Freescale Semiconductor
Application Note

Document Number: AN4781
Rev 0, 09/2013

In-Depth Understanding of Water Tolerance Feature in Touch-Sensing Software Library

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1 Introduction

The water tolerance feature in the Xtrinsic Touch-Sensing Software (TSS) library is a powerful tool to filter out changes in measurements caused by the presence of water in capacitive touch keypads.

This application note describes how the water tolerance feature works, as well as the hardware requirements for proper operation. It also shows some examples of situations in which the water tolerance feature will correctly work and some other cases in which a mixture of water tolerance feature and user software involvement is needed to solve the condition. Additionally, some mechanical recommendations are provided to help improve application robustness.

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2 Water tolerance explained

2.1 Shielding

The *shield* is an electrode properly placed around the common electrode and is intended to compensate signal drift. The TSS library provides the shielding function. It measures the environmental noise that affects the system. This function is intended to detect false touches caused by water drops and to eliminate low-frequency noise modulated on the capacitance signal.

When shielding function is enabled, the shield capacitive value is subtracted from the related electrode capacitive raw data (also called instant signal). This will compensate the signal rise due to water or other circumstances as environmental noise. This way the signal stays around its baseline even when the capacitance rises.

If the instant signal drift caused by a fingertip touch is same in shield and electrode, then the instant signal is fully suppressed by shielding function, and therefore touch cannot be detected. That is why shield should be mechanically protected from finger touch, to avoid fingers being confused for water.

Shielding function by itself is not enough for detecting touches under water conditions. Water Tolerance mode is available since the version 3.0.0 of TSS. It limits the suppression of the signal to a defined threshold and above that threshold, it is again possible to detect a touch. This simple modification to the shielding function allows (with a proper calibration and signal normalization) to get a good performance even under water droplets or thin films.

For more details about the shielding function, see *Touch Sensing Software API Reference Manual* (document TSSAPIRM).

2.2 Water tolerance and not waterproof

A system based on a waterproof design can always work under water conditions. Unlike this, system designed for water tolerance implies a normal operation only under some water levels. A water-tolerant design can also detect a large amount of water and take decisions in this regard, such as turning off the system until the water is clean.

The TSS has shown good performance under water droplets and thin water films. It just needs the proper calibration to detect touches accurately under these conditions.

2.3 Water tolerance implementation in TSS

In order to implement a water tolerance algorithm, the TSS 3.0.0 has included a Water Tolerance mode when the shielding function is enabled. This mode limits the shielding function; so compensation is restricted to the threshold defined in the Sensitivity Registers of the shield. When shield instant delta is greater than its sensitivity, the algorithm stops subtracting this extra signal increases. This allows suppressing only the effect of a water film, and not the effect of a fingertip touch.

Figure 1 shows at first a simple finger touch. Then a water film is placed over the electrode and a second finger touch is made. The following figure depicts the delta caused by the water which has to be subtracted in order to have only the finger touch delta.

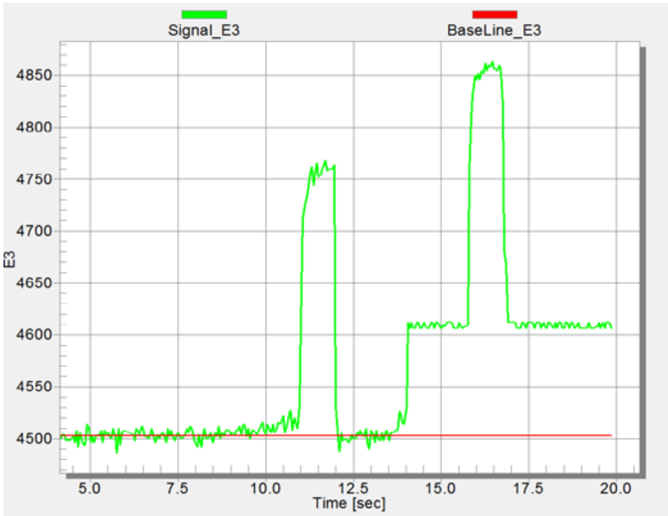

Figure 1. Simple touch vs. touch with water film

If the Water Tolerance mode is enabled and well configured, the effect of a water film over the electrode will be suppressed and just the touch delta remains.

Figure 2 shows an electrode instant signal and its shield. As seen from the shield signal (at the bottom), at time = 10 seconds, a thin water film is placed on the board. But the electrode signal (at top) stays around its baseline. At time = 12.5 seconds, a finger touch is made. The electrode delta seems like a regular touch signal due to the subtraction from the shield.

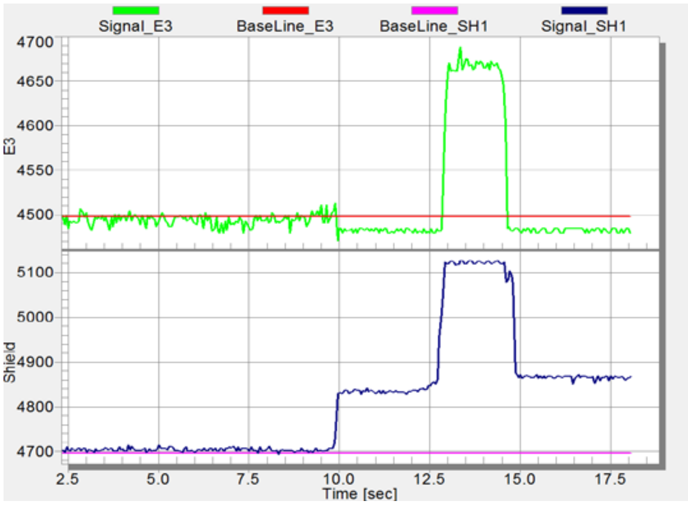

Figure 2. Touch with water film and water tolerance enabled

With the correct calibration, an electrode won't show any increase in its instant signal and delta when a large water drop is placed on its surface.

In addition, the algorithm can detect if a large amount of water is present over the electrodes (by the shield electrode status); so the programmer could take decisions about it, as turning off the system or changing the configuration settings.

2.4 Water tolerance configuration in TSS

2.4.1 Main settings

In order to make a water tolerance system, the shielding function has to be enabled in the TSS_SystemSetup.h file in the System setup module of TSS. A very important difference between TSS library versions 3.0.0 and 3.0.1 is that baseline tracking isn't available either for shields or electrodes in TSS 3.0.0. So, when the shielding function is enabled, every shield and its common electrode will stop refreshing the baseline. TSS 3.0.1 and higher versions allow the DC tracking in the electrode signal. However, it can be updated anytime by the Manual Recalibration Starter bit, if the application requires it.

The following defined MACROS have to be added to the TSS_SystemSetup.h to enable the Water Tolerance mode:

```
#define TSS_USE_SIGNAL_SHIELDING              1

#define TSS_USE_AUTO_SENS_CALIBRATION         0

#define TSS_USE_SIGNAL_DIVIDER                1

#define TSS_USE_SIGNAL_MULTIPLIER             1
```

Only the `TSS_USE_SIGNAL_SHIELDING` definition is really required for the Water Tolerance Mode. It is strongly recommended to use signal divider and multiplier in order to normalize the TSI rough signals, as well as turn the auto-sensitivity calibration (ASC) off and set a fixed threshold instead (turning on the ASC causes a bad performance under water conditions).

To enable the Water Tolerance mode, just set the WaterToleranceEn field in System Configuration register, using this code line.

```
/* Enables the TSS and Water Tolerance */
(void)TSS_SetSystemConfig(System_SystemConfig_Register,(TSS_SYSTEM_EN_MASK  |
                                                     TSS_WATER_TOLERANCE_EN_MASK));
```

Another important configuration is to select the best TSI resolution to make signals consistent with the maximum delta value. TSS 3.0.0 and earlier versions use a 7-bit maximum delta and sensitivity (this is 0-127 counts). For details about TSI auto-calibration settings and TSI resolution, see the chapter 2.1.37, "TSI auto-calibration settings" of *Touch Sensing Software API Reference Manual* (document TSSAPIRM).

2.4.2 Electrodes and controls definition

Next step is to configure the control. You must map each electrode to its corresponding TSI Channel, using the following code line. It must be noted that shields are also electrodes.

```
TSS_Ex_TYPE  TSIn_CHm
```

- x is the electrode number
- n is TSI module number
- m is TSI Channel

After this, you have to assign the shield to its corresponding electrode. Several electrodes can have the same shield but, unless there are any area restrictions, it is recommended to use a single shield for each electrode. This makes it easier to calibrate and will give the system better performance when Water Tolerance mode is required.

To assign a shield to a particular electrode, use the following code definition:

```
TSS_Ex_SHIELD_ELECTRODE  z
```

- x is the touch electrode number
- z is the shield electrode number

Now, control settings must be configured. For this, first of all, define the number of controls that the application is going to use.

```
#define TSS_N_CONTROLS    Y
```

In the code line given above, Y is the number of controls to be used.

Then add these four lines of code to configure the control:

```
#define TSS_Cx_TYPE          ControlType /* Control type */
#define TSS_Cx_ELECTRODES    n       /* Number of electrodes in the control */
#define TSS_Cx_STRUCTURE     ckey0       /* Name of the C&S struct to create */
#define TSS_Cx_CALLBACK      TSS1_fCallBack0  /* User's callback Identifier */
```

Where:

- x is the control number in the range. If there is only one control, it would be TSS_C0 and so on.
- n is the number of electrodes (range 1 to 16).
- ControlType is the specification of control type. The best for Water Tolerance is the keypad. It can be TSS_CT_KEYPAD, TSS_CT_SLIDER, TSS_CT_ROTARY, TSS_CT_ASLIDER, TSS_CT_AROTARY, or TSS_CT_MATRIX.

Note: Using controls and callbacks is not mandatory, but it is preferred as it saves time and processing from the end application. If controls and callbacks are not used, the software can simply poll flags.

2.4.3 Electrodes and controls configuration

After the electrodes and controls are defined, the next step is to configure them. For the electrodes (both shields and touch) set the Electrode Enabler and Sensitivity Configuration registers. It is recommended not to use automatic sensitivity calibration function in Water Tolerance mode, because it shows better results with a fixed sensitivity.

You do this by the *TSS_SetSystemConfig* function. The following code lines can be used to configure the electrodes:

```
 /* Set Sensitivity for each Electrode  */
 (void)TSS_SetSystemConfig(System_Sensitivity_Register + 0, 127u);
 (void)TSS_SetSystemConfig(System_Sensitivity_Register + N, S);

 /* Enablers Settings */
(void)TSS_SetSystemConfig(System_ElectrodeEnablers_Register + Rn, 0xFF);
```

Similarly, all the electrodes can be configured. *N* is the electrode number, *S* is the selected sensitivity, and *Rn* is the register number. See the chapter 3.4.15, “Sensitivity Configuration register” and chapter 3.4.16, “Electrode enablers,” in *Touch Sensing Software API Reference Manual* (document TSSAPIRM), for more details about sensitivity configuration and electrode enablers.

Control configuration includes enabling the touch events (touch, release, or both) and enabling the callback function as long as the control itself. You do this by adding the following two lines of code:

```
(void)TSS_KeypadConfig(cKey0.ControlId,Keypad_Events_Register,
                            TSS_KEYPAD_TOUCH_EVENT_EN_MASK);

(void)TSS_KeypadConfig(cKey0.ControlId,Keypad_ControlConfig_Register,
                            TSS_KEYPAD_CONTROL_EN_MASK|TSS_KEYPAD_CALLBACK_EN_MASK);
```

Where *cKey0* is the control structure identifier defined by user in the TSS_SystemSetup.h file. You can configure several features for the decoder, as maximum number of touches, buffer location, etc. For more details about this structure and how to configure it, see *Touch Sensing Software API Reference Manual* (document TSSAPIRM).

When all electrodes and controls are defined and configured, enable the TSS in Water Tolerance Mode and begin the normalization and calibration process. Enable the library by adding this line of code:

```
(void)TSS_SetSystemConfig(System_SystemConfig_Register, (TSS_SYSTEM_EN_MASK |
                         TSS_WATER_TOLERANCE_EN_MASK ));
```

2.4.4 Signal normalization

The goal of signal normalization is to get the same response in a single electrode and its shield when a touch or a water film is placed over it. It must be noted that the shielding function subtracts the shield delta from the electrode instant capacitive value. So, if the shield signal is much greater than the electrode signal, the subtraction will generate negative deltas. This situation will avoid having a signal large enough to pass the sensitivity threshold in a fingertip touch. On the other hand, if the shield signal is too low, then signal compensation will be useless and it could produce false touches due to the water film.

The surface area of the electrodes and shields is an important variable to be taken into account. Larger areas present larger capacitances, so the electrodes must be designed with the same or proportional areas.

Signal normalization is done using these definitions:

```
TSS_Ex_SIGNAL_MULTIPLIER          Y

TSS_Ex_SIGNAL_DIVIDER             Z
```

Where *x* is the electrode number, *Y* is the signal multiplier and *Z* is the divider. You can add these lines for every electrode in the TSS_SystemSetup.h file, as a part of the electrodes definition. For more details about this feature, see the chapter 2.1.10, “Signal Normalization” of *Touch Sensing Software API Reference Manual* (document TSSAPIRM).

2.4.5 Sensitivity calibration

2.4.5.1 Shield sensitivity

When Water Tolerance mode is enabled, the Sensitivity Configuration registers for a shield set the threshold that limits the shielding function. If a shield delta is larger than its threshold, still only the threshold value will be subtracted from the electrode instant delta, (and the excess value would be ignored).

The sensitivity level must be such a value which is reached by a water film in order to eliminate only the effect of water.

To calibrate the right sensitivity level, it is strongly recommended to turn off the shielding function and then observe the instant signals and deltas. Place a water film over the electrodes (remember water tolerance is intended just for thin water films) and debug your system to find out the level produced by the water in every electrode. This delta level will be the value for the corresponding shield sensitivity.

Calibration of sensitivities will be easier with a graphical user interface as the FreeMASTER tool, which can be downloaded from www.freescale.com/FreeMASTER.

Figure 3 illustrates the effect of the shielding function in removing water delta on the electrodes signals. It shows two graphics with a couple of electrodes instant deltas (E3 and E5). The figure shows only the electrode signals and not the shields. At first, the electrodes are dry, but at time = 32 seconds, a water film is placed over the board covering all of the electrodes area. In the upper part of this figure, the shielding function is not enabled, which is better to check the delta caused by the water. Then the sensitivity of shields is set to 115 and 125 (this is the delta produced by the water on E3 and E5 respectively). The lower part of this figure shows instant electrode deltas after this configuration. It can be easily seen that there is no delta due to water film because of the precise signal subtraction.

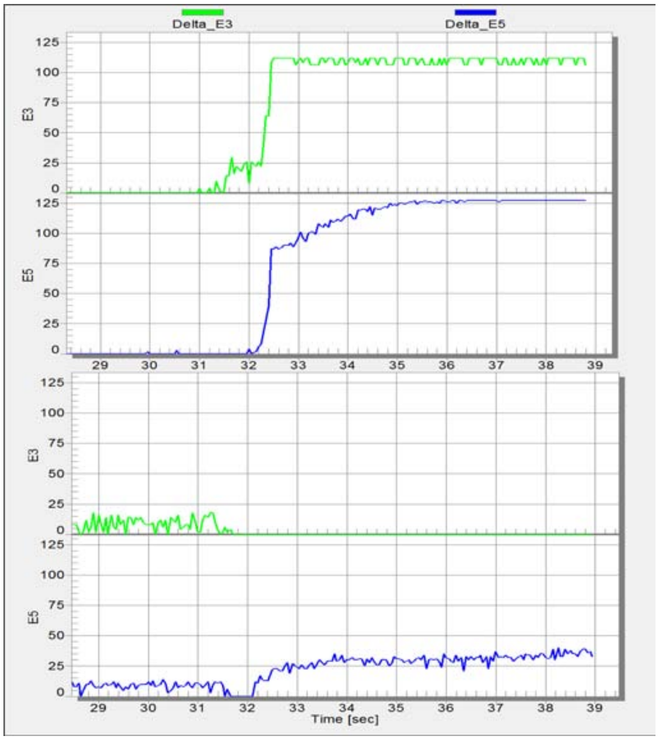

Figure 3. Disabling water tolerance to measure water effect and set a threshold

2.5 Electrode sensitivity

Tuning of the electrode sensitivities must be the last part of the process once you have normalized the signals and eliminated the water effect.

Enable the shielding function and debug the system. Place the water film over the electrodes and corroborate that there isn’t a considerable delta signal. If the delta signal due to a water film or droplet too large to be fully suppressed by the shielding function, go back to recalibrate the shield sensitivity until you get to eliminate all the delta signal caused by water in the touch electrode.

Touch the electrodes in the same way they will be used in the final application and check their delta levels. Adjust the sensitivity to best suit your application.

Note: If there's a lot of crosstalk between electrodes, you must be more cautious with calibration in order to avoid false touches caused by the adjacent electrodes.

Figure 4 shows regular deltas in the electrodes when there's a touch event after calibration process. Once you get these clean signals the sensitivity calibration for touch detection would be easy.

For the best tuning of your system, test it in dry and wet conditions and select the best settings for your application.

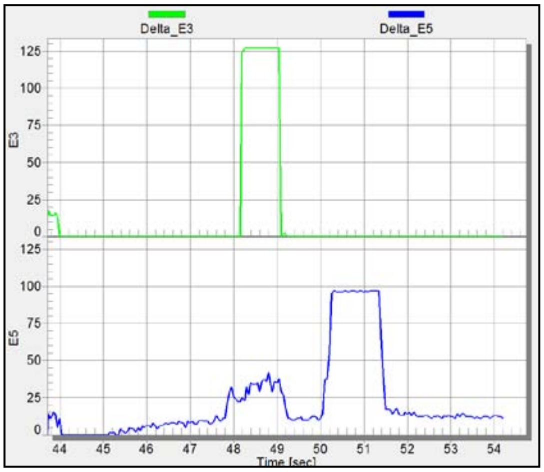

Figure 4. Delta in properly calibrated electrodes

3 Hardware design of water-tolerant capacitive keypad

When there's water on the electrodes, the capacitance is affected due to physical issues. The TSI signals will show an increase as a consequence of this. If there isn't an accurate compensation algorithm or if the sensitivity is too low, this change could produce some errors on touch detection.

In order to reach the best performance on systems were water tolerance is needed, the electrode layout must take into account the following considerations: (see Figure 5)

- Place the electrodes as far as possible from each other. This will reduce the crosstalk.
- Place the shield surrounding the touch electrode.
- Make touch areas very clear both visually and mechanically; this will help avoid finger touches on the shield to be confused for water.
- Use a single shield for every electrode. It makes easier to calibrate for water tolerance.

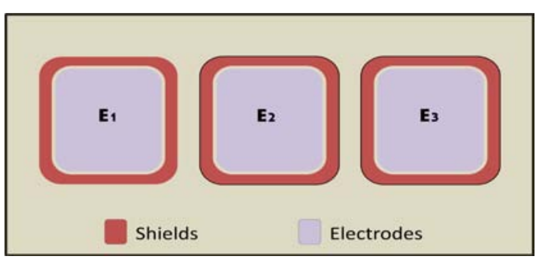

Figure 5. Single shield per electrode arrangement

For more information about layout and placement of touch sensing circuits using Freescale capacitive touch sensing technology, see *Designing Touch Sensing Electrodes* (document AN3863).

4 Examples

4.1 Water droplets

The effect of a water droplet on single electrodes is reflected as an increase in the capacitance. This increase is very small and produces deltas not larger than 10 or 20 counts at the right resolution (this is which generate 0-127 signal deltas). However, if an application uses a very tight sensitivity level, this delta value could cause false touches. It can be avoid by using Automatic Calibration, or just by setting a higher sensitivity threshold.

4.2 Salt water droplets

The salt water is known to be more conductive than fresh water. Its main effect is to reflect an increased capacitance. However, the increase due to salt water is almost the same as with fresh water. The difference between the two is not larger than 5 counts or 10 at most (with the right TSI resolution). Therefore, the application doesn't need special considerations for salt water droplets other than those needed for fresh water droplets.

4.3 Water film

A water film is a very different case from single water droplets. It can be considered as a large water droplet covering all of the electrodes. Due to the physical properties of water, this layer acts as a large electrode whose electric field will interact with electric field of the electrodes.

The first effect of adding a water film over a keypad is a large increase in the capacitance, which means a large increase in the instant capacitive measurements. This signal drift can be as large as produced by a fingertip touch. Consequently, the system will be detecting false continuous touches unless there's an algorithm to suppress this signal deviation.

The TSS is not intended for working on full submersion conditions. But it still can work under a thin water film if it's correctly configured and calibrated. The library uses the shield for suppressing its delta from the delta produced in the touch electrode. If the signals are proportional to its superficial area, this subtraction will maintain the signal close to its original baseline. The shield should be totally covered by water so the signal subtraction is performed accurately. This is why shields must surround its common electrodes in order to implement water film compensation.

The best results will occur if the physical layer is designed to produce the same capacitance in shield and touch electrode when a water film is placed over the board. If shield influence is too high (you can limit it with the Sensitivity Configuration register when Water Tolerance mode is enabled) or the touch electrode signal resolution is too low (you can normalize it to fix your application), then it will be impossible to distinguish a fingertip touch.

5 Mechanical design ideas

When a touch keypad is intended to work on wet conditions as rain or water spills, the user could appeal to mechanical solutions. The following subsections provide some design ideas that could improve the performance.

5.1 Slanted keypad

An easy way to implement a touch panel resistant to water spills could be by a simple slanted keypad. If the appliance is planned for stationary devices such as industrial panels or white line as an electric stove, this solution seems to be good enough to avoid the complications caused by electrodes submersion and spills.

5.2 Concave electrode surface

Another mechanical approach is the use of concave dielectric surfaces above the electrodes instead of flat surfaces. The dielectric above the electric is flat except for each area where an electrode is located. This will help isolate electrodes from large water film areas, which may cause trouble.

6 Conclusions

The TSS offers a solution for systems that require a certain level of tolerance to water environments, such as water droplets, films, and spill. It is not intended for full submersion situations.

The main effect of the library is to eliminate the delta caused by the water on the electrodes and then detect touches without this kind of *offset*.

The implementation of the algorithm needs the addition of an extra electrode to the layout which will act as a shield to the touch electrode. This shield must surround the electrode so it’s exposed to the same external capacitances (as a water film for example). The delta signal caused by the effect of the water in the shield is subtracted from the touch electrode delta, so the signal starts from zero when a finger touches the electrode.

The main configuration of the TSS includes the correct electrode and controls configuration. But the most refined part of the process is the calibration. It includes normalization of signals and setting of sensitivities. It's highly recommended to use a Graphic User Interface (GUI) as the FreeMASTER tool to facilitate this work. It is available on www.freescale.com/FreeMASTER.

In addition to software, the user can try mechanical solutions as using a slanted keypad or a concave overlay to protect the electrodes from the water effect.

7 References

The following documents are available on freescale.com.

- *Touch Sensing Software API Reference Manual* (document TSSAPIRM)
- *Migration Differences Between MPC5604B/C / SPC560B/C4 512 K Cut 1 to Cut 2* (document AN3864)
- *How to Implement a Human Machine Interface Using the Touch Sensing Software Library* (document AN3934)
- *Designing Touch Sensing Electrodes* (document AN3863)

8 Revision history

Revision number	Date	Substantive changes
0	09/2013	Initial release

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Document Number: AN4781
Revision 0, September 2013