

## Improve conducted noise robustness for touch sensing applications on MCUs

### Introduction

Different levels of immunity to conducted RF voltage are required by touch sensing systems, depending on the application (such as home appliances, automotive or health care). Moreover, touch sensing systems are often designed to meet the requirements of industry standards, especially in the EMC compliance domain.

It is important to understand the environment in which the touch application is used, and to apply suitably adapted techniques to address the effects of unwanted noise disturbances.

This document provides a basic overview of conducted immunity testing and some guidelines to keep the system reliable when it is exposed to conducted noise.

STMicroelectronics provides free STMTouch touch sensing firmware libraries, directly integrated into the corresponding STM32Cube® package (such as STM32CubeL4).

**Table 1. Applicable products**

Type	Product series
Microcontrollers	STM32F0 Series, STM32F3 Series
	STM32L0 Series, STM32L1 Series, STM32L4 Series
	STM32WB Series

## 1 General information

This document applies to the STM32 Arm®-based microcontrollers.



*Note: Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.*

## 2 Conducted noise immunity

### 2.1 Signal to noise ratio (SNR)

The signal to noise ratio (SNR) is an important characteristic in the evaluation of a touch sensing system.

The SNR measurement results are only valid for a specified board and for the noise environment at the moment of the measure. This is why the noise immunity is better evaluated by referring to a standard like IEC61000-4-6 where the noise level and the test conditions are specified.

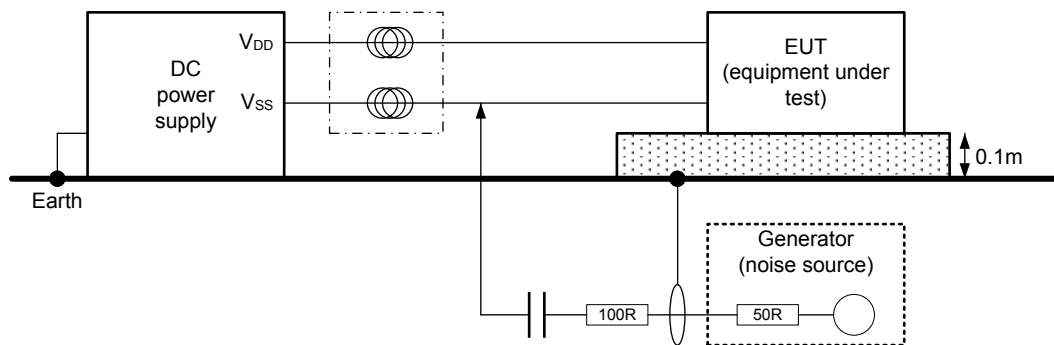
### 2.2 IEC61000-4-6 standard

The IEC61000-4-6 standard specifies the test procedure to evaluate the noise immunity of an EUT (equipment under test).

#### 2.2.1 Standard IEC61000-4-6 test setup

The test consists in using a noise generator to inject modulated noise signals into the EUT power supply lines as shown in the figure below.

Figure 1. Standard IEC61000-4-6 test setup



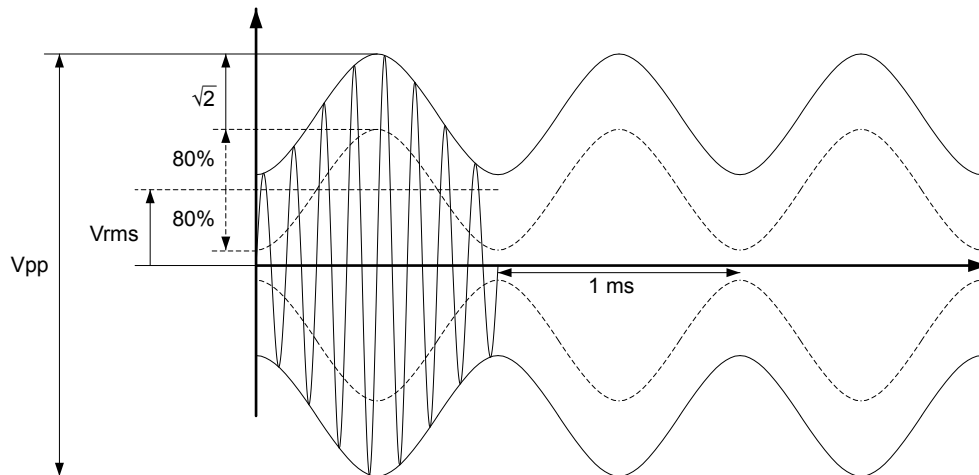
Touch sensing systems are based on capacitor variation measurements. The system must be able to detect capacitive variations as low as few picofarads on the sensor electrodes. Therefore such systems may be sensitive to conducted noise.

In a real touch sensing system, the main source of perturbation is introduced by the finger of the user. This is because the user is in the electric path between the system and the earth. In the test setup shown in Figure 1, the injected signal simulates the noise perturbations to which a system may be exposed. By varying the frequency and the level of the injected signal, the test setup allows the characterization of situations where the touch system becomes unreliable.

### 2.2.2 Injected signal characteristics

The injected signal is a swept modulated noise source with a sine wave envelope as shown in the figure below.

Figure 2. Injected signal



The noise generator frequency range is swept from 150 kHz to 80 MHz. The frequency is swept incrementally, the step size must not exceed 1 % of the preceding frequency value. The signal is 80 % amplitude modulated with a 1 kHz sine wave.

The modulated noise signal amplitude may be expressed either in  $V_{rms}$  or  $V_{pp}$ .

Here is the formula to convert values from  $V_{rms}$  to  $V_{pp}$ :

$$V_{pp} \text{ value} = V_{rms} \times \sqrt{2} \times 1.8 \times 1.2$$

### 2.2.3 Noise immunity evaluation

The EUT noise immunity is evaluated by testing the ability of the EUT to behave according the definition of a given class when it is submitted to a given noise level. The table below summarizes the different noise levels and classes.

Table 2. Test levels

Standard class \ noise level	Level 1 1 $V_{rms}$	Level 2 3 $V_{rms}$	Level 3 10 $V_{rms}$
<b>Class A:</b> system works normally.	Pass/fail	Pass/fail	Pass/fail
<b>Class B:</b> Some degradation in operation may occur (false touch detection or touch masking), but the product recovers once the stress is removed without any operator intervention.	Pass/fail	Pass/fail	Pass/fail
<b>Class C:</b> same as class B but needs an external action (such as reset or power off/on) to return to normal state.	Pass/fail	Pass/fail	Pass/fail
<b>Class D:</b> system loosing function or degradation of performance that is not recoverable	Pass/fail	Pass/fail	Pass/fail

### 2.2.4 IEC61000-4-6 standard limitation

The minimum frequency step recommended by the standard to sweep the injected signal from 150 kHz to 80 MHz is 1 % of the preceding frequency value. At 500 kHz this represents a 5 kHz step.

On most touch sensing systems, these steps are too large to be able to isolate the worst case situations. Some applications with narrow critical wave band can pass 3  $V_{rms}$  if the critical frequency falls just in the middle between tested frequencies. The same application does not pass 1  $V_{rms}$  if the user sets the test exactly on the critical frequency.

It is then important to set smaller steps around the critical frequencies. Sometime the standard bench is not able to do the appropriate step (for example 100 Hz). [Section 4 Test set up proposal to detect worst case](#) proposes a method to detect the worst case.

### 3 Surface charge transfer acquisition principle overview

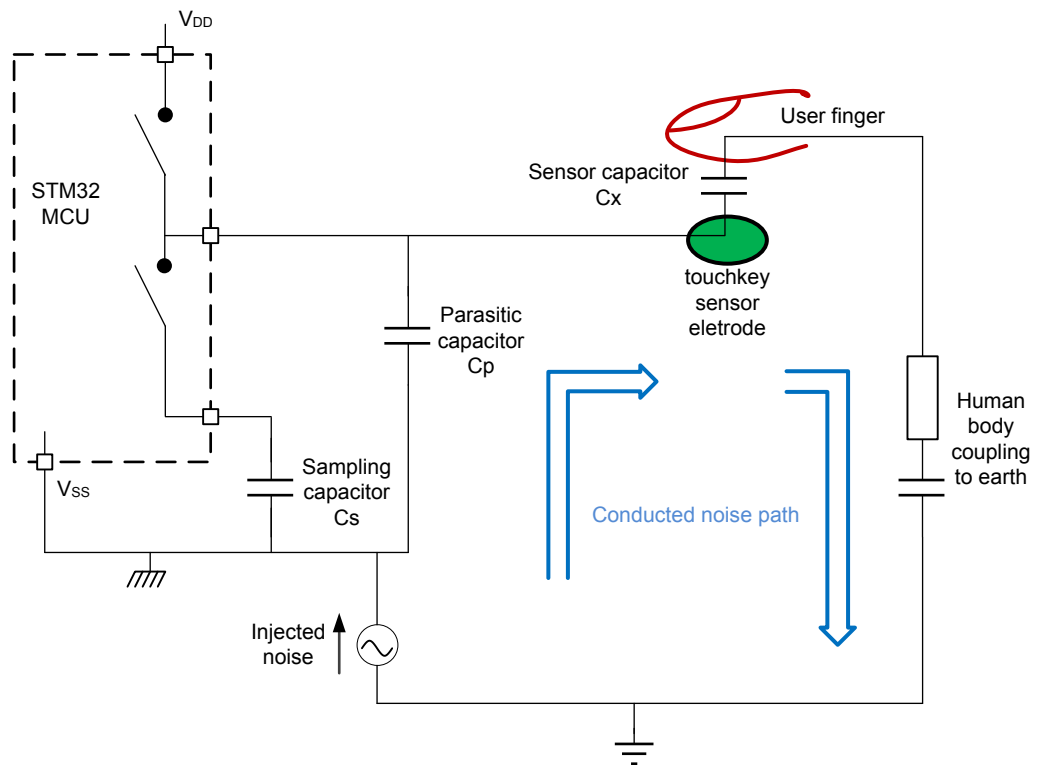
The STM32 microcontrollers use a surface charge transfer acquisition principle, briefly described below.

The surface charge transfer acquisition principle consists in charging a sensor capacitance ( $C_x$ ) and transferring a part of the accumulated charge into a sampling capacitor ( $C_s$ ). This sequence is repeated until the voltage across  $C_s$  reaches a given threshold ( $V_{IH}$  in our case). The number of charge transfers required to reach the threshold is a direct representation of the size of the electrode capacitance.

When the sensor is touched, the sensor capacitance to the earth is increased so the  $C_s$  voltage reaches the threshold with less count and the measurement value decreases. When the measurement value falls below a defined threshold, a detection is reported.

The noise injection disturbs the measurement proportionally to its amplitude and depending on its frequency. The worst case is generally found at a noise frequency close to the charge transfer frequency (assuming no techniques are used to spread this frequency).

**Figure 3. Charge transfer equivalent capacitance model**



## 4 Test set up proposal to detect worst case

Most of the IEC61000-4-6 compliant generators do not offer the ability to generate a step smaller than 1 kHz. In order to determine the most critical noise frequency, it is usually required to use 100 Hz steps or even 10 Hz steps. The setup detailed in this section is an alternative to find out the most critical noise frequencies and to evaluate the robustness of the EUT at these frequencies.

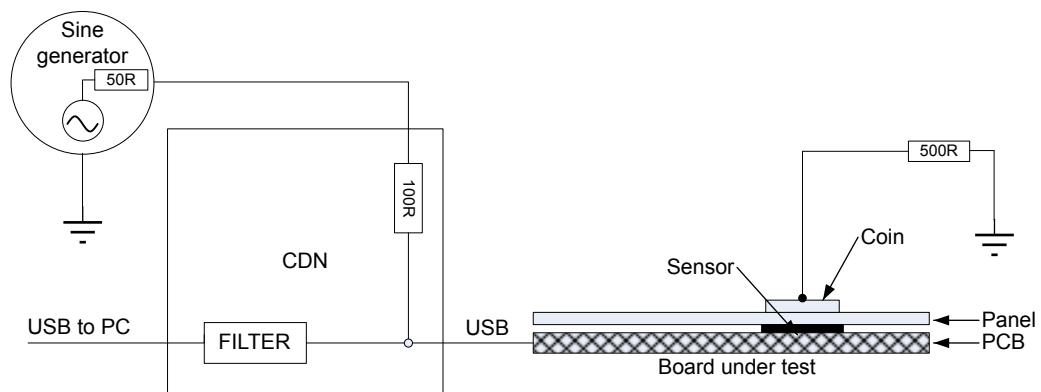
**Note:** *The noise frequencies impacting the equipment are around the charge transfer frequency and up to 40 MHz. Higher noise frequency does not have an impact on the equipment operation.*

### 4.1 Test setup

In order to simulate a human finger, a copper coin (from 10 to 16 mm diameter) with a 500  $\Omega$  serial resistor connected to GND can be used.

The CDN adaptor is the same as the one used in IEC61000-4-6.

**Figure 4. Test condition**



### 4.2 Generator settings

The following steps are needed to set the generator:

1. Select "sine wave" and "sweep" mode.
2. Sweep menu: time = 300 s, return time = 0, linear, interval = 1 ms
3. Set Vpp value on the generator to obtain the corresponding voltage injected on the EUT in case of standard test.

Example: to test in the same condition as the standard at 3 Vrms, the user must adjust the generator voltage to inject 15 Vpp measured on the board with oscilloscope.

**Note:** *On the AFG3102 Tektronix® generator, the modulation is not available in sweep mode.*

4. Set the start and end frequencies such that the sweep range does not exceed 60 kHz for a 300 s duration. This recommendation allows the detection of the worst case level with sufficient accuracy (typically less than 5 % error).

**Note:** *An external amplifier may be needed in case the generator is not able to reach the appropriate injection level.*

### 4.3 Data logging and data processing

#### Data logging

The log function of the STM Studio tool can be used to collect data from variable (refer to the *STM-Studio-STM32* databrief for more details).

Example: “MyChannels\_Data[x].Delta” and “MyTKeys[(x)].p\_Data->Stateld”

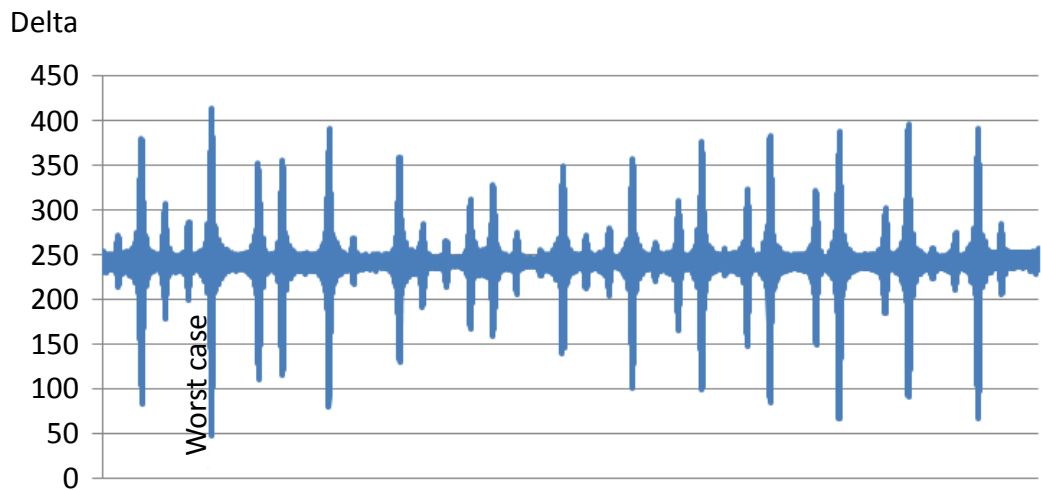
#### Data processing

A graphical tool is recommended for analysis of the results. For example with Microsoft® Excel 2D the user can obtain the chart shown in the figure below.

In this example the frequency sweep starts at 500 kHz and ends at 550 kHz. Noise level is set on the generator to 4.6 Vpp (no modulation). The detect out threshold is set to 50, the sensor is touched and the detection is valid if the measured delta is upper 50 else the touch detection is lost (error is reported). It means that 4.6 Vpp is the limit to avoid detection loss (4.5 Vpp pass)

As a comparison, IEC61000-4-6 standard recommendation to use 1 % frequency steps would have lead to explore only ten frequencies in this range, so the chances to detect worst case would have been very low!

Figure 5. Data processing



## 5 How to improve noise immunity

The two following directions can be followed to improve noise immunity:

- Decrease noise level.
- Increase signal (measurement sensitivity).

*Note:* In order to obtain a real benefit on the SNR, the noise reduction must not degrade the sensitivity and vice versa.

### 5.1 Proposed improvement techniques

Several improvement techniques are introduced below:

- Active shield  
This feature increases the measurement sensitivity.
- Spread spectrum  
When activated, the spread spectrum creates several acquisition frequencies. This feature is particularly appropriate for reducing overall noise level inside the measurement when the noise is concentrated on certain frequencies (as opposed to a white noise).
- Detection thresholds  
Adjusting these parameters allows the optimization of the reported detection that is a compromise between false detection and detection loss.
- SW filter  
This feature, such as debounce filter, can be used to remove short and unwanted detections.
- Frequency hopping  
Upon detection of excessive noise on a dedicated channel, the firmware is able to change the acquisition frequency in order to move out of the disturbed frequency range. There may be some situations where frequency hopping and spread spectrum cannot be activated both at the same time. This is useful to get a Class B operation with no false touch detections (generally preferable than having some false touch detections).
- Channel blocking  
This feature uses an additional channel to detect noise and cancel touchkey detection if noise reaches a determined threshold.
- Impedance path to earth  
Decreasing the impedance path to earth is a good way to cancel the conducted noise effect (use of a metallic chassis, system ground and earth connected together). For instance, an application offering a direct connection between the earth and the system ground is not impacted by the conducted noise.

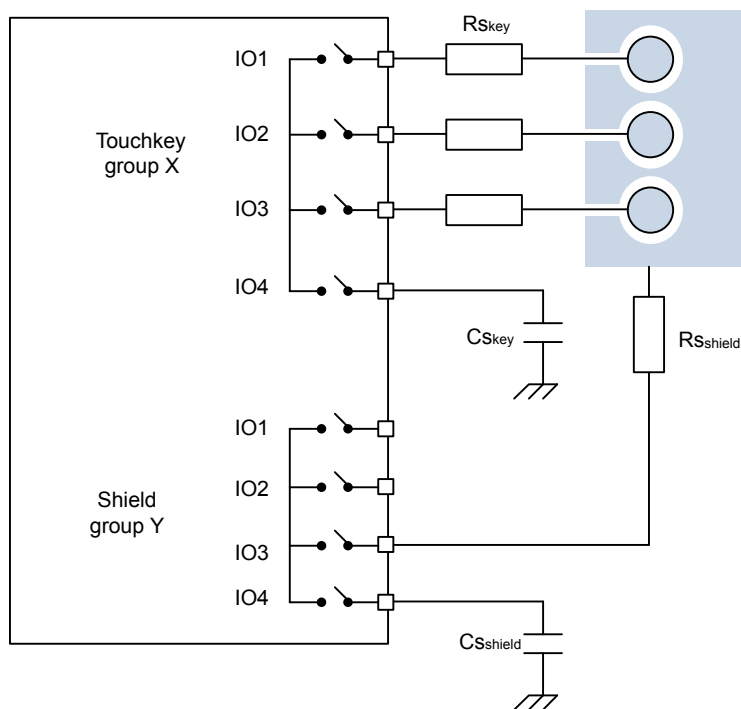
*Note:* Such an approach does not improve the system performances when performing the conducted noise test according to the IEC61000-4-6 standard.



## 5.2 Active shield

The active shield is an electrode that wraps around the sensor. The goal is to minimize the parasitic capacitance between the sensor and the ground. To drive the shield electrode, a channel of a dedicated group with its own  $C_s$  can be used (see the figures below).

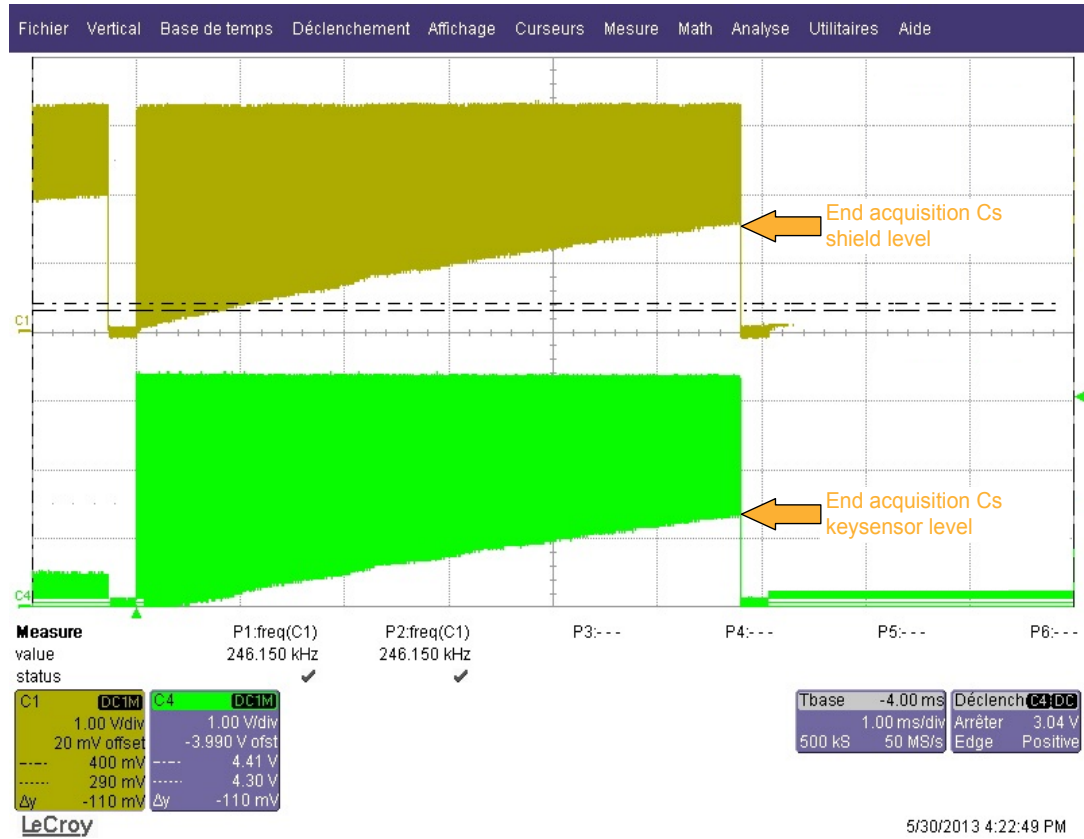
**Figure 6. Active shield**



It is important to check the shield electrode waveform.  $C_s$  shield capacitance value and  $R_s$  shield serial resistor value must be adjusted in order to obtain the same signal shape as sensor electrode waveform (same amplitude, same response time).

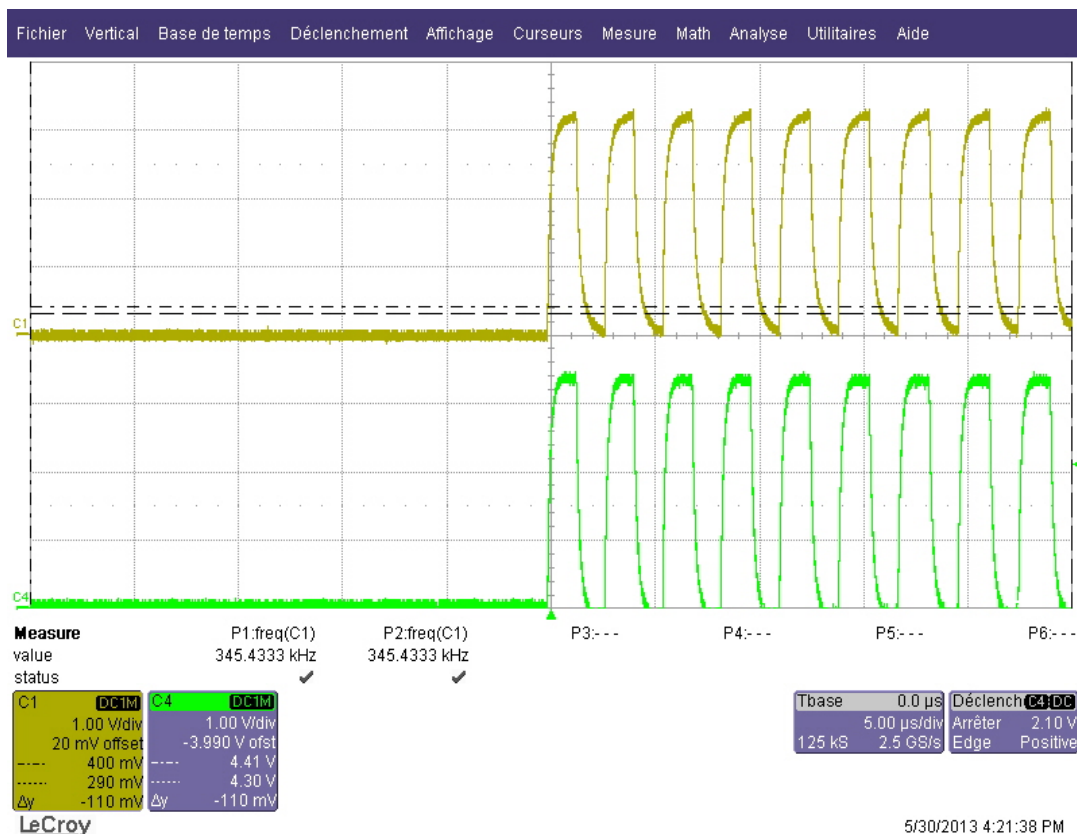
The figure below shows the electrode sensor waveform in green and shield electrode waveform in yellow. Cs shield is adjusted to obtain approximately the same charge level at the end of the acquisition.

Figure 7. Electrode and active shield waveforms



The figure below is a zoom of the previous one at the beginning of acquisition: Rs and Cs shields are adjusted to obtain approximately the same rise and fall time on the shield electrode as sensor electrode waveform.

**Figure 8. Waveform detail**



When the active shield is properly implemented, the count value is about twice as much as the count value without active shield. Since the noise level is not increased, the SNR is improved by a factor of 2, and noise immunity as well.

The negative impact of this feature is the requirement to dedicate two more I/Os and one more touch sensing group.

### 5.3 Spread spectrum

Without spread spectrum, the main noise susceptibility is found at the acquisition frequency and its value is  $1/TCD$  ( $TCD$  = transfer cycle duration).

The main frequency (HCLK) in the STM32 MCUs comes from the PLL output. Preferably the highest frequency recommended by specification is used to offer an optimum response time (example: 48 MHz for the STM32F0 Series).

This frequency is divided in the TSC cell by programmable prescaler (PGCLK). This frequency determines the basic timing units for CTPH, CTPL as follows:

Transfer cycle duration =  $(1 / (PGCLK) \times ((CTPH + 1) + (CTPL + 1))) + (\text{dead time} = 2 \times 1 / (HCLK))$

By enabling the spread spectrum feature (TSLPRM\_TSC\_USE\_SS to 1), the noise susceptibility is distributed on multiple frequencies. This is done by adding HCLK timing units (period) to CTPH.

TSLPRM\_TSC\_SSD allows to set the number of distributed frequencies as follows:

from  $0 = 1 \times t_{SSCLK}$  to  $127 = 128 \times t_{SSCLK}$

It is recommended to set TSLPRM\_TSC\_SSD to 127. In this case the number of distributed frequencies is  $2^7 = 128$ . The results is a noise immunity improved by approximately a factor of 7.

The negative impact of this feature is the degradation of the acquisition speed and thus the response time.

TSLPRM\_TSC\_SSD set to 127 adds an average of  $64 \times (1 / 48 \text{ MHz}) = 1.33 \mu\text{s}$  to each count. For a 2000 counts acquisition duration, 2.6 ms is added due to spread spectrum activation.

Usually end users need a response time in less than 60 ms. Assuming the application uses 3 banks, that means individual acquisition must be reported in less than 20 ms. If moreover a debounce filter is used (set to 2), this time constraint must be divided further by a factor of 3. This leads to a maximum target time for one acquisition equal to 6.6 ms.

One acquisition time = count number x transfer cycle duration (see “transfer cycle duration” formula above)

### 5.4 Threshold adjustment

The two following thresholds can be adjusted:

- DETECT\_IN: threshold to set a detection, recommended to be set to 2/3 of delta signal while touched with a normalized finger
- DETECT\_OUT: threshold to reset a detection, set to 1/3 of delta signal

Example: if the delta when there is a touch is 150 counts, set TSLPRM\_TKEY\_DETECT\_IN\_TH to 100 and TSLPRM\_TKEY\_DETECT\_OUT\_TH to 50.

Those values can be adjusted knowing they are a compromise between the two following requirements:

- Avoid false detection on untouched adjacent key sensors.
- Avoid detection loss.

### 5.5 SW filter (debounce)

The SW filter allows the reduction of false detections or detection losses. It is configured with TSLPRM\_DEBOUNCE\_DETECT and TSLPRM\_DEBOUNCE\_RELEASE parameters.

Setting the TSLPRM\_DEBOUNCE\_DETECT parameter to 2 means that three consecutive acquisitions with a touch detected are needed to report a touch detection.

There is a trade-off. Increasing this parameter results in a longer response time between the moment when a user touch change occurs and when it is actually reported to the system.

## 6 STM32303C-EVAL board example

### 6.1 Firmware

The firmware used with the STM32303C-EVAL is the STM32F303\_Ex01\_2TKeys\_EVAL and it belongs to the STM32F3xx STMTouch library. The results provided in this section are obtained with the configuration values presented in the table below.

**Table 3. User configuration settings related to immunity improvements**

Parameter	Configuration value
HCLK	48 MHz
TSLPRM_TKEY_DETECT_IN_TH	100
TSLPRM_TKEY_DETECT_OUT_TH	50
TSLPRM_DEBOUNCE_DETECT	2
TSLPRM_TSC_CTPH	1
TSLPRM_TSC_CTPL	1
TSLPRM_TSC_PGPSC	5
TSLPRM_TSC_USE_SS	1
TSLPRM_TSC SSD	127

### 6.2 Performance

The performances of an STM32303C-EVAL board, with the configuration described above, are the following:

- Acquisition performed in 1200 counts
- Acquisition duration: 4.7 ms (target < 6.6 ms)

### 6.3 Conducted noise evaluation

The conducted noise evaluation results performed on the STM32303C-EVAL board according to IEC61000-4-6 standard is above 3 Vrms class A,

with the following test conditions:

- Frequency range from 150 kHz to 80 MHz
- 1 % frequency steps
- Dwell time 0.5 s

On worst case bandwidth, no false detection or loss is observed up to 4 Vrms, from 200 to 400 kHz with 100 Hz steps.

## 7 Conclusion

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The touch sensing controller peripheral of the STM32 devices shows a high noise immunity level in compliance with IEC61000-4-6 standard (above 3 Vrms class A). These results can easily be reached by putting in practice the following recommendations:

- Implement an active shield electrode and enable the active shield feature in the firmware.
- Enable the spread spectrum feature in the firmware.
- Optimize the detection thresholds.
- Use the debounce filter.

## Revision history

**Table 4. Document revision history**

Date	Revision	Changes
03-Jul-2013	1	Initial release.
11-Jun-2014	2	Added support for STM32L0 Series. Updated last bullet in Section 4.1. Proposed improvement techniques.
22-Oct-2015	3	Added support for STM32L4 Series.
14-Mar-2018	4	Updated: <ul style="list-style-type: none"> <li>Figure 2. Injected signal</li> <li>Figure 5. Data processing</li> </ul> Added Section1. General information.
18-Jan-2019	5	Updated: <ul style="list-style-type: none"> <li>Title of the document</li> <li><a href="#">Table 1. Applicable products</a></li> </ul>

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