation of a mutual capacitance touch surface using the Peripheral Touch Controller (PTC) module. The kit provides a 4 by 4 touch surface (16 mutual capacitance sensors) and a 7 by 7 blue LED matrix for a visual feedback.

Figure 4-2 QT2 Sensor Internal View and Pin Mapping with SAM D21 Xplained Pro



QT2 Xplained Pro	SAM D21 Xplained Pro
X1	X2
X2	X3
X3	X8
X4	X9
Y1	Y6
Y2	Y7
Y3	Y12
Y4	Y13

5. Lumped Mode for Improved Response Time

The PTC can perform acquisition only on a single sensor channel at a given time. Thus in a measurement cycle, each and every sensor channel needs its dedicated time for the acquisition to complete. Only when acquisition has been completed on all the sensors, the device proceeds to post processing stage, where it resolves the user interaction with sensors.

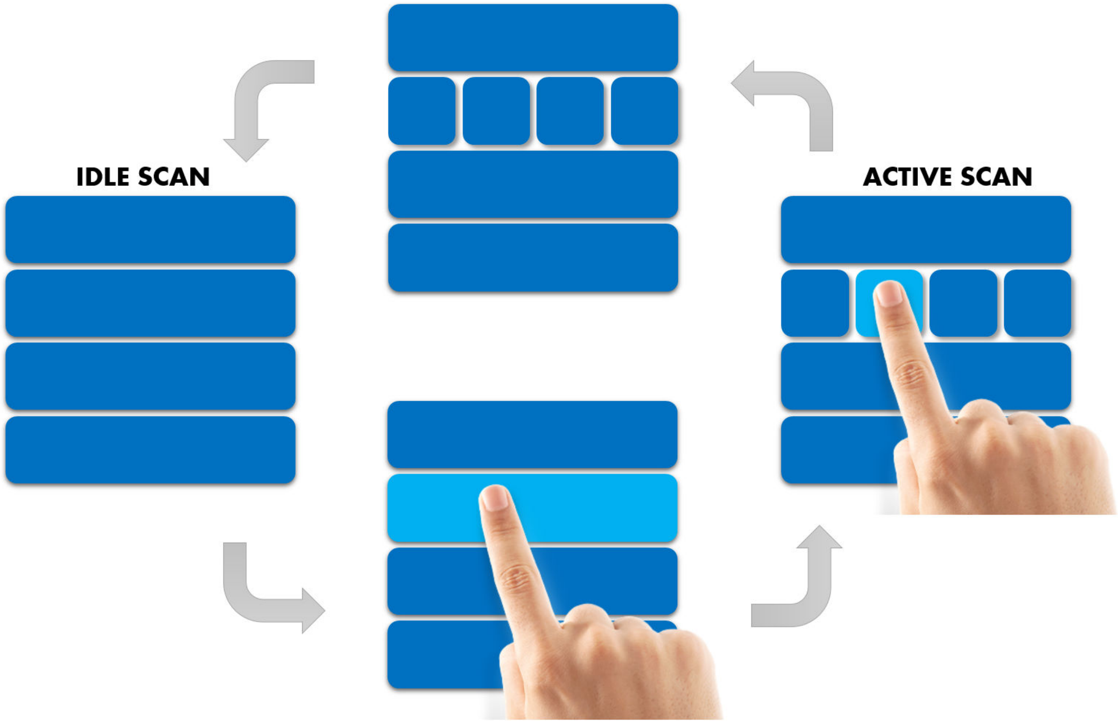
Although scan time for an individual sensor is very minimal, due to the sequential nature of the scan, it could introduce a significant latency in the touch detection process in applications which require a large number of sensors.

5.1. Smart Scan

Using the Lumped mode feature a scanning strategy can be deployed which will perform minimum number of scans to resolve touch on a particular sensor.

- All sensors in the design can be configured in to form multiple lump groups
- In an idle state, where there is no touch activity on the system, only the lump sensors can be enabled
- When touch is detected on a Lump sensor, it immediately enters active state. All individual sensors that form the Lump sensor can also be enabled.
- Once the touch is released, the individual sensors are disabled and the system returns back to idle state

Figure 5-1 Sensors in Smart Scan



5.2. Demo Firmware - Smart Scan

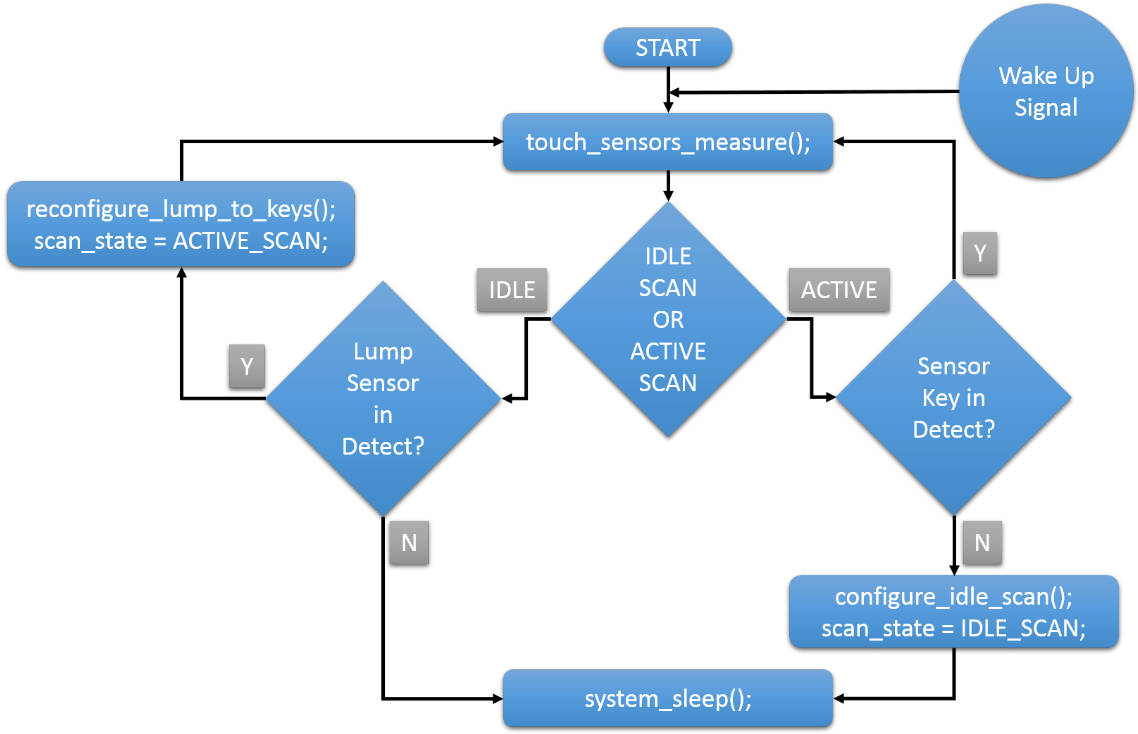
Each of the 16 sensors are linked with a corresponding LED to provide visual feedback. Touch activity can also be viewed using QTouch Analyser.

The 16 sensors on QT2 Xplained Pro extension board have been configured into four lump sensors. The configuration has been made with lumping the 4 X lines together, thereby forming four horizontal lump sensors with individual Y lines.

Touching anywhere on the sensor panel pushes one or more lumps into detect. The detect activity on the lump activates its constituent sensor keys. The corresponding LEDs for the keys in detect glow to indicate a valid touch detect.

The function `smart_scan()` is responsible for the intelligent sensor configuration based on the touch activity.

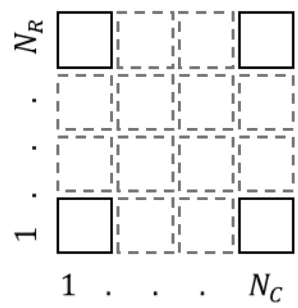
Figure 5-2 State Machine for Smart Scan Demo Firmware



5.3. Improvement in Response Time

In order to find the theoretical improvement in response time through the implementation of Smart Scan strategy let us consider a hypothetical touch panel.

Figure 5-3 Hypothetical Touch panel



Keys in the touch panel are arranged in a grid format. This touch panel has (N_R) number of rows and (N_C)number of columns, forming a rectangular grid of $(N_R * N_C)$ sensor keys in total.

In traditional scanning, the PTC needs to perform acquisition on all sensor channels to detect touch on a single channel. Thus total number of scans is equal to total number of enabled sensors.

$$\text{total number of scans} = \text{number of enabled sensors} = (N_R * N_C)$$

During Smart Scan, all the keys in a row are configured to form Lump sensor. Thus, the number of lump sensors will be equal to number of rows in the sensor grid. In the idle state, only the lump sensors are enabled and scanned.

$$\text{scans in idle mode} = \text{number of enabled lump sensors} = (N_R)$$

In case of a touch detect in one of the lumps, the system transitions to active mode. It will disables the lump sensor in detect and enables the sensors which form that particular lump sensor. The remaining lump channels are still kept on scan in order to detect any subsequent touch on the remaining part of the touch panel. The number of scans will be equal to the number of enabled sensors.

$$\text{scans in active mode} = \text{enabled lump sensors} + \text{enabled keys} = ((N_R - 1) + N_C)$$

The total number of scans required for a touch to be detected would be equal to the number of scans in idle mode and active mode.

$$\text{total number of scans} = \text{scans in idle mode} + \text{scans in active mode}$$

$$\therefore \text{total number of scans} = (N_R) + ((N_R - 1) + N_C) = 2N_R + N_C - 1$$

Considering an example of a 6x5 sensor panel, where $N_R = 6$ and $N_C = 5$

With traditional scan,

$$\text{total number of scans} = (N_R * N_C) = 6 * 5 = \boldsymbol{30}$$

With Smart Scan,

$$\text{total number of scans} = 2N_R + N_C - 1 = 2 * 6 + 5 - 1 = \boldsymbol{16}$$

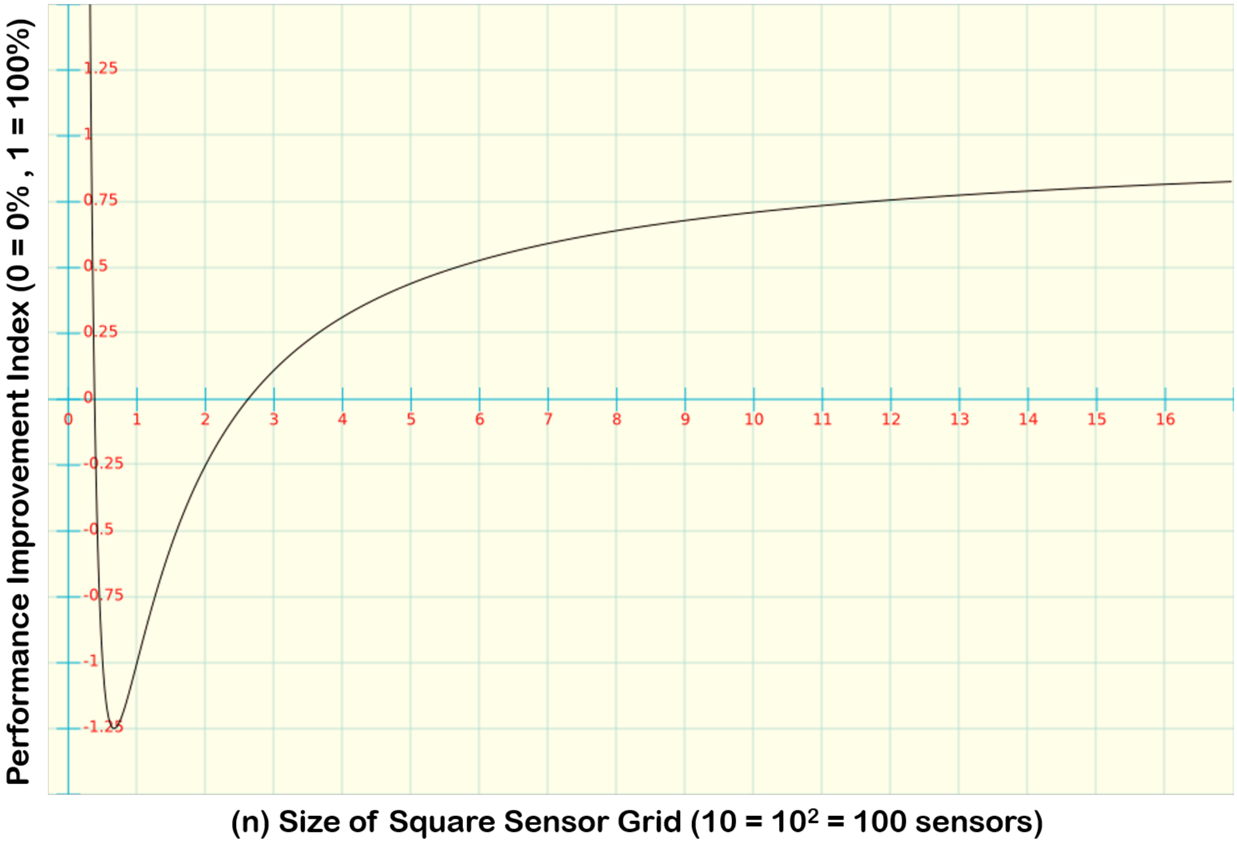
We can estimate the relative improvement in the system by the following formula

$$P_{relative}\left(N_R, N_C\right) = \frac{N_R N_C - (2N_R + N_C - 1)}{N_R N_C}$$

For the simplicity of graphical projection let us consider a square sensor grid $\therefore N_R = N_C = n$

$$P_{relative}\left(n, n\right) = \frac{n^2 - \left(3n - 1\right)}{n^2}$$

Figure 5-4 Graph Plot for relative improvement in response time with Smart Scan



We can observe a dramatic improvement in the relative response time Smart Scan strategy as the number of keys increase in the system. For example, a touch panel with 36 keys, in a 6x6 configuration we can observe an improvement of more than 50% in the response time.

5.4. Further Adaptations with Smart Scan

The demo firmware provided along with this application note implements the basic Smart Scan strategy. There can be some additional further adjustments done in the strategy to improve response time and user experience even further. However, these modifications would be somewhat specific to the end application.

5.4.1. Distributed Drift Compensation

Signal measurement in capacitive touch sensors are affected by environmental changes of temperature and humidity. Drift compensation in the QTouch Library allows for the Reference tracking, thereby adjusting the system for the gradual environmental changes.

Smart Scan strategy keeps the sensors disabled until they are required. However, the drifting feature is only applicable to the enabled sensors. Thus, implementation of Smart Scan can lead to signal offsets, which can cause issues such as stuck-on and false detects. To overcome such issues it is desirable to enable all the sensors at periodic intervals to allow drifting.

Applications with large number of sensors in the system can take significant time for performing acquisition on all the sensors in a single scan cycle. If a user interacts with the system during this phase, it is likely that they will observe a high latency in the touch response.

An improved strategy would be to perform the drift compensation for all the sensors in a distributed manner. Instead of enabling all the sensors simultaneously, only one sensor can be enabled along with the lumps during the idle scan. The currently enabled sensor can be disabled and the next sensor can be enabled for the next idle scan cycle. This process can be continued till all sensors have been subjected to drift compensation. After the last sensor has been compensated, this cycle can be repeated again starting from the first sensor.

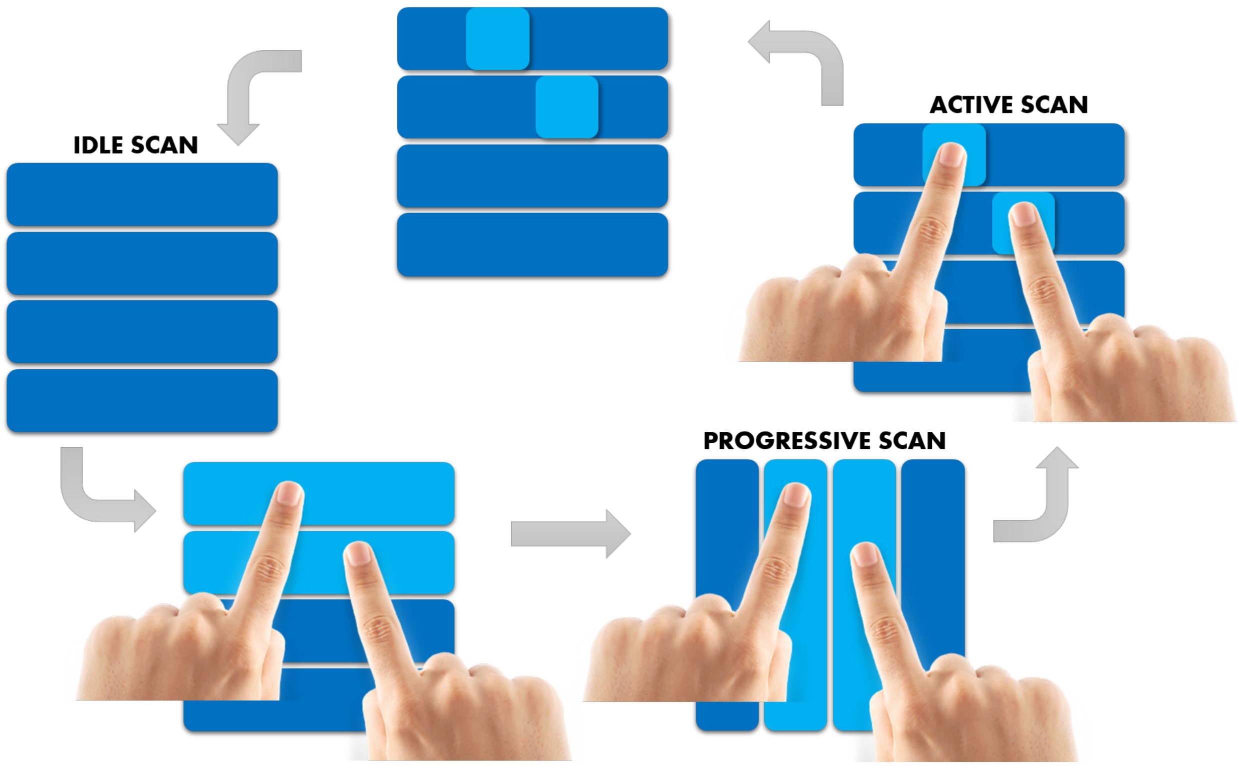
5.4.2. Augmented Smart Scan

Another improvement can be added to the Smart Scan strategy to further improve the response time. Instead of moving to active scan from the idle scan directly, there can be a progressive scan. In idle scan, we divide the sensor panel into many horizontal lump sensors (X Lumps).

In progressive scan, we can re-configure the sensor panel as a combination of many vertical lump sensors (Y Lumps). Scanning of horizontal and vertical lumps will exactly provide the nodes in detect. At this point, only the required sensors can be enabled and scanned for confirmation of touch. No need to enable all the individual sensors that form a lump sensor.

This strategy could be useful in applications where frequent multi-touch is expected.

Figure 5-5 Sensors in Augmented Scan



6. Lumped Mode for Improved Power Efficiency

The power consumption for capacitive touch increases almost linearly with increase in the number of sensors channels. Using the Lumped Mode feature, several sensor channels can be combined together to form a lumped sensor. This effectively reduces the number of sensor channels that need to be scanned in a particular measurement cycle.

6.1. Power Consumption Improvement with Smart Scan

When implementing the Smart Scan strategy, only a limited number of sensor channels are enabled and scanned during each measurement cycle. In addition to improvement in reponse time, it also results in major power savings.

6.2. Lumped Sensor in Low Power Mode

Low Power mode utilizes the SleepWalking feature to perform capacitive touch sensing autonomously on a single sensor channel. A Lumped sensor can be configured as a Low Power Sensor.

Refer to the application note AT12405: Low Power Sensor Design with PTC for details.

Figure 6-1 Configuring Lump Sensor as Low Power Sensor Using QTouch Project Builder

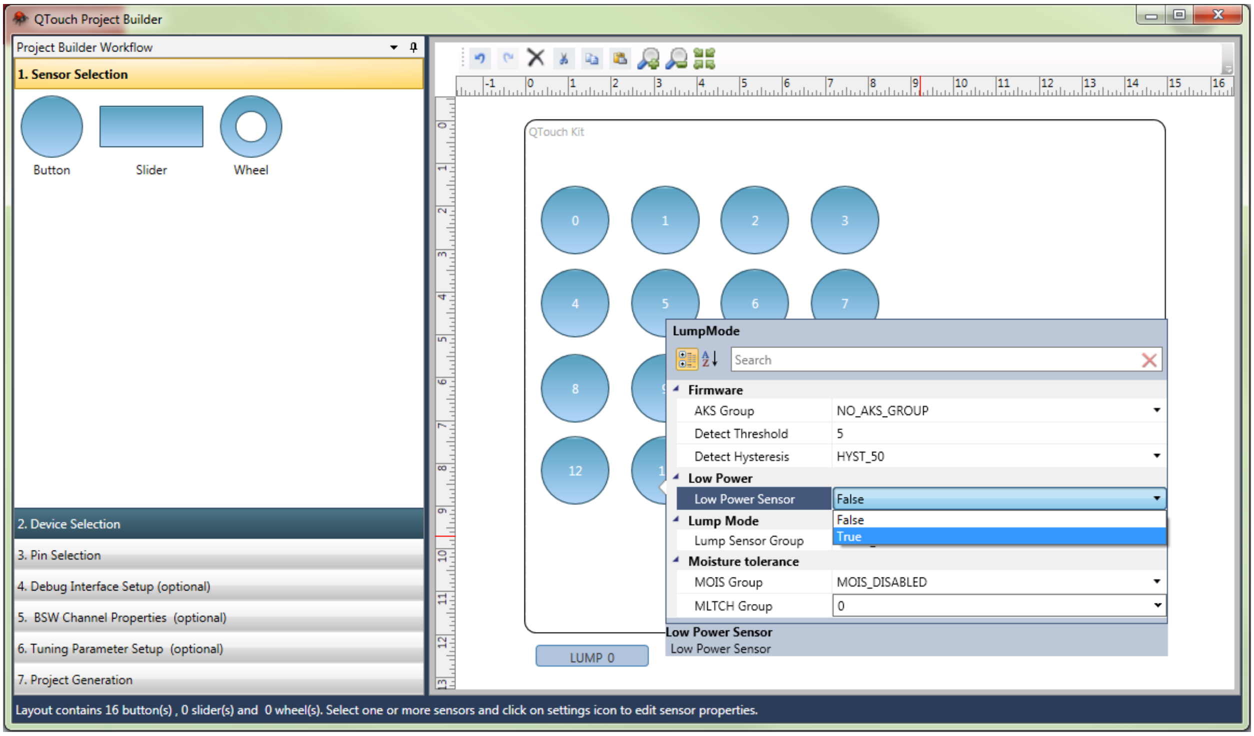
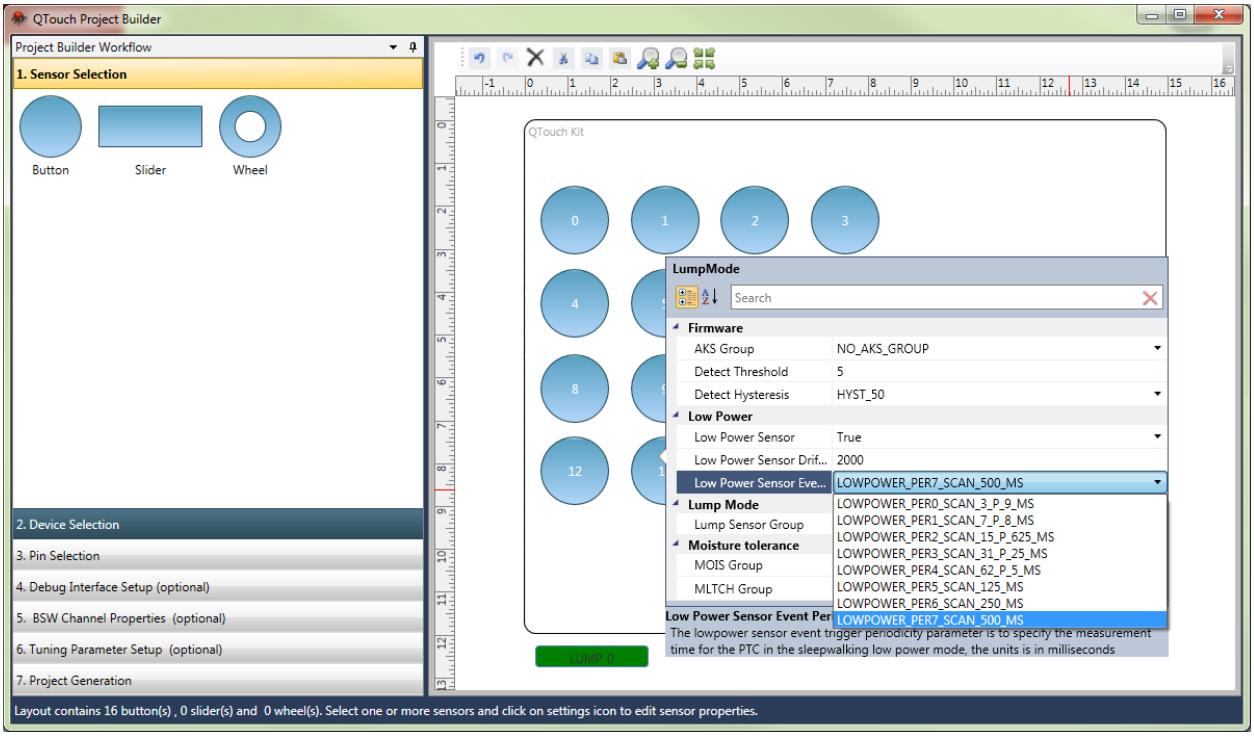


Figure 6-2 Adjusting Scan Rate of Low Power Sensor Using QTouch Project Builder



7. Lumped Mode for Dynamically Configurable User Interface

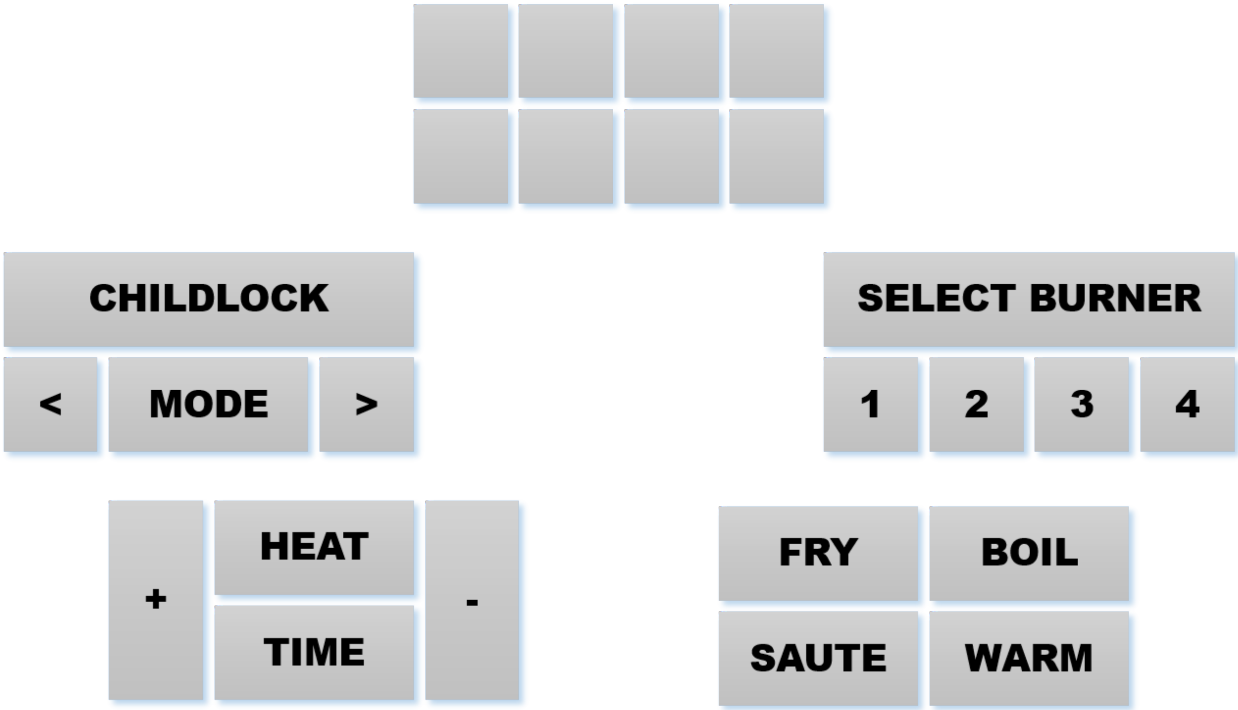
The Lumped Mode feature enables designers to create some interesting user interface applications which require sensors to vary their size dynamically as per UI requirements.

The sensors can be designed on a transparent ITO layer and placed over a graphic LCD screen. As the user performs actions on the touch panel, the on screen graphics change accordingly.

7.1. Use Case for Lumped Mode User Interface

The following image provides a use case example that could be implemented in a cook-top input interface.

Figure 7-1 Dynamic User Interface



A total of eight physical sensor channels form the sensor panel. Lumping the same eight physical sensors can be reconfigured to create different logical sensors based on the functions that are needed in the current state.

7.2. Demo Firmware - Dynamic UI

In this demo, the sensor channels have been configured as four small lump groups, as indicated in SCREEN 7, as the smallest building block of the UI. All other lumps can be imagined as combinations of these sensors. In total, there are nine different lump sensors that have been formed using the 16 channels.

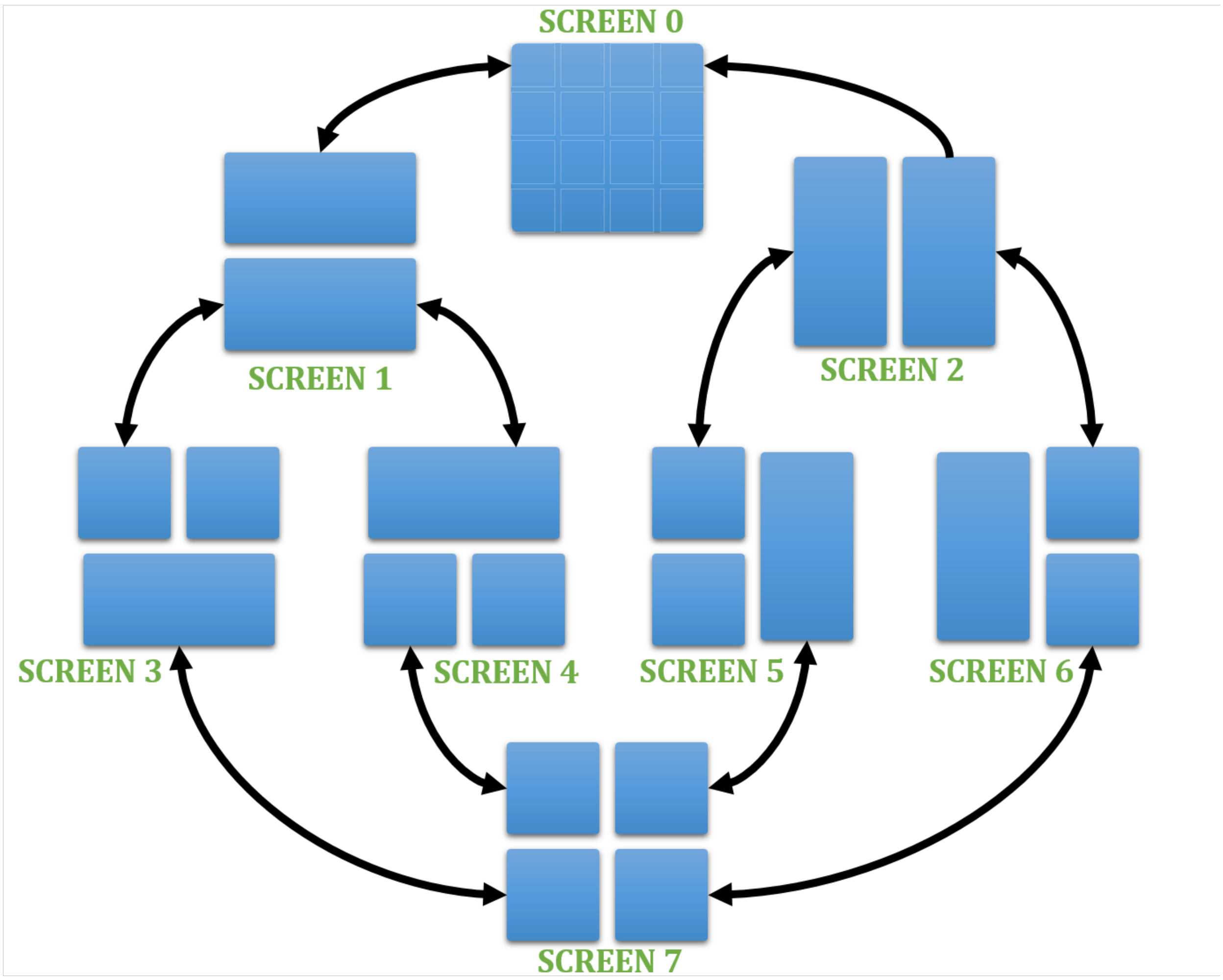
Each lump sensor has a unique LED combination, which intuitively represents the lump sensor in the LED screen. There is activity in the LED screen to indicate breaking or merging of the lumps.

The dynamic configuration action is triggered by a long press to sensors as follows

- Touching a bigger lump for some time will split it into two smaller lumps.
- Simultaneously pressing two smaller lumps, for some time, will merge the smaller lumps into one bigger lump.

The firmware supports eight screen modes, which are illustrated in the following image.

Figure 7-2 Screen Modes in Demo Firmware



8. References

QTouch Library Peripheral Touch Controller – User Guide

http://www.atmel.com/Images/Atmel-42195-Qtouch-Library-Peripheral-Touch-Controller_User-Guide.pdf

Atmel SAM D21 Xplained Pro – User Guide

http://www.atmel.com/images/atmel-42220-samd21-xplained-pro_user-guide.pdf

Atmel QT2 Xplained Pro – User Guide

http://www.atmel.com/Images/Atmel-42369-QT2-Xplained-Pro_User-Guide.pdf

AT12405: Low Power Sensor Design with PTC

http://www.atmel.com/Images/Atmel-42441-Low-Power-Sensor-Design-with-PTC_ApplicationNote_AT12405.pdf

9. Revision History

Doc Rev.	Date	Comments
42533A	09/2015	Initial document release.

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