NuMaker ML56SD Touch Key Design Guide

Application Note for NuMicro® ML56 Series

Document Information

Abstract	This application note describes how to develop the touch key system. This document includes the introduction and guideline of capacitive touch key technology, PCB design, sample code, touch key library and NuSenadj developing tool. An actual development touch key system example is provided in Chapter 7.
Apply to	NuMicro® ML56 series microcontrollers.

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1 Overview

The design guide shows how to implement a high performance capacitive touch key sensing system with NuMicro® ML56 series. It first introduces the fundamental technology of capacitive touch key feature in NuMicro® ML56 series, and uses the NuMaker-ML56SD development board as an example to explain the hardware design rules, firmware library functions, and related PC developing tool.

The capacitive touch key sensing function has been widely implemented to industrial products and consumer electronics. Nuvoton NuMicro® ML56 series is embedded with a reliable, stable and simple-to-use capacitive touch key sensing controller to bring the touch key function into products. In addition to the capacitive touch key sensing function, the ML56 series also integrates programmable digital and analog peripheral functions, such as Timer, ADC, LCD, and communication interfaces, which add flexibility of the product function design, and effectively reduces the time-to-market and the total BOM cost.

1.1 ML56 Capacitive Touch Key Features

- Supports up to 14 touch keys + 1 reference pad.
- Programmable sensitivity levels for each channel.
- Graphical user interface (GUI) tool for user to develop the touch key system.
- Supports any touch key wake up for low power applications.
- Good waterproof function, support finger touch with 2 mm depth water droplet. Touch key system parameters are shown in the Table 1-1.

System Parameters	Description
PCB Layout	Please follow the touch key PCB design guidelines in Chapter 3.
Pulse Width	Pulse Width = 500 ns. Please refer to Section 7.3.2.
Times	Times = 128. Please refer to Section 7.3.3.

Table 1-1 Touch Key System Parameters Setting for Waterproof

- IEC 61000-4-6 conducted noise immunity (CNI) with 10 Vrms noise voltage. Touch key system parameters are shown in the Table 1-2.

System Parameters	Description
PCB Layout	Please follow the touch key PCB design guidelines in Chapter 3.
Pulse Width	Pulse Width = 2 us. Please refer to Section 7.3.2.
Times	Times = 128. Please refer to Section 7.3.3.
IIR	New = 6, Old = 2. Please refer to Section 7.3.3.
Debounce	Entry = 1, Release = 1. Please refer to Section 7.3.3.

Table 1-2 Touch Key System Parameters Setting for Noise Immunity Test

1.2 Design Flow

When designing a touch key system with the NuMicro® ML56 series, there are some factors affecting the overall touch sensing performance. Follow the instructions in Figure 1-1 through the whole design flow and mass production to obtain the high performance and stable touch key system.

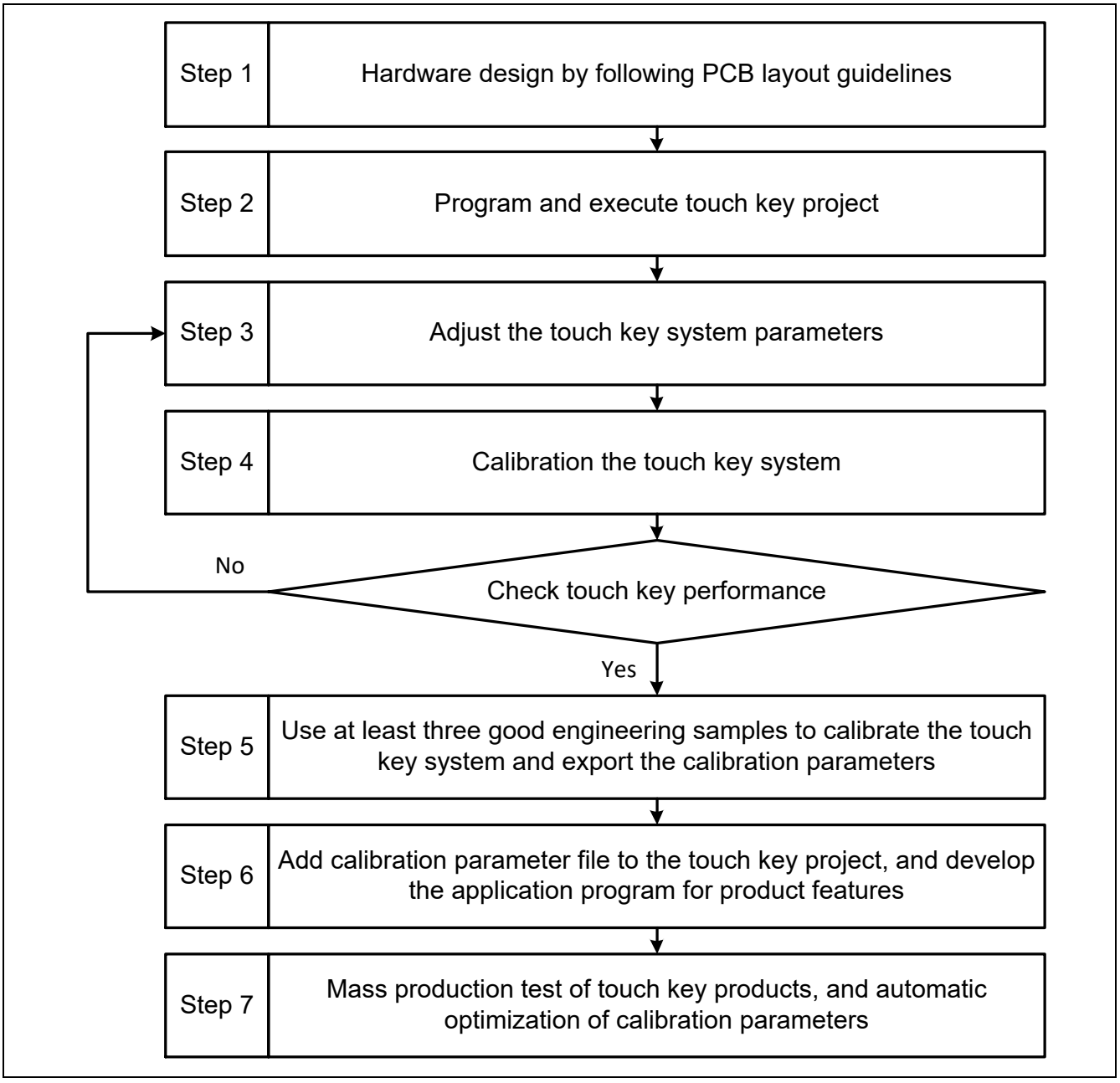


Figure 1-1 Touch Key Design Flow Chart

2 Capacitive Touch Key Technology

The capacitive touch sensing technology enables the measurement of the capacitance changes between a sensor and its environment to detect the presence of a finger on or near a touch surface.

2.1 Capacitive Touch Key Fundamentals

A typical touch key sensor consists of a copper pad etched on the surface of a printed circuit board (PCB). An insulating cover serves as a touch surface for the sensor, as shown in Figure 2-1.

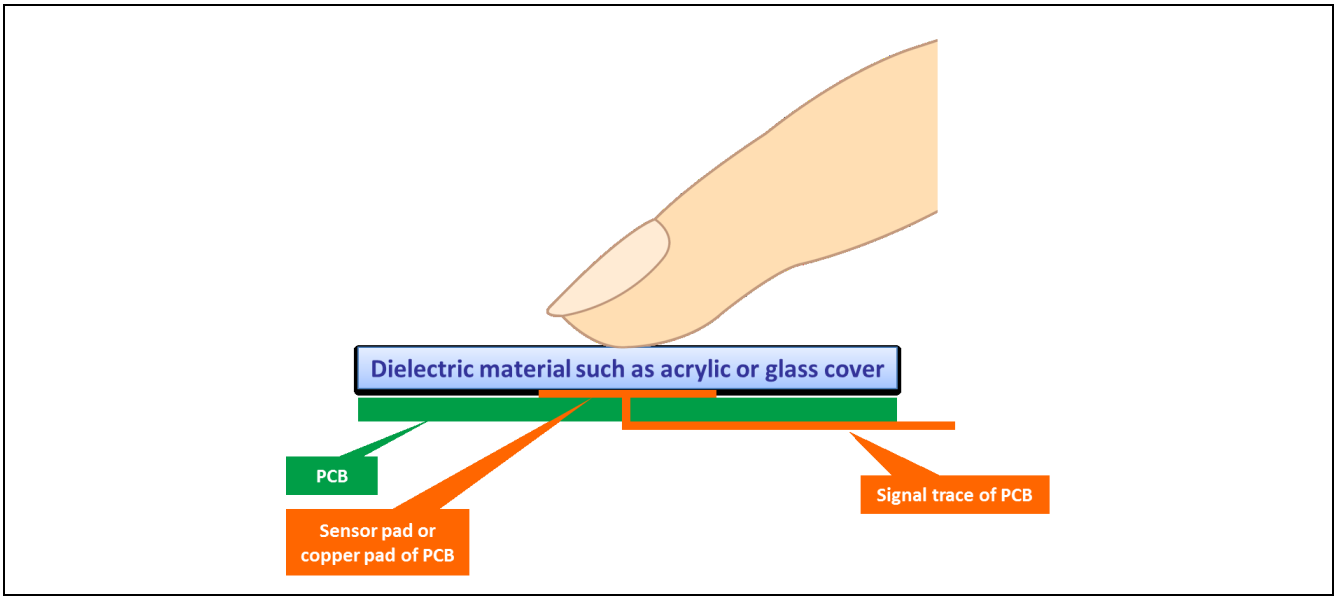


Figure 2-1 Typical Touch Sensor

The PCB traces and via connect the sensor pads to the touch key input pins of NuMicro® ML56 series. As shown in Figure 2-1, the total amount of capacitance on sensor pin is modeled as equivalent lumped capacitor. The ML56 series converts these capacitance values into equivalent digital counts. These digital counts are then processed by the controller to detect if any finger touches.

The capacitance of the sensor without a finger touch is called as “parasitic capacitance”, C_P. Parasitic capacitance results from the electric field between the sensor (including the sensor pad, traces, and via) and other conductors in the system such as the ground planes, traces, any metal in the product’s chassis or enclosure, etc. The sensor pin and internal capacitances of the ML56 series also contribute to the parasitic capacitance. Figure 2-2 shows how a sensor

pin of the ML56 series is connected to a sensor pad with traces and via. Typically, a shield hatch surrounds the sensor pad. The actual electric field distribution is complex.

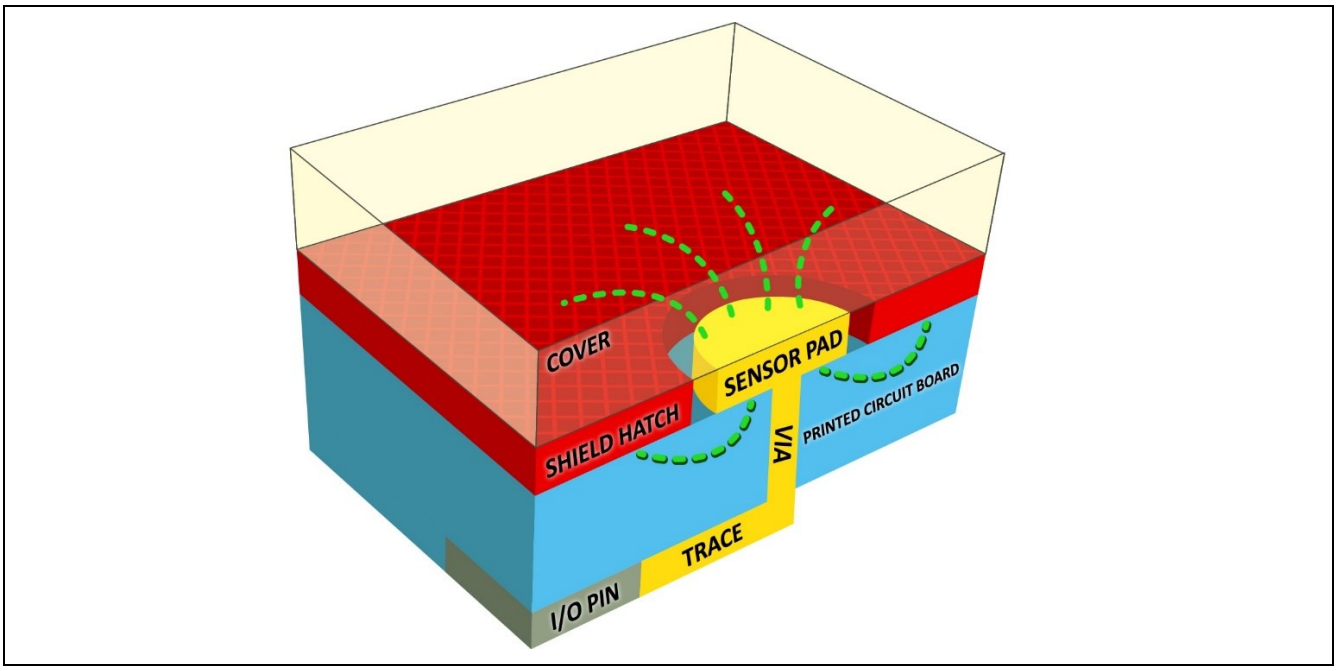


Figure 2-2 Parasitic Capacitance

When a finger presents on the cover, the conductive nature and large mass of human body from a grounded, conductive plane is parallel to the sensor pad, as shown in Figure 2-3.

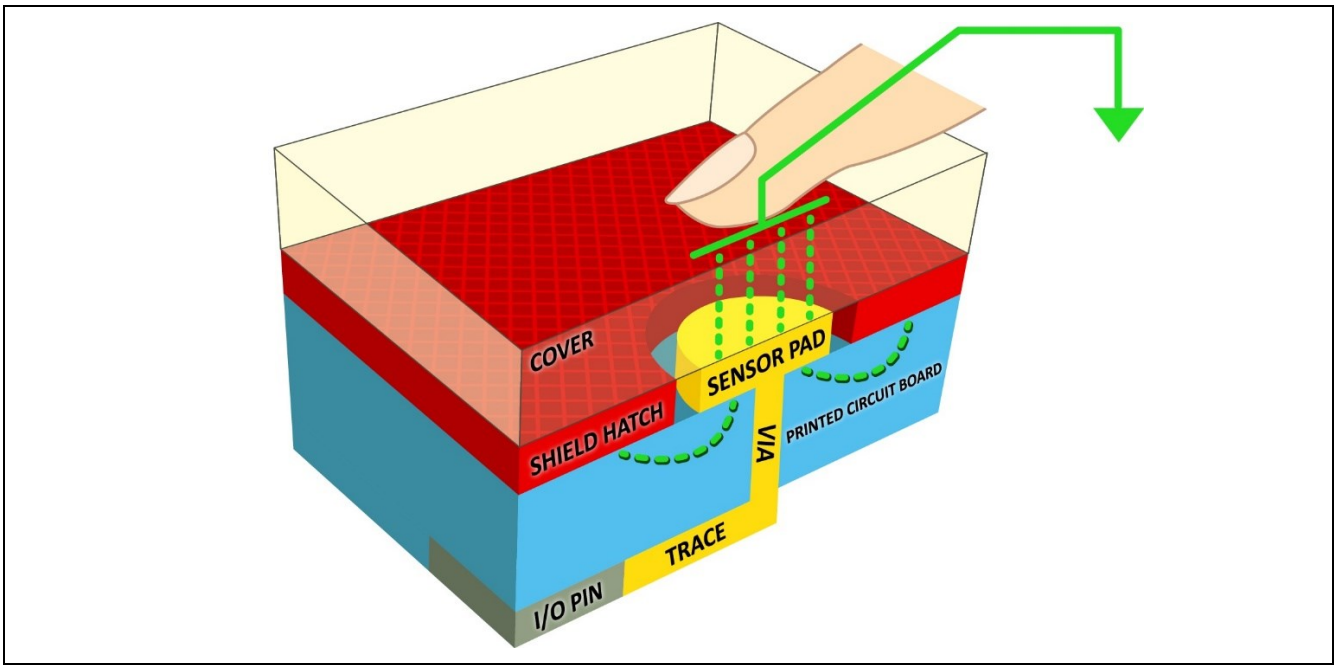


Figure 2-3 Capacitance Formed by a Finger Touch

This arrangement forms a parallel plate capacitor. The capacitance between the sensor pad and the finger is:

$$C_F = \varepsilon_0 \varepsilon_r A/d$$

Where: ε_0 = Free space permittivity

ε_r = Relative permittivity of the cover

A = Area of finger and sensor pad overlap

d = Cover Thickness

C_F is known as the finger capacitance. When a finger touches the touch key, the parasitic capacitance C_P and finger capacitance C_F are parallel to each other because both represent the capacitance between the touch key pin and ground. Therefore, the total capacitance C_T of the sensor is the sum of C_P and C_F.

$$C_T = C_P + C_F$$

The touch key controller converts the capacitance C_T into equivalent digital counts called raw data. Because a finger touch increases the total capacitance of the touch key, an increase in raw data indicates a finger touch.

2.2 Capacitive Touch Key Method

The touch key sensing method, as shown in Figure 2-4, implements two switching capacitor banks for injecting charges to C_P (or C_T) and C_R which is the parasitic capacitance of reference pad channel.

After touch key calibration, C_P and C_R are balanced with C_B and C_{CB} (comparator output is "low"). A finger touches presents on sensing touch key results in C_T (C_T = C_P + C_F), makes negative input terminal voltage of the comparator be lower than positive side and comparator output is "high". This means C_T and C_R are not balanced, and the touch key controller will increase C_{CB} to C_{CB}' to make C_T and C_R are balanced again (comparator output is "low"). A finger touch can be detected by checking the difference of C_{CB} and C_{CB}'. Please refer to Figure 2-5.

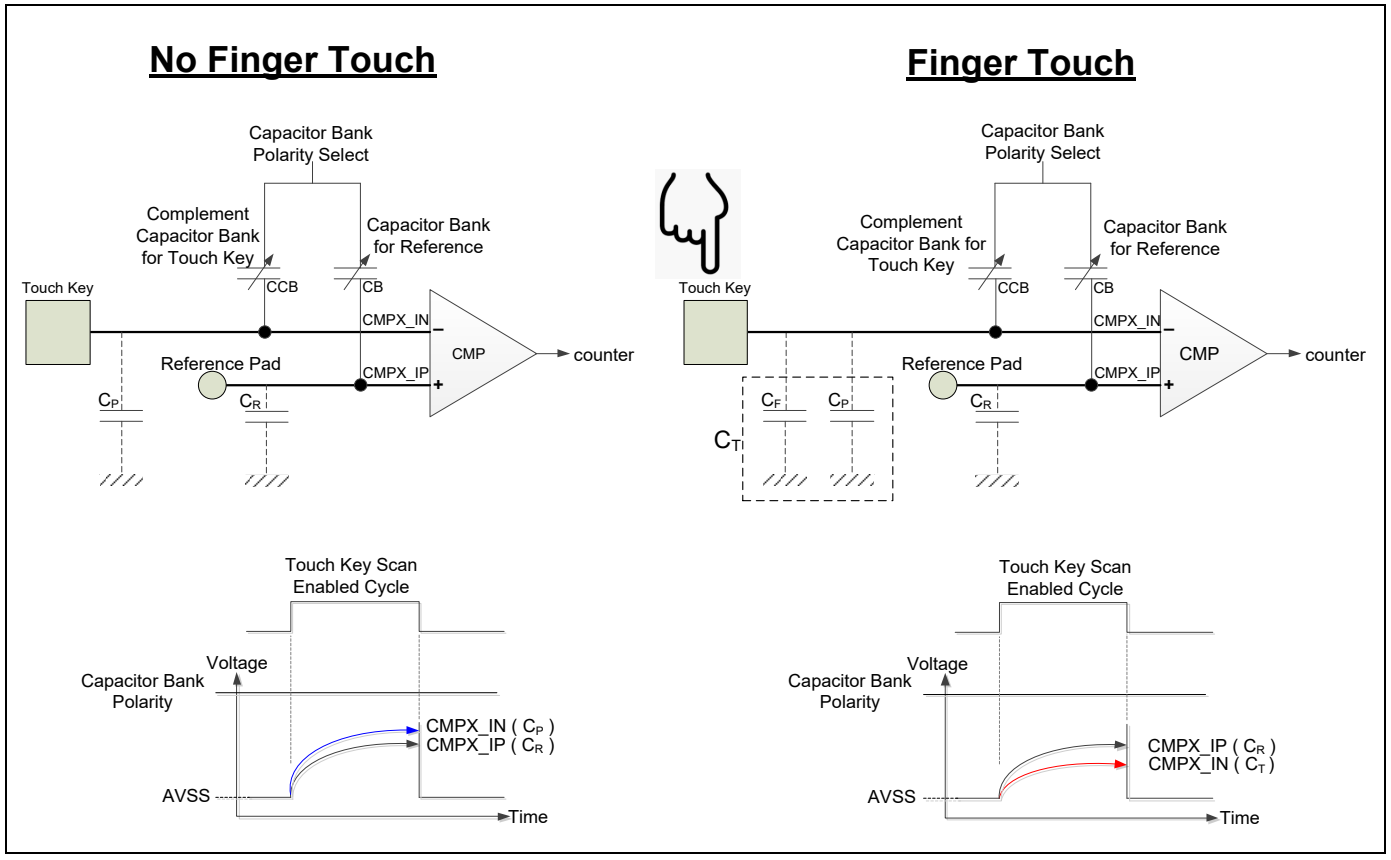


Figure 2-4 Touch Key Sensing Method

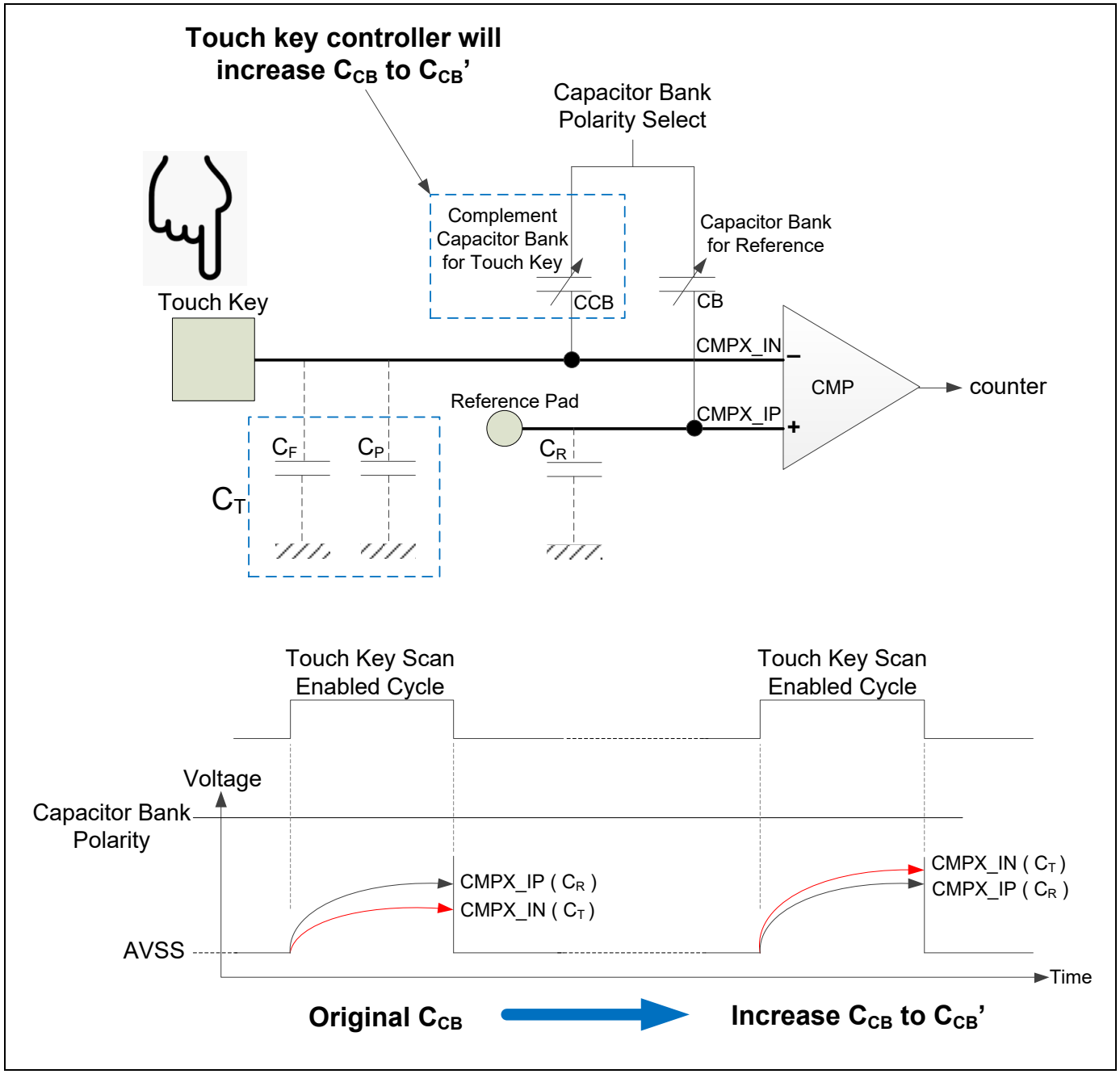


Figure 2-5 Finger Touch Detection Method

Figure 2-6 plots the NuSenadj raw data from a number of consecutive scans during which the sensor is touched and then released by finger. The finger touch causes C_T increased by C_F, which in turn causes raw data to increase (or say C_{CB} to C_{CB}') proportionally. By comparing the C_{CB}' shift level from C_{CB}, the steady state to a predetermined threshold, the algorithm can determine whether the sensor is in an ON (Touch) or OFF (No Touch) state. For more details about raw data and finger threshold, please refer to Chapter 5 Introduction of Touch Key Development Tool.

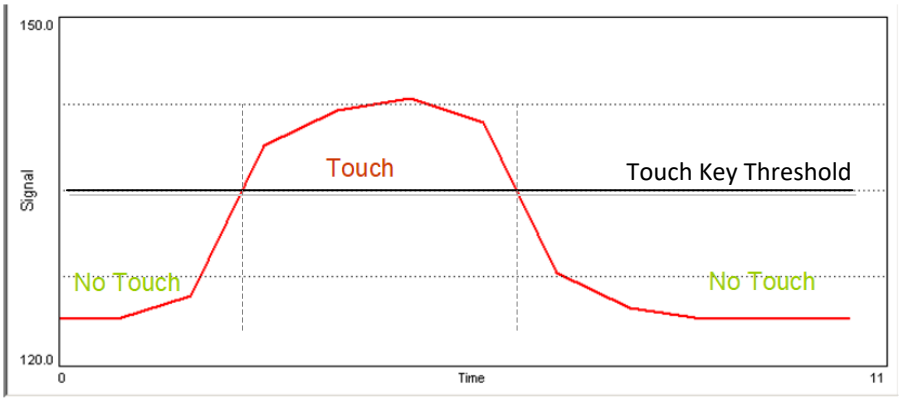


Figure 2-6 NuSenadj Raw Data Plot

2.3 Touch Key Calibration and Auto Environment Compensation

The schematic design, PCB layout, sensor pad dimensions, cover material and thickness may have impacts on touch key system performance. Beside these factors, touch key sensing method needs some hardware and software parameters to be set to make it operates reliably. To find the optimum values of these parameters, touch keys need to be calibrated. NuSenadj developing tool has the touch key calibration function to set the hardware and software parameters automatically.

Touch key auto environment compensation is an algorithm that baseline tracking each touch key automatically at power-up and keeps compensating environment variation affects touch key performance during runtime. The baseline tracking makes touch keys can tolerate manufacturing variations of PCBs and covers. It also automatically eliminates noise effect from various sources such as AC lines, switch-mode power-supplies, power inverters and radiation.

3 Touch Key PCB Design

3.1 Introduction

This section provides application schematics and printed circuit board (PCB) design guidelines for implementing capacitive touch sensors in NuMicro® ML56 series MCU products.

3.2 PCB Design Considerations

3.2.1 Designing a Touch Key PCB

In a typical capacitive touch key application, the capacitive touch sensors are formed by the copper area (electrodes) of a PCB. The following sections show how to design a NuMicro® ML56 series capacitive touch key PCB.

3.2.2 Application Schematics

The NuMaker-ML56SD is a capacitive touch key design reference for developing touch key applications, as shown in Figure 3-1.

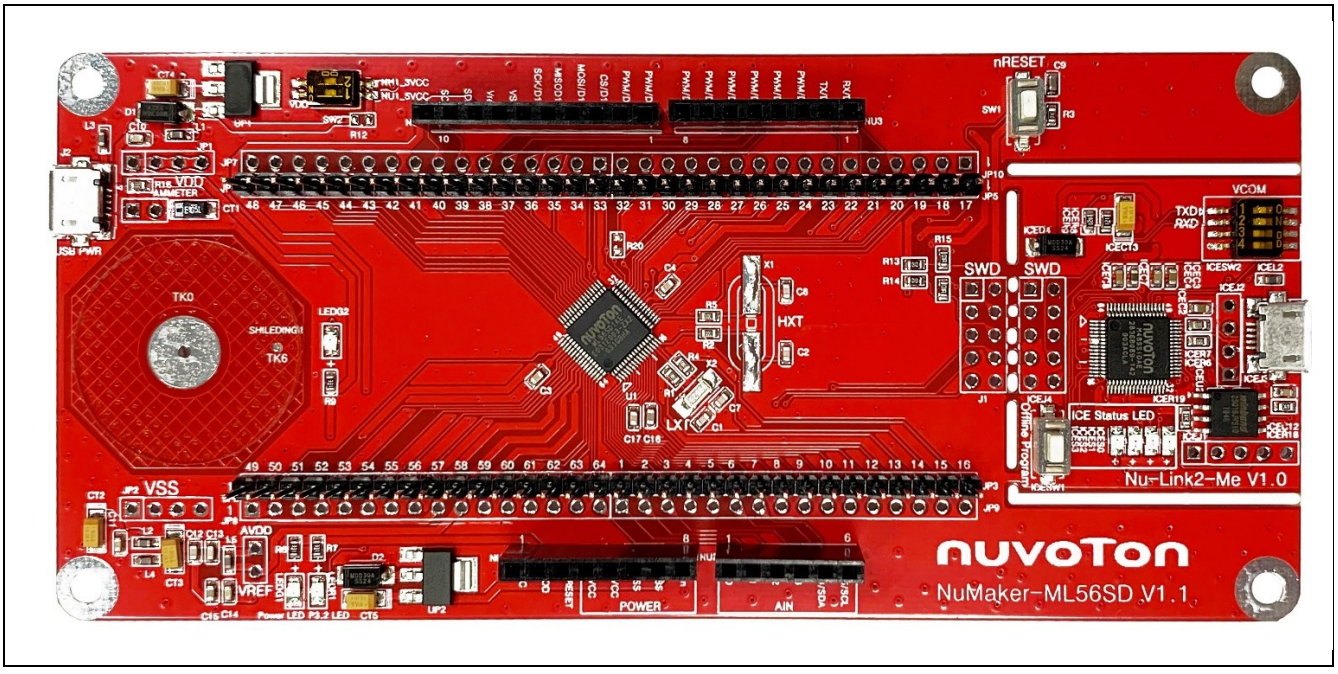


Figure 3-1 Picture of NuMaker-ML56SD

The touch key schematics of NuMaker-ML56SD are shown in Figure 3-2.

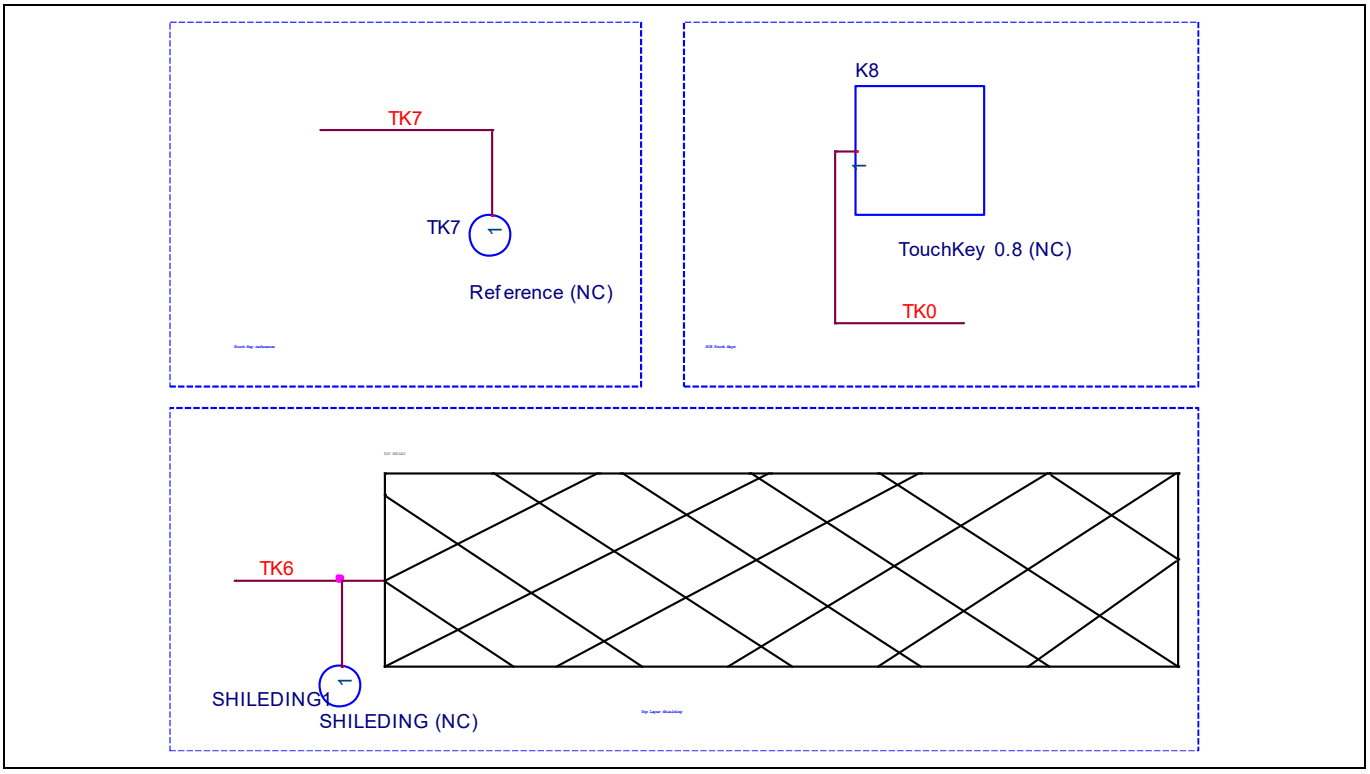


Figure 3-2 Touch Key Schematics of NuMaker-ML56SD

3.3 Touch Key PCB Design Guidelines

As simple shape is described as round or rectangular and the size similar to a figure is a good starting point for the design of touch sensing applications. However, according to the function on the electrodes, the geometry of the electrodes can be modified to achieve better results or improve sensitivity. The shape and size modifications are described in the following sections.

3.3.1 Design Checklist

The following sections provide some general layout guidelines for touch key PCB. Firstly, please refer to the overall design checklist below:

Check Item	Items	Min.	Max.	Recommendations/Remarks
Touch key channel select	Touch key channel	1	14	-
	Reference pad channel	1	1	It is recommended to select reference pad channel at touch channel TK7 or TK14 for better noise susceptibility.
	Shielding electrode channel	1	1	It is recommended to select shielding electrode channel at clock out pins (P3.2 / P4.6 / P5.7) for better sensitivity and waterproof capability.
Placement	Target chip & touch keypad placement	-	-	Mount the target chip and touch key electrodes on difference sides. Minimize the trace length between target chip and keys.
PCB layer	1-layer PCB	-	-	Usually done with a mechanical spring type sensor. Make a through hold for each touch key at the end of trace for connecting to spring sensor.
	2-layer PCB	-	-	Top layer – Touch key sensors with hatched shielding electrode. Bottom layer – target chip and other components with hatched ground plane
PCB layout	Touch sensor shapes	-	-	Round or rectangle shape is recommended for better sensitivity
	Touch sensor size (diameter)	6 mm	15 mm	≧ 10 mm diameter is recommended.
	Reference pad size (diameter)	1 mm	2 mm	Round with 1 mm diameter is recommended for normal case.
	Reference pad location	-	-	Keep it untouchable. Away from any high speed (> 50 kHz) signal and placed it on bottom layer.

	Communication lines	-	-	Do not run each capacitive touch sensor traces parallel to high frequency communication lines.
	Cover thickness	0 mm	-	Max. ≦ 5 mm for Acrylic is recommended. Max. ≦ 10 mm for Glass is recommended.
	Cover adhesive	-	-	467 MP/468 MP adhesives by 3M are recommended.
	Distance between touch keys	4 mm	-	≧ 2 times cover thickness is recommended (For example, 4 mm distance between touch keys for 2 mm cover thickness). Enlarge the distance between keys will get better waterproof.
	Distance between any touch trace	0.3 mm	-	≧ 2 times trace width is recommended.
	Distance between touch keys and ground plane	0.5 mm	2 mm	1 mm is recommended.
	Trace width	0.15 mm	0.2 mm	0.15 mm (6 mil) is recommended.
	Trace length	-	20 cm	≦ 10 cm is recommended.
	Distance between any touch trace to ground plane	0.5 mm	1 mm	-
	Hatched ground plane	-	-	Hatched ground 6 mil trace and 50 mil grid (12 % filling)
	Every touch key via number	0	2	Recommend ≦ 1
	Via hole size for	0.15	0.2 mm	0.15 mm (6 mil) is recommended.

	sensor trace	mm		
	Hatched shielding electrode	-	-	Hatched shielding electrode around touch sensors with 6 mil trace and 50 mil grid(12 % filling)
	Shielding electrode to key spacing	0.5 mm	2 mm	0.5 mm (20 mil) is recommended.

Table 3-1 PCB Design Checklist

3.3.2 Touch Sensor Channel Selection

For keeping the best touch sense quality, please follow below guidelines to determine touch sensor channels:

- Touch Key Channels
  - ✓ NuMicro® ML56 series supports up to 14 + 1 touch sensor channels. Please notice to select continually touch sensor channels when designing touch key applications for signal consistency and better touch key sensitivity.
- Reference Pad
  - ✓ It is recommended to select one reference pad at touch sensor channel TK7 or TK14 for better noise susceptibility.
  - ✓ Any of the TK channels can be assigned as reference pad channel, and at least one channel must be assigned as reference pad channel. TK14 is assigned as reference pad channel automatically if no other channel is assigned as the reference pad channel.
  - ✓ Maximize the distance between the reference pad and other signals to minimize crosstalk.

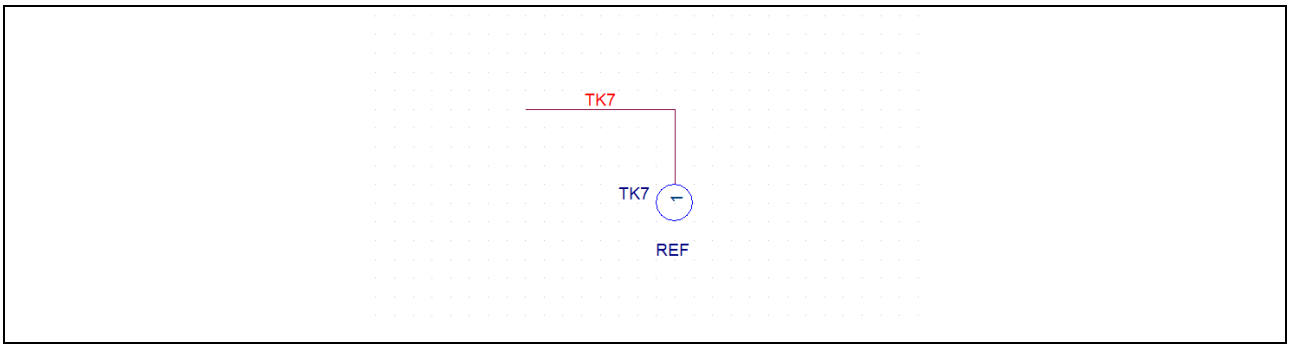


Figure 3-3 Reference Pad

- Shielding Electrode

- ✓ Put the shielding electrode around the touch sensor to get better signal quality and waterproof capability.
- ✓ It is recommended to select shielding electrode channel at clock out pins (P3.2 / P4.6 / P5.7).

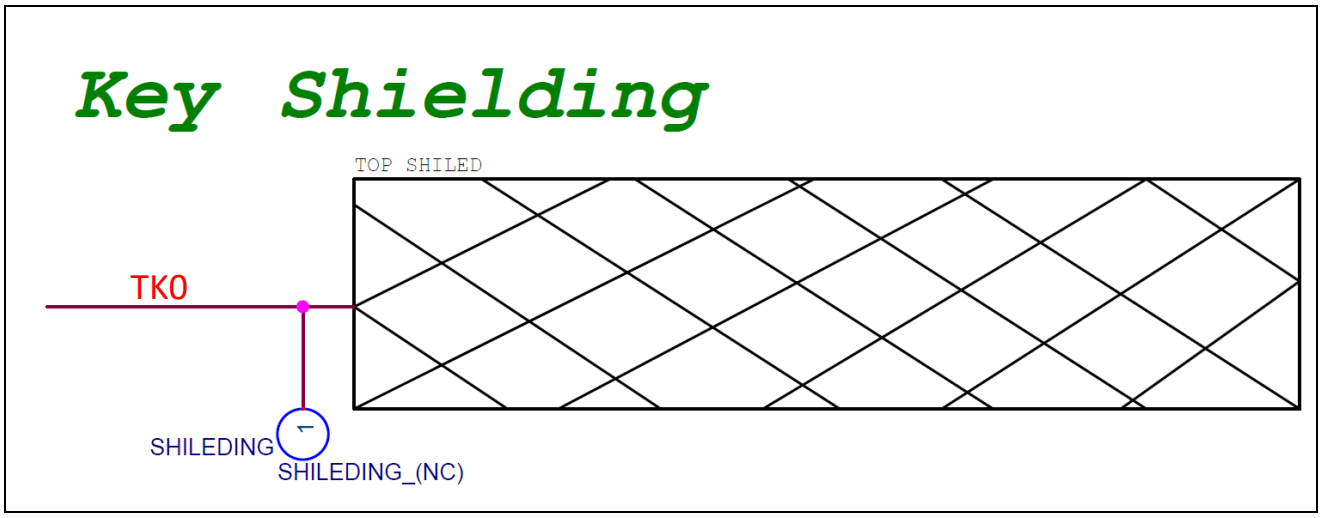


Figure 3-4 Shielding Electrode

3.3.3 PCB Placement

It is very important to minimize the distance between the target chip and the capacitive touch sensors.

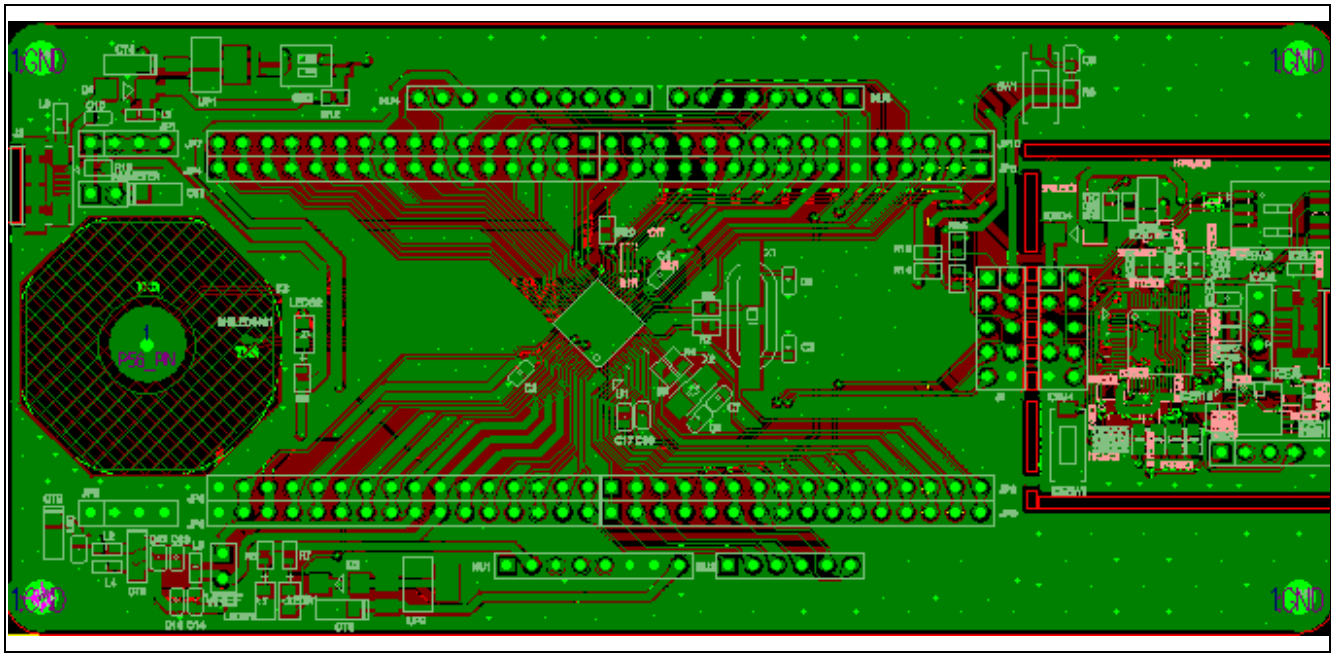


Figure 3-5 NuMaker-ML56SD Placement

3.3.4 PCB Layout Rules

- Touch Key Shapes
  - It is recommended to have a 10 x 10 mm electrode area for good sensor sensitivity.
  - The touch key electrode can have a hole drilled through it to provide backlighting without influencing the capacitive sensor performance. however, it also needs to increase the electrode size to fill the gap of the led hole to keep same sensitivity.
  - Larger touch sensor electrode work better for thicker cover.
  - Larger touch sensor electrode will also increase the noise susceptibility. It also has the disadvantage that sensor pickup from unrelated nearby activity is also increased.

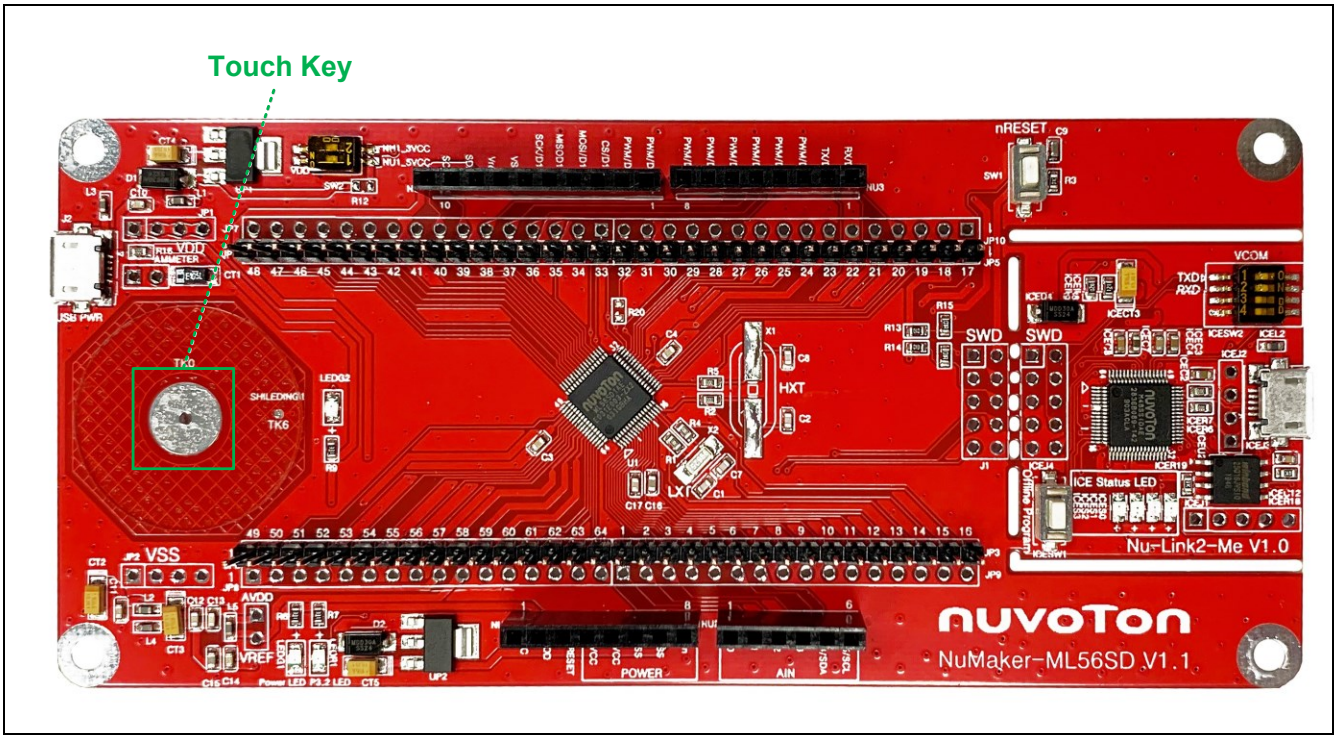


Figure 3-6 NuMaker-ML56SD Layout Example

Acrylic Cover Thickness	Key Pad Diameter Size
0.5 mm	6 ~ 8 mm
1 mm	6 ~ 10 mm
2 mm	6 ~ 12 mm
3 mm	8 ~ 12 mm
4 mm	8 ~ 12 mm
5 mm	10 ~ 15 mm

Table 3-2 Recommended Pad Diameter Size with Difference Acrylic Cover Thickness

Note: In general, glass has twice performance than acrylic in cover thickness with same key pad diameter size.

- Distance Between Keys
  - Maximize the distance between each touch keys to minimize crosstalk.
  - The crosstalk is directly affected by the distance between key electrodes as well as cover thickness.
  - A simple criteria to follow is to have electrodes separated 2 to 3 times as much as the cover thickness to be used.
- Trace Length and Width
  - Recommended touch trace width is 6 mil (0.15 mm).
  - The distance between any touch trace must be ≧ 2 times trace width.
  - Keep trace length as short as possible between ML56 chip and touch key sensors (< 10 cm is recommended).
  - Similar trace length between target chip and each touch key sensors is suggested.
  - Let touch key trace away from high speed signals to avoid cross-talk.
  - Routing in different PCB layer between target chip and the touch electrodes is recommended. To use a clearance of about the same width as the traces to isolate the hatched ground from the trace. For example, for a 6 mil trace, use 6 mil clearance on either side of the trace.
- Reference Pad
  - It is recommended to assign the reference pad at touch channel TK7 or TK14 for better noise susceptibility.

- Maximize the distance to other signals to minimize cross-talk.
- Round shape electrode with 1 mm diameter size is enough for normal case.
- Put reference pad untouchable on PCB bottom layer.
- Hatched ground plane around reference pad with 6 mil trace and 50 mil grid (12 % filling).

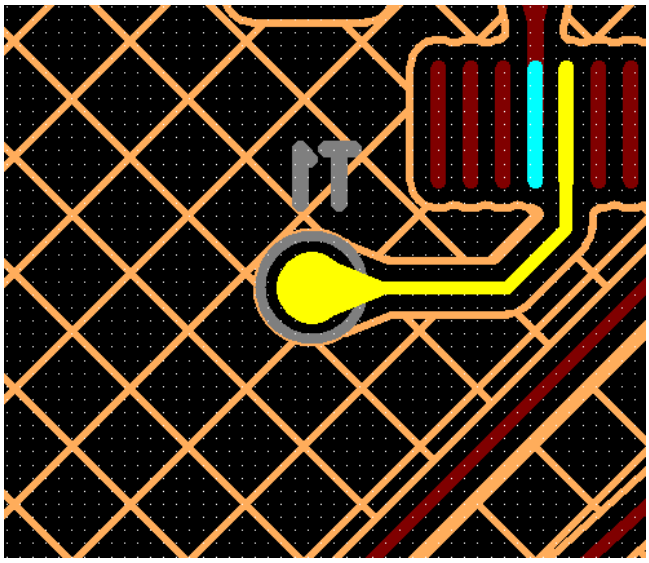


Figure 3-7 Reference Pad PCB Layout

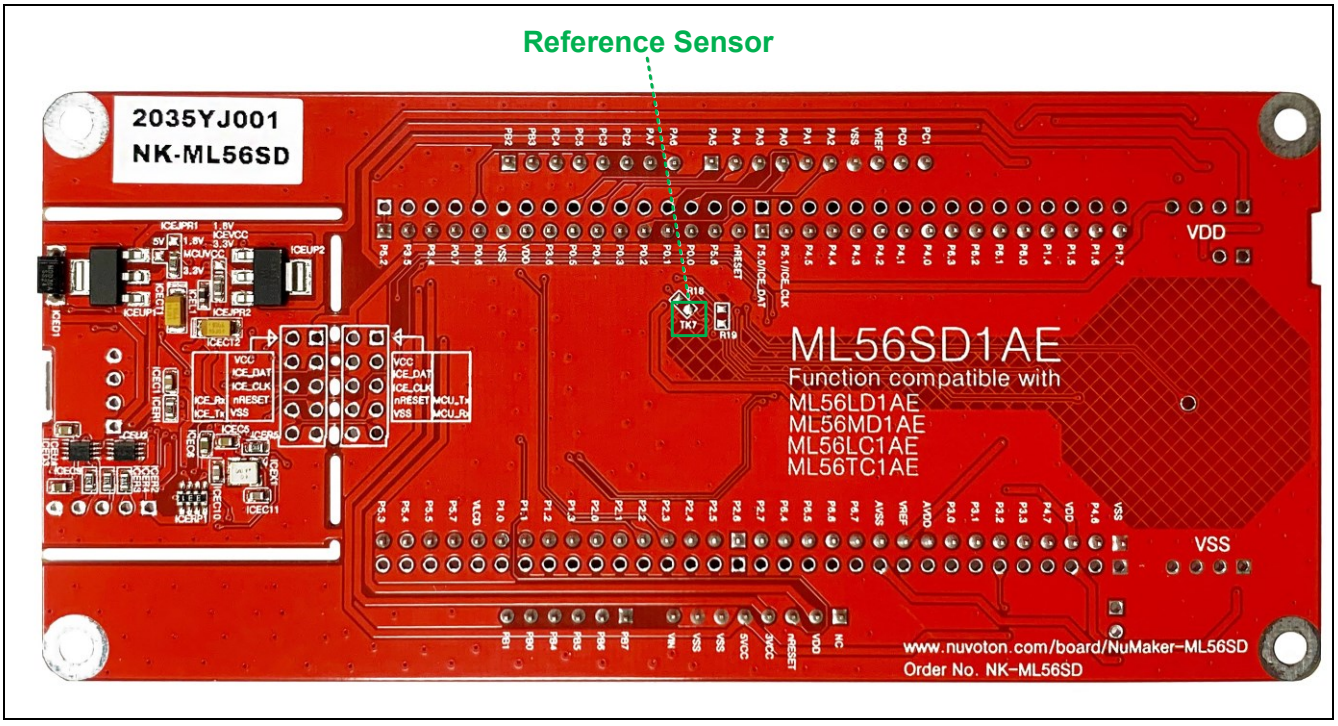


Figure 3-8 NuMaker-ML56SD Layout Example

- Hatched Electrode Pattern
  - Recommended X hatch pattern is round 12 % ~ 15 %, which is defined as the minimum line width of 6 mils and line spacing may be approximately around 50 mils.

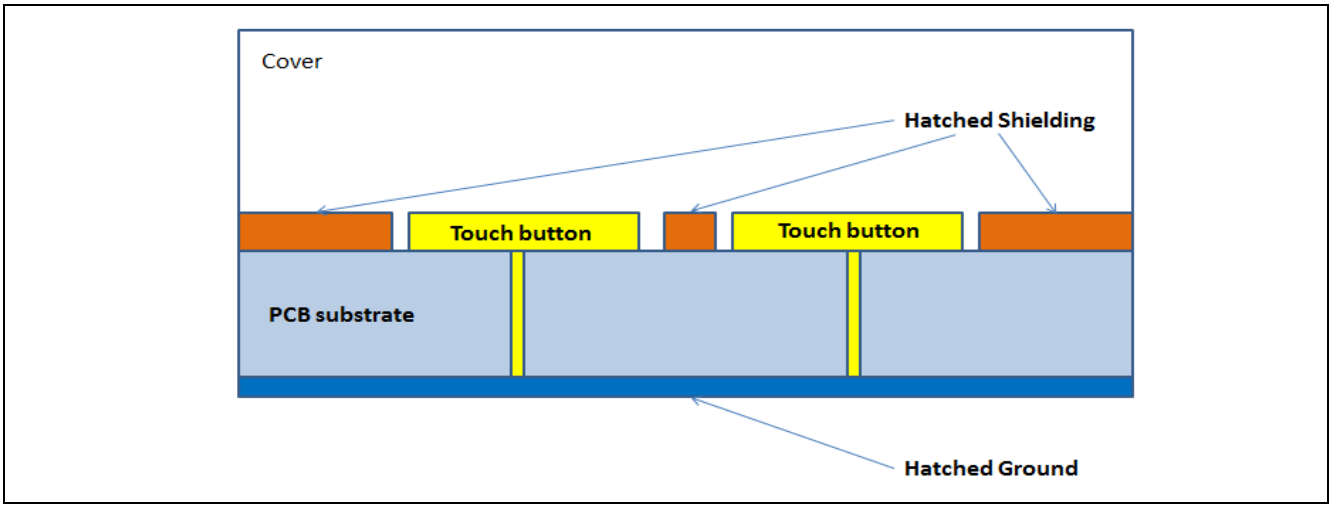


Figure 3-9 Example of Hatched Shielding Electrode and Hatched Ground

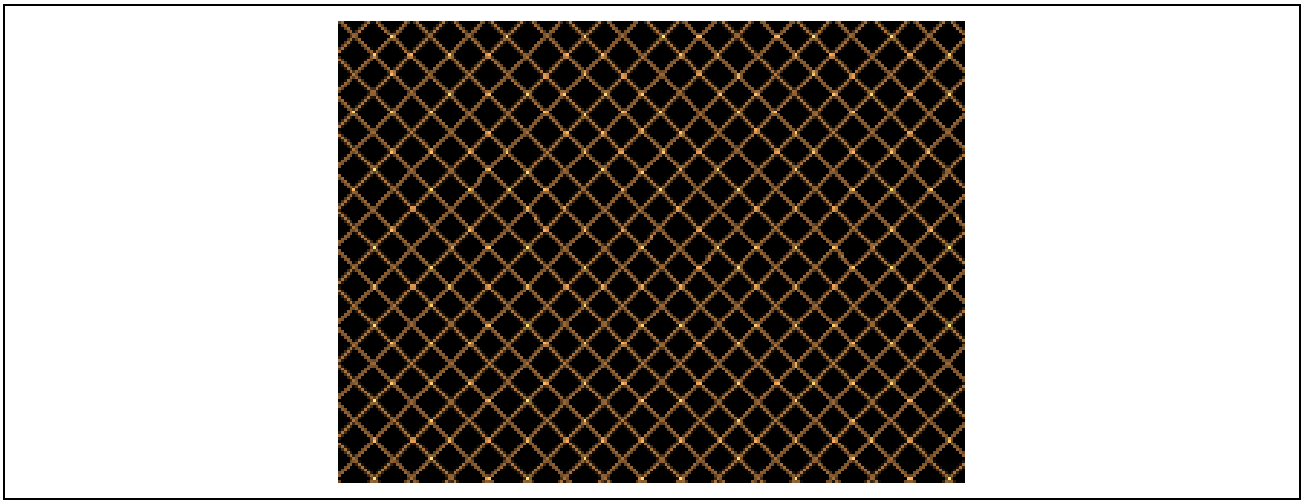


Figure 3-10 Hatched Electrode Filled with 12 % Pattern

- Ground Plane
  - Hatched ground plane with 6 mil trace and 50 mil grid (12 % filling).
  - It is recommended that the traces of the touch key have a good hatched ground plane surround.
  - It is recommended to have hatched ground plane under the touch keys and shielding

electrode.

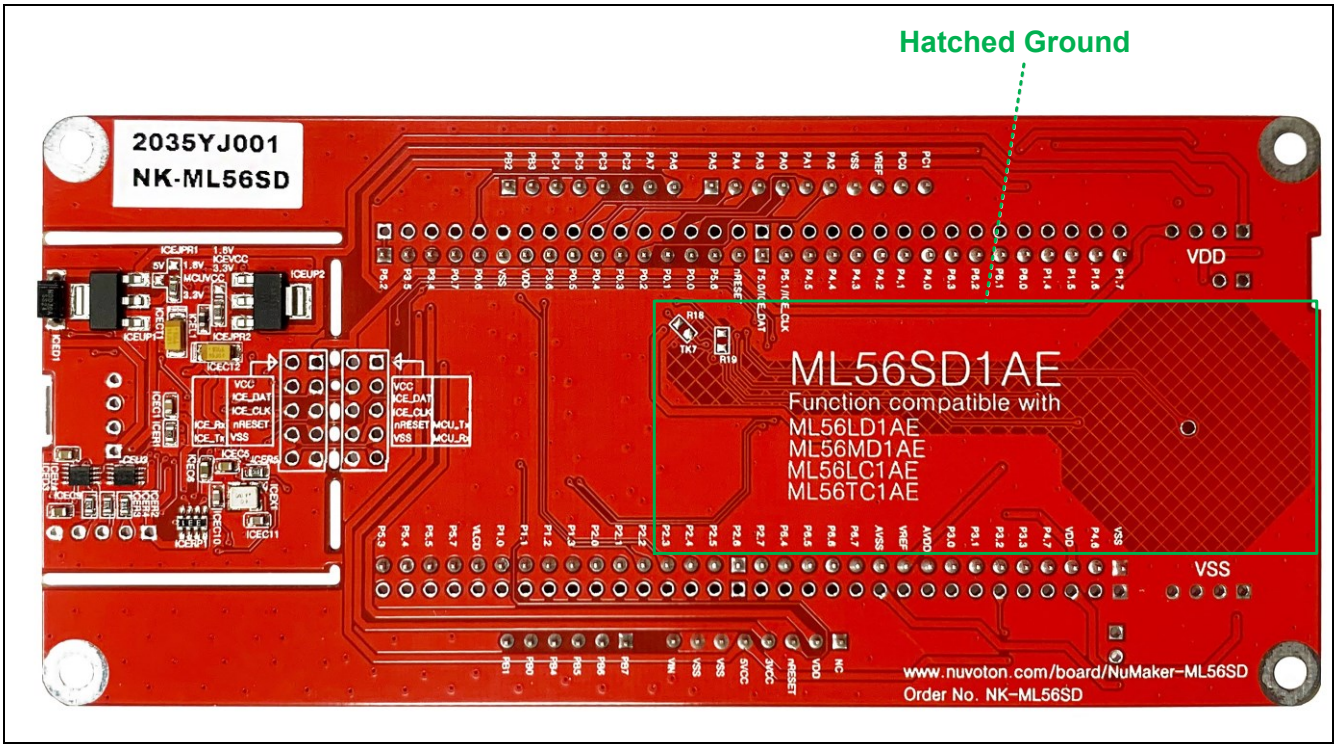


Figure 3-11 NuMaker-ML56SD layout example

- Shielding Electrode

  To provide better sensitivity and waterproof functionality, it is recommended to select shielding electrode channel at clock out pins (P3.2 / P4.6 / P5.7), and put touch keys with shielding electrode around which provides the same phase signal around keys. Please put the keys and hatched shielding electrode on PCB top layer, and put the target chip and other components on the bottom layer.

  - Hatched around sensors with 6 mil trace and 50 mil grid (12 % filling).
  - Maximize the distance to other touch key trace and signals to minimize cross-talk.
  - Adding hatched ground plane between shielding electrode trace and other touch key trace can reduce cross-talk.
  - Let shielding electrode to touch keys spacing with 0.5 mm ~ 2 mm is recommended for normal case.
  - Larger shielding electrode area will also increase the noise susceptibility. Needs to fine tune the shielding electrode size based-on the PCB actual condition.

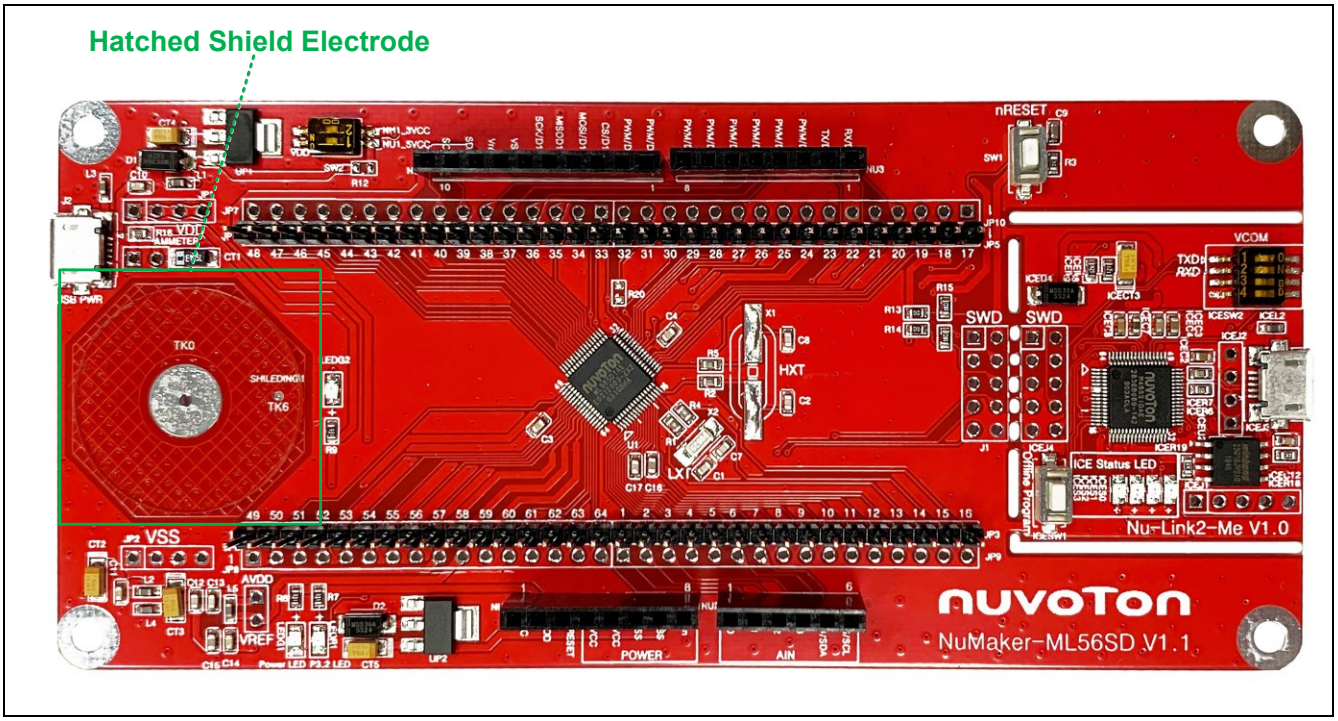


Figure 3-12 NuMaker-ML56SD layout example

- Shielding electrode area needs to keep filled around the touch key in > 10 mm width to let touch signal large enough and keep noise budget as big as possible.

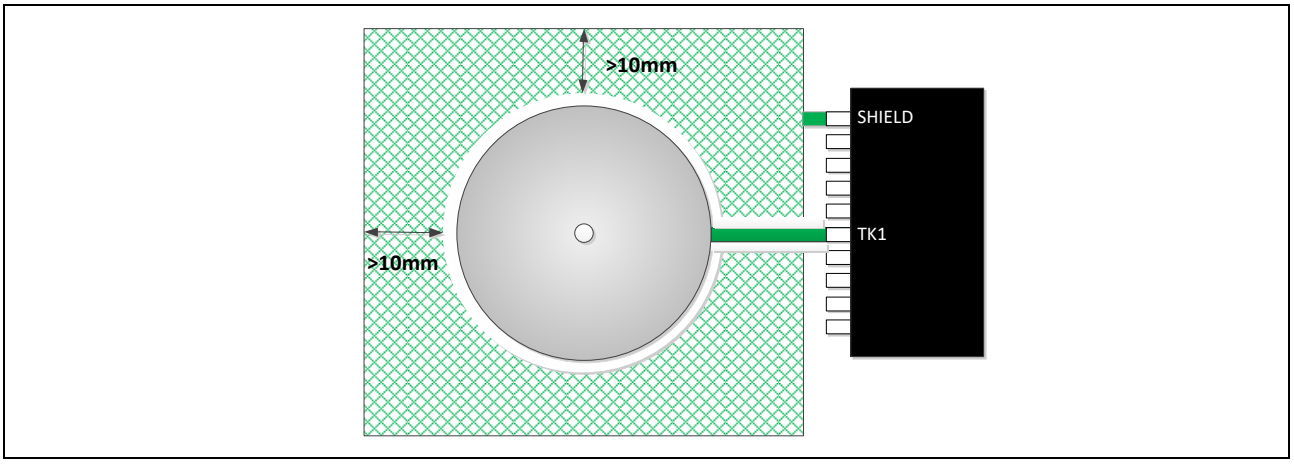


Figure 3-13 Shielding Electrode Layout Rule

- Touch Trace Via
  - The via can been placed at any location inside the touch sensor.

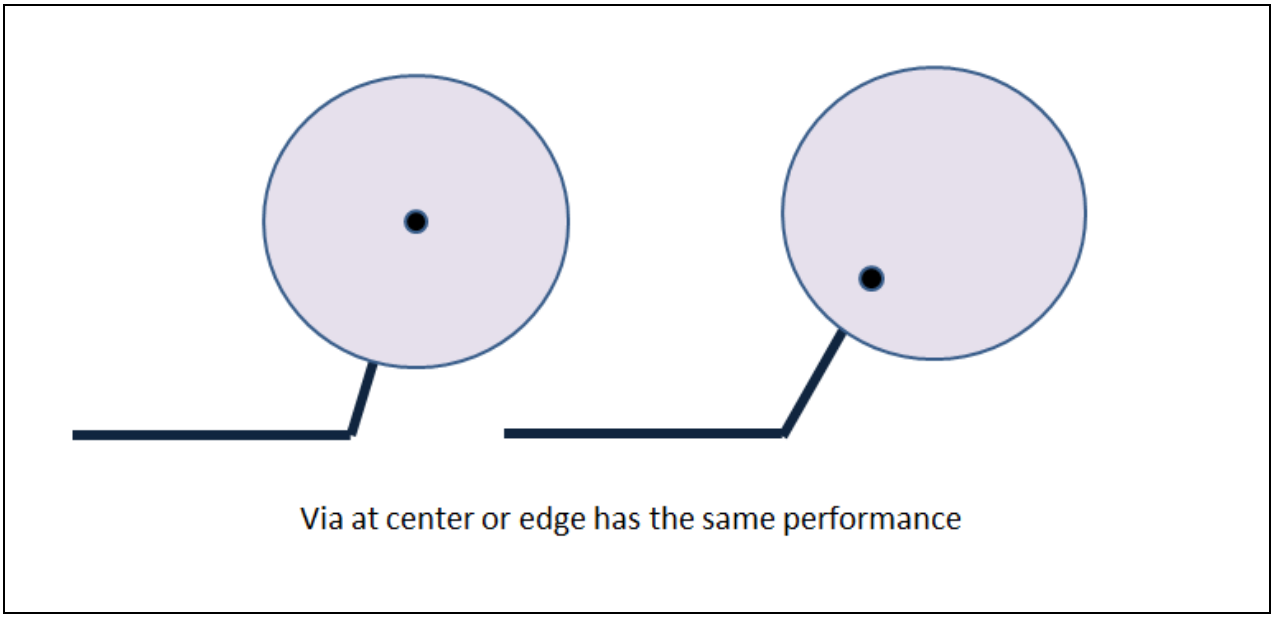


Figure 3-14 Via Location of a Sensor Electrode

- Communication Lines
  - Do not run the traces of each capacitive touch key sensor too close or parallel to high frequency communication lines.
- Cover Thickness
  - The maximum thickness of the cover can be used for touch detection is dependent on the sensor electrode size and sensor spacing.
  - As the cover thickness increases, the touch sensor sensitivities will decrease.
  - Larger electrode sizes work better for thicker covers.

Cover Type	Thickness
Glass	Recommend ≦ 10 mm
Arcylic	Recommend ≦ 5 mm

Table 3-3 Suggested Cover Thickness

- Cover Adhesive
  - Cover materials must have good mechanical contact with the sensing PCB. Two widely used non-conductive adhesives for covers are 467MP and 468MP (by 3M).

3.4 Bridging the Gap Between PCB and Cover

When the touch key PCB and the product mechanism cover cannot be closely adhered through the adhesive, conductive sponge can be used to bridge the gap between the PCB and the mechanism cover. The thickness of the conductive sponge should be slightly larger than the gap to ensure close contact.

- The gap between the PCB and the mechanism cover is recommended < 6 mm.
- The conductive sponge should be pasted to the PCB touch Keys with conductive adhesive.

Figure 3-15 Conductive Sponge

4 Sample Code and Touch Key Library

This chapter introduces how to use the touch key library and sample code of touch thermostat. The touch key library is added to an application by linking in the library file. The library provides APIs for the application to generate the touch key calibration data and check touch key status to reduce the application complexity. Features of this library are listed below:

1. Supports up to 14 touch keys.
2. Supports reference pad and shielding electrode features.
3. Supports different types of applications: touch key, slider and wheel.

For details, please download and unzip the The Board Support Package (BSP) Keil for ML51 Series.

5 Introduction of Touch Key Development Tool

NuSenadj is a graphical user interface tool for user to develop their touch key system and calibration associated environment variables to adjust sensitivity of the touch key. Figure 5-1 shows the GUI of NuSenadj. For more details, refer to section 5.1 NuSenadj User Interface.

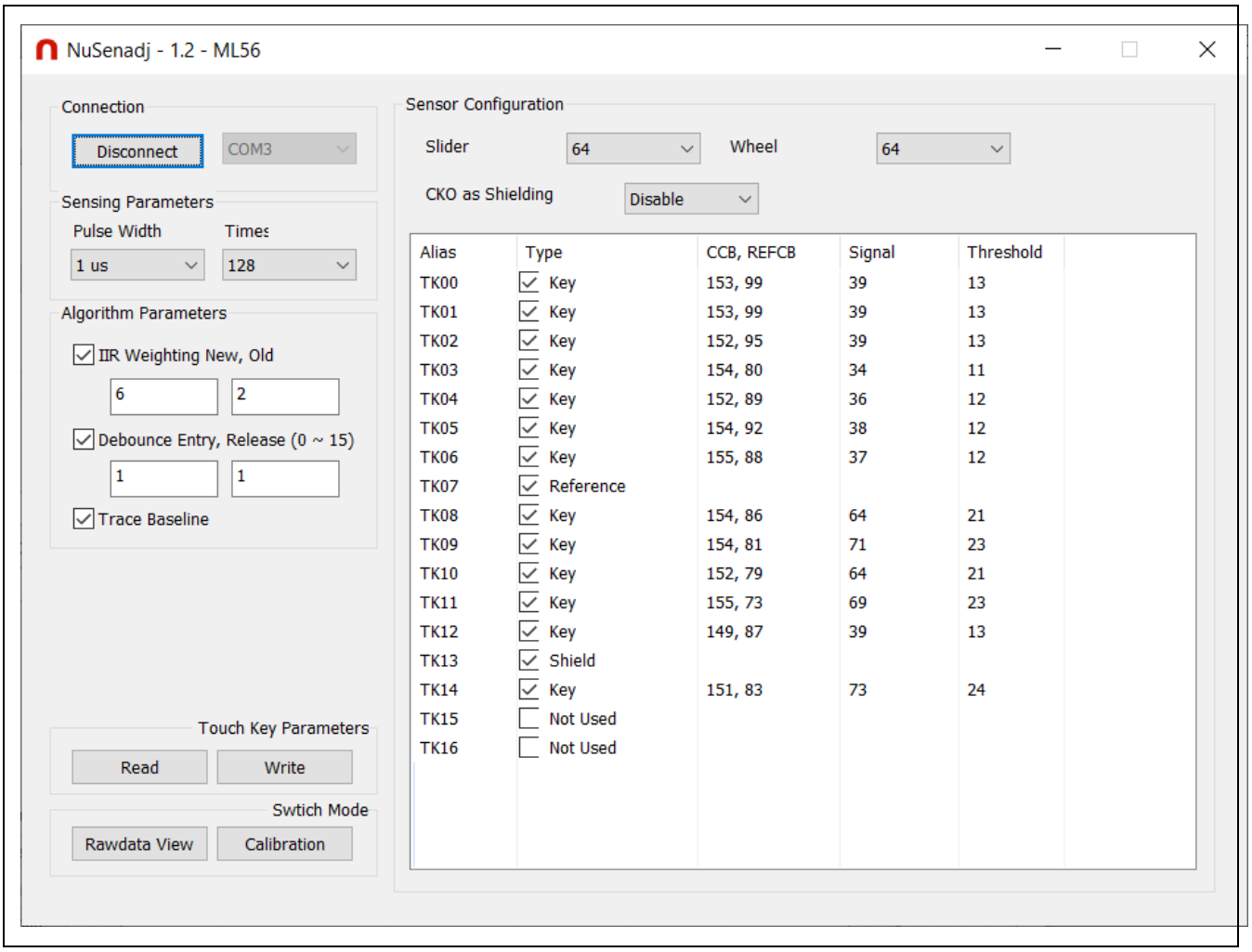


Figure 5-1 NuSenadj User Interface

5.1 NuSenadj User Interface

The main window is composed of the parts described in the following sections.

5.1.1 Connecting to Touch Key Demo Board

In the Connection panel, user can select the serial port that connects to the touch key demo board and then click "**Connect**", as shown in Figure 5-2. If the serial port is not in the list, select

"**Scan Port**" to refresh the list.

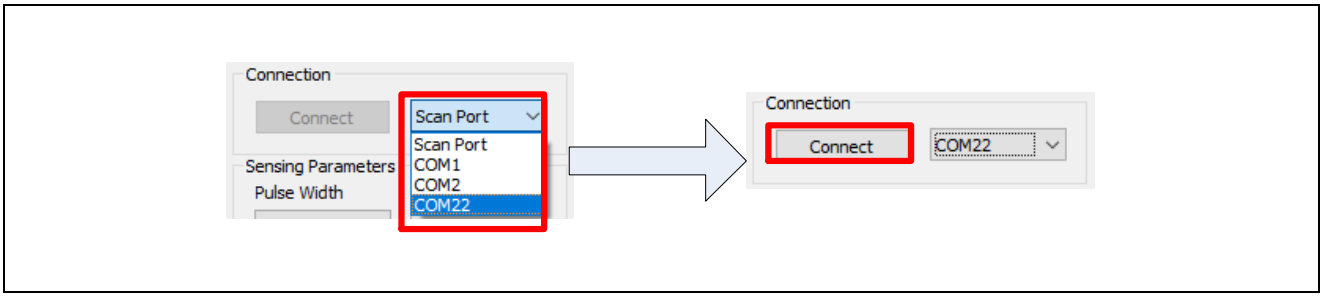


Figure 5-2 Select Connection Port

After clicking the "Connect" button, NuSenadj will send a series of command to read back on-board configuration. The next two sections will describe all the configuration options. In "**Touch Key Parameter**" panel, user can click "**Write**" button to make all configuration take effect, or click "**Read**" to restore all the changes.

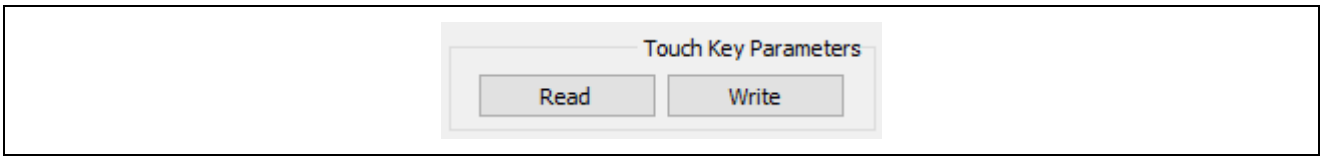


Figure 5-3 Touch Key Parameters Panel

5.1.2 Touch System Configuration

User can adjust Sensing Parameters, Algorithm Parameters in the left part of NuSenadj. The detailed description is shown below:

- **Sensing Parameters**: Touch Key Sensing Time Control, the larger Sensing Time will get larger SNR but increase the latency of reporting rate.

  Sensing Time = "**Pulse Width**" x "**Times**"

  Pulse Width can be set as 500ns, 1us, 2us, 4us or 8us.

  Times can be set as 16, 32, 64, 128, 255, 511 or 1023

- **Algorithm Parameters**:
  - **IIR Weighting New, Old**: Selecting the checkbox will enable IIR Filter function. The Weighting New, Old can control the ratio of current raw data and previous one. In general, it is considered that the little change of raw data as noise, and user can enable IIR Filter to be against noise. It will get larger SNR but increase the latency of response time when user enables IIR Filter.
  - **Debounce Entry, Release (0 ~ 15)**: The debounce times for key pad press and release detection. In unit of scanning frame, the larger "Debounce Times" will let the press event and release event more stable but increase the latency of response time. Debounce times for Entry and Release can be set from 0 to 15.

- **Trace Baseline**: Selecting the checkbox will enable baseline tracking function. The baseline is a raw data when touch key pad is not touched. When enabled, the firmware will update the baseline when outside environment like temperature and humidity changed. Baseline is generated by "**Calibration**".

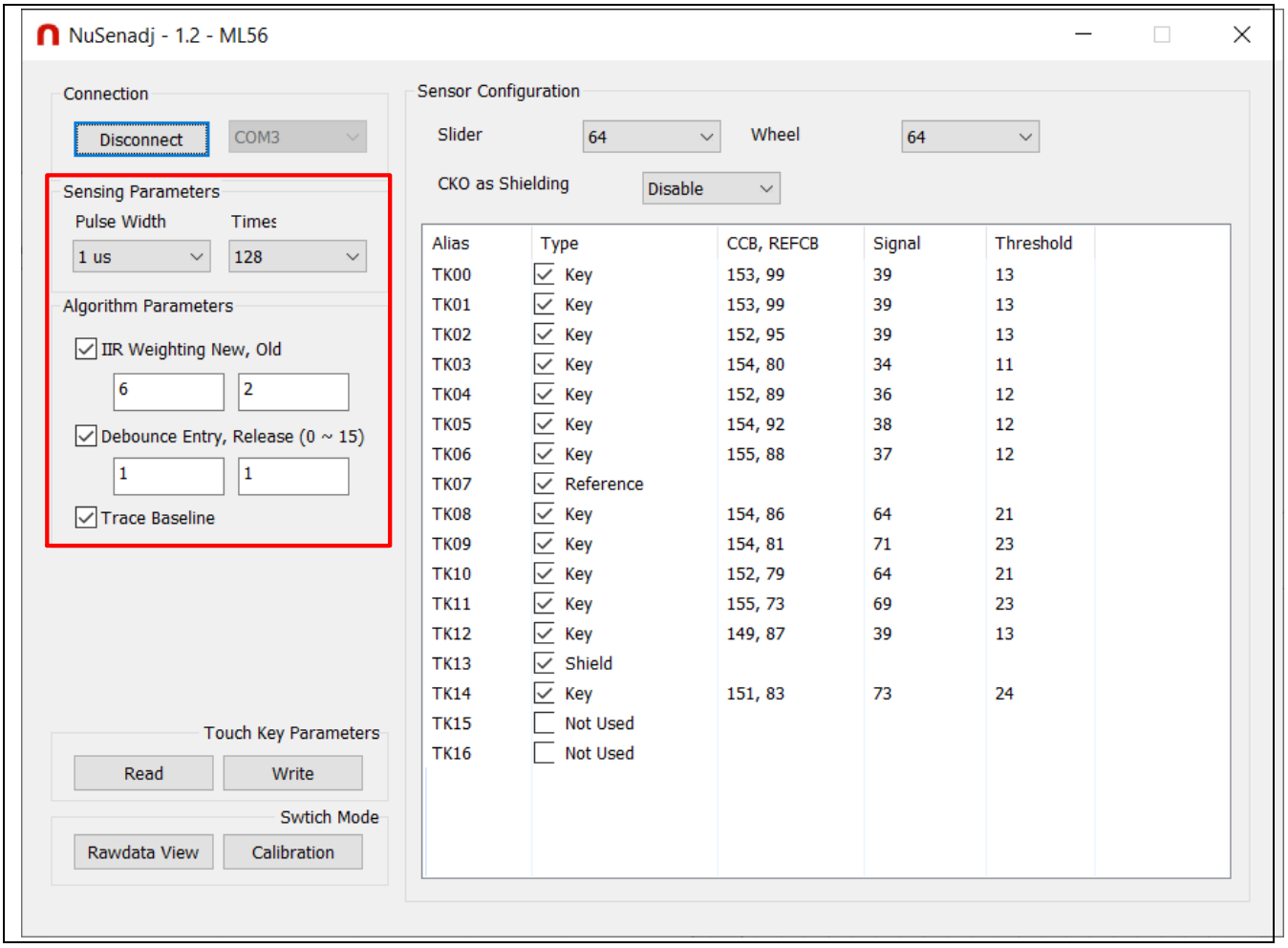


Figure 5-4 Sensing and Algorithm Parameters

5.1.3 Sensor Configuration

In the right part of NuSenadj, it shows “Sensor Configuration”, where user can configure the sensor for including reference pad, shielding electrode and key sensors. The detailed description is shown below:

- **Alias**: User can rename the selected touch key sensors to what user wants to call, e.g. up and down.
- **Type**: User needs to click the checkbox to enable the selected channel, and then select the sensor type in the dropdown list, as shown in Figure 5-5.

  Sensor type can be **Key**, **Shield** or **Reference** when enabled.

  - **Key**: The simplest sensor type consists of a single sensor. A key gives one of two possible output states: active (finger is present) or inactive (finger is not present). These two states are called ON and OFF states respectively.
  - **Shield**: shielding electrode is used for waterproof function; user can choose one sensor to implement PCB layout design, or none to disable waterproof function.
  - **Reference**: User can select a sensor in the pull-down menu as reference pad. It always has to choose one sensor as reference pad.
- **CCB, REFCB**: CCB (complement capacitor bank for touch key) and REFCB (capacitor bank for reference pad). These values are **Read-only**. These values can only be generated by “**Calibration**”.
- **Signal**: Touch signal for key sensors. This value is **Read-only**. The signal is recorded during calibration process when user touch the specific sensor.
- **Threshold**: The threshold of touch key sensors. The baseline is a raw data when touch key is not touched. If the raw data from scanned touch key sensor is more than baseline by Threshold, it will be considered that the scanned key is touched. This value is recommended to be generated by calibration process.

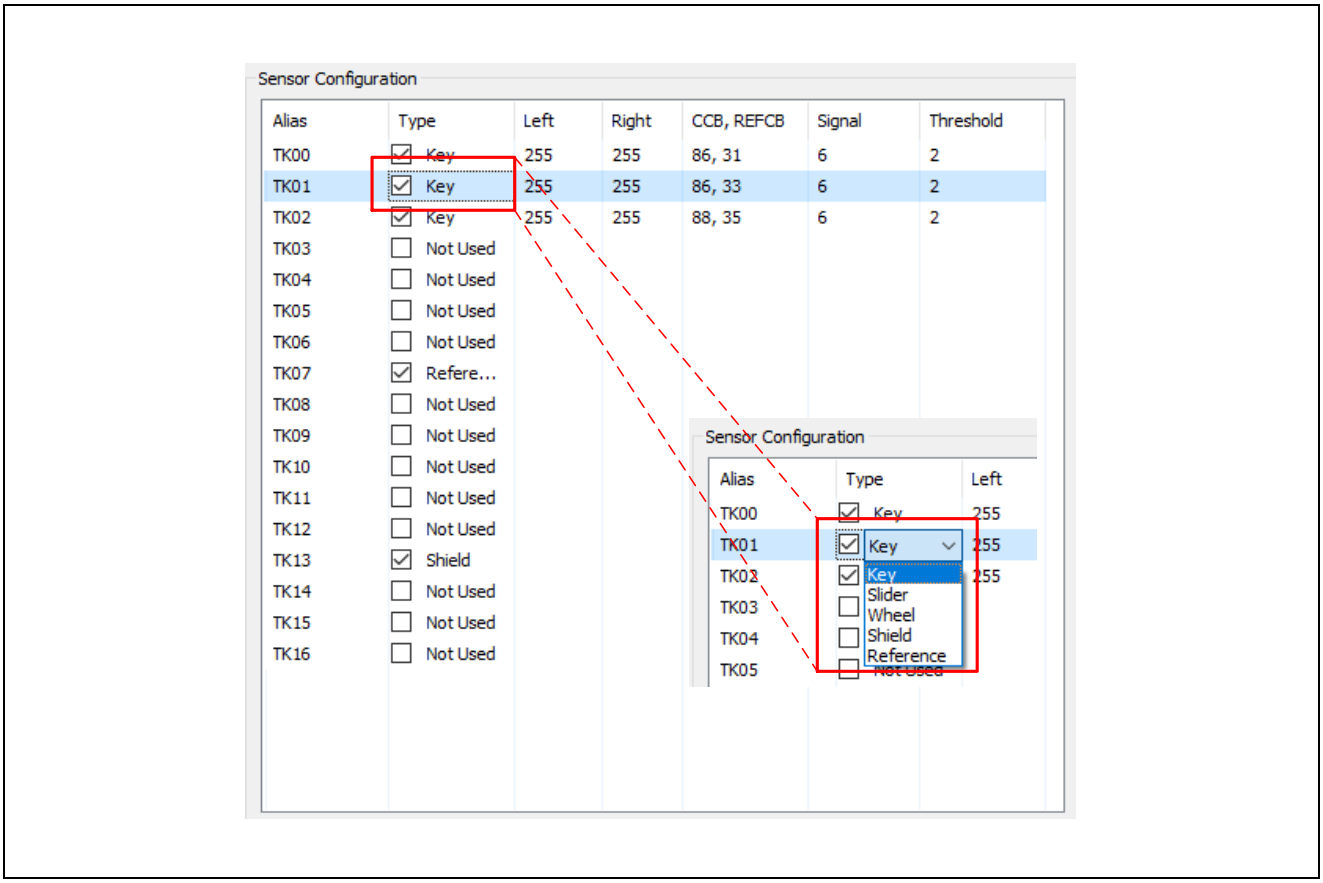


Figure 5-5 Select Sensor Type

5.1.4 Starting Calibration and Developing Touch Key System

User must do Calibration after changing any configuration. Clicking "**Calibration**" in "**Switch Mode**" panel will bring up the Calibration Window as shown in Figure 5-6.

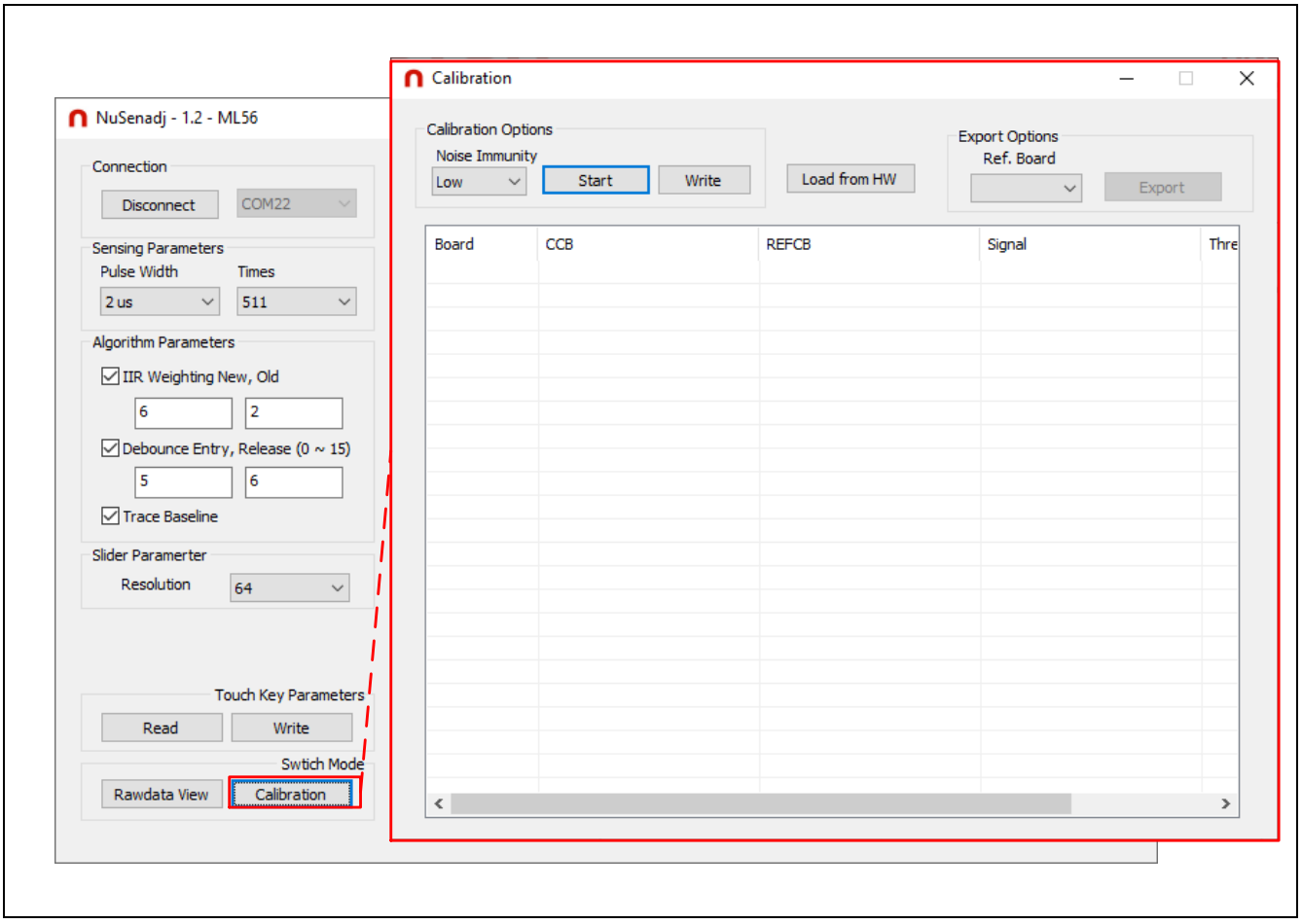


Figure 5-6 Calibration Window

The calibration process will fine tune the sensor configuration for the current touch system configuration. User can use several pieces of development board to build a set of environment variables, and then use this data to develop the others. The detailed description about calibration is shown below:

- **Calibration Options**:
  - **Noise Immunity**: There are three degrees of Noise Immunity Level, Low, Medium and High. User can demand the performance of touch key sensors by this option.
  - **Start**: Click "**Start**" to find the current Reference Pad Capacitor Value for single key sensors and slider sensors. If the Reference Pad Capacitor Value is fine, click "**Yes**" to continue tuning threshold. In the next step, Auto Fine Tuning will get baseline and tune the touch threshold of all enabled touch key sensors. It will ask user to touch all enabled touch key pads during auto tuning. The touch threshold for each enabled touch key channels will be set according the Noise Immunity Level. After auto tuning, the calibration data will be shown in the list.
  - **Write**: Click "**Write**" to apply to current development board.
- **Load from HW**: User can also get calibration data from connected board directly. Click

this button to load the calibration data stored in touch key and add to the record list.

- **Export Options**: Export Options are available when there are more than three valid calibration data available in the record list.
  - **Ref. Board**: User must select one calibration data as reference. Every selected records will compare to this Ref. Board channel by channel. If one of the difference in CCB, REFCB, Signal or Threshold exceeds 20, the export will report error.
  - **Export**: If all the selected data with low variance is compared to **Ref. Board**, the NuSenadj can produce three bin files and one text file. These bin files can be used to develop their own products.

5.1.5 View Raw Data

User can watch the pure raw data in this view. If the SNR is not as good as expected, user can go back to change the configuration and calibration again as described in previous sections. By clicking "**Rawdata View**" in the "**Switch Mode**" panel, a window pops up as shown below.

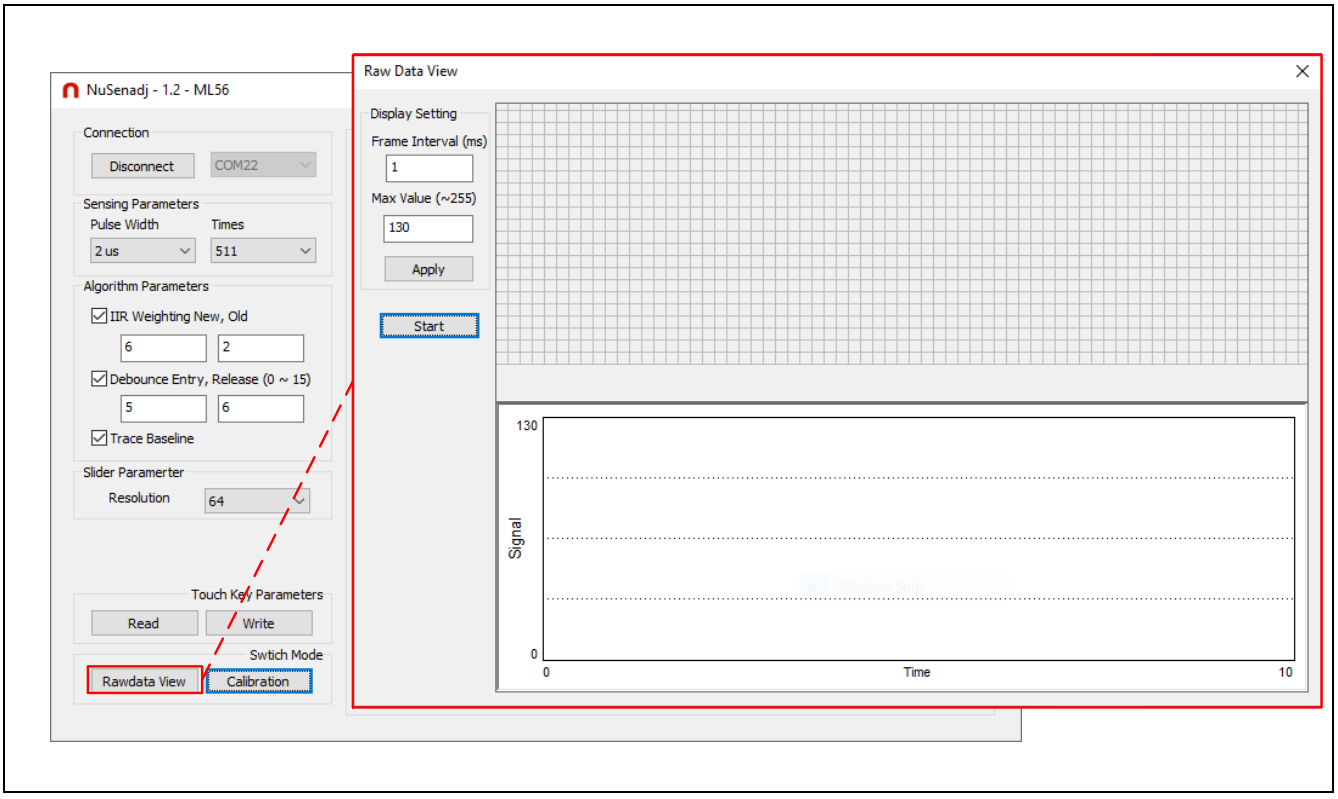


Figure 5-7 Raw Data View Window

The detailed description of this mode is shown below:

- **Display Setting**: All these settings are used by tool only.
  - **Frame Intervals (ms)**: After displaying the current frame in Bar chart and Line chart,

the tool will delay according to this value before getting next frame.

- **Max Value (~255)**: User can fill in the number from 0 to 255 to re-range the CCB value interval in line chart.
- **Apply**: Click to make the Display Setting take effect.

- **Star/Stop**: Start or Stop to show CCB value and line chart in window “Raw Data View”.

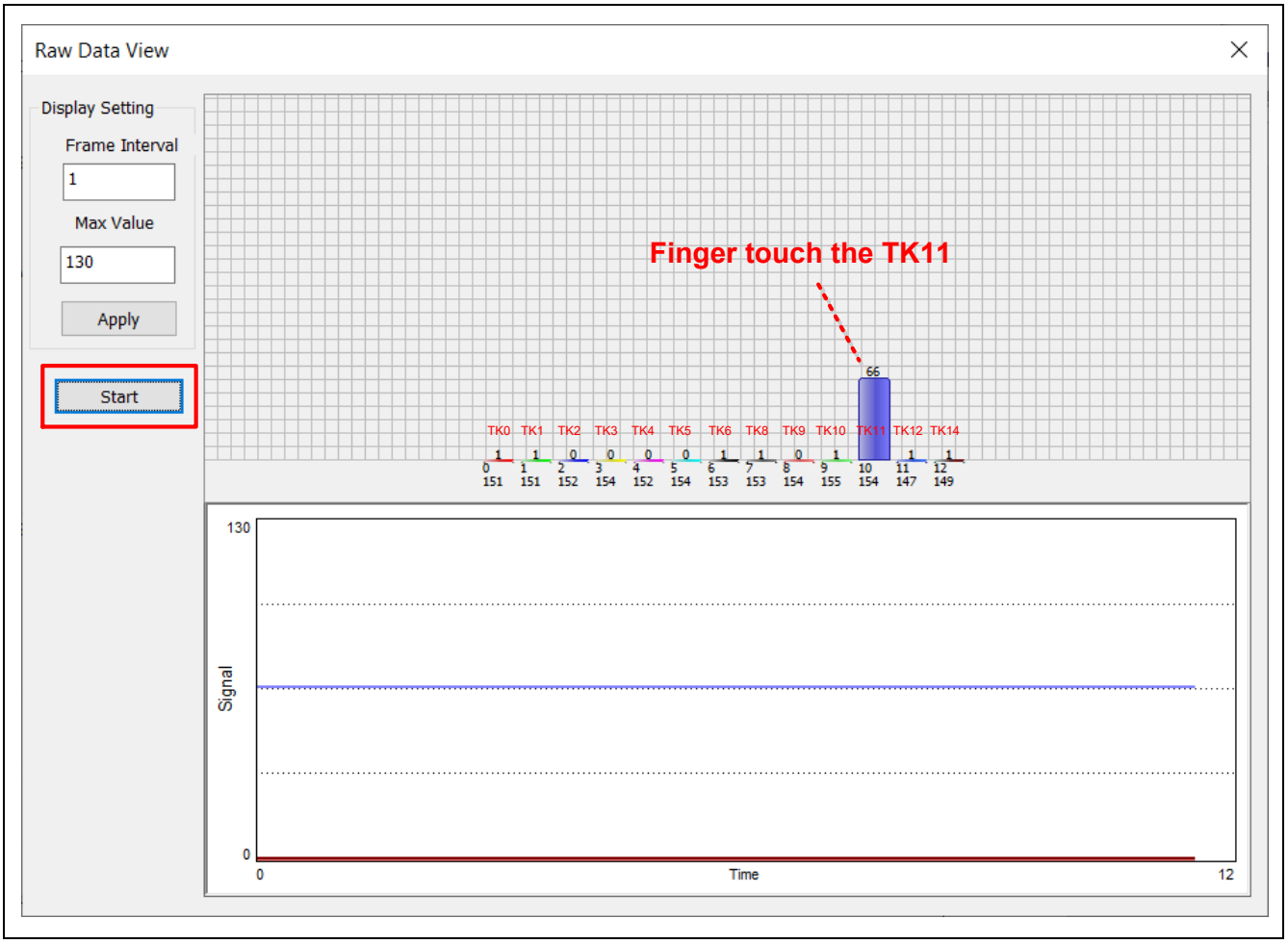


Figure 5-8 Show Raw Data

6 Introduction of Touch Key Mass Production Tool

In the previous chapter, NuSenadj is used to generate the calibration data for user's touch product. In mass production stage, another tool called "NuSenadj – Mass Production (referred to as "MP tool" hereafter)" is used to test the product.

6.1 Connecting to Customer's Product

The main window is composed of the parts described in the following sections.

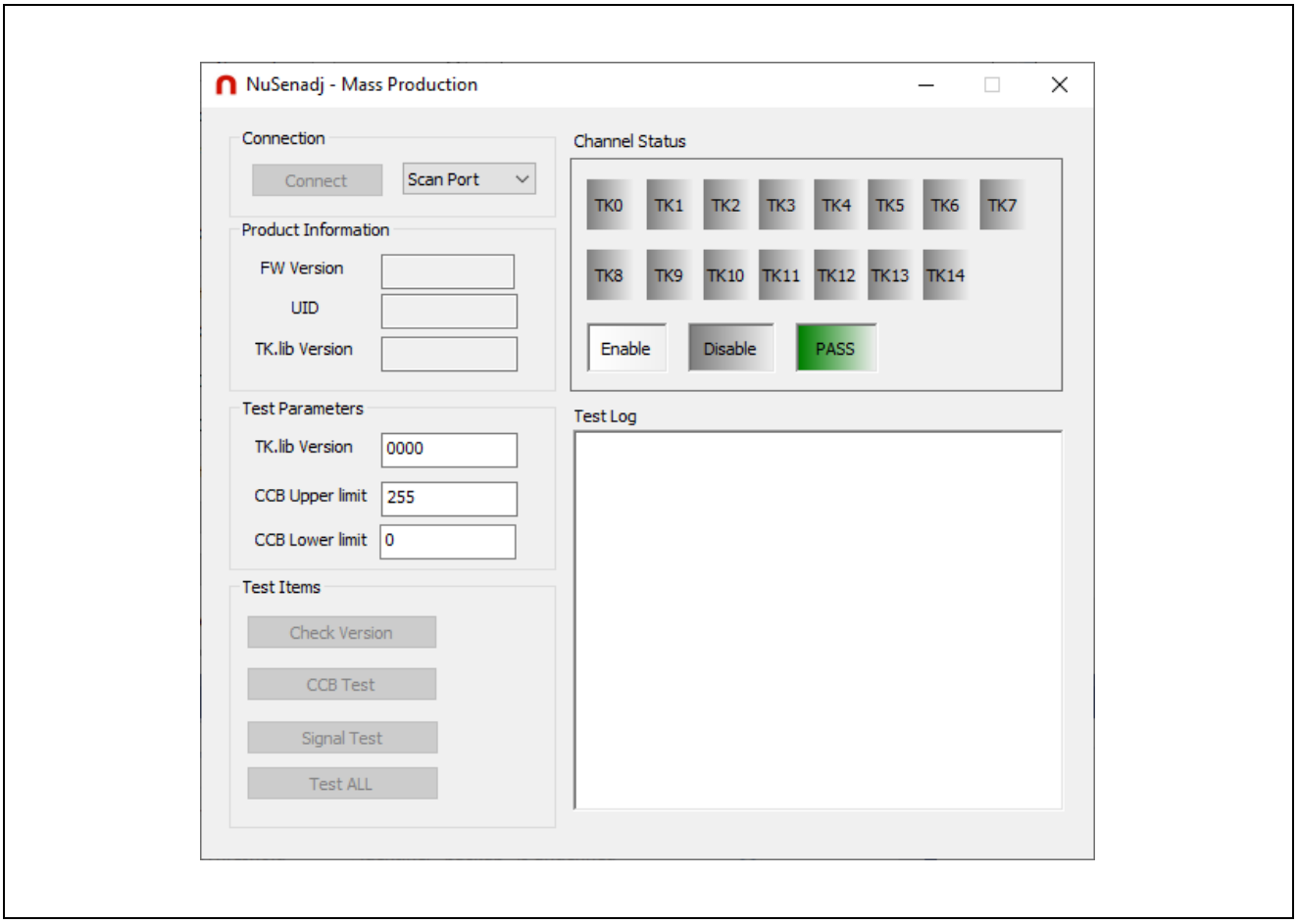


Figure 6-1 MP Tool User Interface

After clicking "**Connect**" button, the MP Tool will send a series of commands to read back on-board configuration including Production Information and Channel Status as shown in Figure 6-2. After connection, only Enable and Disable Status are available. In some test item, user needs to touch every enabled channel to get PASS Status.

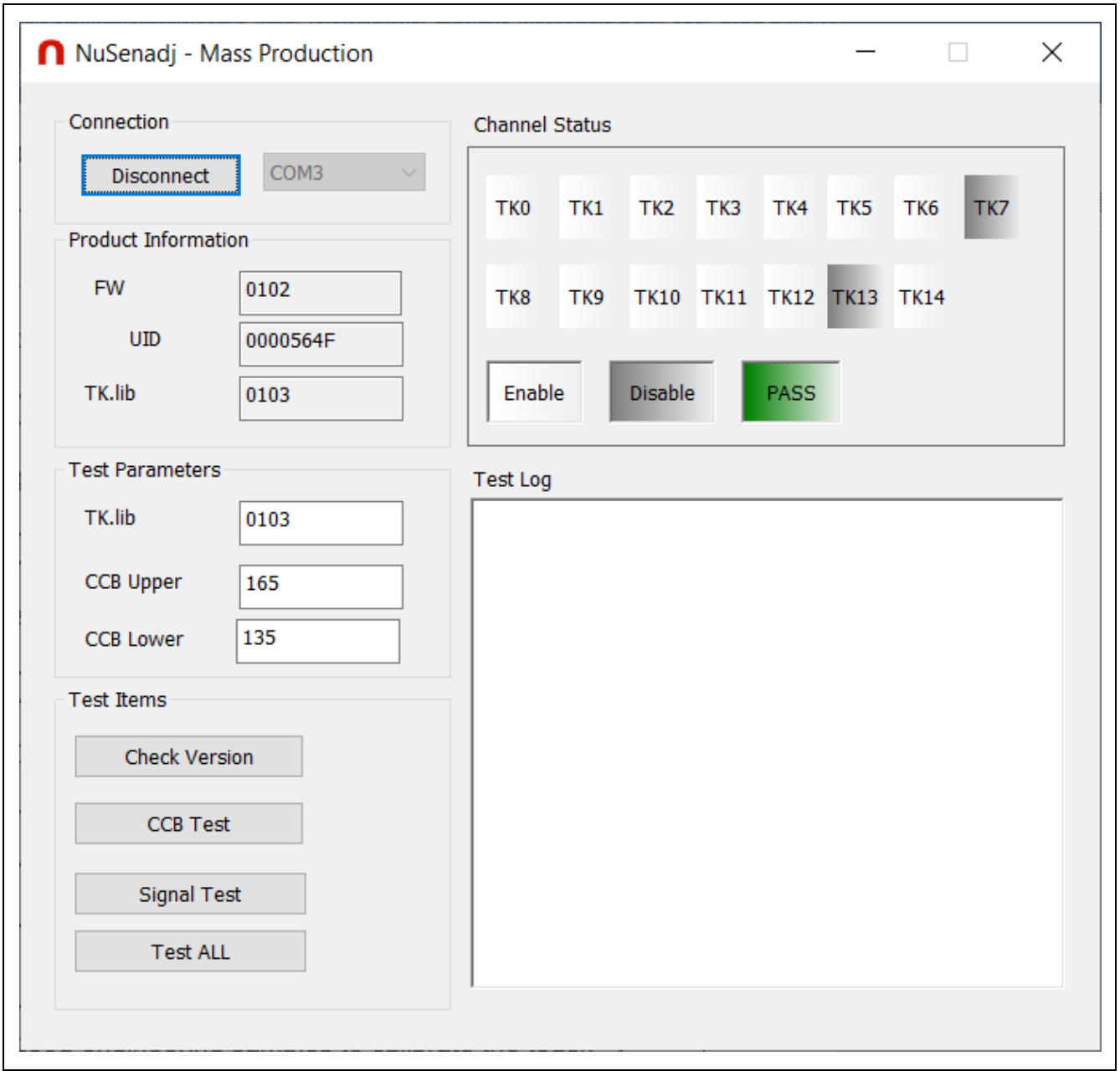


Figure 6-2 On-Board Configuration

6.2 Specifying Test Parameters

Before doing the test item, user needs to specify the Test Parameters as shown in Figure 6-3. The detailed description is shown below:

- **Test Parameters**:
  - **TK. Lib Version**: This is the minimum required version for customer's product. This is a 2-Byte hexadecimal number. User can set this value to "0000" to skip version check.
  - **CCB Upper limit, CCB Lower limit:** In CCB Test process, the MP Tool will send the

test command to do the short test. User can assign the upper and lower limit as the judgment condition of touch key short test.

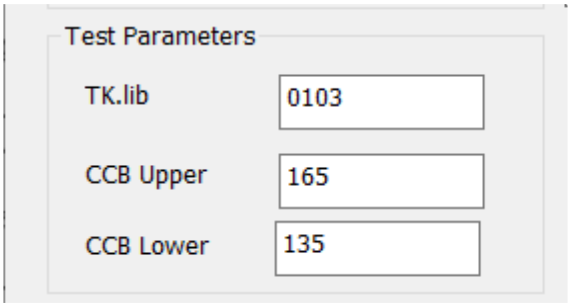


Figure 6-3 Test Parameters Panel

6.3 Doing the Test Items

There are four test items as shown in Figure 6-4. These test items will be described in the following sections. The test result is also shown in Test Item Panel.

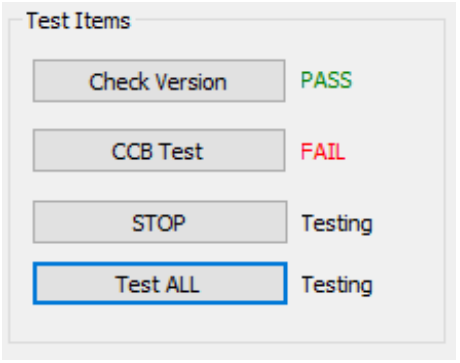


Figure 6-4 Test Items Panel

6.3.1 Check Version

This is a simple test item. The MP Tool will compare the on-board library version with the user specified version. User must make sure that the library version used in the final product must be equal or greater than the library version used in the development stage.

6.3.2 CCB Test

Even all the board is generated in the same product line, there could be some problems arise during assembling all the components. The CCB Test item can catch this problem. In the CCB Test flow, the MP Tool will trigger the touch key short test flow inside the product. If the test

failed, please check the hardware status.

6.3.3 Signal Test

In Signal Test, user needs to touch every channel used in the touch product. The MP Tool will continue to read back the run time signal and compare with the on-board channel threshold. If the touch signal is greater than the channel threshold, the MP Tool will update the Channel Status Panel, as shown in Figure 6-5. If all the channels are marked as PASS Status, this test item will stop automated. User can click "**STOP**" to cancel this test item.

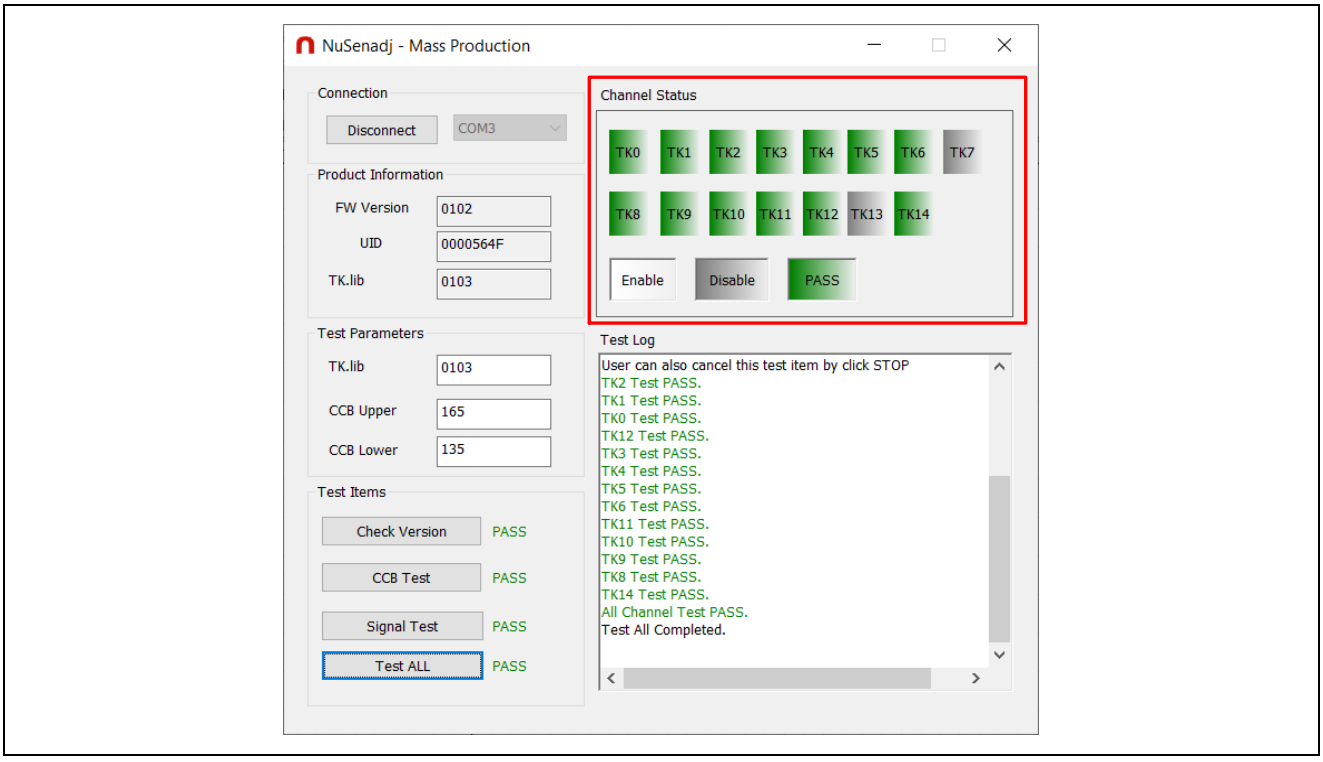


Figure 6-5 Channel Status Panel

6.3.4 Test ALL

"Test ALL" is the combination of the other three items. Please refer to previous section for the specific test item.

6.4 Test Log

The MP Tool will show test messages in Test Log.

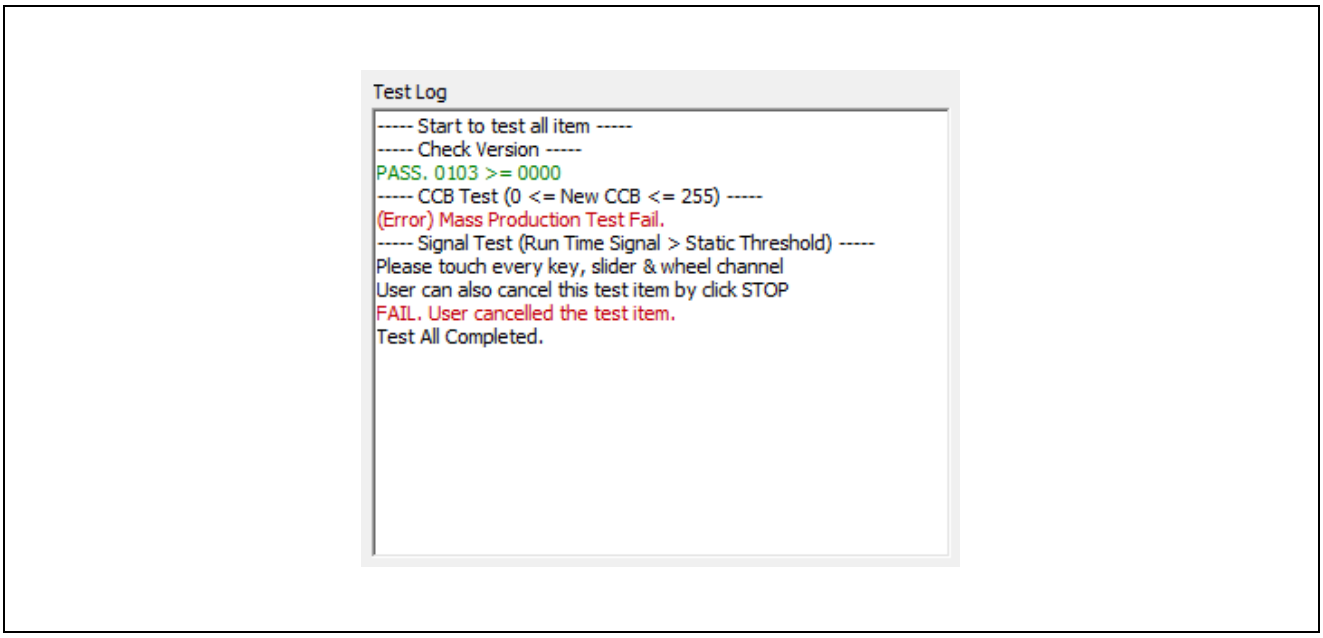


Figure 6-6 Test Log

7 Starting to Develop Touch Key System

7.1 Design Flow

When designing a touch key system with the NuMicro® ML56 series, there are some factors affecting the overall touch sensing performance. Follow the instructions in Figure 7-1 through the whole design flow and mass production to obtain the high performance and stable touch key system.

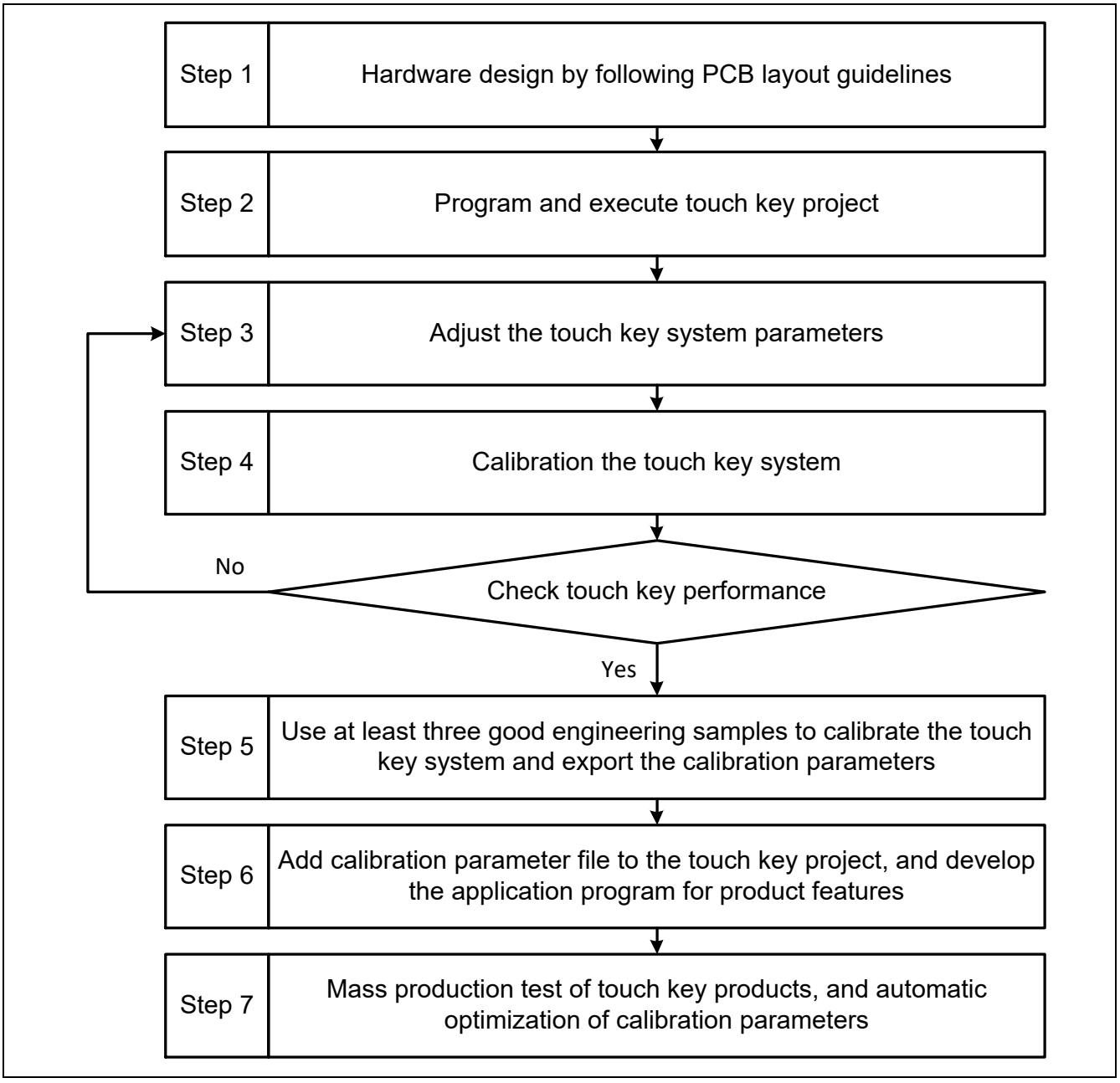


Figure 7-1 Touch Key Design Flow Chart

7.2 Touch Key Development Board Overview

The NuMaker-ML56SD is a development board for Nuvoton NuMicro® ML56SD microcontrollers. The NuMaker-ML56SD consists of three parts: an ML56 platform, an on-board Nu-Link2-Me debugger and programmer and a TNLCD daughter board. The NuMaker-ML56SD is equipped with a touch key and a cover.

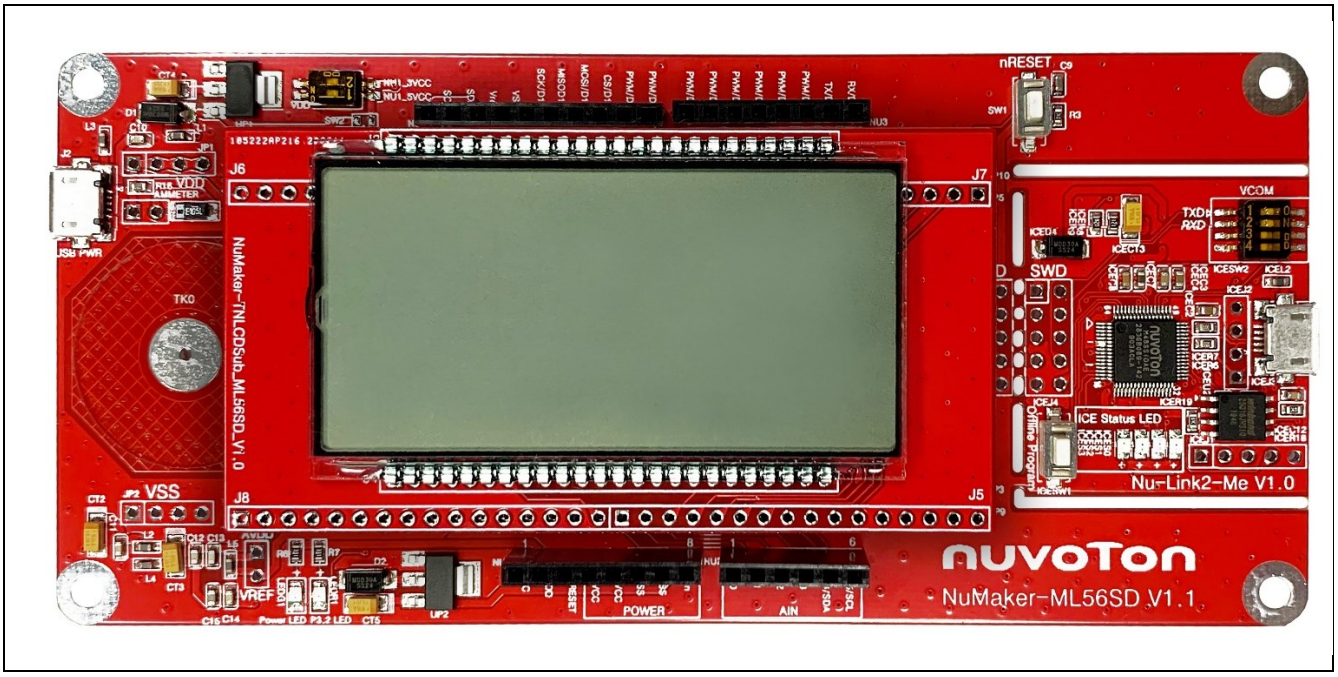
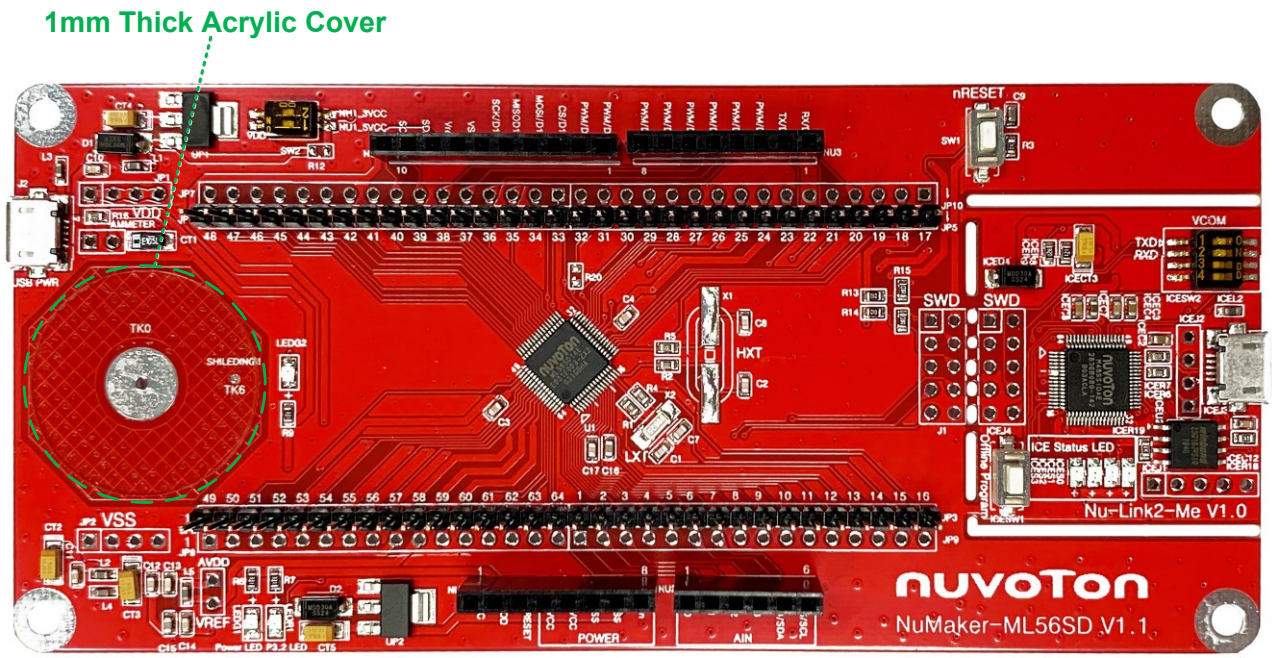


Figure 7-2 NuMaker-ML56SD PCB Assembly

When the touch key of NuMaker-ML56SD PCB Assembly is covered with the cover, the adjustment and calibration of the touch keys parameters can meet the actual product application. Please refer to Figure 7-3.



NuMaker-ML56SD

Figure 7-3 NuMaker-ML56SD with Cover

For the details of the NuMaker-ML56SD, please refer to the UM_NuMaker-ML56SD_EN.

7.3 Adjusting Touch Key System Parameters

Open the virtual COM (VCOM) function by changing Nu-Link2-Me VCOM Switch No. 1 and 2 to ON.

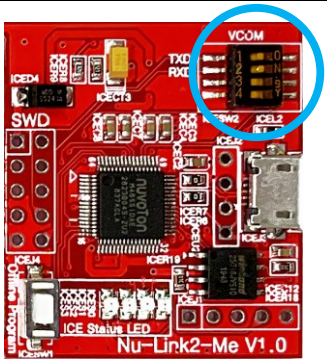


Figure 7-4 Open VCOM Function

Connect the ICE USB connector to the PC USB port through USB cable.

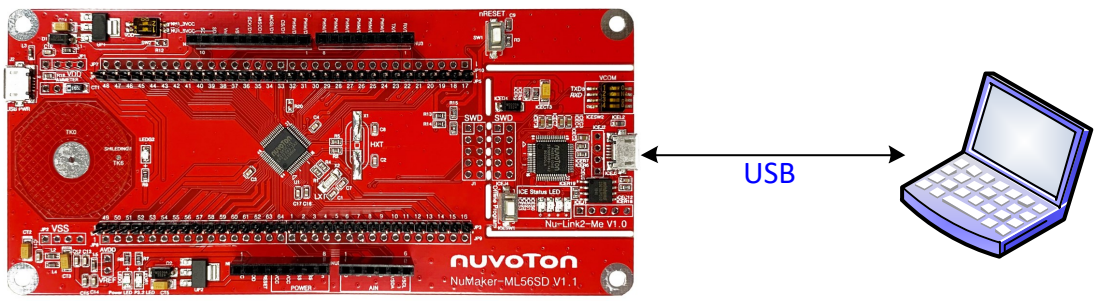


Figure 7-5 System Connection Diagram

Open BSP \SampleCode\NK_ML56SD\NK_ML56SD_LCD_TK_PD\KEIL\TouchKey.uvproj.

1. Select TK_Calibration project
2. Compiler
3. Download

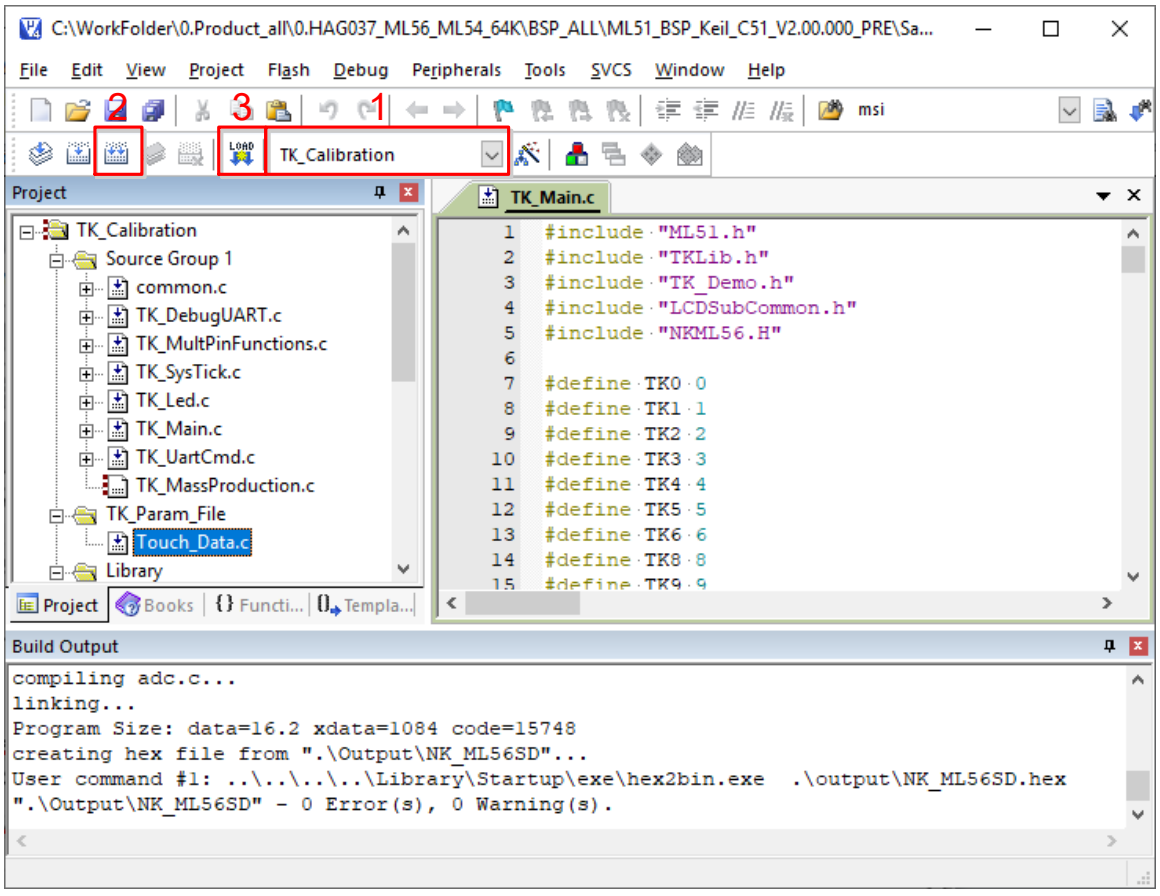


Figure 7-6 Compile and Download the Project

Run the NuSenadj on PC and then choose the COM Port that connects to NuMaker-ML56SD.

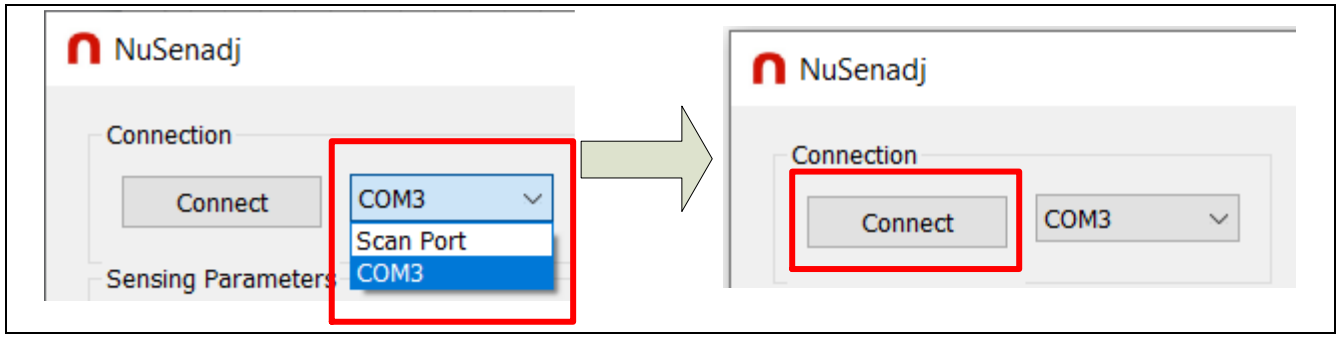


Figure 7-7 NuSenadj Connection

7.3.1 Sensor Configuration

Specify the reference pad channel, shielding electrode channel and touch key channels according to the application schematic. Please refer to Figure 7-8 and Figure 7-9.

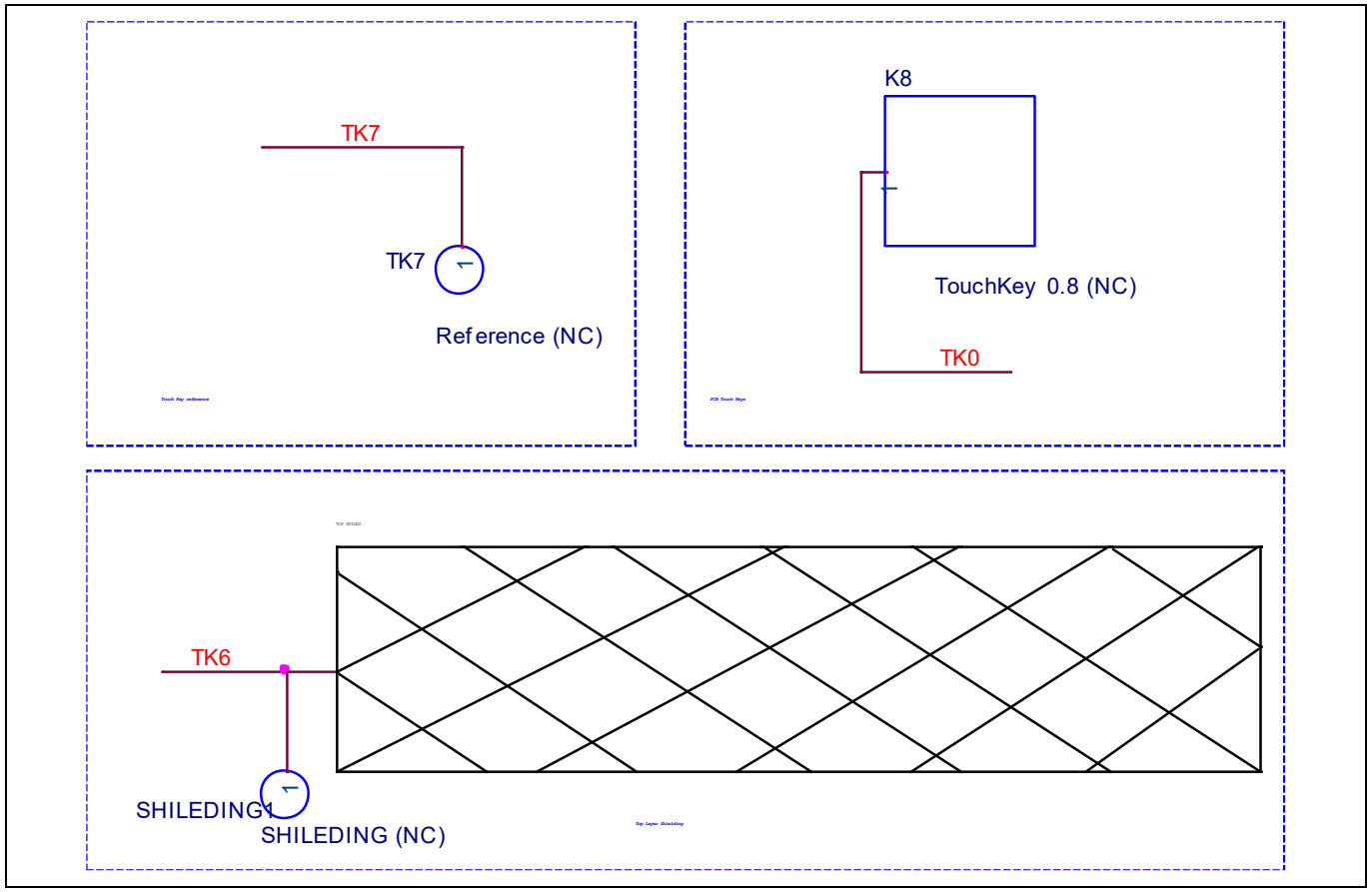


Figure 7-8 Touch Key Application Schematic

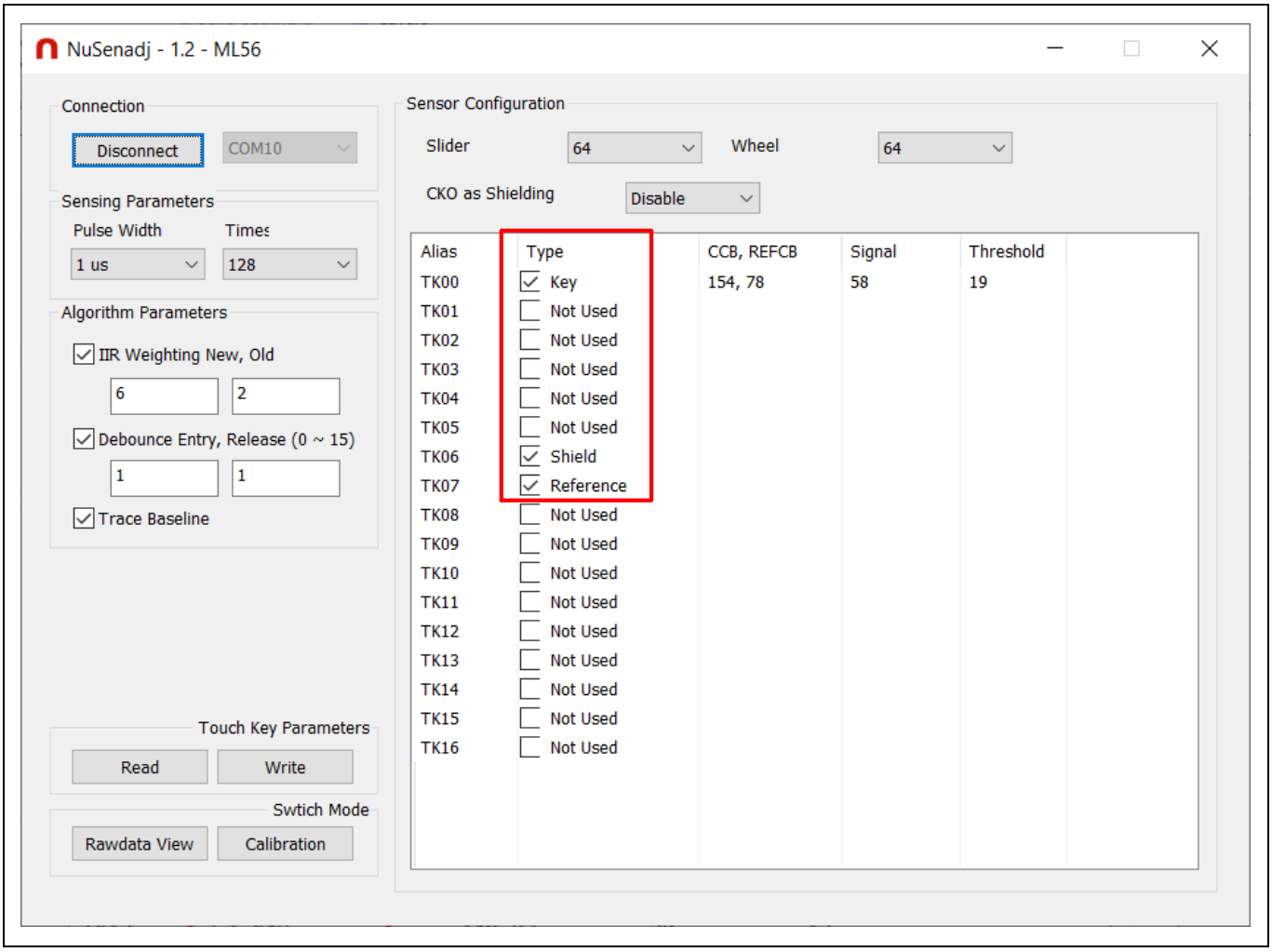


Figure 7-9 Specify the Touch Key Channels

7.3.2 Touch Sensitivity

- Pulse Width (Touch key sensing pulse width time control)
  - ✓ Touch key sensitivity can be adjusted by setting Pulse Width properly, shorter Pulse Width setting comes with poor sensitivity and less power-consumption, vice versa.
  - ✓ Good waterproof function when Pulse Width is set to 500 ns.
  - ✓ In order to pass the IEC 61000-4-6 conducted noise immunity (CNI) with 10-Vrms noise voltage test, set the Pulse Width to 2 us.

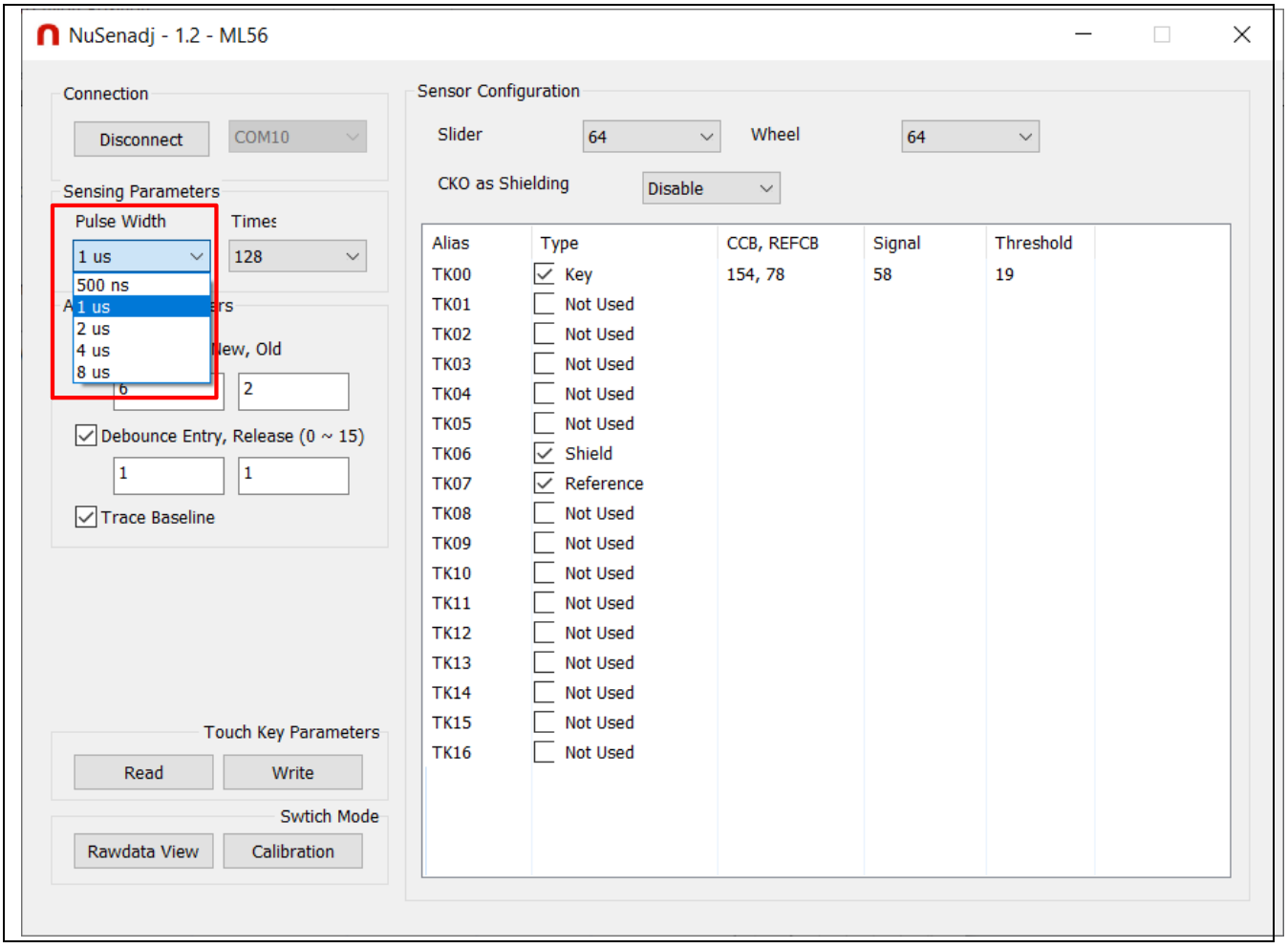


Figure 7-10 Sensing Parameters

7.3.3 Stability of Touch Performance

- Times (Touch key sensing time control)
  - ✓ Touch key raw data stability can be adjusted by setting Times properly, shorter Times setting comes with poor raw data stability and less power-consumption, vice versa.
  - ✓ Good waterproof function when Times is set to 128.
  - ✓ In order to pass the IEC 61000-4-6 conducted noise immunity (CNI) with 10-Vrms noise voltage test, set the Times to 128.
- IIR (IIR filter)
  - ✓ IIR filter can control the ratio of current raw data and previous one. In general, it is considered that the little change of raw data as noise, and user can enable IIR Filter to be against noise. It will increase the touch response time when user enables IIR Filter.

- ✓ In order to pass the IEC 61000-4-6 conducted noise immunity (CNI) with 10-Vrms noise voltage test, set the IIR filter parameter New = 6, and Old = 2.
  - ➢ Touched signal = (Current New signal * 6 + Last Old signal * 2) / 8

■ Debounce (Touch key debounce)

- ✓ Touch key stability can be adjusted by setting Debounce properly, the debounce times for touch key entry (on) and release (off) detection, shorter Debounce setting comes with faster touch response time, vice versa.
- ✓ In order to pass the IEC 61000-4-6 conducted noise immunity (CNI) with 10-Vrms noise voltage test, set the Debounce parameter Entry = 1, and Release = 1.

■ Trace Baseline (Baseline is generated by “Calibration”)

Touch key auto environment compensation is an algorithm that baseline tracking each touch key automatically at power-up and keeps compensating environment variation affects touch key performance during runtime. The baseline tracking makes touch keys can tolerate manufacturing variations of PCBs and covers. It also automatically eliminates noise effect from various sources such as AC lines, switch-mode power-supplies, power inverters and radiation.

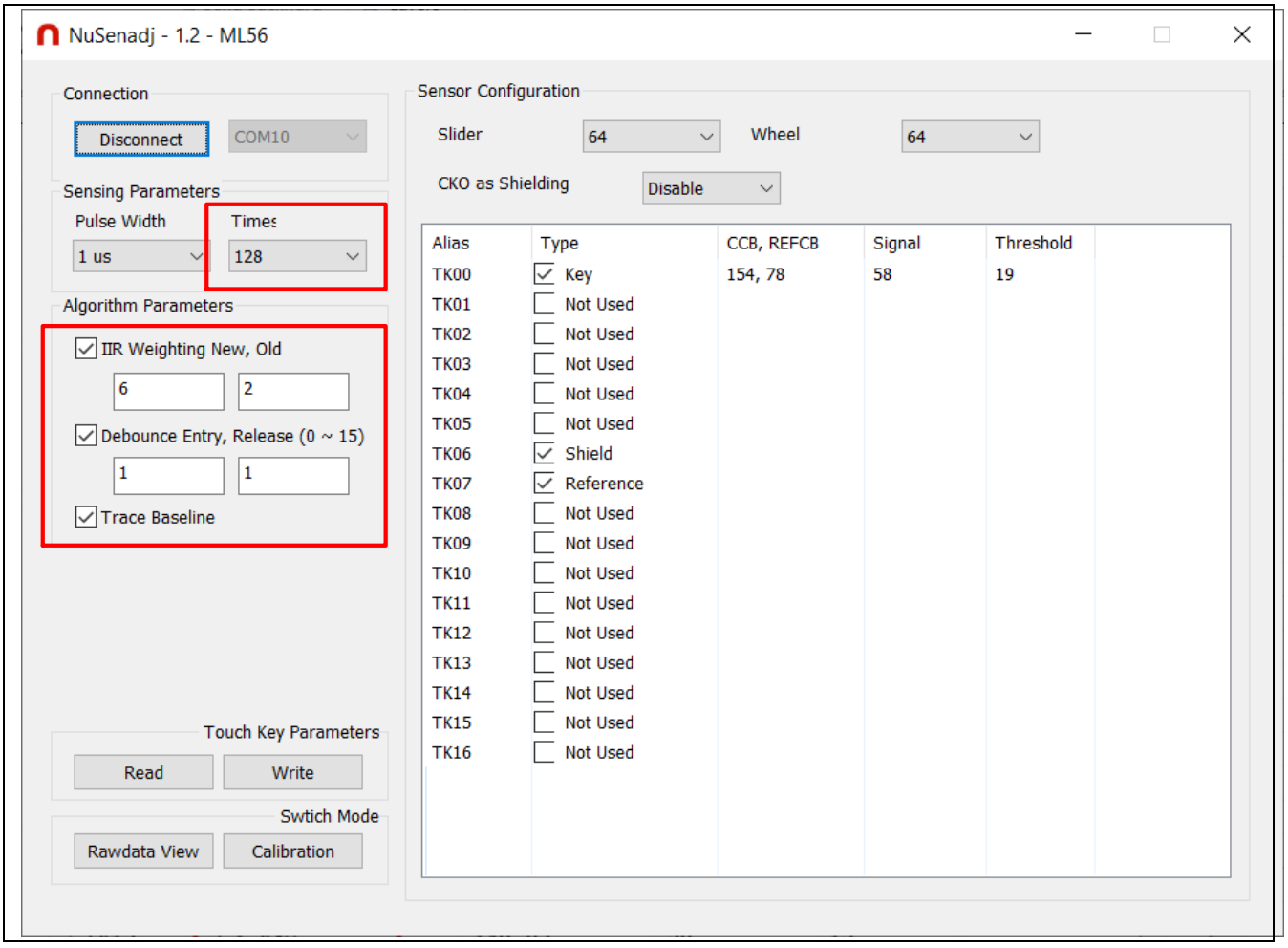


Figure 7-11 Algorithm Parameters

7.3.4 Writing All Touch Key Parameters

After sensor configuration and sensing parameters setting, user should specify Store Address and write current configuration and parameters to Data Flash by clicking "**Write**" button in the left part of NuSenadj.

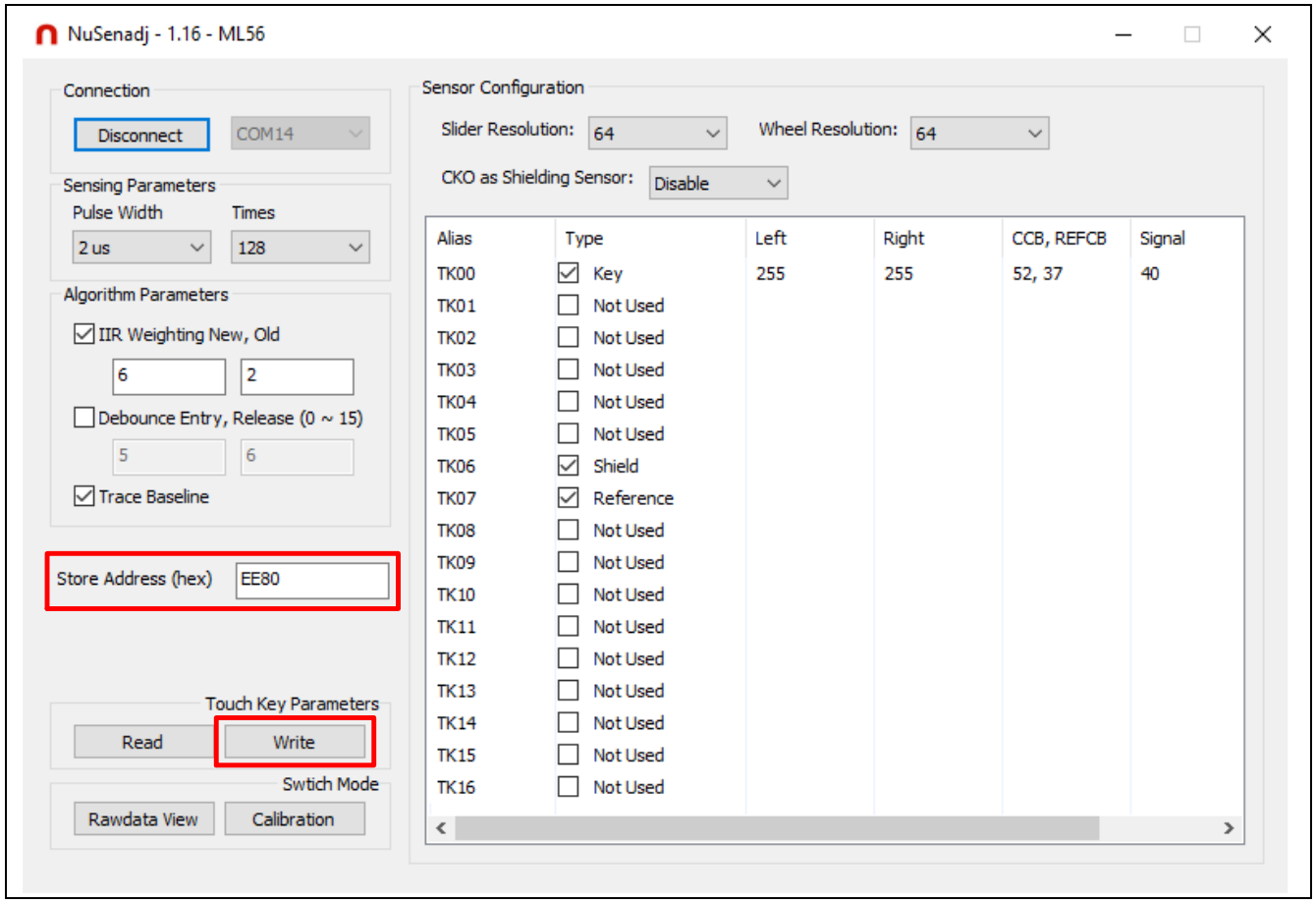


Figure 7-12 Write Touch Key All Parameters

7.4 Calibrating Touch Key System

Proper calibration of touch key is important for touch performance. Touch key calibration will automatically adjust CB (Capacitor Bank), CCB (Complement Capacitor Bank) and touch threshold.

The operating voltage of ML56 touch key for calibration must be the same as the actual operating voltage of the final product. If the final product is powered by a battery, the operating voltage of the touch key for calibration must be equal to the battery full charge capacity voltage.

Use the Calibration touch key by clicking "**Calibration**" button in the left part of NuSenadj, as shown in Figure 7-13.

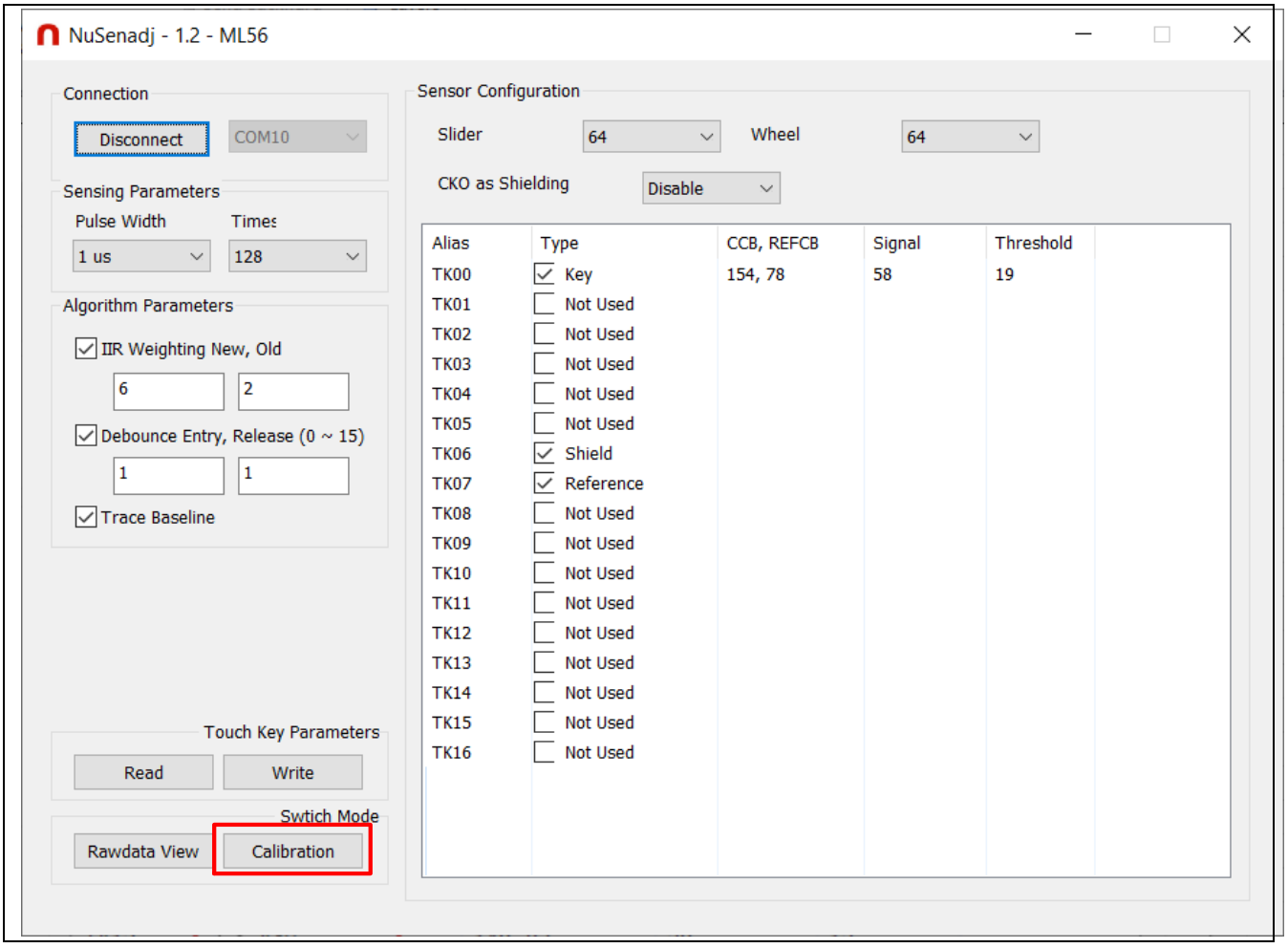


Figure 7-13 Enter the Calibration Environment

7.4.1 Selecting the Noise Immunity Level

There are three degrees of Noise Immunity Level that can be selected: Low, Medium and High. The Noise Immunity level relates to threshold of touch key, user can demand the performance of touch key sensors in current setting.

The Noise Immunity Level is explained as follows:

- Noise Immunity Level is equal to “Low”

  Threshold = Finger Touch Signal * 1/3

- Noise Immunity Level is equal to “Medium”

  Threshold = Finger Touch Signal * 1/2

- Noise Immunity Level is equal to “High”

  Threshold = Finger Touch Signal * 2/3

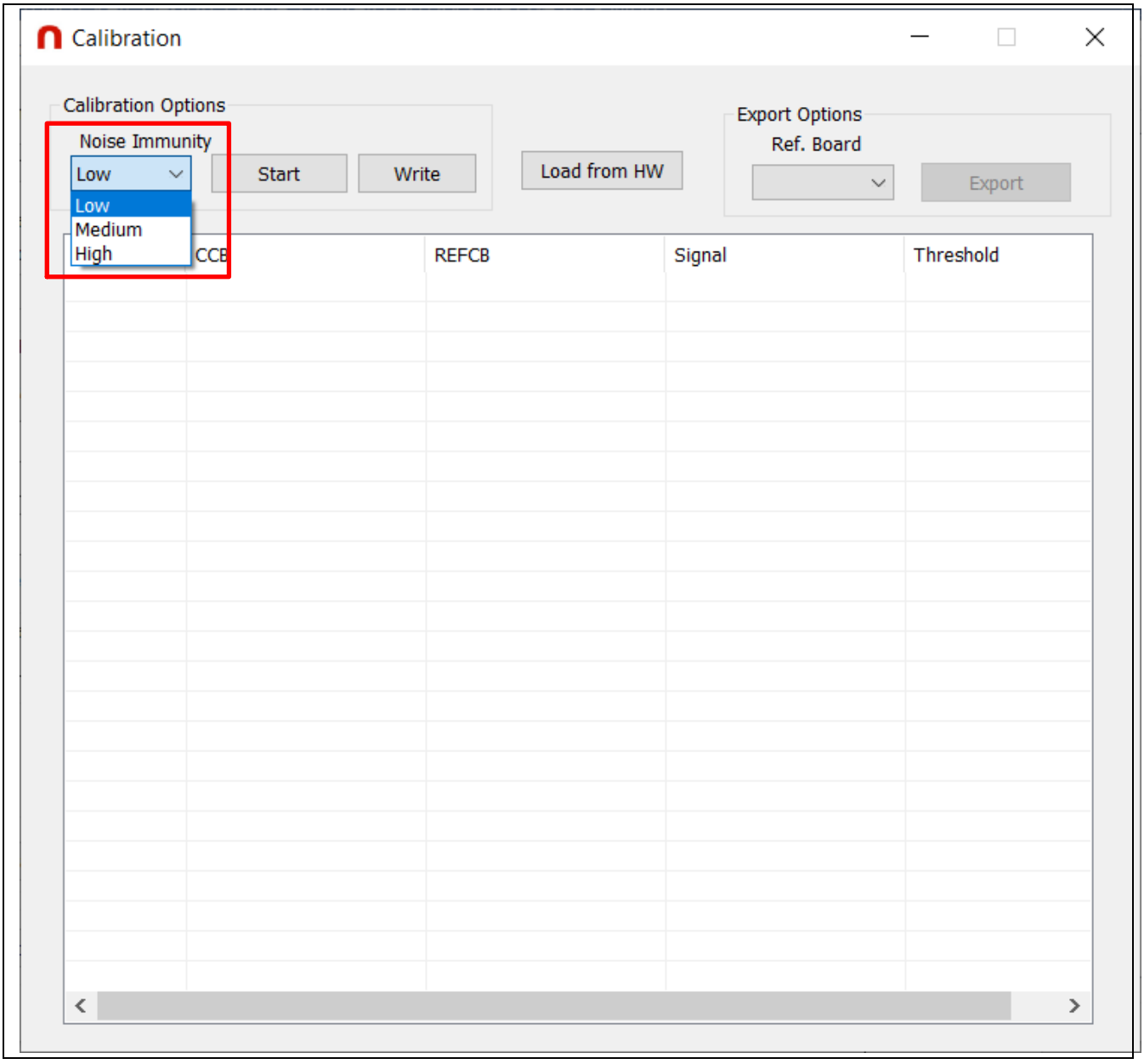


Figure 7-14 Select the Noise Immunity Level

7.4.2 Starting Calibration the Touch Key System

After selecting the Noise Immunity level, click "**Start**" button to start the touch key system calibration flow. Please refer to Figure 7-15.

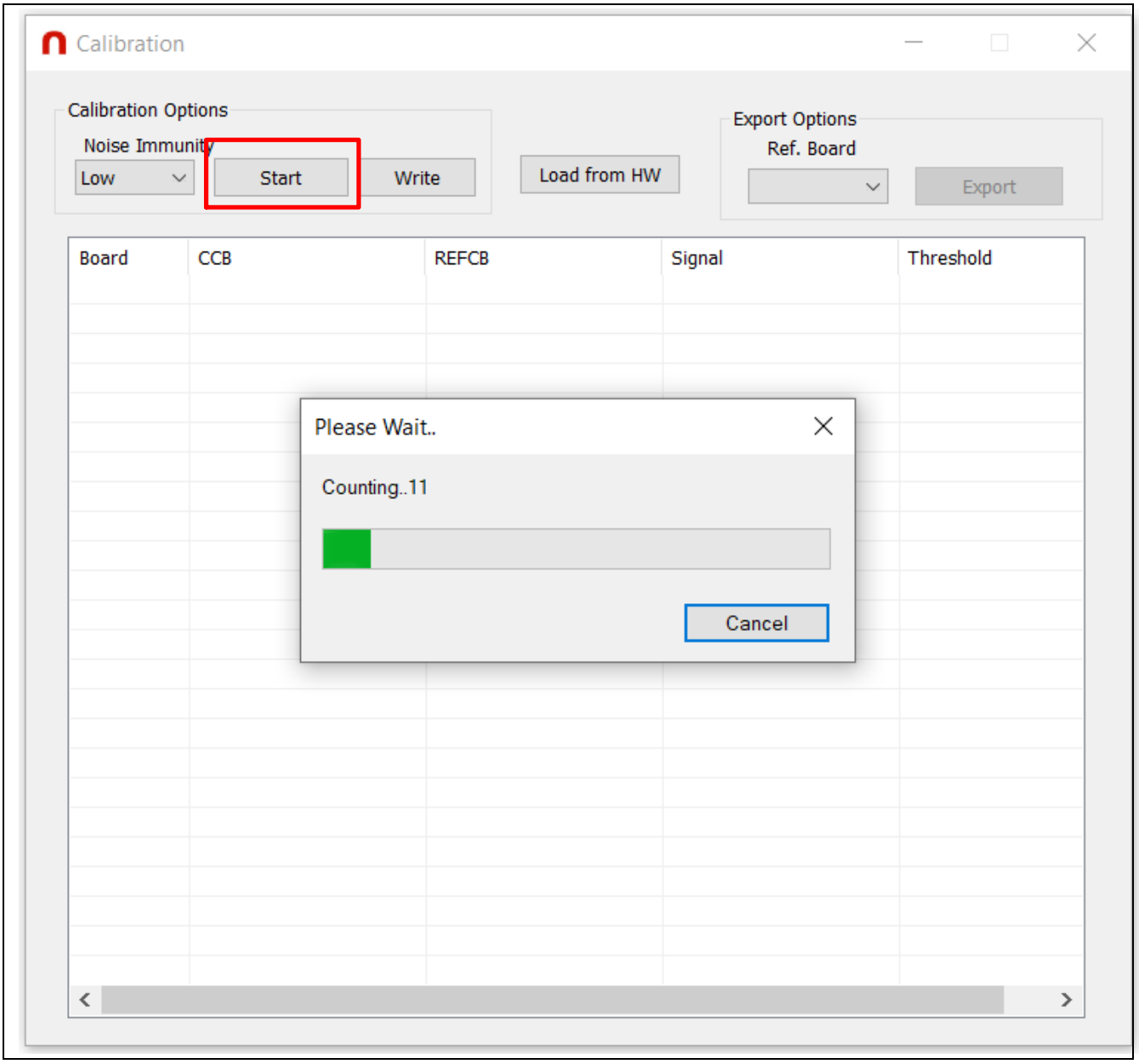


Figure 7-15 Start Touch Key Calibration

After calibration, NuSenadj will request user to touch the specific key until the user clicks "**OK**" in the NuSenadj reminder window. Then, follow the above step to complete all touch keys. The NuSenadj can automatically generate a suitable threshold for each touch key. For the location of touch keys, please refer to Figure 7-16.

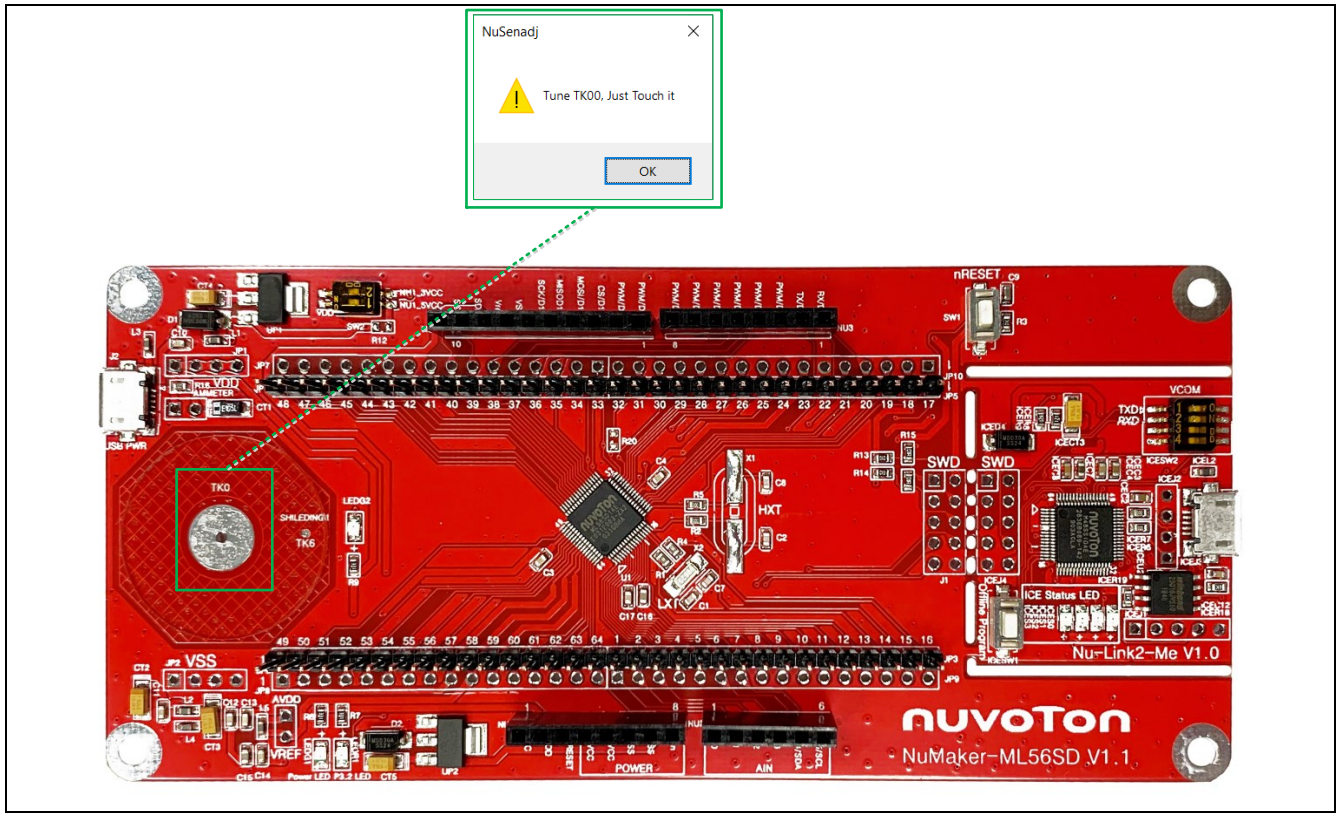


Figure 7-16 Location of Touch Keys

In order to make the touch threshold automatically generated by NuSenadj more accurate, the 8mm diameter copper rod (the diameter of copper rod is selected according to the actual touch specification) is used to simulate finger touch, which can avoid errors caused by different finger contact areas. The copper rod should be connected to the system ground, as shown in Figure 7-17.

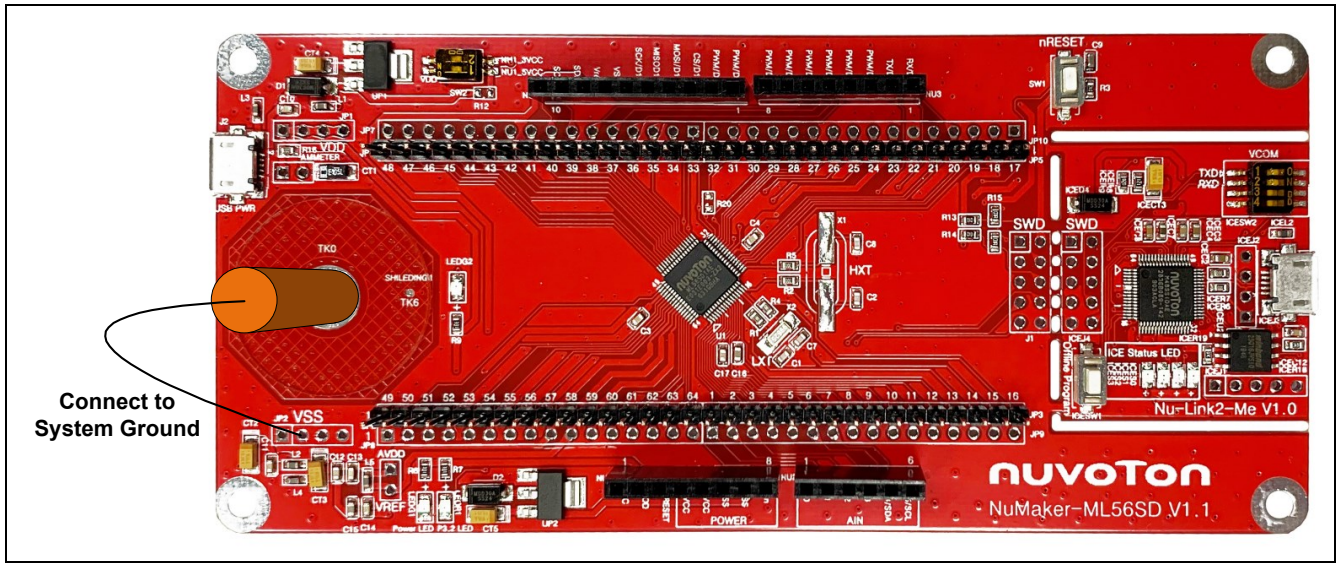


Figure 7-17 Use Copper Rod to Touch the Touch Key

After all touch keys are touched, the calibration flow is done. The calibration data will be written to Data Flash when "**Write**" button on the Calibration frame is clicked, as shown in Figure 7-18.

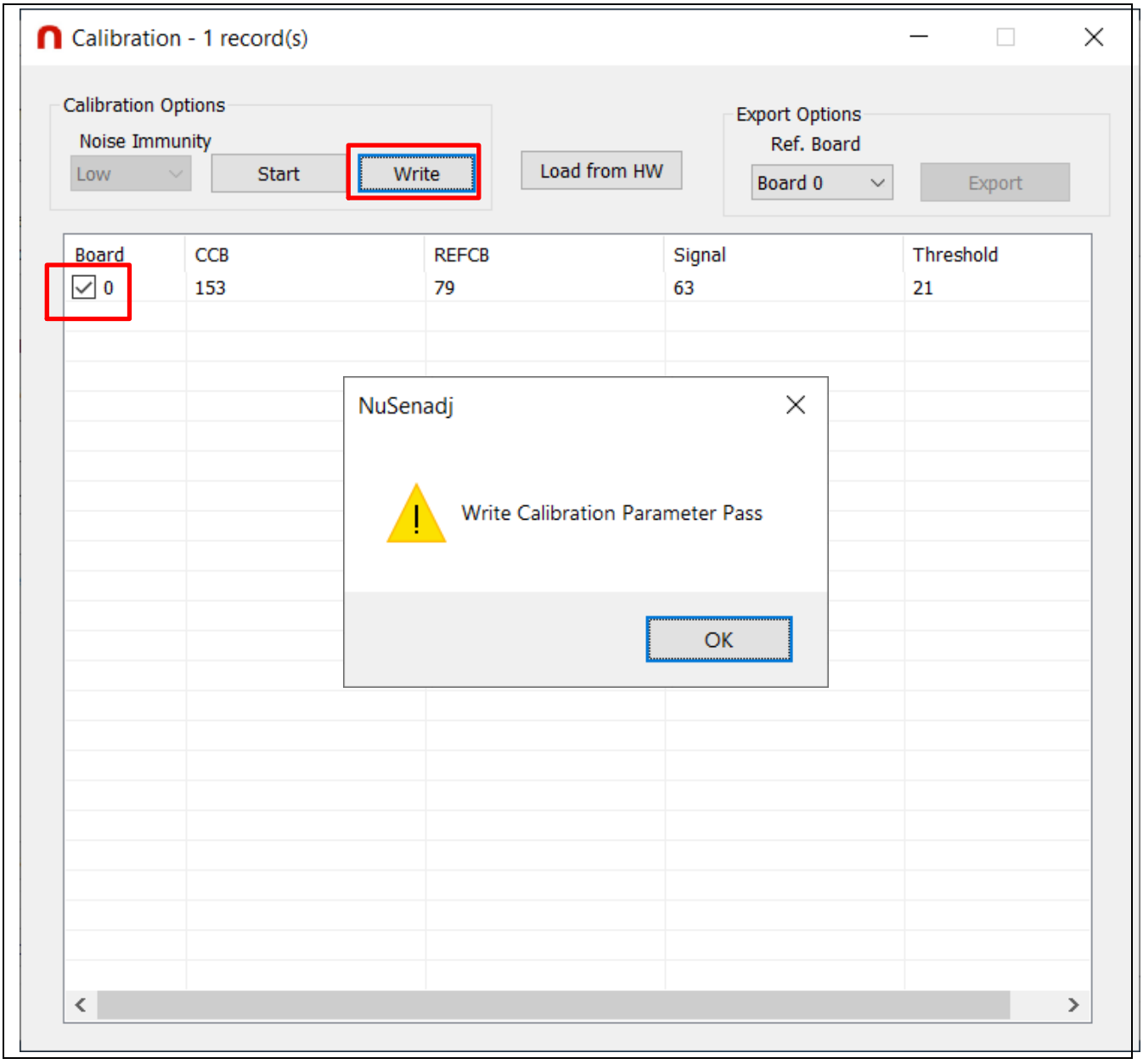


Figure 7-18 Write Calibration Parameters into Flash

7.5 Touch Key Performance Confirmation

By clicking “**Rawdata View**” button, user can get the CCB (Complement Capacitor Bank) value of every touch key that is enabled and line chart that shows the trend of CCB over time in “Raw Data View” window. The user can check touch key performance using “Raw Data View”, as shown in Figure 7-19 and Figure 7-20.

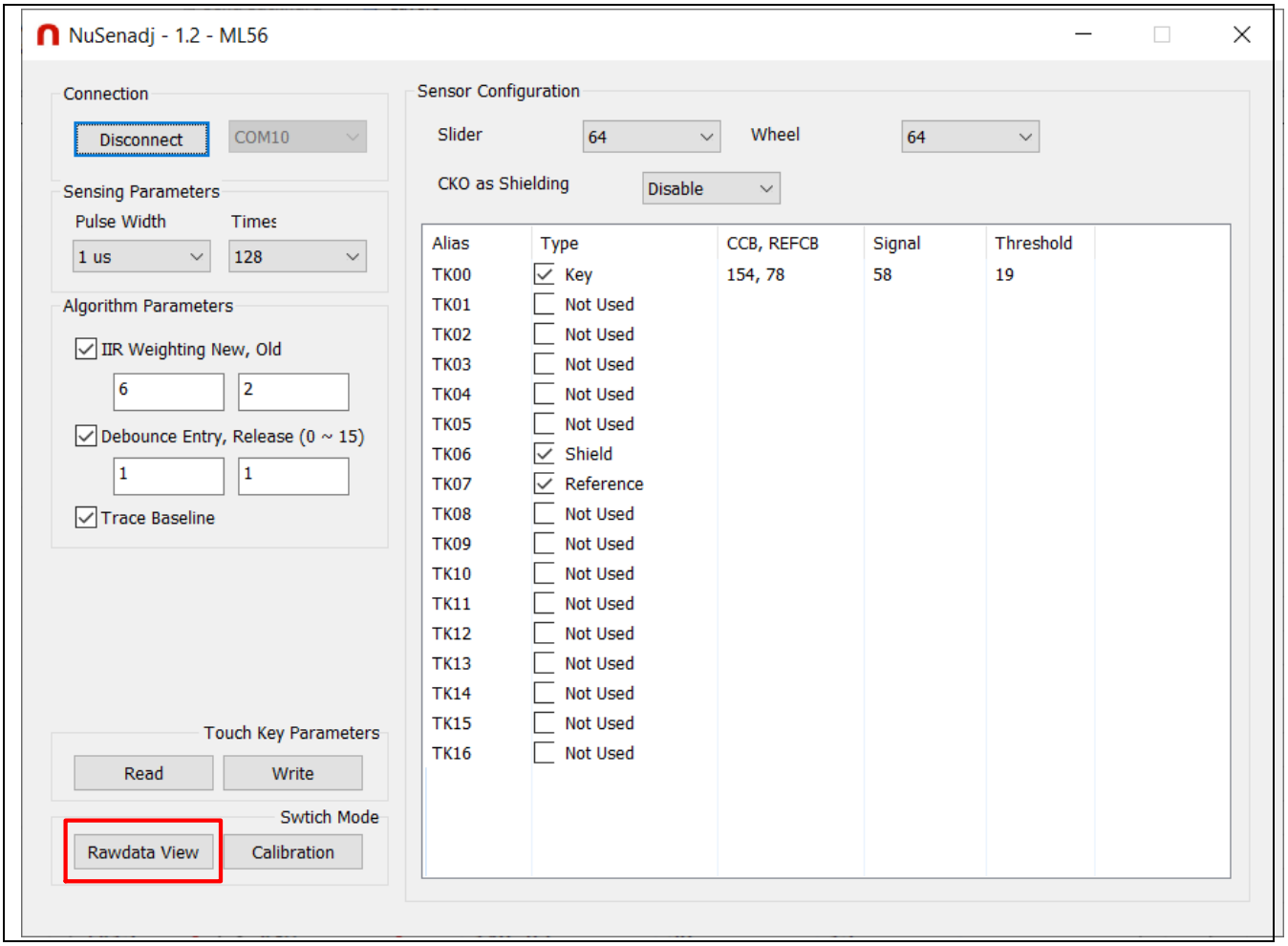


Figure 7-19 Enter the Raw Data View Environment

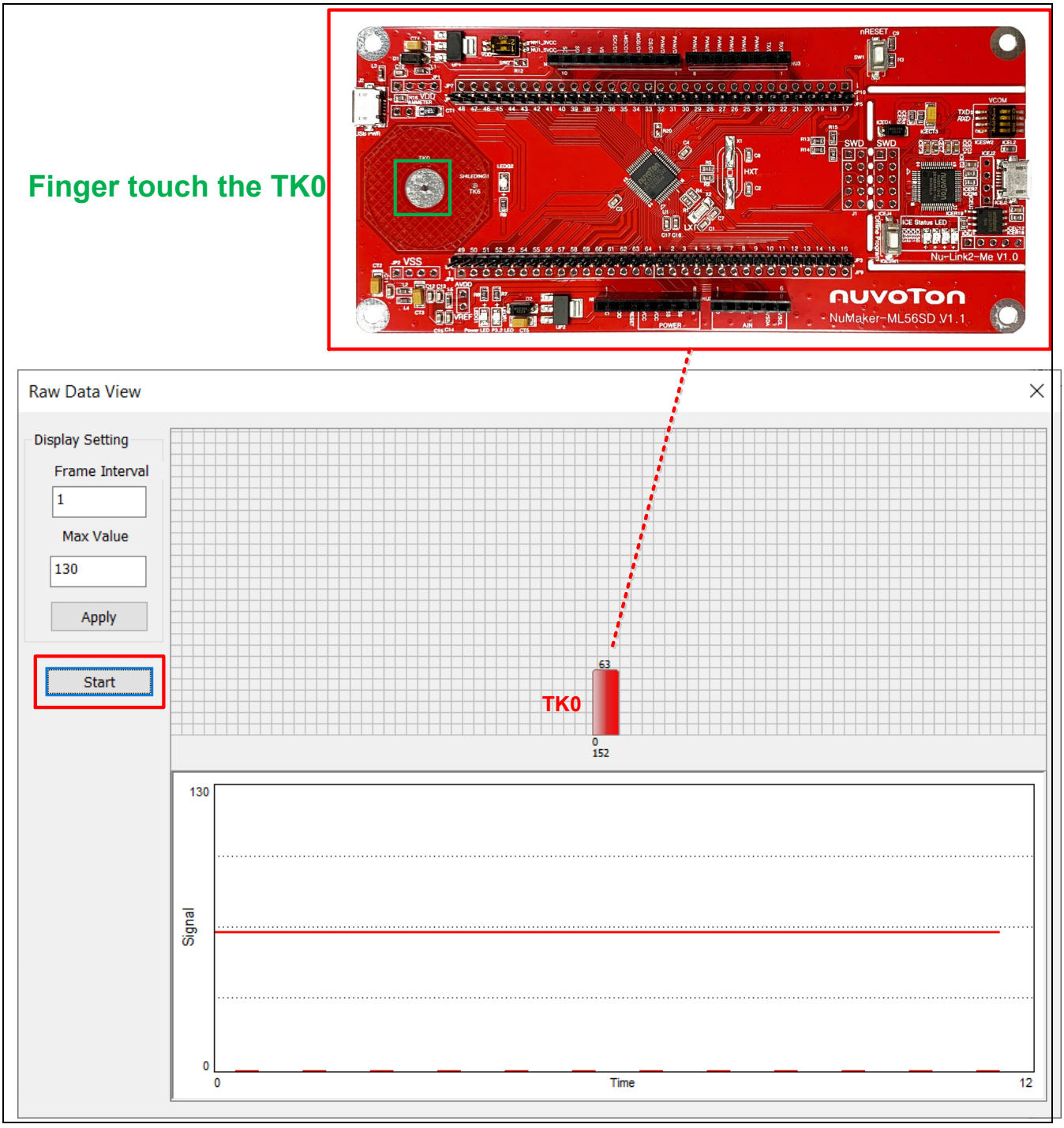
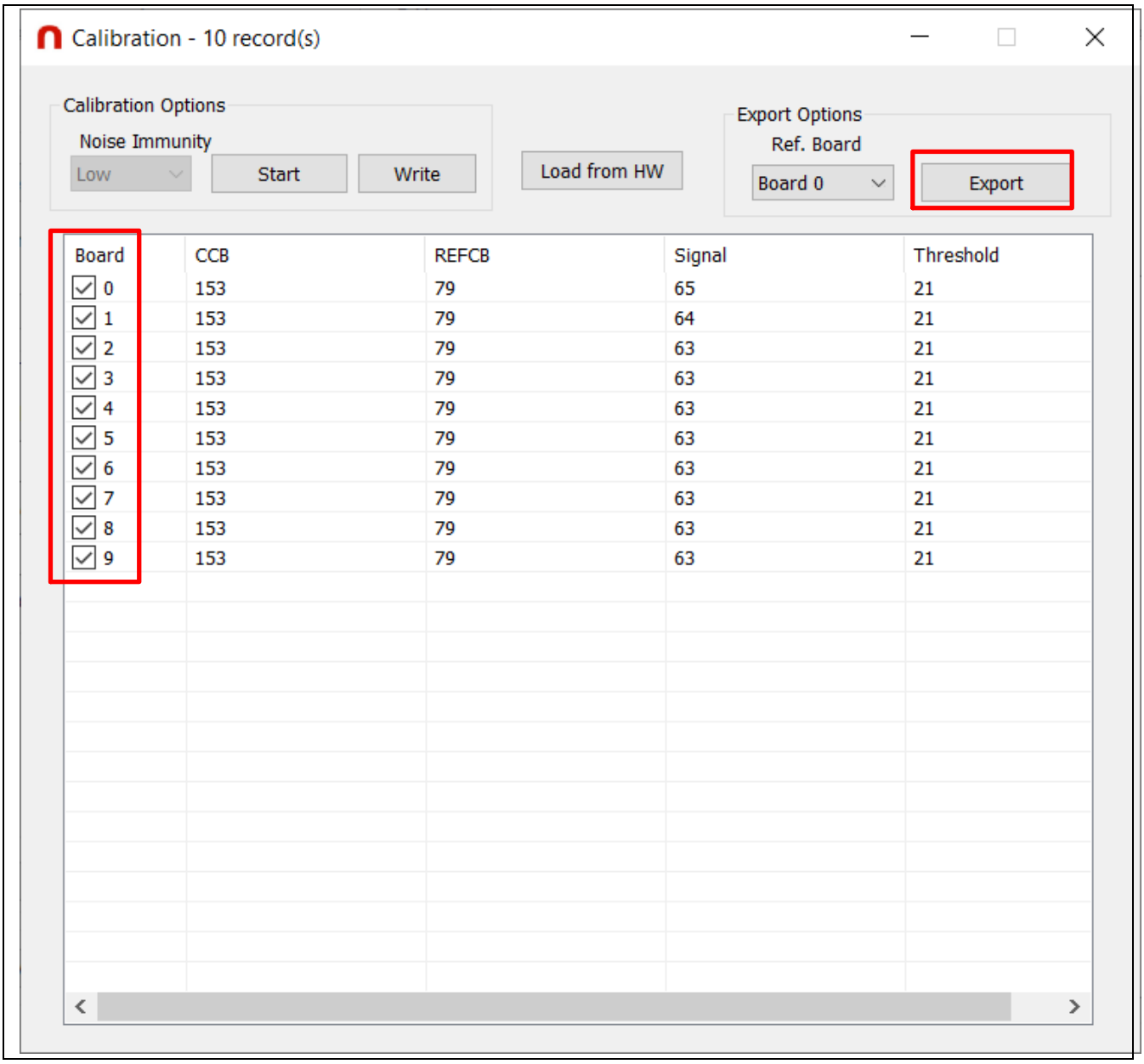


Figure 7-20 Show Touch Key Raw Data

7.6 Exporting Calibration Parameters

In the engineering development stage, at least three pieces of engineering samples will be used for touch key calibration, and the calibration data “TK_Data.c and RecTune.txt” will be export when “**Export**” button on Calibration frame is clicked, as shown in Figure 7-21.

If the engineering sample has abnormal calibration result values, it will not be adopted by NuSenadj, and NuSenadj will request another engineering sample for calibration.



Board	CCB	REFCB	Signal	Threshold
0	153	79	65	21
1	153	79	64	21
2	153	79	63	21
3	153	79	63	21
4	153	79	63	21
5	153	79	63	21
6	153	79	63	21
7	153	79	63	21
8	153	79	63	21
9	153	79	63	21

Figure 7-21 Export Calibration Parameters

The calibration data “TK_Data.c and RecTune.txt” storage path is the same as NuSenadj. The TK_Data.c file can be used directly for mass production, this file can be included through the touch key application project, as shown in Figure 7-22.

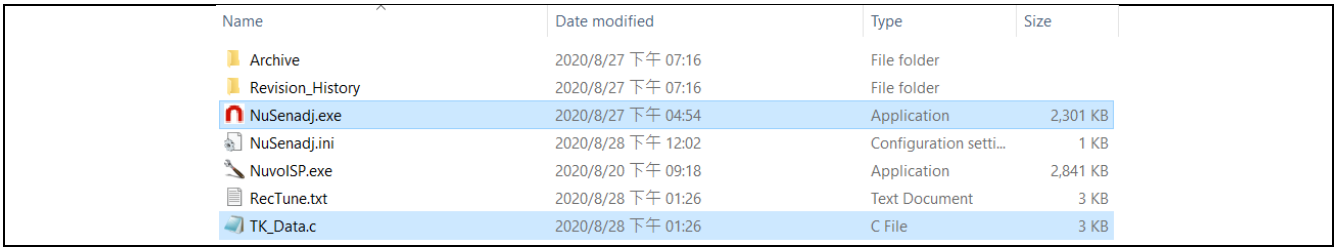


Figure 7-22 Export Calibration Parameters Storage Path

7.7 Adding Calibration Parameters to the Project

Please follow the steps below and refer to the Figure 7-23.

1. Select NK-ML56SD project.
2. Add the calibration parameter file **TK_Data.c** to project.
3. Go to the BL51 locate tab, under options for target.
4. Use the BL51 **CODE** directive to specify the location of the constant segment. In the input line, add **?CO?TK_Data(0xEE80)** that locates the calibration parameter to absolute memory address EE80h. This address value must be the same with the Store Address setting value of “NeSenadj” tool.

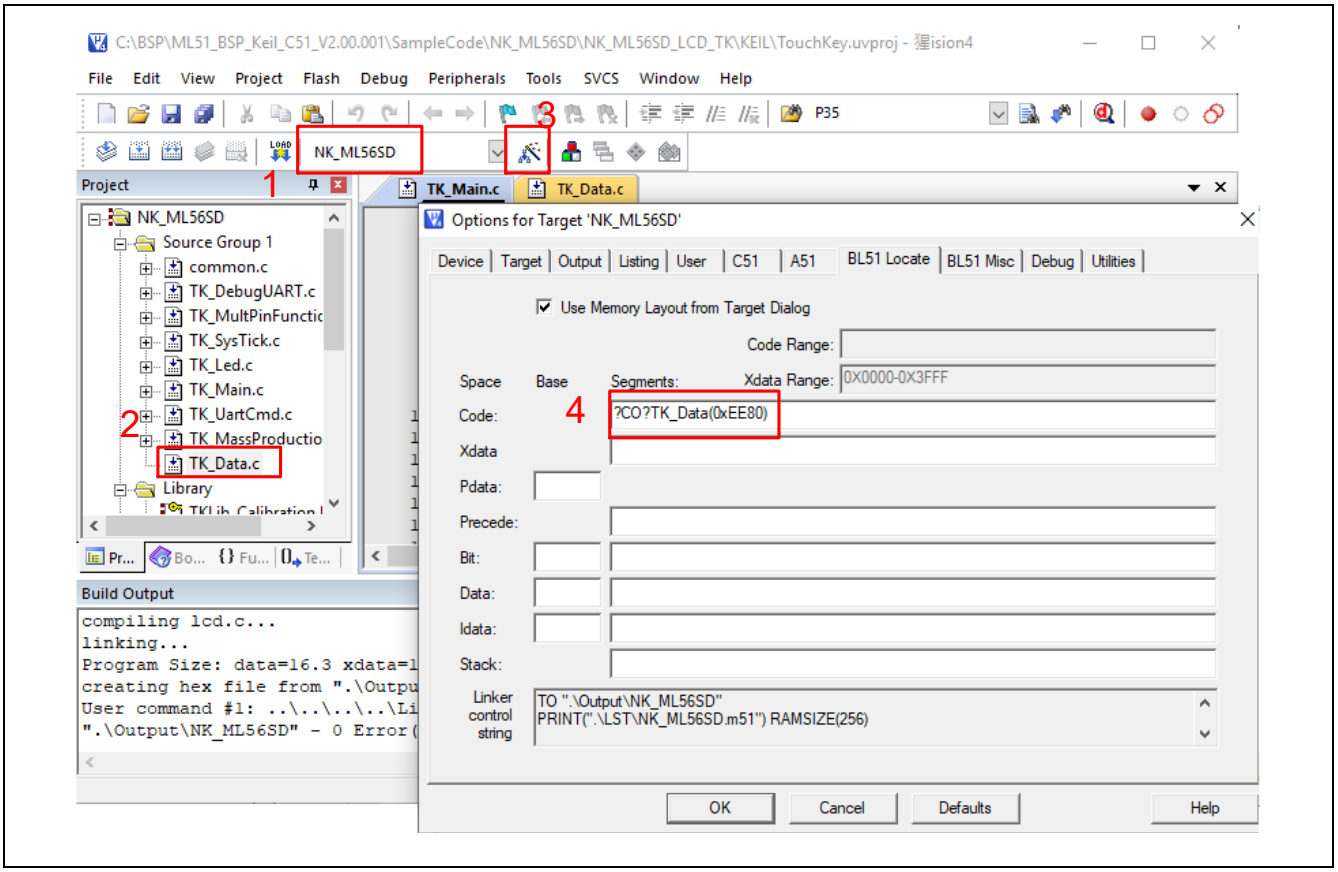


Figure 7-23 Locating Calibration Parameter at Specific Address

7.8 Mass Production Testing

The mass production test of the touch keys is carried out to test the touch keys function of the final product. A log file will be automatically generated after mass production test is completed.

The test items are as follows:

- Check Version

  Confirm the correctness of the touch key library version currently used by the product.

- CCB Test

  Use the CCB (Complement Capacitor Bank) value corresponding to the current hardware environment to determine whether the touch key is short or not.

- Signal Test

  The relationship between touch signal and touch threshold can be used to confirm whether the assembly of the touch key cover is abnormal.

  In order to make the Signal Test more accurate, it is recommended to use a test jig and include copper rod to simulate finger touch (the diameter of copper rod is selected according to the actual touch specification), which can avoid errors caused by different finger contact area. The copper rod should be connected to the system ground.

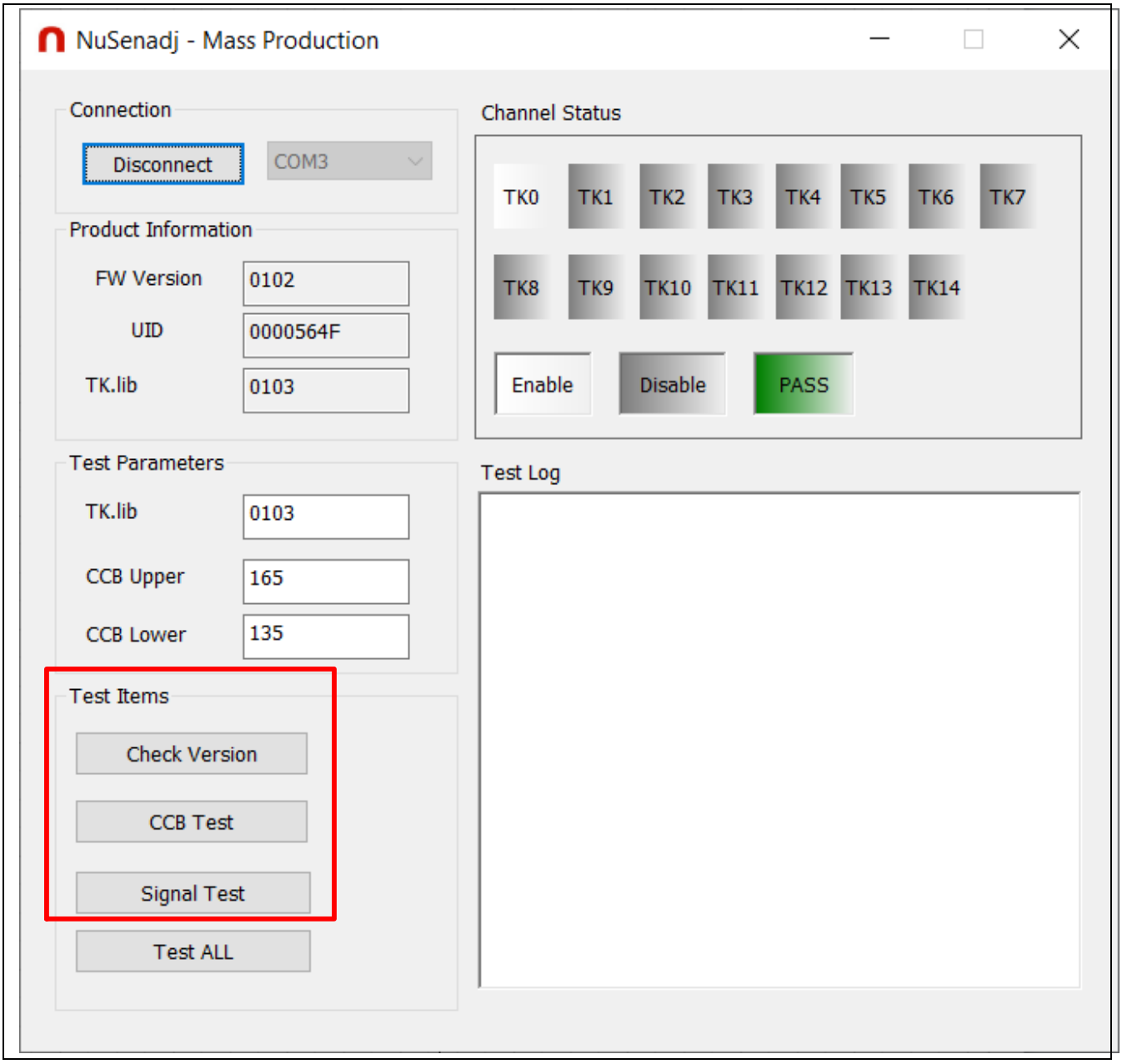


Figure 7-24 Mass Production Test Items

7.8.1 Test Environment Setup

The mass production test process can only be carried out after the assembly of the touch key cover is completed.

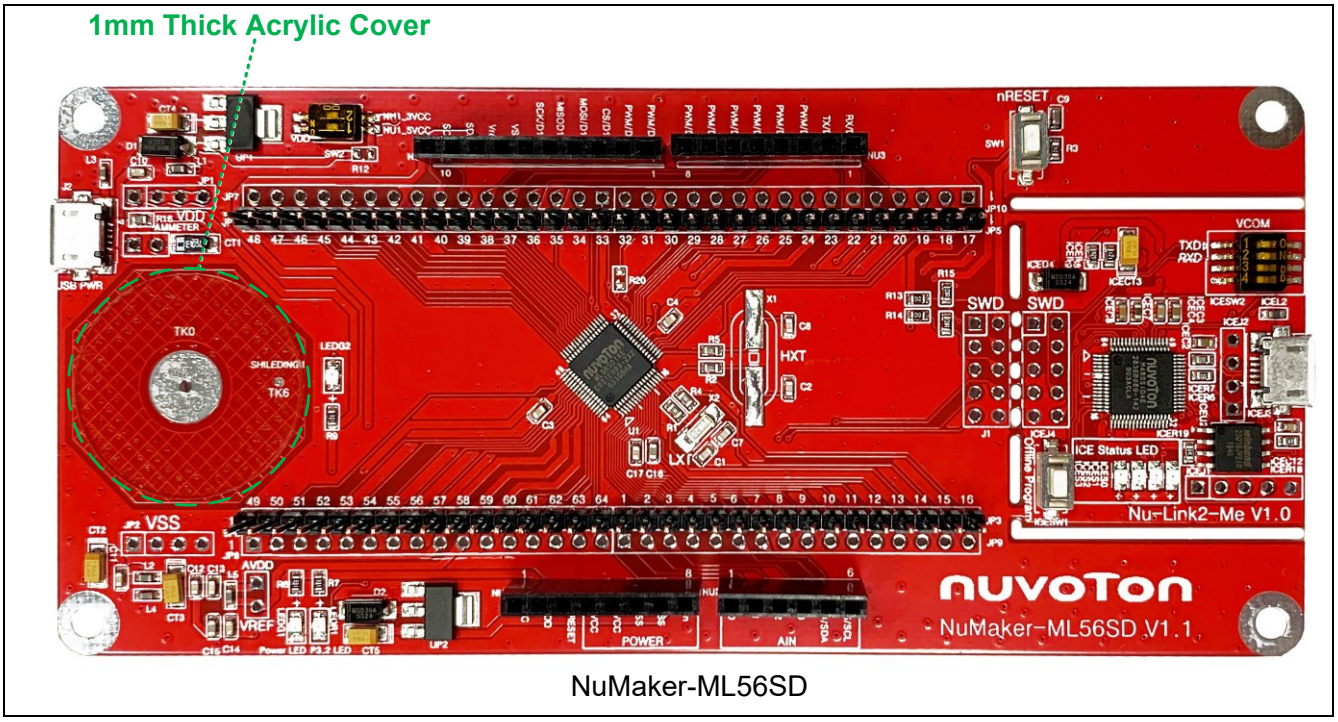


Figure 7-25 Assembly of the Touch Key Cover

Connect PC and the NuMaker-ML56SD through Nu-Link2-Pro or Nu-Link2-Me at first, and run the NuSenadj_MP on PC and then choose the COM Port that connects to NuMaker-ML56SD.

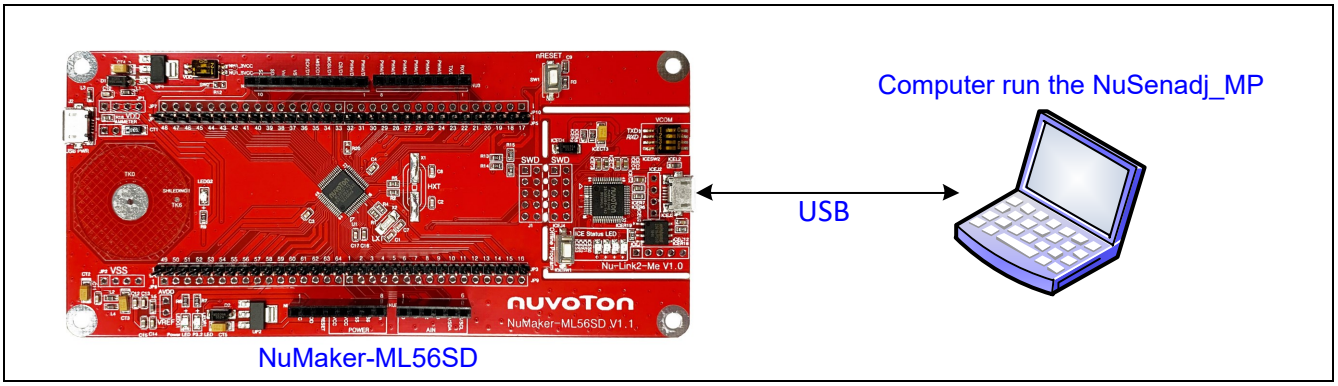


Figure 7-26 Touch Key Mass Production Testing Connection Diagram

7.8.2 Mass Production Test Parameters Setting

- TK.lib

  Confirm the correctness of the touch key library version. Please fill in the touch key library version used by the current product.

- CCB Upper

  The upper limit of the “CCB Test” judgment condition. The value of CCB (Complement Capacitor Bank) will have different values due to different product designs. For the origin of CCB value, please refer to Section 7.4.

- CCB Lower

  The lower limit of the “CCB Test” judgment condition. The value of CCB (Complement Capacitor Bank) will have different values due to different product designs. For the origin of CCB value, please refer to Section 7.4.

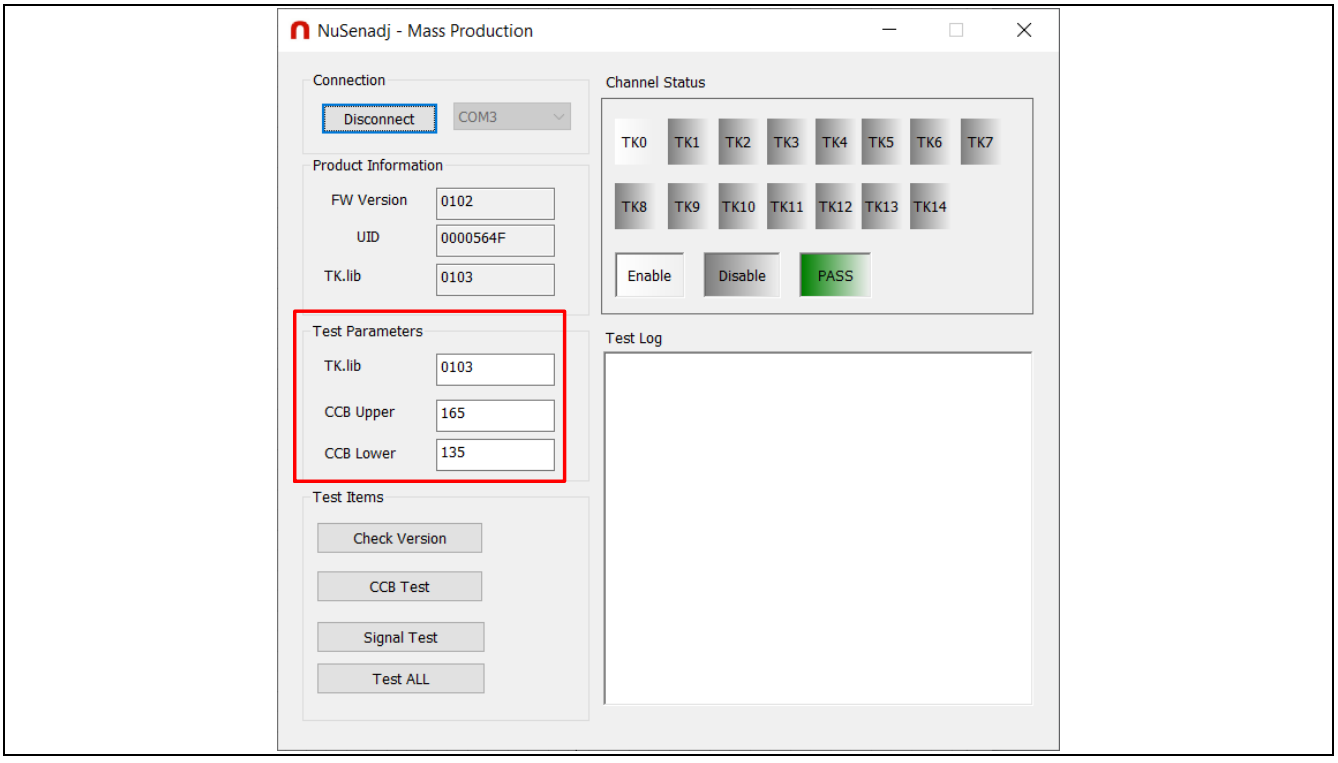


Figure 7-27 Mass Production Test Parameters Setting

7.8.3 Start Mass Production Testing

After test parameters setting, clicking "**Test ALL**" button to start mass production testing flow.

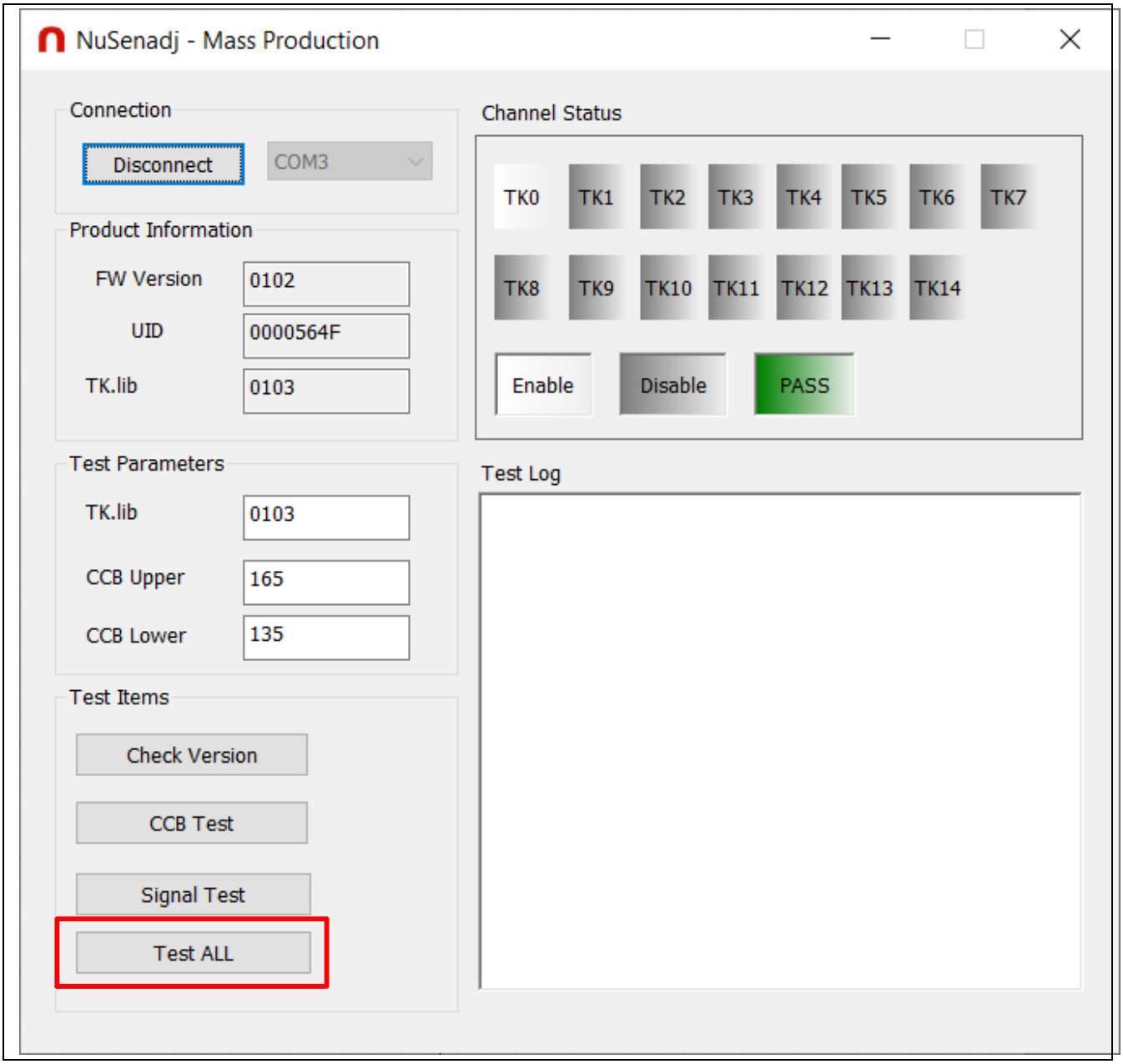


Figure 7-28 Start Mass Production Testing

Mass production test result of good touch keys sample.

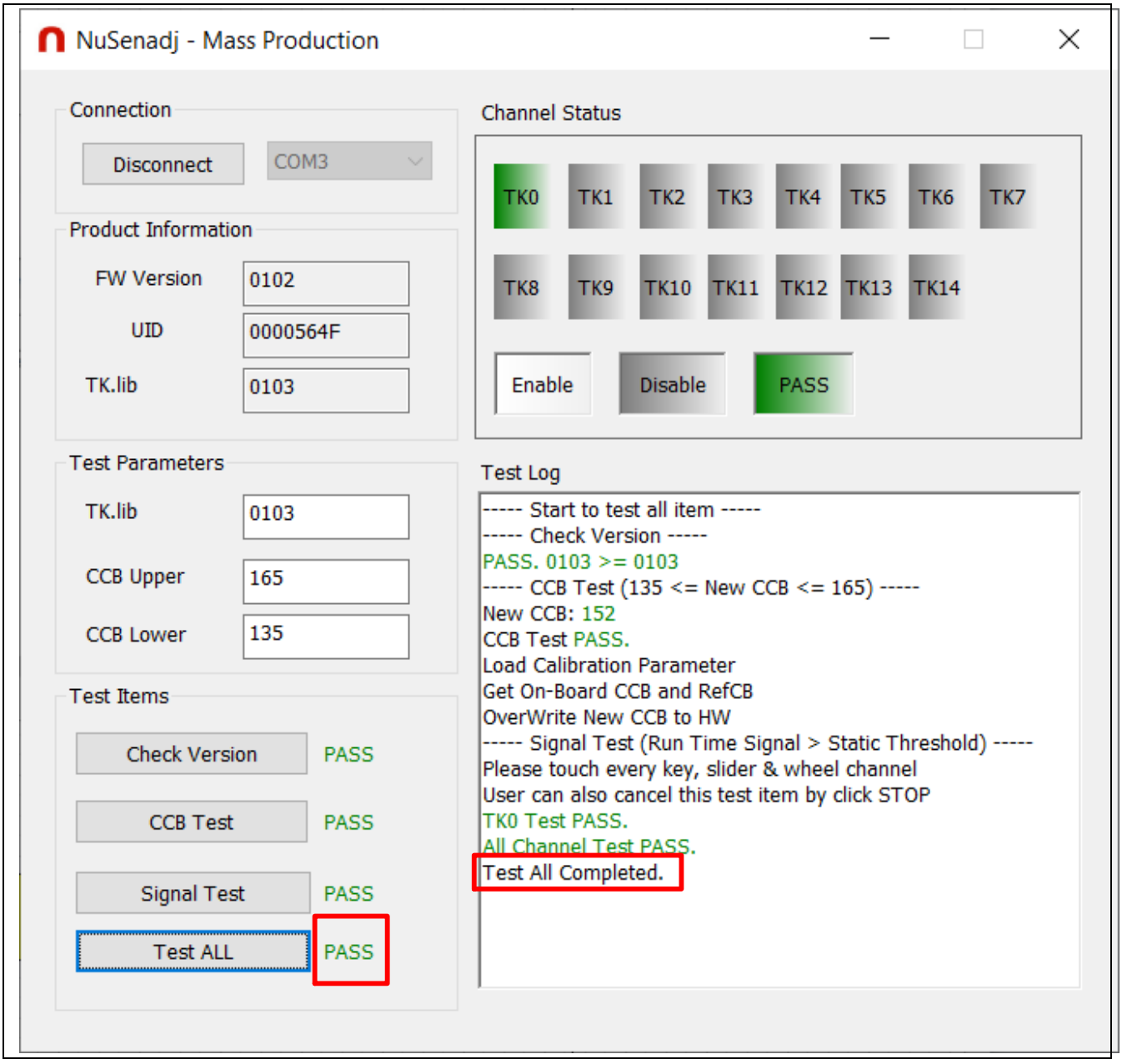


Figure 7-29 Mass Production Test Result

8 Conclusion

The design guide shows how to implement a high performance capacitive touch key sensing system with NuMicro® ML56 series, and provides the following introduction:

- Capacitive touch key fundamentals and sensing method.
- Touch key PCB design guidelines.
- Introduces how to use the touch key library and sample code of touch thermostat.
- Introduction of touch key development and mass production tool.
- Introduces how to develop touch key system.

REVISION HISTORY

Date	Revision	Description
2021. 05. 11	0.01	Initial version
2021. 06. 15	0.02	Modify the mass production test content and the path of the touch key project

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