SAM D20 QTouch Robustness Evaluation Kit

Part Number: **ATSAMD20-QTRDEMO**

The SAM D20 QTouch Robustness Evaluation kit demonstrates the high capacitive touch performance of the Peripheral Touch Controller (PTC) while achieving best-in-class conducted immunity and moisture tolerance required in home appliance and industrial applications.

The demo is part of the QTouch Safety Platform, key features of the QTouch Safety Platform are:

- IEC 61000-4-6 10V Conducted Immunity tolerant QTouch Safety Library
- Ships with IEC/UL 60730 Class B certified QTouch Safety Library firmware
- Advanced noise and moisture countermeasures – adjustable for any environmental conditions
- FMEA support
- Fast response time

Contents

- SAM D20 QTouch Robustness Demo kit
- USB TypeA/MicroB cable 1.5m

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APPLICATION NOTE

AT09363: PTC Robustness Design Guide

Atmel QTouch

Introduction

Capacitive touch interfaces are increasingly becoming popular in all electronics goods. To seamlessly integrate with wide variety of appliances the capacitive touch interfaces must exhibit robust operation.

The Peripheral Touch Controller (PTC) is a hardware module providing high touch performance while achieving best-in class noise immunity, moisture tolerance, and faster response time. This document describes the guidelines, tips, and tricks to improve the robustness of PTC based touch designs.

Features

- Factors affecting noise performance, moisture tolerance, and response time
- Hardware design considerations
- Tuning guidelines

Table of Contents

1 Overview

Capacitive touch interface needs to perform under challenging conditions like noisy environment, exposure to moisture, varying temperatures. This requires the capacitive touch interface to comply with stringent EMC standards.

This document describes methods to achieve:

- High Noise Immunity
- Moisture Tolerance
- Fast Response Time

1.1 Practical Challenges

Noise immunity, moisture tolerance, and response time performances are inter-dependent on each other. Increasing the noise immunity has an adverse effect on the response time. Designing for higher moisture tolerance can reduce noise performance. To achieve faster response time, requires minimum time for touch acquisition and signal post processing that affects the moisture tolerance and noise immunity of the system.

Thus it is required that touch design follows the guidelines to achieve the best combination of the robustness features.

2 Noise Immunity

Noise immunity simply refers to a product's immunity to unwanted 'noisy' voltages and currents. The source of this unwanted noise can include RF transmitters, switched-mode power supplies, other interconnected devices that have electronic activity in RF range, electrostatic discharge (ESD), lightning, supply voltage fluctuations, load switching, etc. The electronic systems are expected to work reliably under these noisy conditions.

There are test standards that duplicate the behavior of the above said noises and check whether the system operation is predictable. These standards are generally called as "Electromagnetic Compatibility (EMC) Standards". The EMC standards comprises of numerous standards for different types of noise sources.

2.1 EMC Standards

This section provides an overview of few typical EMC test standards to which capacitive touch interfaces are subjected.

2.1.1 IEC 61000-4-2 – Immunity to Electrostatic Discharge (ESD)

ESD refers to a sudden flow of current between two charged object due to static electricity. In general this current is very high and can cause permanent damage to the microcontroller. The main sources of ESD are plug-and-play electronic devices, human contact, etc.

In general, touch applications are touched through a touch panel which is made of dielectric material. So, the touch applications are inherently protected from ESD. Some special attention should be given if the expected ESD stress level is more than the breakdown voltage of the touch panel or if the circuitry is not completely covered by the enclosure.

2.1.2 IEC 61000-4-4 – Immunity to Electrical Fast Transients (EFT)

EFT occurs when a gaseous discharge occurs when opening a switch through which current was flowing. The effect of the transient discharge is huge if the conductor was carrying huge amount of current. The EFT couples with the cables which are closer in proximity and travels on the line until it finds a discharge path.

This charge lasts only for a short duration (in the order of few nanoseconds (ns)). Touch applications are expected to operate normally without any false detect during the test.

2.1.3 IEC 61000-4-5 – Immunity to Surge Voltage

Enormous amount of charge gets formed on the transmission lines when lightning hits transmission lines. This charge gets distributed throughout the line and redirected to earth at various stages. There are cases where this charge is observed even on the main supply of houses. The amount of charge is huge and it is equivalent to a few Kilo-Voltage (KV). Similar kind of charge (with lesser amplitude) gets formed on the lines when huge load is disconnected from the supply in industries or in power-grids.

The charge takes time, in the order of few micro-seconds (µs) to get discharged. Touch applications are expected to operate normally without any false detect during the test.

2.1.4 IEC 61000-4-6 – Immunity to Conducted Disturbances

Conducted noise will generally be in common-mode (CM) and appear across all connecting cables to a device.

Capacitive touch applications are generally not affected by CM noise until human interaction takes place. This is because the power supply lines maintain a stable difference between VDD and GND and as no return path is provided to the noise source reference(usually EARTH), the circuit functions normally.

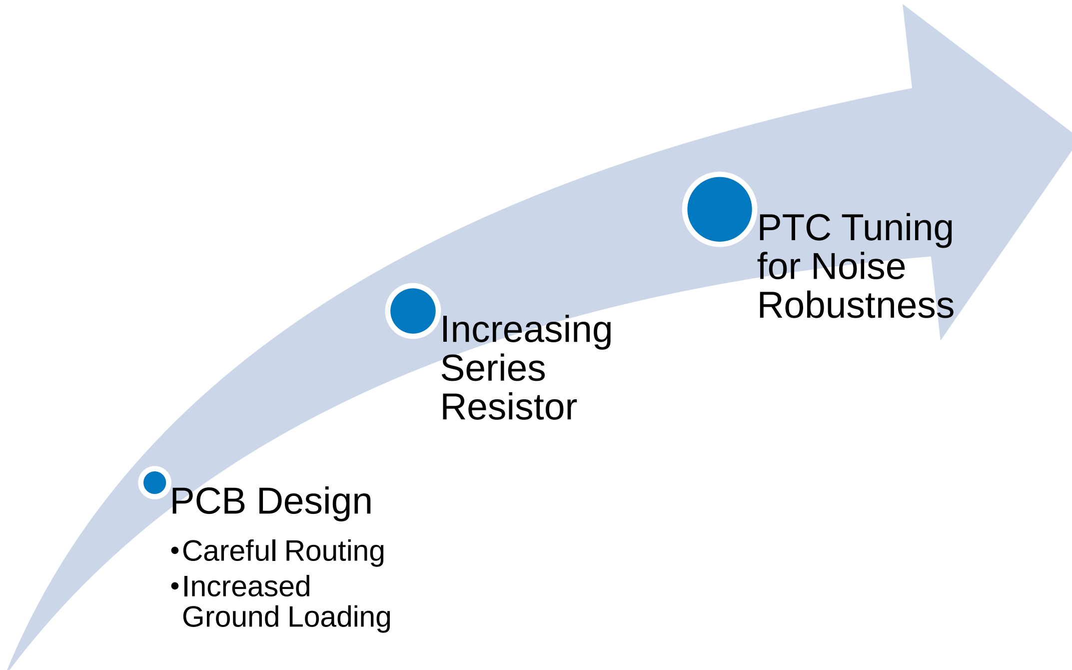
Once human interaction takes place, however, the user's finger now provides a return path and effectively couples noise directly into the capacitive sensor. When this noise reaches levels where normal filtering algorithms become ineffective, errors are introduced into the touch acquisition and the system becomes unreliable. This can manifest itself by way of no touch detect, false detect or in some cases, a complete system lock-up.

2.2 Improving Noise Immunity

To apply suitable techniques and address the effects of unwanted noise disturbances, it is important to understand the environment in which the touch application needs to operate. The noise immunity of a system can be increased significantly by complying with the recommended guidelines throughout the different phases of a design cycle.

Following aspects need careful attention as they can directly affect noise performance:

- Schematic Design
- PCB Design
- Optimizing Series Resistor
- Enclosure
- PTC Configuration



2.2.1 Schematic Design

2.2.1.1 External Series Resistor Sense Lines

Use at least 1kΩ external series resistor closer to the MCU pin on the sense lines for both self-capacitance and mutual-capacitance sensors as shown in Figure 2-1 and Figure 2-2. The external series resistor helps to reduce the effect of ESD, if breakdown occurs on the touch panel or if ESD strikes circuit directly.

Figure 2-1. Mutual Capacitance Series Resistor

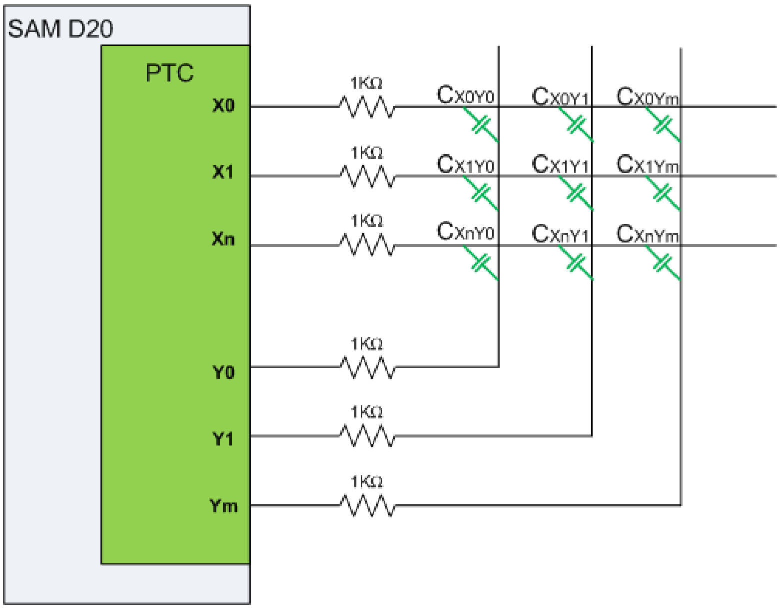
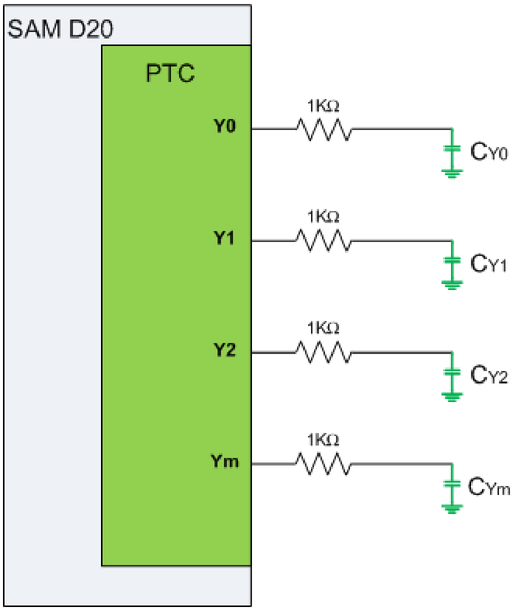


Figure 2-2. Self-Capacitance Series Resistor



General

Some PTC pins have high parasitic capacitance. Using these pins require higher prescaler setting. Higher prescaler setting would affect the response time.

Note: PTC pins Y0 and Y2 of SAM D20 and SAM D21 devices have high parasitic capacitance.

Parallel Capacitor

It is good to have provision to connect a small capacitor (in the order of few pF) between the sense lines and the GND. This capacitor should be placed closer to the sensor electrode after the series resistor. This capacitor provides alternate low impedance path for conducted noise. Initial prototype PCBs must have this provision and if required a capacitor can be populated during EMC testing.

Dedicated Voltage Regulator

It is recommended to use dedicated voltage regulator for higher noise immunity. Use linear voltage regulator preferably as it generates lesser noise compared to switching regulator. Ripple on the regulator output should be less than ±5% of supply voltage. If the design intends to use same voltage regulator for all circuit, then initial prototype PCBs must have provision to connect a dedicated voltage regulator to MCU. This provision can be used during various performance testing.

Decoupling Capacitor

Ensure that all the VDD lines of MCU have at least one dedicated decoupling capacitor. Using three capacitors, 1µF, 100nF, and 1nF on each VDD line reduces effect of different frequency band noises.

Series Resistor on VDD Lines

Include a series resistor (10Ω) or ferrite bead, between the regulator and VDD pin(s) of the MCU. This reduces the effect of EFT/Surge on the MCU.

Bulk Capacitor

Use bulk capacitors closer to the voltage regulator. Refer to the voltage regulator datasheet which specifies the typical value and type of the recommended capacitors.

Use 10µF bulk capacitor on VDD line closer to MCU under following conditions.

- If separate plane for VDD is not available
- If MCU is placed at a distance more than 10cm from voltage regulator
- If output of the voltage regulator is shared with other circuitry
- If voltage regulator and MCU are placed on different PCBs

Ensure that the shunt capacitor’s voltage rating is more (in the order of KV) if it is used before EFT suppressor. Otherwise the capacitor can break.

Transient Voltage Suppressors (TVS) Diodes

If the system is expected to operate under high level of ESDs, Transient Voltage Suppressors (TVS) diodes can be used on the sense lines. Ensure that the TVS diodes are placed closer to the area where ESD strike can occur (in most cases it is sensor electrode).

If TVS diodes are used on sense lines ensure that the capacitance of the same less than 1pF.

Metal-Oxide Varistors (MOV)

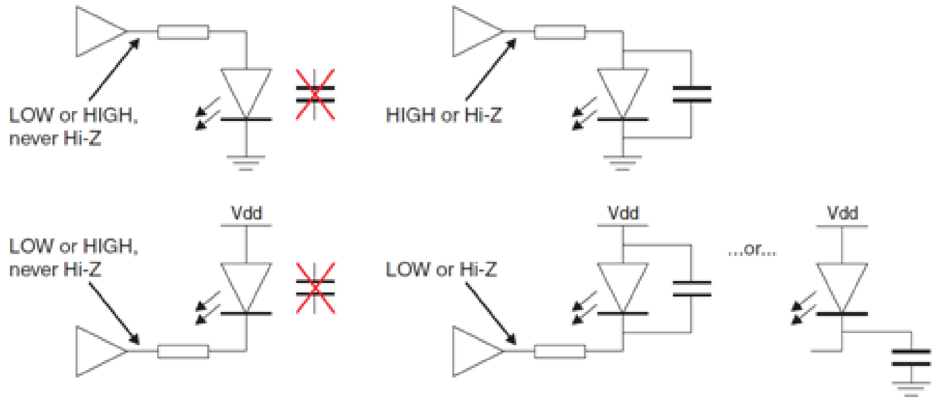
Mains powered applications are likely to suffer due to high voltage surges. MOVs are required to protect the circuit from high voltage surges. Surge voltage varies depending on geographical location. MOVs should be selected based on the geographical location where the application is intended to operate.

Bypass capacitor for LEDs

The changing capacitance from switching LEDs can cause detection instability and stuck-on state in nearby sensors. This is particularly true if LEDs are pulled down or up to switch on, but are allowed to float when off.

If such LEDs or signal traces for LEDs are less than 4mm away from capacitive sensors, they must be bypassed with a capacitor that has a typical value of 1nF.

Figure 2-3. Bypass Capacitor for Nearby LEDs



2.2.2 PCB Design

2.2.2.1 Sensor Design

Ensure parasitic capacitance of the sensor including the electrode and sensor traces, is not more than 30pF. In case of Sliders/Wheels, the parasitic capacitance of each channel should not be more than 30pF.

The "Compensation Capacitance (CC)" calibration value can be used to find whether the parasitic capacitance is high. If CC calibration value of a channel is greater than or equal to 16383, then the parasitic capacitance of that channel is more than 30pF.

For additional details on how to read the CC calibration value refer to Atmel® QTouch® Library Peripheral Touch Controller User Guide[3].

For additional details on the sensor design refer to QTAN0079 Buttons, Sliders and Wheels Sensor Design Guide[1].

2.2.2.2 Layout Considerations

Sensor Placement

It is better to group the sensor electrodes to one side of the panel. Placing sensors randomly in the panel will result in unequal parasitic capacitance. To ensure that the sensor electrode which has highest parasitic capacitance is fully charged, the prescaler setting needs to be increased which affects response time. Grouping the sensors on the panel can help in achieving better moisture tolerance.

Noise Sources

If high noise generating components, like, relays, crystal oscillator, inductor, switching regulator, etc, are used ensure that they are properly isolated from the touch circuitry.

Stacked PCB Design

In stacked PCB design, ensure that the noise from the other PCB does not affect touch circuitry by properly providing physical gap. In case physical gap is not possible, it is recommended to use a ground plane to isolate the noise from the other PCB.

Enough Space on Edges

Avoid placing touch sensors close to the edges of the PCB. It is recommended to provide enough clearance between the PCB edge and the sensor electrode. Use of ground traces routed on the PCB edges helps to improve noise immunity.

Discrete

- Ensure that the series resistors of sense traces are placed close to the MCU pin
- If series resistors are used for VDD lines, ensure that they are placed closer to the MCU pin
- Ensure that pull-up resistor and de-coupling capacitor for RESET line are placed closer to the MCU pin
- Ensure that the de-coupling capacitors are placed closer to the VDD pin
- Ensure that TVS diodes are placed closer to noise source to ensure that a surge voltage is clamped before the pulse is coupled into adjacent PCB traces

2.2.2.3 Routing

Shorter Sensor Traces

Traces from the microcontroller pins to the sensor electrode should be as short as possible. Making long traces increases loading on the sense line. In practice, using protection mechanism (say ground shielding) is easy to make in short traces comparing to that of longer traces.

Thinner Traces

To prevent false touches over sensor traces keep trace width between 0.1mm and 0.5mm. The sensor traces should be routed on the non-touch side and should be connected to the sensor electrode preferably through a PCB via. This makes the sense traces insensitive to finger touch.

Nearby Traces

- Sense traces should not be placed near other traces and components, as this may cause loading and interference. Longer sense traces will load the sensor and reduce the sensitivity. Traces with switching signals that are placed close to the sense traces can cause noise in sensors.
- GND traces should not be placed near sense traces. This will load the sensor and reduce the sensitivity. To reduce loading the sense traces and GND traces should cross at 90° on separate layers. If shielding from noise sources is necessary a thin meshed ground may be used behind electrodes (<40% copper). Meshed ground can also be helpful in increasing SNR.

X and Y Traces

For mutual-capacitance, PTC X- and Y-lines should not be routed for longer length. Combination of that X and Y forms a channel and trace area becomes sensitive to touch. It is better to group the X traces together and Y traces together and route them physically separated on the PCB.

Figure 2-4 shows an example of incorrect X- and Y- traces routing.

- Sufficient gap is not provided between X- and Y- traces
- X- and Y- traces are not grouped together

Figure 2-4. Incorrect X- and Y-Traces Routing

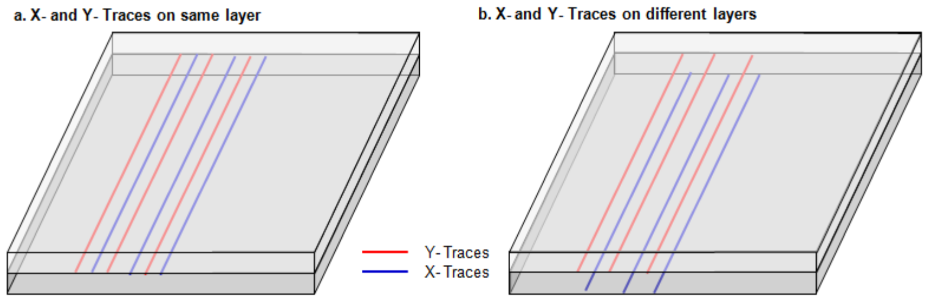


Figure 2-5 shows an example of correct X- and Y- traces routing.

- X- and Y- traces are grouped together
- Sufficient gap is provided between X- and Y- trace groups

Figure 2-5. Correct X- and Y-Traces Routing – Example 1

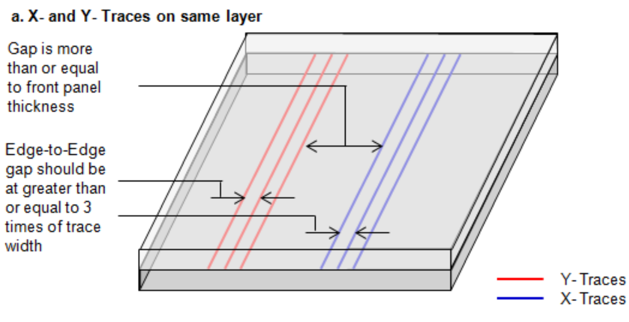
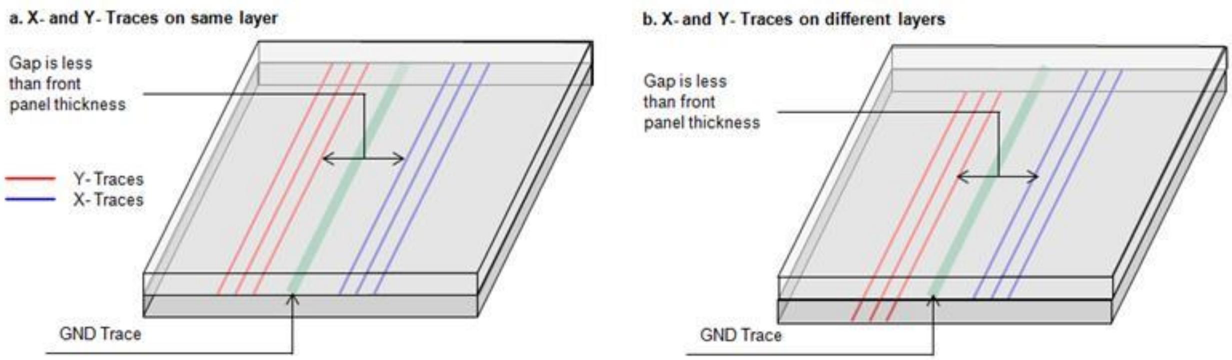


Figure 2-6 shows an example of correct X- and Y- traces routing.

- X- and Y- traces are grouped together
- Not able to provide sufficient gap between X- and Y- trace groups. So, a ground trace is routed between X- and Y- trace groups

Figure 2-6. Correct X- and Y-Traces Routing – Example 2



Ground Shield

In all layers GND trace/plane should surround all other signal traces. This can be achieved by placing thick ground trace on the edges of the PCB on all layers. Alternatively copper pour can be used in empty space of the PCB and can be connected to GND. The GND trace acts as a barrier between noise and the signal. Using "stitching vias" located closer to each other on the edge of the PCB helps in reducing the effect of noise even from the sides of the PCB.

Note: Having ground plane surrounding the sensor electrode reduces moisture tolerance. A compromise between noise reduction and moisture tolerance can be achieved by providing a gap of 3-5mm between sensor electrode and ground plane.

2.2.2.4 Improve Return Path (Ground Plane)

Additional improvements in noise immunity can be achieved by providing better return path. This can be in the form of a ground flood on the same plane or as a meshed ground plane behind the sensor. The ground fill provides a low impedance path for the noise, directing it away from the MCUs input pins. Effective return path can be achieved using "stitching vias" to connect ground fill on multiple layers of a PCB.

In multi-board systems, the ground connections between boards should be made via multiple pins. The multiple pins should be spread across the board to avoid longer return path. This can be achieved by connecting the mounting holes to ground plane and use conductive screws.

Although adding ground plane reduces sensitivity, the improvement in SNR is much more significant when operating in noisy environments. In most cases, loss of sensitivity due to ground loading can be compensated by adjusting the Gain setting or Detect Threshold.

For example, the SAM D20 QTouch Robustness Demo hardware incorporates ground planes in the form of ground floods and meshed ground to improve noise immunity.

Figure 2-7 and Figure 2-8 show the ground planes used in SAM D20 QTouch Robustness demo hardware.

Figure 2-7. Ground Flood on MCU Board

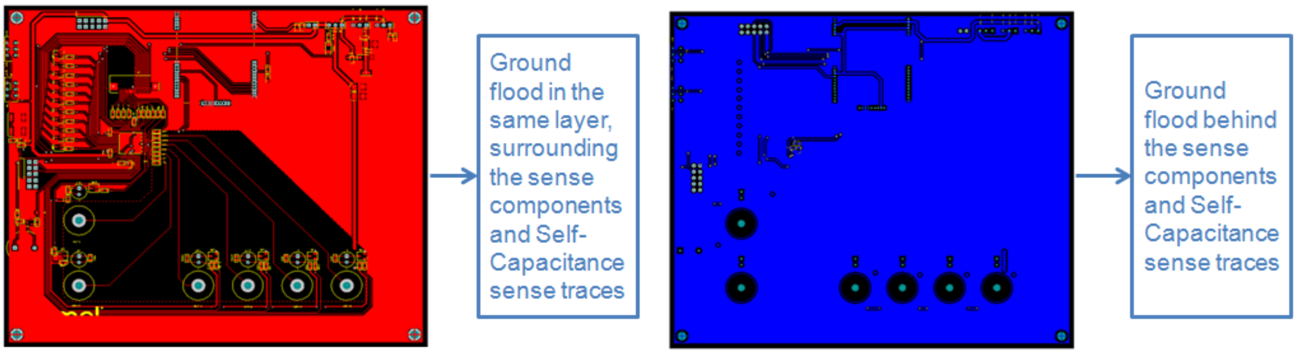
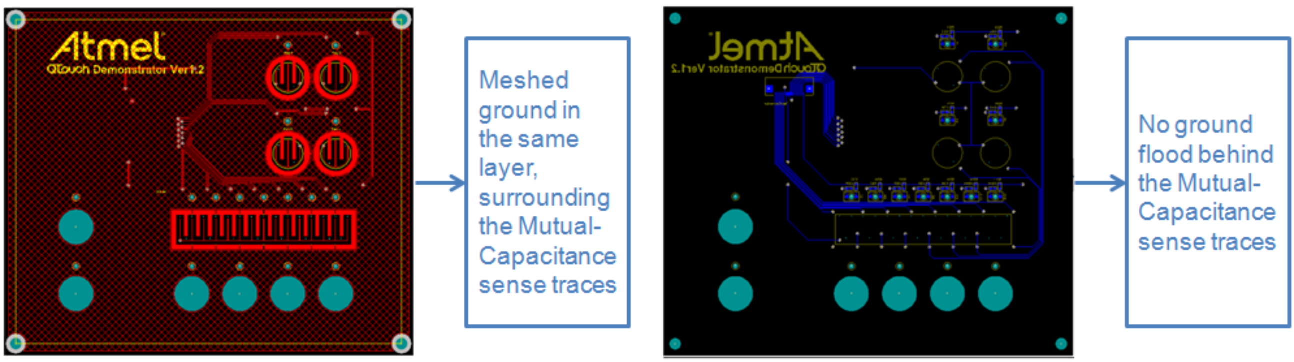


Figure 2-8. Ground Mesh on the Sensor Board



2.2.3 Increasing Series Resistor

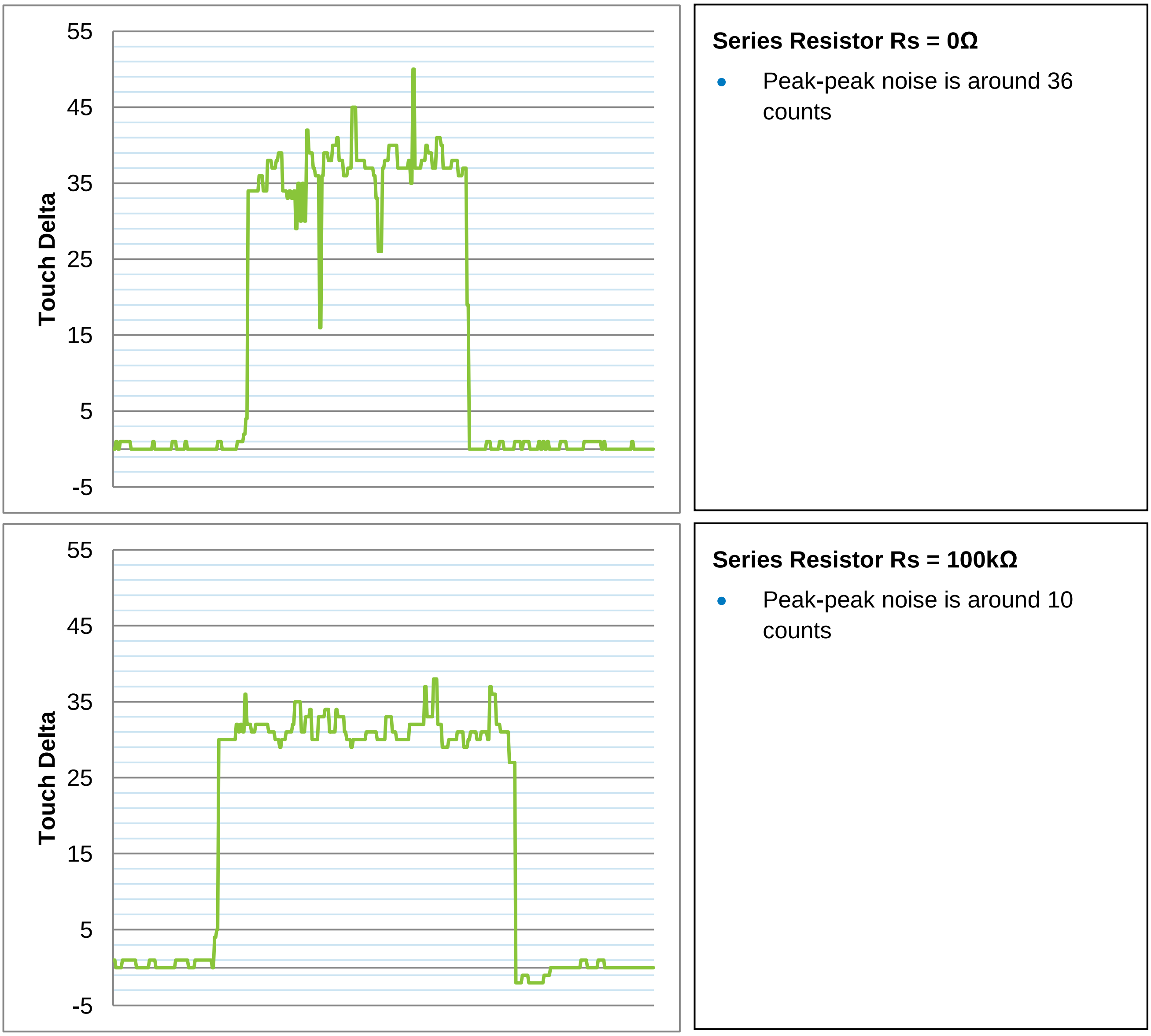
- Increasing the impedance of the sense traces between the Sensor Electrode and the microcontroller input can significantly improve immunity to conducted noise and ESD. A larger series resistor in the acquisition path provides high impedance to noise while maintaining the overall signal integrity.
- The PTC incorporates an internal series resistor that can be configured to a value ranging from 0Ω to 100kΩ. If ESD occurs, the charge passes through the IO port before it is attenuated by the internal series resistor. It is better to use an external series resistor, say 1kΩ, for better ESD protection.
- In some extreme environments the internal series resistor of 100kΩ may not be sufficient. In such cases an external series resistor can be used in conjunction with or without the internal series resistor to further increase the impedance of the sense trace. Increasing the external series resistor from a typical value of 1kΩ to 1MΩ, ensuring complete ‘charge transfer’ can typically improve noise immunity by a factor of two or more.
- Depending on the noise disturbance in the given application an optimal series resistor value can be chosen to achieve the required level of noise suppression while meeting other performance criteria such as power consumption and response time.

For example, in SAM D20 QTouch Robustness Demo the self-capacitance sensors use an external series resistor of 220kΩ in order to pass CI testing at 10V. No internal series resistor was used. In self-capacitance, using external series resistor is more effective comparing to internal series resistor.

The mutual-capacitance sensors are able to pass CI testing at 10V with an internal series resistor of 100kΩ. An external series resistor of 1kΩ is used for ESD protection.

Figure 2-9 shows the difference in noise level observed in signal value when the touch system is subjected to conducted noise with varying resistance in the sense path.

Figure 2-9. Signal Value Noise Vs Series Resistor



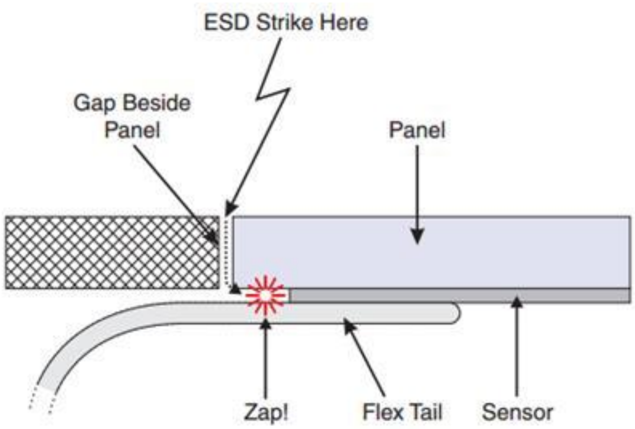
Adding a high value Series Resistor will require an increased 'charge transfer' time that increases capacitance measurement time, thereby increasing the response time and power consumption. Refer Section 2.2.5.3 for the procedure to ensure complete charging of the sensor electrode.

2.2.4 Enclosure

Designing a proper enclosure can help in improving ESD performance. In most application glass/acrylic is used as touch panel over the touch user interface and plastic as the enclosure for other parts.

In such designs, there is chance to form a small gap between the glass/acrylic and the plastic enclosure. An ESD strike through this gap can cause significant damage.

Figure 2-10. ESD Penetrates Through Gap in Touch Panel



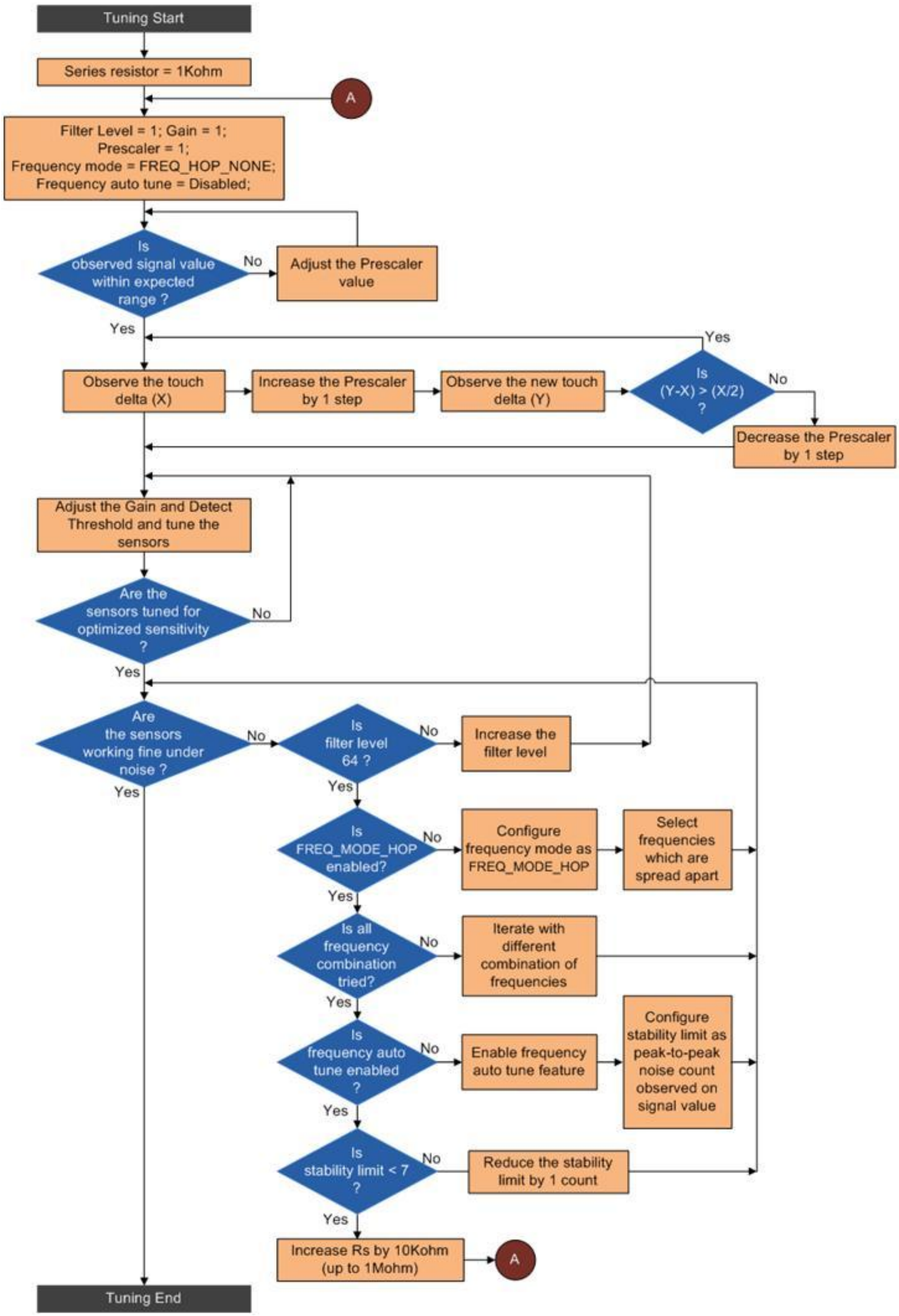
It would be good to use a thin layer of flexible conducting EMI filter in these gaps. These filters, in general connected to GND, can form a low impedance return path for the external noise and improves the noise immunity.

2.2.5 PTC Tuning

2.2.5.1 PTC Tuning Flow

Figure 2-11 shows typical flow of tuning PTC parameters. The critical parameter and its effects on touch acquisition are described in subsequent sections.

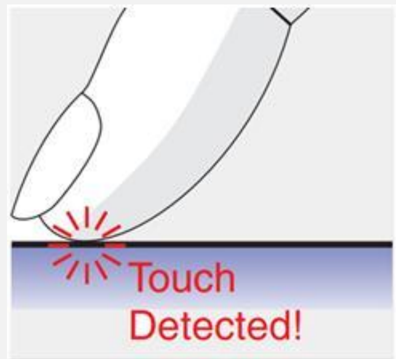
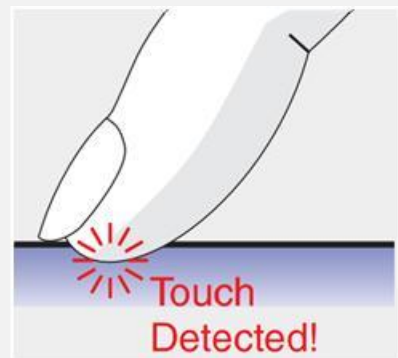
Figure 2-11. PTC Tuning Flow Chart



2.2.5.2 Sensitivity Tuning

Before tuning the PTC parameters for better noise performance, the sensors should be tuned for optimized sensitivity. Table 2-1 shows differences in sensitivity.

Table 2-1. Sensitivity Tuning

Over-Sensitive	Optimally Sensitive	Under-Sensitive
		
If the sensor is reporting detect before contact with the touch surface, then the sensor is over sensitive.	A sensor is at the optimized sensitivity when it only detects the finger as it lightly contacts the touch surface.	If the sensor does not detect the touch or requires a heavy touch to activate, then the sensor is under sensitive. Note: Capacitive Touch is not sensitive to pressure, but to the expanded area of the flattened finger.
Reduce Gain	No action required	Increase Gain
Increase Detect Threshold	No action required	Decrease Detect Threshold

The optimized sensitivity can be achieved by:

- Ensuring complete charging of the sensor electrode
- Adjusting Gain and Detect Threshold parameters

Section 2.2.5.3 provides details on how to achieve complete charging of the sensor electrode.

Increasing Gain increases sensitivity and vice-versa. The Gain is configured per channel basis. For Slider/Wheel sensors, the Gain needs to be tuned for all the channels. Each step increase in Gain setting increases the touch delta by a factor of 2.

For example, if the touch delta value is 40 with GAIN_2, then the same will be ~80 with GAIN_4.

Increasing Detect Threshold reduces sensitivity and vice-versa. The Detect Threshold can be configured between 10 and 255.

In the tuning process, the Gain setting should be used to coarse tune the sensitivity and Detect Threshold to fine tune the sensitivity. To achieve optimized sensitivity, both Gain and Detect Threshold should be adjusted.

Table 2-2. Sensitivity Related Parameters

Parameter	File
DEF_xxxxCAP_GAIN_PER_NODE	Touch.h
detect_threshold in touch_xxxxcap_sensor_config() API	Touch.c

2.2.5.3 Prescaler

In order to obtain stable and repeatable results, it is important to ensure complete charging in each acquisition sample. With the increased series resistor, the rise time of the charge pulse will increase. The duration of the charging pulse needs to be sufficiently long to allow complete charging. This is true even with increased parasitic capacitance.

The prescaler setting determines the clock frequency of the PTC. This in turn affects the acquisition frequency and determines the width of the charging pulse. Complete charging can be ensured by observing the signal values.

The expected signal values for a given combination of Filter Level and Gain setting are mentioned in Atmel QTouch Library Peripheral Touch Controller User Guide[3]. If the deviation between the observed signal value and expected signal value is greater than 10 counts, prescaler setting should be increased until the signal value is within the expected range.

Note: The QTouch library provides option to configure different prescaler and series resistor settings during calibration process and periodic touch acquisition. In order to get the expected signal values as mentioned in Atmel QTouch Library Peripheral Touch Controller User Guide[3], the prescaler and series resistor settings should be the same during calibration and periodic touch acquisition. Table 2-3 lists the macros which configure the prescaler and series resistor during calibration and periodic touch acquisition.

If there is incomplete charging due to higher series resistor or higher parasitic capacitance, the observed touch delta will be less. The prescaler should be adjusted such that sensor electrodes are completely charged. Complete charging can be achieved by selecting the prescaler as follows.

A. Configure the prescaler for which the signal values are within the expected range.
B. Observe the touch delta (X).
C. Increase the prescaler by one step and observe the touch delta (Y).
D. If the difference between Y and X is more than 50% of X, then and go to step B.
E. If the difference in delta value is not more than 50% then reduce the prescaler setting by one step and use it for touch acquisition.

For example, assume the following:

- Signal value is within the expected range with prescaler setting PRSC_DIV_SEL_2
- With PRSC_DIV_SEL_2, the touch delta is 20 counts
- With PRSC_DIV_SEL_4, the touch delta increased to 35 counts
- With PRSC_DIV_SEL_8, the touch delta increased to 38 counts

In this example, increasing the prescaler to PRSC_DIV_SEL_8 is giving only marginal improvement in touch delta comparing to PRSC_DIV_SEL_4. So, it is better to use PRSC_DIV_SEL_4.

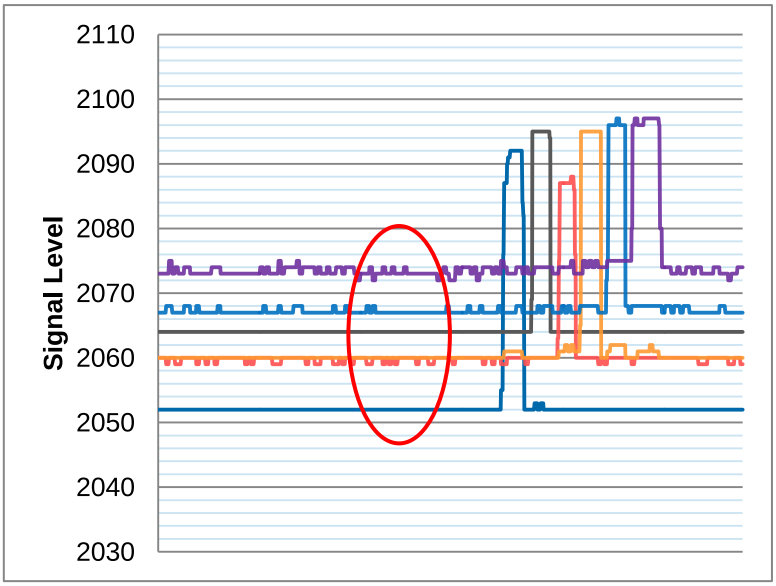
Note: The mutual-capacitance can work with higher PTC clock frequencies comparing to self-capacitance due to low parasitic capacitance.

In SAM D20 QTouch Robustness demo:

- Mutual-capacitance sensors required a prescaler setting of one (ADC clock = 1MHz) for complete charging with 100kΩ internal series resistor used. With prescaler = 1, Filter Level = 64, Gain = 4, the signals observed on the Channels were closer to 2048. All signal values observed are within the expected range of 2048 ±10 counts.
- Self-capacitance sensors required a prescaler setting of two (ADC clock = 512kHz) for complete charging with an external series resistor of 200kΩ used. With prescaler = 2, Filter Level = 64, Gain = 4, the signals observed on the channels were closer to 2048. All signal values observed are within the expected range of 2048 ±10 counts.

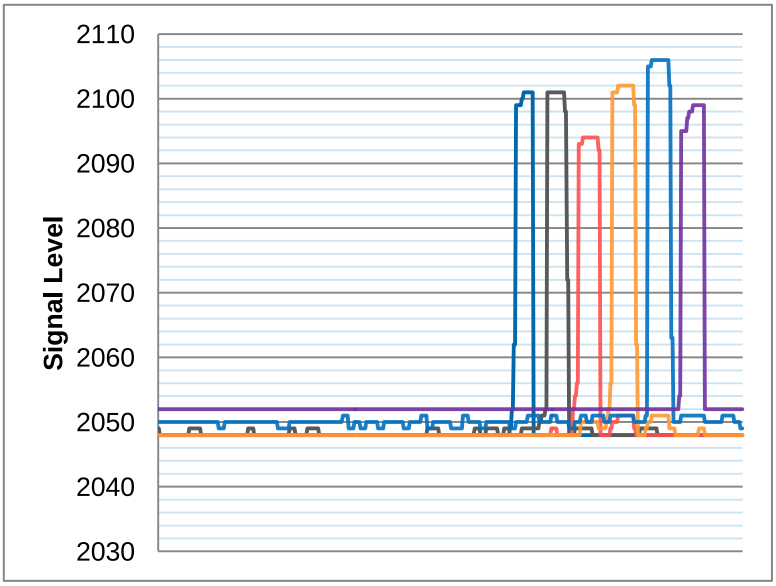
Figure 2-12 shows the effect of signal value with increasing prescaler setting.

Figure 2-12. Signal Value Noise Vs Prescaler



Prescaler = 1

- Deviation between expected signal value (2048) and actual signal value. This is marked by a red circle.
- Touch delta values are not even on all channels and few channels show lower touch delta values.



Prescaler = 2

- The signal values of all the channels are closer to the expected signal value (2048).
- Touch delta values observed are more compared to that with prescaler set to 1.

Table 2-3. Prescaler Related Parameters

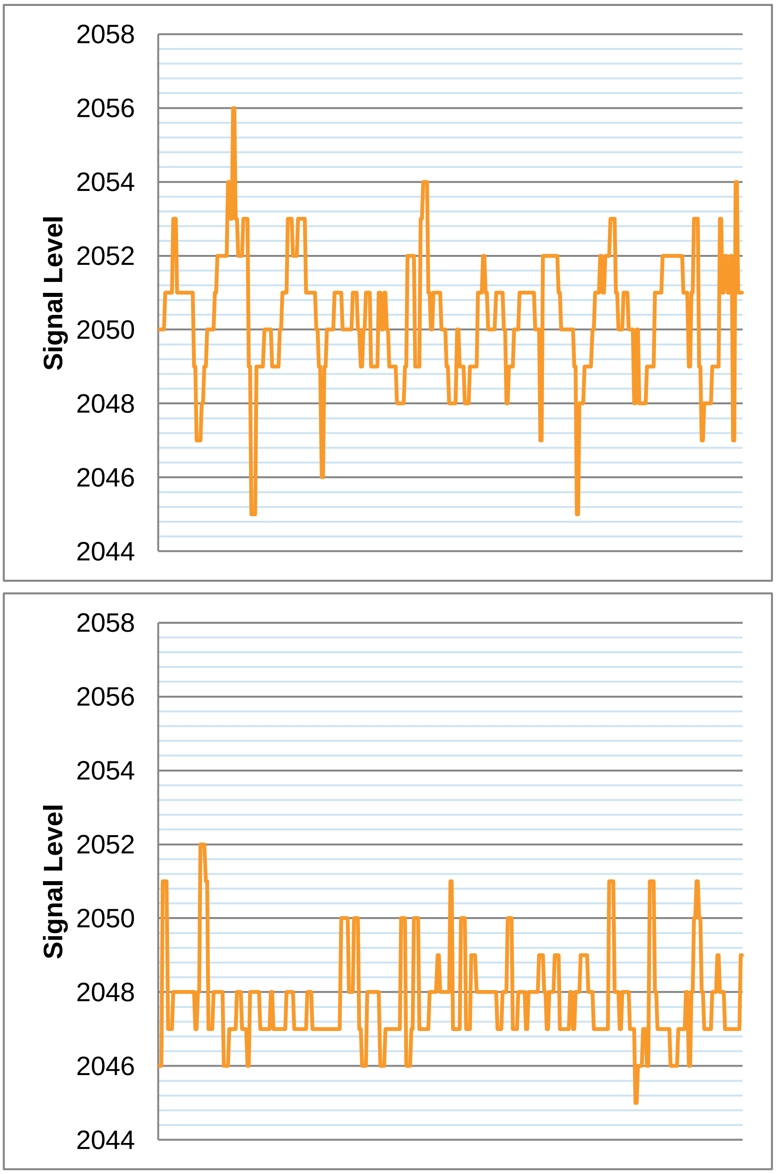
Parameter	File
DEF_xxxxCAP_CC_CAL_CLK_PRESCALE	Touch.c
DEF_xxxxCAP_CC_CAL_SENSE_RESISTOR	Touch.c
DEF_xxxxCAP_CLK_PRESCALE	Touch.h
DEF_xxxxCAP_SENSE_RESISTOR	Touch.h

2.2.5.4 Filter Level

The QTouch library provides the option to do over-sampling and averaging. The averaging acts as low-pass filter and reduce the noise level significantly. “DEF_xxxxCAP_FILTER_LEVEL” parameter defined in touch.h file determines the over-sample counts. More information on this parameter can be found in Atmel QTouch Library Peripheral Touch Controller User Guide[3].

[Figure 2-13](#) shows the difference in signal variation of a self-capacitance sensor with respect to change in filter level.

Figure 2-13. Signal Value Noise Vs Filter Level



Filter Level = 32

- The peak-to-peak signal variation is 11 counts

Filter Level = 64

- The peak-to-peak signal variation is six counts. This is almost half compared to that of filter level 32.

Table 2-4. Filter Level Related Parameter

Parameter	File
DEF_xxxxCAP_FILTER_LEVEL	Touch.h

2.2.5.5 Frequency Mode

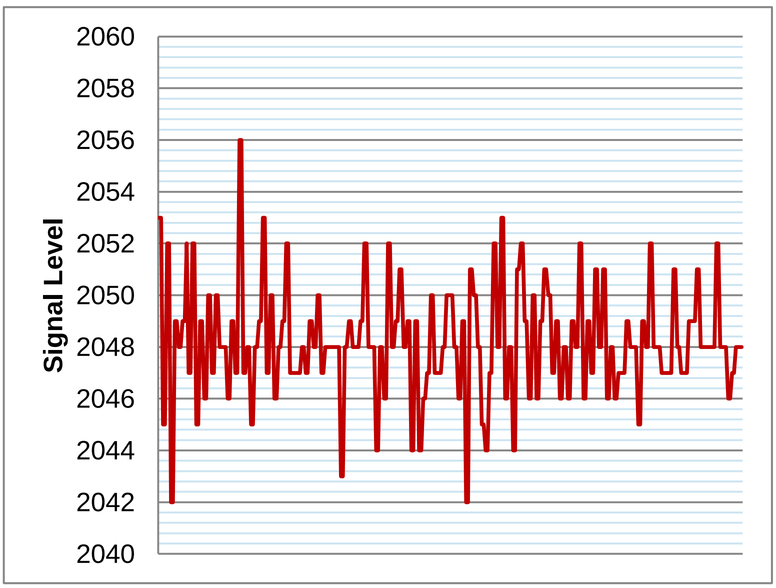
The noise level on the signal value increases if the frequency of the noise is closer to the touch acquisition frequency. If increasing the filter level is not helping in reducing the noise level, then it is better to change the acquisition frequency. QTouch library provides an option to perform touch acquisition on three different frequencies. “DEF_xxxxCAP_FREQ_MODE” parameter defined in touch.h file determines mode used by the QTouch library for touch acquisition. “FREQ_MODE_HOP” mode uses three frequencies to perform touch acquisition and applies median filter on the resulting three signal values. The user can configure the frequencies on which the QTouch library performs touch acquisition. The user can select three frequencies from a list of sixteen frequencies using “DEF_MUTLCAP_HOP_FREQS” parameter in touch.h file.

More information on these parameters can be found in Atmel QTouch Library Peripheral Touch Controller User Guide[3].

Combination of three different frequencies and median filter helps in eliminating the noise level in most of the cases. To identify the correct frequencies for a given system, user needs to iterate with different combination of frequencies and select the best possible combination that show less noise levels. Better noise rejection can be achieved by using combination of spread-apart frequencies. For example, combination of frequencies 2, 4, and 8 will reject noise better comparing to combination of frequencies 4, 5, and 6.

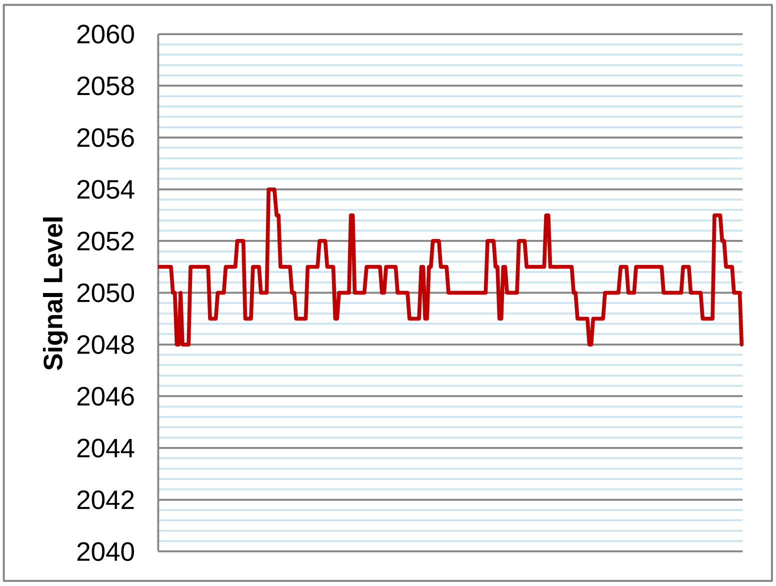
Figure 2-14 shows the effect of noise on delta value between “FREQ_MODE_NONE” and “FREQ_MODE_HOP”.

Figure 2-14. Signal Value Noise Vs Frequency Mode



Filter Level = 32

- The peak-to-peak signal variation is 11 counts



Frequency Mode = FREQ_MODE_HOP

- Peak-to-peak signal variation is around six counts

Table 2-5. **Frequency Mode Related Parameters**

Parameter	File
DEF_xxxxCAP_FREQ_MODE	Touch.h
DEF_xxxxCAP_HOP_FREQS	Touch.h

2.2.5.6 Frequency Auto Tune

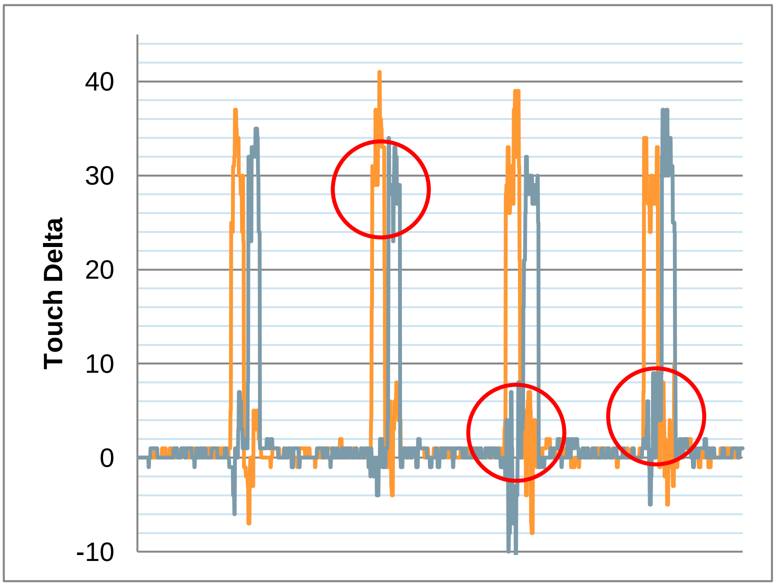
Frequency auto tune is an advanced feature provided by QTouch Library. This feature measures the noise on the frequencies used in "FREQ_MODE_HOP" and dynamically replaces the nosiest frequency. This feature is helpful if the system is subjected to different noises of varying frequencies. The frequency switch happens if the signal value is unstable and exceeds the stability limit consistently for auto tune count times. "DEF_xxxxCAP_FREQ_AUTO_TUNE_SIGNAL_STABILITY_LIMIT" sets the stability limit and "DEF_xxxxCAP_FREQ_AUTO_TUNE_IN_CNT" sets the auto tune count.

More information on these parameters can be found in Atmel QTouch Library Peripheral Touch Controller User Guide[3].

Note: The frequency auto tune feature is applicable only if "FREQ_MODE_HOP" frequency mode is used.

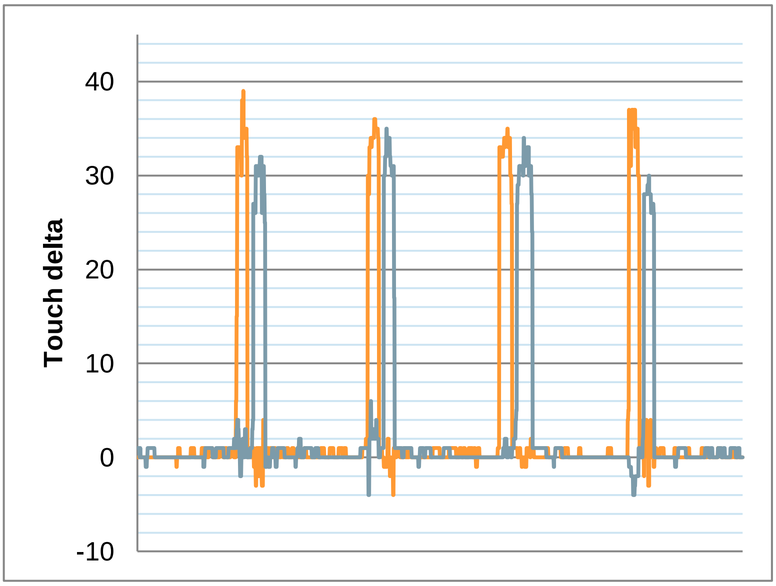
Figure 2-15 shows the difference in noise level observed on touch delta values with and without Frequency Auto Tune feature.

Figure 2-15. Delta Value Noise Vs Frequency Auto Tune



Frequency Auto Tune Disabled

- Under noise, huge amount of noise is observed on the signal value when the finger touches a sensor electrode. The peak noise levels are marked by red circle.



Frequency Auto Tune Enabled

- The noise level on the signal value is significantly reduced

Table 2-6. Frequency Auto Tune Related Parameters

Parameter	File
DEF_xxxxCAP_FREQ_AUTO_TUNE_ENABLE	Touch.h
DEF_xxxxCAP_FREQ_AUTO_TUNE_SIGNAL_STABILITY_LIMIT	Touch.h
DEF_xxxxCAP_FREQ_AUTO_TUNE_IN_CNT	Touch.h

The SAM D20 QTouch Robustness demo uses Frequency Auto Tune feature with the following configuration.

Mutual-Capacitance Sensors

DEF_MUTLCAP_FREQ_AUTO_TUNE_SIGNAL_STABILITY_LIMIT = 10

DEF_MUTLCAP_FREQ_AUTO_TUNE_IN_CNT = 12

Self-Capacitance Sensors

DEF_SELFCAP_FREQ_AUTO_TUNE_SIGNAL_STABILITY_LIMIT = 20

DEF_SELFCAP_FREQ_AUTO_TUNE_IN_CNT = 12

3 Moisture Tolerance

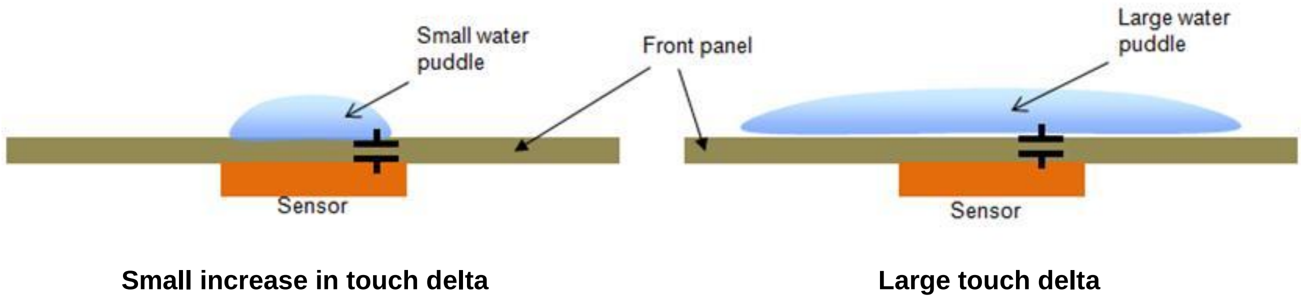
The PTC measures the change in capacitance over a sensor electrode to determine touch. Water is conductive in nature. Interaction of moisture with sensor or the sense lines causes a change in capacitance. This causes disturbances in the capacitive measurements and might lead to erratic behavior of the touch panel. A conductive film of water acts very much like a human finger and can causes false touch detection.

3.1 Impact of Moisture on Capacitive Touch Sensors

The general observation of exposing touch sensor to moisture is increase in delta values, which eventually lead to false detects. This is true for both self-capacitance and mutual-capacitance sensors, but there is slight difference in the way the moisture affects both of these methods.

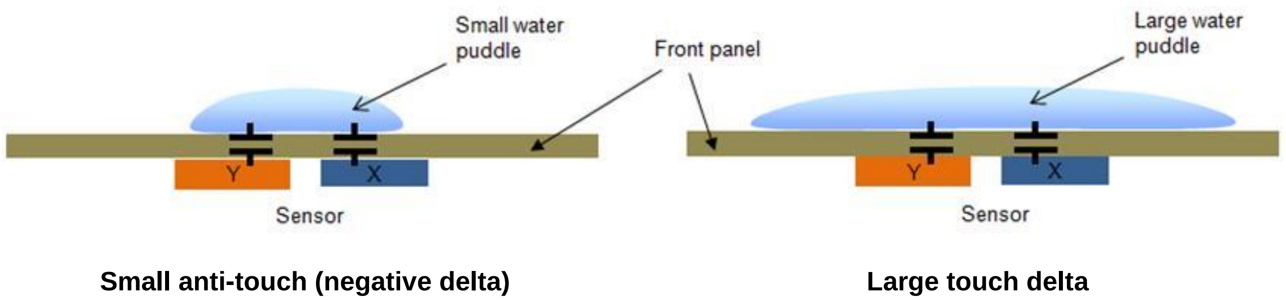
In self-capacitance, water accumulation over sensor increases the effective area of the sensor electrode. This increases the overall capacitance of the sensor as well as increases the coupling with ground. With increase in quantity of water the change in signal values exceeds the detect threshold and lead to false detect.

Figure 3-1. Effect of Moisture on Self-Capacitance Sensor



In mutual-capacitance, water accumulation over the sensor increases the coupling between the X and Y electrodes. This increased coupling leads to a reduction in the electrode capacitance. Thus an isolated puddle of water over the mutual-capacitance sensor shifts the signal to produce negative delta values. This is called as anti-touch effect. However as the water puddle increases in size, it couples with ground and leads to increase in delta values, thereby leading to a false detect.

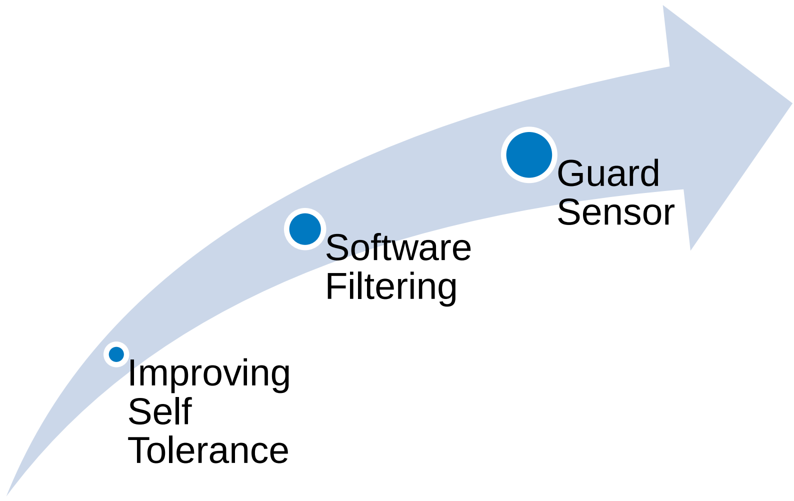
Figure 3-2. Effect of Moisture on Mutual-Capacitance Sensor



3.2 Improving Moisture Tolerance

Following aspects can be looked into for improve moisture tolerance.

- Hardware Design for improved self tolerance to moisture
- Software Filtering
- Guard Sensor



3.2.1 Improving Self Tolerance

To improve the moisture tolerance of a touch panel, it is necessary to improve its self tolerance so that it can reject a certain amount of moisture without any special implementations.

- Selecting Touch Acquisition Method
  - The mutual-capacitance sensors have a natural ability to reject moisture due to the anti-touch effect. The use of mutual-capacitance sensors should be preferred in designs where moisture tolerance is a concern. Water drops or small puddles can be handled by mutual-capacitance sensor design itself.
  - Ground fill or other lines should be avoided near the sensor area. The ground plane offers very easy path for water droplets to bridge and cause capacitive changes that appear similar to a normal touch.
  - Reducing ground in the PCB decreases the overall noise immunity of the design. A careful compromise has to be done.
- Tune Detect Threshold
  - The Detect Threshold should be kept as high as possible
- Mechanical Design

  When a touch panel is intended to work in conditions like water spill or rain, the below mechanical recommendations should be considered.
  - Mounting the touch panel at an inclined angle or vertically mounted is highly beneficial since it allows the water to flow down and thereby prevents water accumulation on panel surface
  - Size of sensor electrodes should not be made very large compared to fingers. A large sensor allows more area for the moisture to interact and reduce the finger sensitivity.
  - Use of concave touch panel surface above the sensor electrode instead of flat surfaces to avoid water to stay on the button surface

3.2.2 Software Filtering

Avoiding false detects due to large water presence (or water flow) is very challenging. Software filter can be implemented to monitor delta on all sensors and take appropriate measures based on the delta changes.

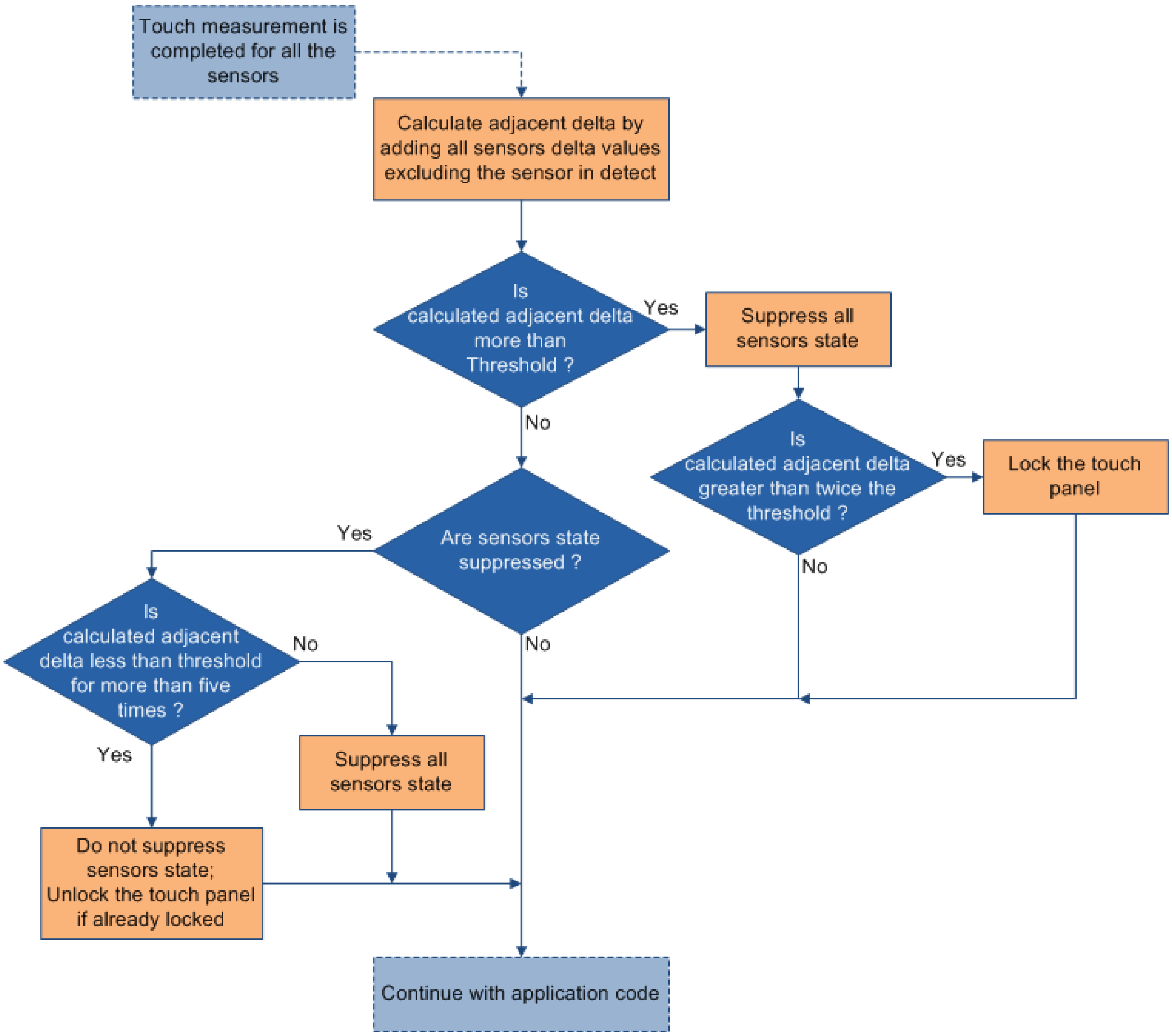
The idea is to ignore all touches in case there are ambiguous deltas on surrounding sensors and locks the panel if surrounding sensors delta changes is high. This is helpful in case of sudden water spill on the touch panel as it causes increase in delta on many sensors.

The use case for this filter depends on the nature of the application and the physical configuration of the sensors on the touch panel. This is an effective solution for designs which have sensors spaced closer to each other and requires minimal or no simultaneous touch detection on multiple sensors.

Adjacent Delta Monitoring

The flow chart in Figure 3-3 explains how the adjacent delta monitoring can be used to prevent false detects due to water presence.

Figure 3-3. Flow Chart – Adjacent Delta Monitoring



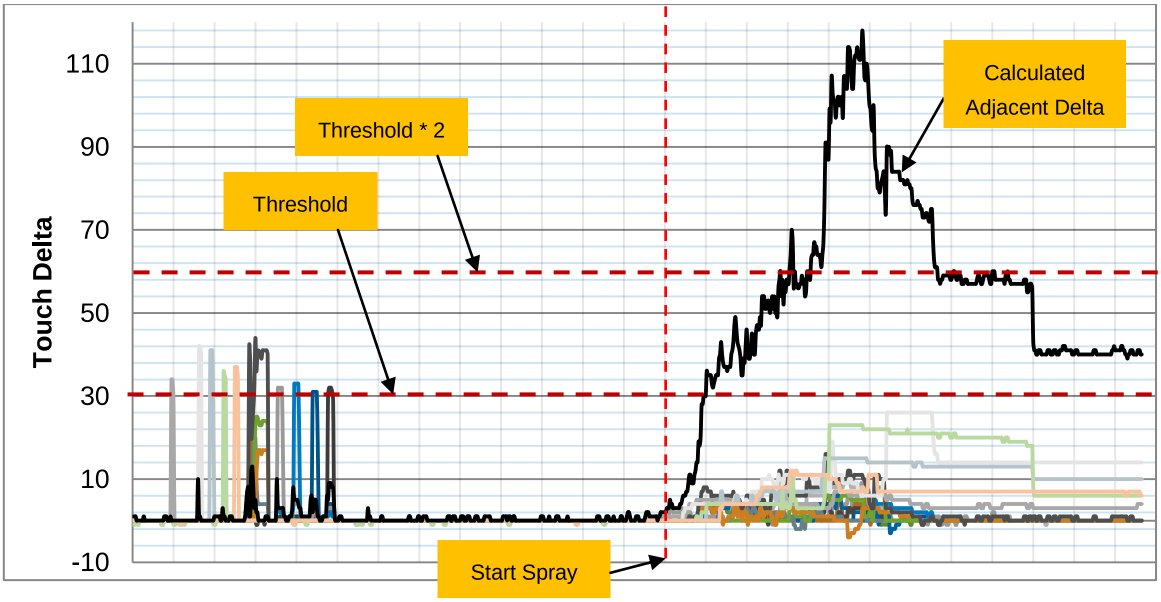
The adjacent delta monitoring can be performed on a group of sensors that are physically closer to each other. The above flow chart shows adjacent delta monitoring for one group. The same can be repeated for multiple groups of sensors.

There may be condensation on PCB due to fast changes in the ambient temperature. This may cause larger changes in capacitance on the sensor traces and causing false detects. Adjacent Delta Monitoring is an effective solution to prevent false detects due to PCB condensation.

The SAM D20 QTouch Robustness demo uses adjacent delta monitoring technique to improve moisture tolerance.

Figure 3-4 shows how the adjacent delta monitoring suppresses false detects during water spray over the touch panel.

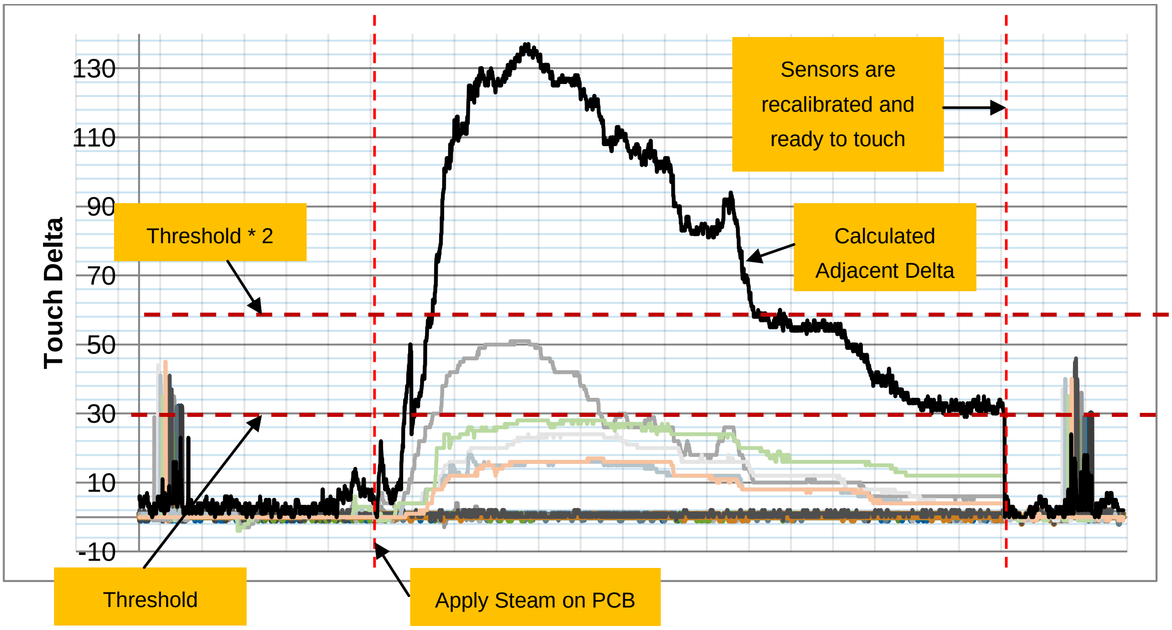
Figure 3-4. Effect of Water Spray Over the Touch Panel



The adjacent delta value increases as soon as the water is sprayed over the touch panel. The sensor states are suppressed when adjacent delta value reaches the threshold (say 30 counts). With additional spraying, there is further increase in adjacent delta. The panel is locked when adjacent delta reaches a value twice the threshold (say 60 counts).

Figure 3-5 shows how the adjacent delta monitoring suppresses false detects when steam is applied over the PCB.

Figure 3-5. Effect of Steam Over PCB

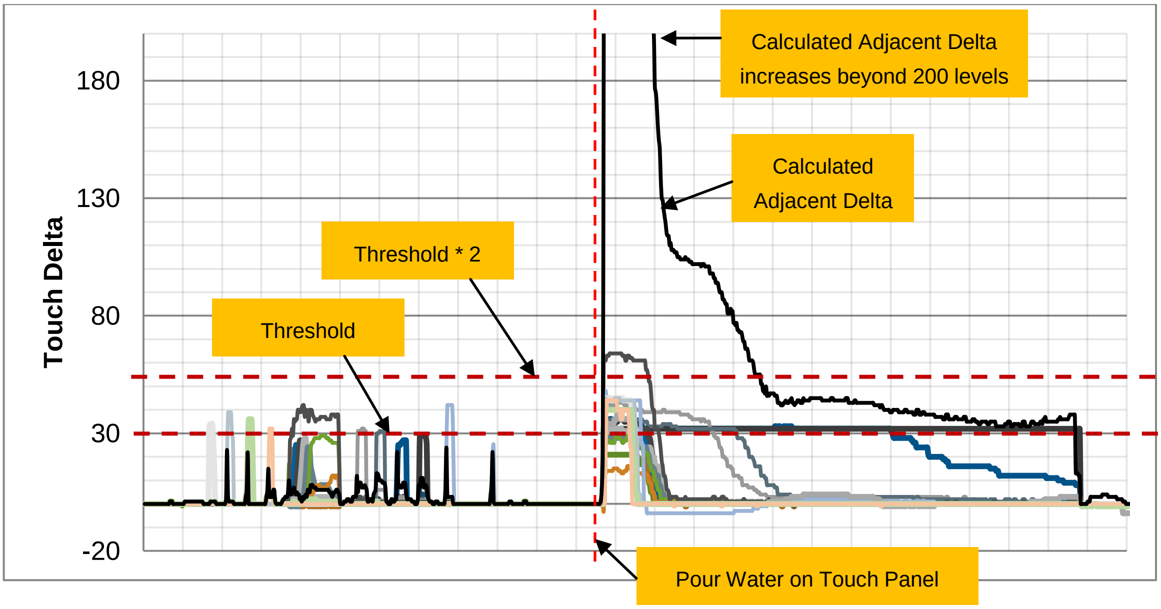


The adjacent delta value increases as soon as the steam is applied on the PCB. The sensor states are suppressed when adjacent delta value reaches threshold (say 30 counts). With more steam, there is further increase in adjacent delta. The panel is locked when adjacent delta value reaches a value twice the threshold (say 60 counts).

When steam is removed, eventually water droplets from the PCB will evaporate and the delta reduces. When the adjacent delta goes below the threshold (say 30 counts) the sensors are re-calibrated and the touch panel is ready for normal operation.

Figure 3-6 shows how the adjacent delta monitoring suppresses false detects when huge amount of water is poured over the touch panel.

Figure 3-6. Water Pour Over Touch Panel



The adjacent delta value increases rapidly when huge amount of water is poured over the touch panel. The panel is locked when adjacent delta value reaches two times the threshold (say 60 counts). When water is wiped, the adjacent delta reduces and goes below the threshold (say 30 counts). The sensors are re-calibrated and the touch panel is ready for normal operation.

3.2.3 Guard Sensor

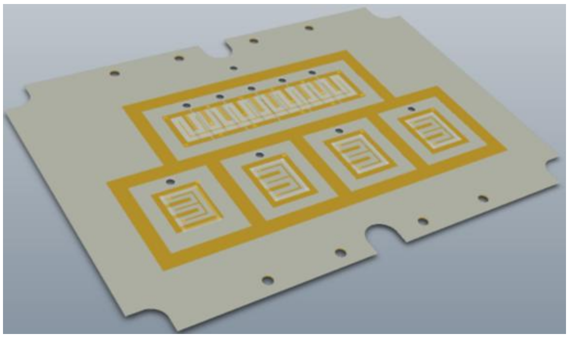
The use of a guard sensor is an effective solution for detecting different forms of moisture formations on the touch panel. The guard sensor is a special sensor that is strategically located and has slightly higher sensitivity. If any unintentional touch occurs, this activates the guard sensor. This indicates that a false detect has occurred. Usually the electrode for the guard sensor is a conductive fill that surrounds the electrodes for other sensors.

In a moisture tolerant touch design, the guard sensor plays an important role in detecting the presence of water and helps to suppress the false detects. An over-sensitive guard sensor will have proximity effects and an under-sensitive guard sensor will not be able to detect the presence of moisture accurately. This increases the complexity of designing the guard sensor to get the right balance.

Since guard sensor is a large electrode and has higher sensitivity, it will be more sensitive to noise. In such cases design needs to be done carefully to avoid larger guard sensor electrodes.

Figure 3-7 shows an example of how a guard sensor can be realized.

Figure 3-7. Example Guard Sensor

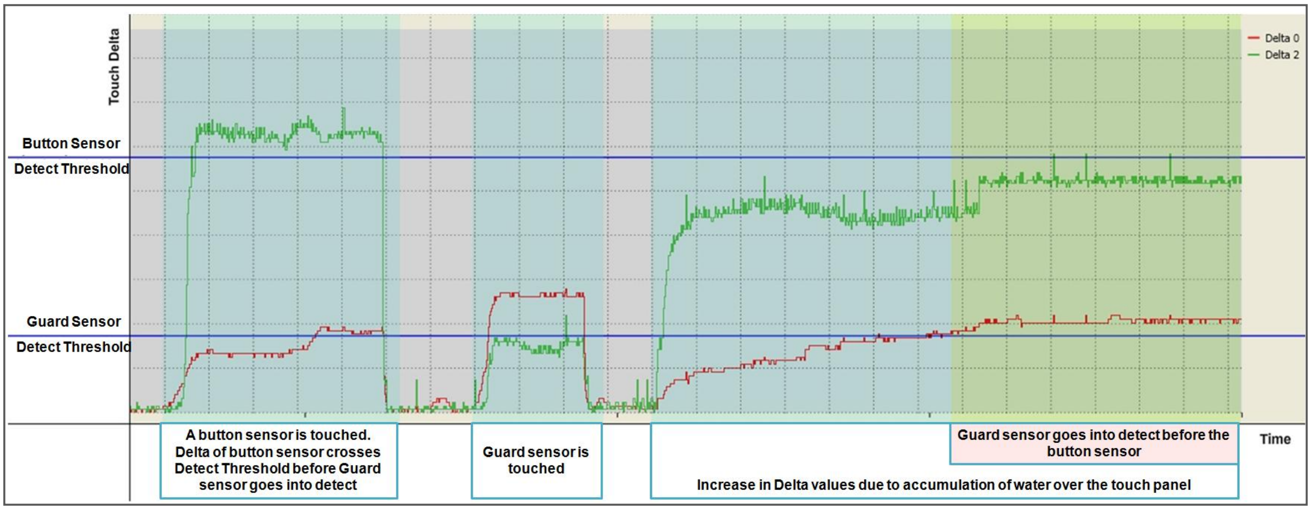


3.2.3.1 Tuning Guard Sensor for Moisture Tolerance

Performance of any capacitive touch interface depends upon how well it has been tuned. For moisture tolerant touch design there are some special considerations.

Figure 3-8 is a graph recorded from a well tuned system for a button and guard sensors. The green plot represents the delta values of a button and the red plot represents the delta values of the guard sensor. The detect threshold for the button as well as the guard sensor has been represented by the blue lines. The three events in the graph are highlighted in light blue and are explained below.

Figure 3-8. Touch Delta Variation in Guard and Button



In the first event, the button is touched. It is observed that the delta value for that button quickly crosses its detecting threshold and reports touch detection. Due to proximity effect there is a rise in the delta value of the guard as well, but the delta value is not high enough to cross the detect threshold for the guard.

In the next case the guard sensor is touched. The guard sensor immediately crosses it's detect threshold. Some rise in delta value is observed in the button due to proximity effect.

In the last event, water is poured over the button and it forms a water puddle spreading across the touch panel. The delta values start to steadily increase in both the guard sensor as well as the button. The delta value is proportional to the amount of water accumulated over the button. After a certain amount of water accumulation, the delta value of the guard sensor reaches it's detect threshold.

More information on Guard Sensor implementation can be found in AVR3002: Moisture Tolerant QTouch Design[4] application note.

4 Touch Response Time

The time taken by the application to react to a finger touch is the response time. This time includes the time taken by the microcontroller to perform the touch acquisition and post-processing to report a valid touch. Better user experience can be achieved with lower response time. With lower response time, the number of touch detection increases per second.

4.1 Ideal Response Time

The response time requirement depends on the application. For applications such as computer keyboard or a game console extremely fast response time is expected, whereas a washing machine can provide adequate user experience with much longer response times.

It is highly impossible for a human to touch a button more than eight times per second. Detecting one touch per ~125msec is good enough for user interface applications.

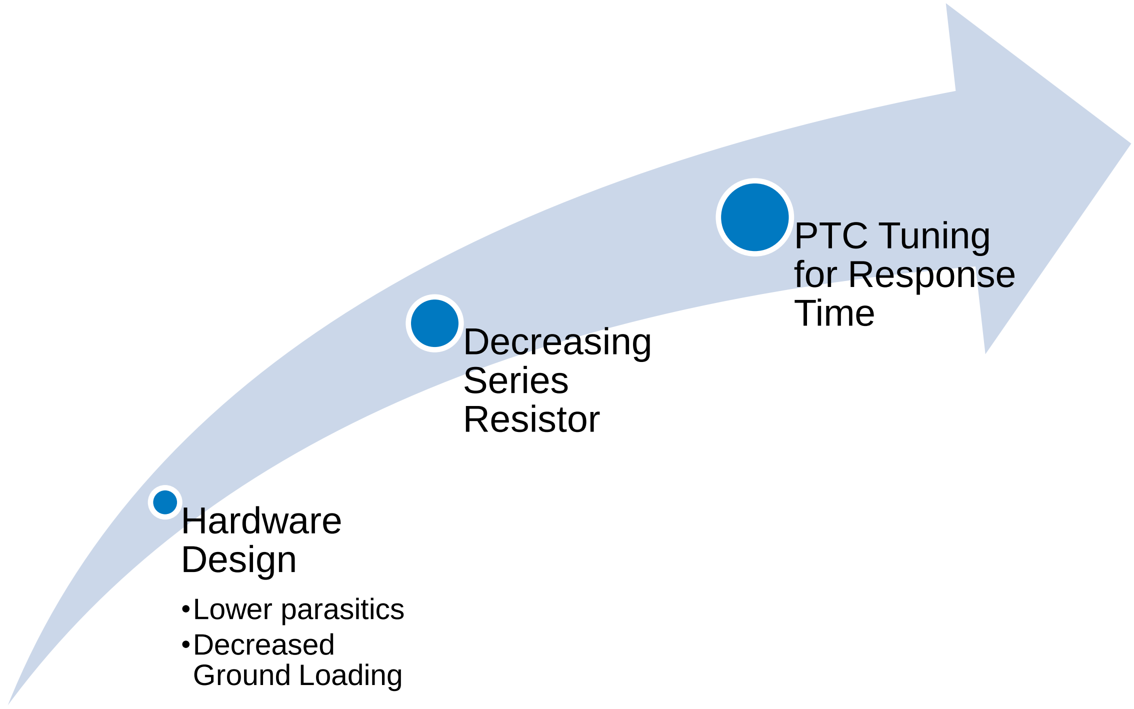
It is possible for human finger to move over the slider/wheel much faster comparing to touching a button. If application has sliders/wheels, than lesser response time provides better user experience.

If the delay between a finger touch and any visual indication (say LED illumination) is more than ~70msec (16 frames per seconds), then this may be perceived as a delay. Applications which provide visual indications require response time less than 70msec.

4.2 Improving Response Time

Following factors affects touch response time:

- Hardware Design
- Optimizing Series Resistor
- PTC Tuning



4.2.1 Hardware Design

Increasing parasitic capacitance (Cp) increases touch acquisition time and vice-versa.

Parasitic Capacitance can be reduced as follows.

- Reduce the trace length
  - Longer sense traces running from the MCU to the sensor electrode increases the parasitic capacitance
  - In mutual-capacitance, avoid routing X- and Y -lines close to each other
- Have a ground plane beneath the sensor electrode only if it is required
  - Hatched ground flood can be used in low-noise systems
- The size of the sensor electrode should be optimum
  - Bigger sensors have higher parasitic capacitance. So, adequate sensor size should be used
  - For spring based designs, it is recommended to use thinner wire gauge for springs. The pad size for soldering the spring should be optimum to minimize the amount of solder.

4.2.2 Optimizing Series Resistor

- Increasing Rs increases touch acquisition time and vice-versa. Select optimum Rs value for which system performance is acceptable.
- Avoid through-hole resistor as it increases parasitic capacitance.

4.2.3 Increasing CPU Clock

- Increasing CPU clock frequency reduces post-processing time. CPU should be clocked at the maximum clock frequency to get reduced response time and better user experience.

4.2.4 PTC Tuning for Response Time

The QTouch Library provides various parameters for optimized touch performance. By properly tuning these parameters, best possible response time can be achieved.

Table 4-1. PTC Tuning for Response Time

Feature	QTouch Library Parameter	Recommendation
Filter Level	DEF_xxxxCAP_FILTER_LEVEL	• All applications do not require filter level 64 • Reducing the filter level to 32 from 64 would reduce the touch acquisition time by almost half • Reducing the Filter Level reduces touch response time

Feature	QTouch Library Parameter	Recommendation
Auto Over Sample	DEF_xxxxCAP_AUTO_OS	• Auto Over Sample does additional touch acquisition while touching and removing finger. This increases touch response time. • Enable Auto OS feature only if it is “really” required. If Auto OS feature is used, then use appropriate Auto OS level. • Reducing Auto OS level reduces touch response time.
Frequency Mode	DEF_xxxxCAP_FREQ_MODE	• FREQ_MODE_HOP applies median filter on the signal value. When the sensor is touched, due to median filter, it needs additional one touch acquisition cycle to start DI process. This increases the response time by one cycle time. • Some level of noise can be tackled by adjusting the filter level and auto OS. • Application which requires extreme noise mitigation only should use FREQ_MODE_HOP.
Clock Prescaler	DEF_xxxxCAP_CLK_PRESCALE	• Increasing the pre-scale value increases touch acquisition time and vice-versa. Higher electrode capacitance (Cx) or higher series resistor (Rs) requires slower clock (lower pre-scale value) for complete charging. • Increasing the pre-scale level from one to two increases the touch acquisition time.
Internal Series Resistor	DEF_xxxxCAP_SENSE_RESISTOR	• Increasing series resistor value may require increase in prescaler value. • Set internal resistor value to zero if only external resistor is used.
Detect Integration	DEF_xxxxCAP_DI	• Increasing DI increases repeated acquisition during touch and removing finger. This increases touch response time. • DI can be reduced to two in low-noise systems.
Frequency Auto Tune	DEF_xxxxCAP_FREQ_AUTO_TUNE_SIGNAL_STABILITY_LIMIT	• Setting “lower” value for these

Feature	QTouch Library Parameter	Recommendation
	DEF_xxxxCAP_FREQ_AUTO_TUNE_IN_CNT	parameters would trigger unwanted auto frequency tuning and increase the touch response time. • Set proper value such that auto frequency tuning is triggered only for appropriate noise level.
Quick Re-burst	DEF_xxxxCAP_QUICK_REBURST_ENABLE	• Resolving calibration or re-calibration or DI requires multiple touch acquisitions. • Enabling quick re-burst feature does repeated touch acquisitions only on sensors which requires multiple touch acquisitions. • Enabling quick re-burst feature reduces touch response time.
PTC Interrupt Priority	DEF_TOUCH_PTC_ISR_LVL	• The PTC interrupt priority level decides how fast the QTouch library services PTC’s End-Of-Conversion interrupt. • Lower priorities would increase the touch response time.
Scan Rate	DEF_TOUCH_MEASUREMENT_PERIOD_MS	• Increasing sampling interval reduces the user experience. • Optimum value depends on the application and the time taken to perform touch acquisition on all configured sensors. • Minimum value is the time taken to perform touch acquisition on all configured sensors.

5 Reference

[1] AVR3001: QTouch Conducted Immunity: www.atmel.com/Images/doc8425.pdf

[2] QTAN0079 Buttons, Sliders and Wheels - Sensor Design Guide: http://www.atmel.com/Images/doc10752.pdf

[3] Peripheral Touch Controller - User Guide: http://www.atmel.com/Images/Atmel-42195-Qtouch-Library-Peripheral-Touch-Controller_User-Guide.pdf

[4] AVR3002: Moisture Tolerant QTouch Design: www.atmel.com/images/doc42017.pdf

[5] IEC Standards – 61000-4 Series: http://www.iec.ch

[6] AVR040: EMC Design Considerations: http://www.atmel.com/Images/doc1619.pdf

6 Revision History

Doc Rev.	Date	Comments
42360A	11/2014	Initial document release.

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