GigaDevice Semiconductor Inc.

Touch Sensor Application Guidelines

Application Note
AN063

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1. Introduction

Touch Sensing Interface (TSI) provides a convenient solution for touch keys, sliders and capacitive proximity sensing applications. The controller is based on charge transfer method of self-capacitance. Placing a finger near the electrode adds capacitance to the system and TSI is able to measure this capacitance change using charge transfer method.

This application note describes the charge transfer acquisition principle of TSI module and touch sensitivity analysis which guides users to use TSI module to design PCB touch keys.

2. Terminology

Software involved:

Channel: a channel used for signal acquisition.

Group: a set of channel pins and a sampling pin.

Bank: a set of channels that can be collected in parallel.

Measurement: the charge transfer period value at a certain time after starting measurement.

Reference: the reference value of charge transfer in the untouched state. The software can obtain the average value of charge transfer reference by sampling several times.

Delta: the difference between the reference value and the measurement.

Hardware involved:

C_X: parasitic capacitance of sensor electrode.

C_P: parasitic capacitance.

C_T: equivalent touch capacitance.

C_S/$C_{SSHIELD}$: sampling capacitance / sampling capacitance of the shield electrode.The larger the value is the slower the response time is and the higher the sensitivity is.

R_S/$R_{SSHIELD}$: serial resistance / serial resistance of shield electrode is used to absorb coupling noise and interference and enhance ESD protection. The higher the value is the stronger the anti-noise ability is.

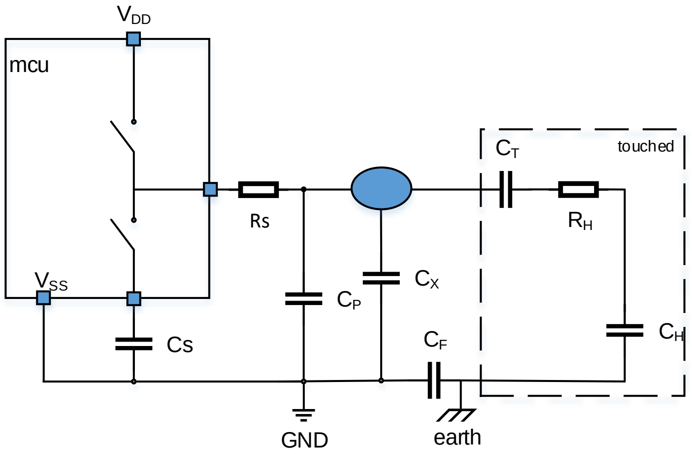
3. Charge transfer acquisition principle

Surface charge transfer acquisition principle is as follows:

1. Charge the sensor electrode C_X.
2. Transfer the accumulated charge on C_X to the sampling capacitor C_S.
3. Repeat steps 1-2 until the voltage V_S on the C_S reaches the threshold voltage V_{th}.
4. Acquisition completed, read the number of charge transfer sequences.

The number of charge transfer sequences indicates the capacitance of the sensor electrode. When the sensor electrode is touched, the capacitance of the sensor electrode to the ground will increase (the maximum charge can be stored will increase, so the number of transfer sequences will decrease). Charge transfer acquisition principle is shown in ***Figure 3-1. Equivalence principle of TSI charge transfer acquisition***.

Figure 3-1. Equivalence principle of TSI charge transfer acquisition



The equivalent measuring capacitance C_M is shown below:

$$C_M=\frac{1}{\frac{1}{C_T}+\frac{1}{C_H}+\frac{1}{C_F}}+C_P+C_X$$

Where:

C_S: sampling capacitor

C_X: parasitic capacitance of sensor electrode

C_T: coupling capacitance between human body and sensor electrode

C_P: parasitic capacitance

C_F: feedback capacitance between earth and application ground

R_S: serial resistance

R_H: equivalent resistance of human body model

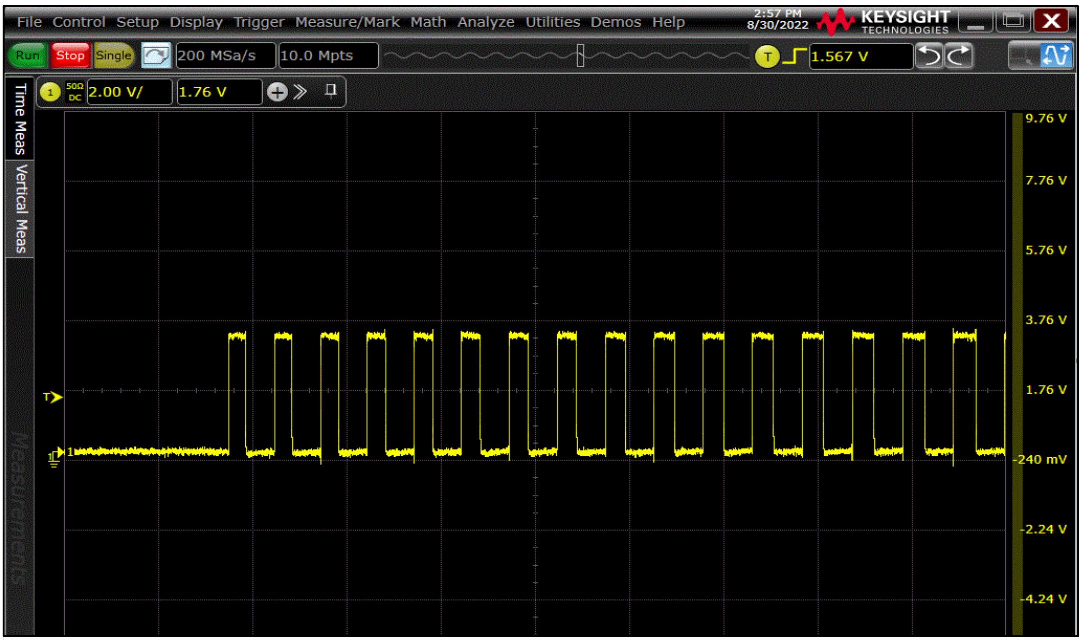
C_H: equivalent capacitance of human body model

Note: Since C_T is much smaller than C_F and C_H， so C_T, C_H and C_F in serial is approximately equal to C_T, than is $C_T \approx C_T+C_H+C_F$.

To ensure that charge transfer can be carried out correctly, it is necessary to ensure that the waveform on the C_X pin is a complete charge and discharge process. After charging, ensure that the C_X voltage is V_{DD}. Increasing the charge and discharge time can effectively ensure the integrity of the process, but it will increase the response time of the system, so it is necessary to monitor the C_X pin waveform through oscilloscope, and adjust the charge and discharge time by software to find a balance that meets the application of the system. The complete waveform of charge and discharge is shown in ***Figure 3-2. Channel pin charge transfer waveform*** and ***Figure 3-3. Channel pin charge transfer waveform in transfer period***.

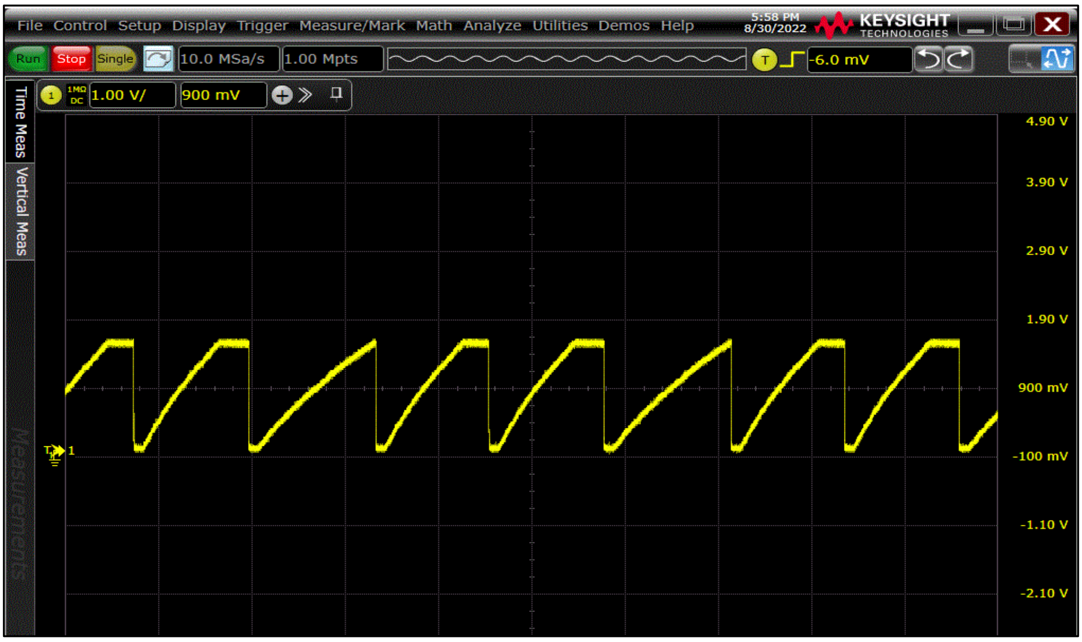
Figure 3-2. Channel pin charge transfer waveform

Figure 3-3. Channel pin charge transfer waveform in transfer period



By measuring the voltage on the C_S pin, the time of the sequence transfer completed and the threshold voltage V_{th} can be obtained, as shown in ***Figure 3-4. Waveform on the sample pin***.

Figure 3-4. Waveform on the sample pin



4. TouchKey design

The TouchKey has only two states: touched and released, which belong to the simplest touch sensor. When designing TouchKeys, the following factors should be considered to improve the robustness of TouchKeys.

1) The shape of the sensor electrode can be customized, it is recommended to use round or oval shape (just as the shape of the finger belly).
2) Recommended to use sensor electrodes of the same size and shape, which can reduce the difference between electrodes and facilitate the difference compensation at the software end.
3) The surface size of the sensor electrode should be consistent with the touch range (such as finger belly size, a rectangle with side length of 12mm or a circle with diameter of 12mm is recommended), otherwise the touch sensitivity will be reduced.
4) The size of the sensor electrode should be at least 4 times the thickness of the touch panel (such as the thickness of the touch panel is 2mm, the width of the sensor electrode shall be at least 8mm).

According to the capacitance formula of plate capacitor, $C_T = \frac{S\varepsilon_r}{4\pi kd}$. Where, S represents the size of the overlap between the sensor electrode area and the touch area of the finger; d represents the distance between the sensor electrode and the conduction object (generally for the thickness of the panel); ε_r represents relative permittivity; k is the electrostatic constant.

Note: Increasing the electrode size of the sensor can increase the equivalent parasitic capacitance of the electrode. However, when the electrode size exceeds the area touched by the finger, the capacitance of C_X will only increase, while the capacitance of C_T will not increase, which will decrease the sensitivity. If the C_X capacitor is too large, the time required by the electrode to complete the charge and discharge will increase, resulting in slow system response time and increased power consumption.

The sensor electrode is generally placed on the PCB board in solid fill mode, as shown in ***Figure 4-1. Solid fill mode of TouchKey electrode***. You can also use mesh fill mode, as shown in ***Figure 4-2. Mesh fill mode of TouchKey electrode***. When mesh fill mode is used, the parasitic capacitance of sensor electrode can be reduced. In this case, the problem of decreased touch sensitivity caused by the drop of touch area can be effectively solved.

Figure 4-1. Solid fill mode of TouchKey electrode

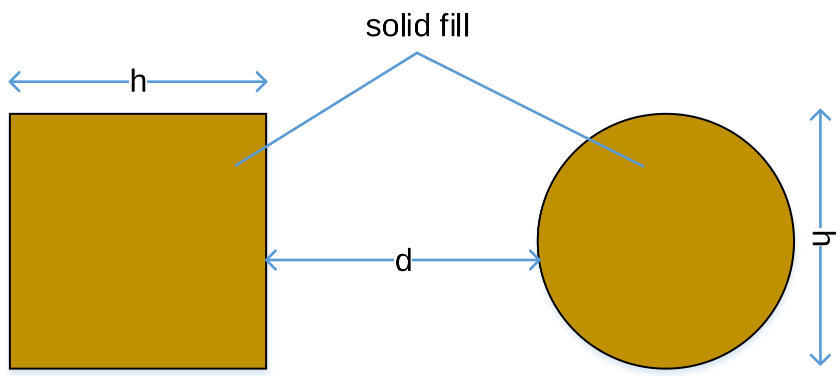
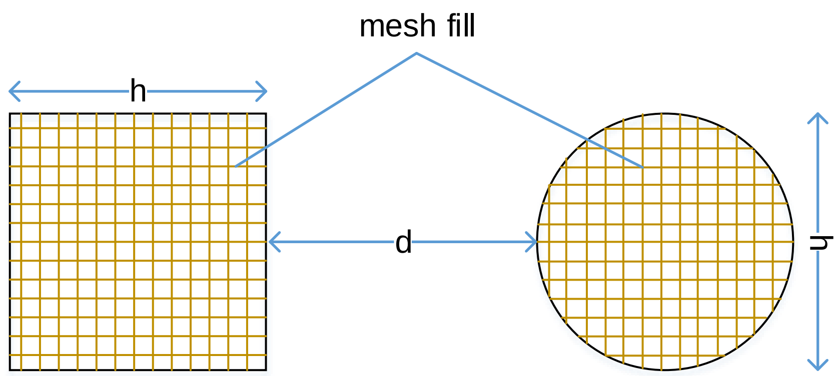


Figure 4-2. Mesh fill mode of TouchKey electrode



The design requirements of the TouchKey layout on the PCB should be follow the ***Table 4-1. Layout requirements for TouchKeys***. Where h represents the size of touch keys, d represents the distance between touch keys, and t represents the thickness of touch panel.

Table 4-1. Layout requirements for TouchKeys

parameter	minimum value	recommended value	maximum value
h(height)	7mm	12mm	15mm
d(distance)	2mm	4mm	-
t(thickness)	1mm	2mm	3mm

5. Sensitivity analysis

Generally, non-conductive material is added on the sensor electrodes as a touch panel, but the using of the touch panel will reduce the sensitivity of touch sensing. In the design, users need to pay attention to the following aspects to improve the sensitivity of the system.

1) Reduce the air gap between the touch panel and sensor electrodes.
2) Reduce the thickness of the touch panel. The thickness of the panel will affect the the C_T capacitance, and the thicker the panel, the stronger the diffusion of the electric field will be, and the greater the coupling on the adjacent sensor electrodes.
3) Choose a material with a high dielectric constant as the touch panel (such as plexiglass).
4) The ground plane should not be too close to the sensor electrode and shield electrode, otherwise large parasitic capacitance will be brought in.
5) Avoid metal materials around sensor electrodes and shield electrodes.
6) Ensure the effective fit between the touch panel and the sensor electrodes;
7) In special occasions, touch springs can be used instead of sensor electrodes;
8) On the basis of satisfying the complete charge and discharge, reduce the charge and discharge time。

The dielectric constants of several common materials such as ***Table 5-1. Relative dielectric constants of common materials***.

Table 5-1. Relative dielectric constants of common materials

materials	ε_R
Air	1.000585
Glass	4-10
Mica	6-8
Nylon	3.0
Plexiglas	3.4
PVC	4.0
PE	2.3-3.4
PS	2.4-2.7
FR4	4.2-4.7
PMMA	2.6-4

6. PCB design

6.1. Layout design

The quality of the PCB layout will directly affect the robustness and reliability of the touch sensing system. The following aspects should be paid attention to in the PCB layout design.

1) The length of the channel trace should be as short as possible (within 15cm).
2) The width of the channel trace should be as thin as possible (6-8mil).
3) The angle of the channel trace should be greater than 90 degrees.
4) The distance between the channel trace and the ground or other traces should be at least 1mm.
5) The traces space of channels in the same bank should be at least twice the trace width, and the trace space between different banks should be at least 2mm.
6) The distance between sensor electrodes should be at least twice the thickness of the panel to reduce the coupling between adjacent sensor electrodes and prevent false triggering. For high-density PCB boards, sensor electrode size, distribution, and panel thickness need to be balanced to meet design requirements.
7) Channel trace and the high-frequency signal trace should be crossed to reduce crosstalk.
8) Two-layer board is recommended to be filled with mesh ground (25%-40%) on both sides, the sensor and ground are placed on the same side, and the devices and traces are placed on the other side.
9) C_S and R_S are as close as possible to the MCU pins to enhance ESD protection and improve anti-interference.
10) Passive shield or active shield should be used to improve the noise immunity and sensitivity of the system.

The width and length of the channel trace affect the parasitic capacitance of the trace. The wider and longer of the trace (equivalent area S is larger) is the larger the parasitic capacitance is. In addition, long traces tend to introduce coupled noise. Sensor electrodes should be placed as close as possible to the MCU and symmetrically distributed to balance the effects of parasitic capacitance.

Note: Polygon plane will increase C_X, which decreases the sensitivity (reduced C_T/C_X). To balance noise immunity and sensitivity, mesh copper can be used instead of solid copper.

6.2. Shield design

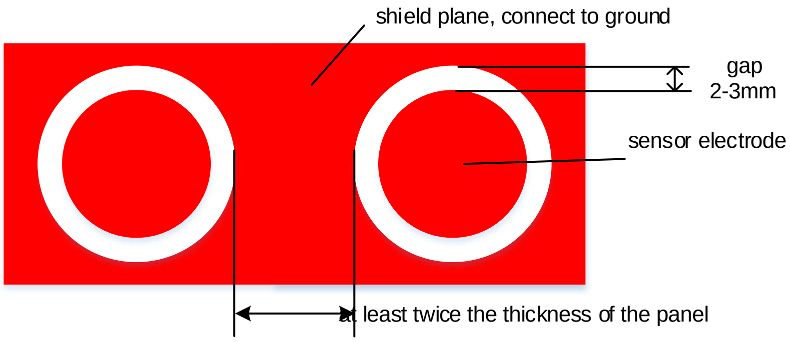
In order to reduce EMI interference and false triggering caused by false touches on the channel traces, it can be improved by designing shield. It includes passive shield and active shield, as shown in ***Figure 6-1. Passive shield design*** and ***Figure 6-2. Active shield design***.

Passive shield:

1) Connect the shield electrode to a DC level (usually a single point ground).
2) The backside of the sensor electrode can be covered with copper to reduce EMI interference and false touches on the backside, and the use of mesh copper can reduce the capacitive load (~50%). If the risk does not exist on the back, this area can be cutout to reduce C_X.
3) Coplanar layer with sensor electrodes require copper (solid / mesh) to isolate sensor electrodes and reduce EMI.
4) Copper plating will reduce the tolerance of the moisture.

The shield electrode increases the parasitic capacitance C_X of the sensor electrode, which makes the response time lag; and because the electric field of the sensor electrode is absorbed by the ground, the sensitivity is reduced. When the gap between the sensor electrode and the shield plane decreases, the increase of the sensor electrode parasitic capacitance C_X will lead to an increase in the RC time constant; when the gap between the sensor electrode and the shield plane increases (the impedance path to ground becomes longer), then noise tolerance is reduced and, in addition, moisture tolerance is improved due to longer bridging distances between sensor electrodes and shield planes.

Figure 6-1. Passive shield design

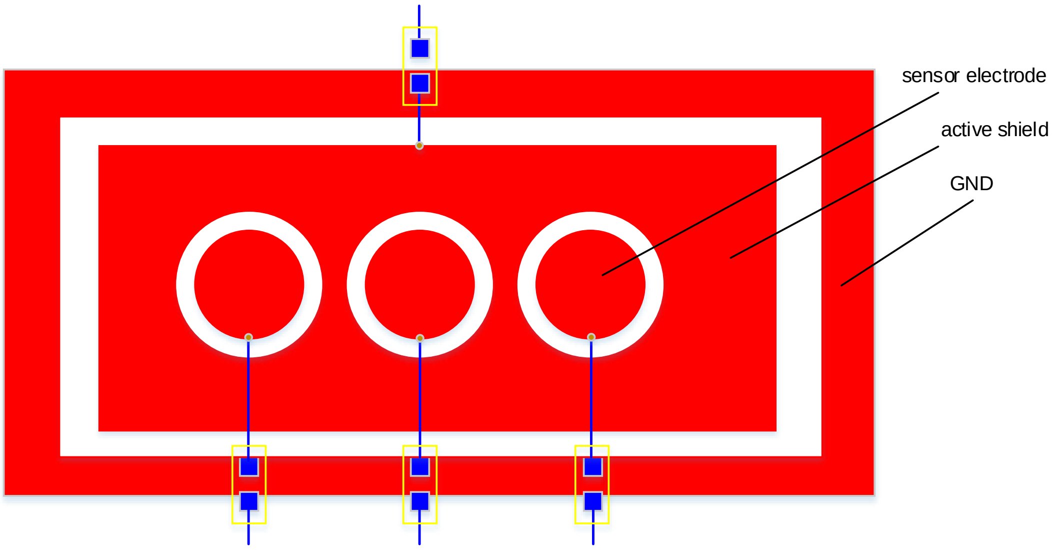


Active shield:

1) Connect the shield electrode to the channel pin, and this channel pin does not share a group with other channels.
2) Reduce the load capacitance between the sensor electrode and the adjacent electrode (since the sensor electrode and the shield electrode are charged and discharged at the same time, the charging and discharging time of the parasitic capacitance is offset, and the sensitivity of the system can be improved).
3) Improve water film / moisture tolerance.

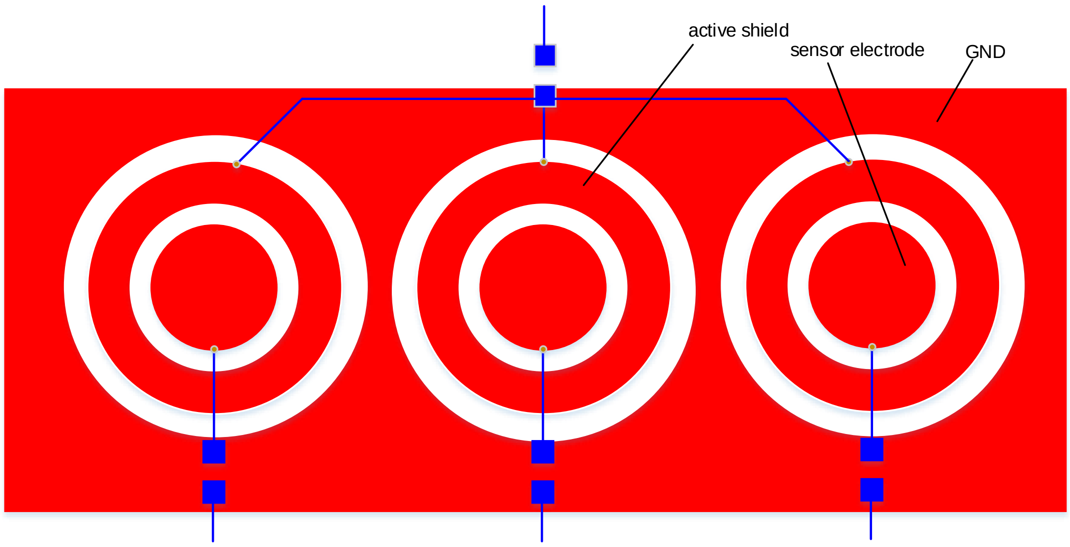
Note: When using active shield, the shield electrode needs to be driven with the same signal as the sensor electrode.

Figure 6-2. Active shield design



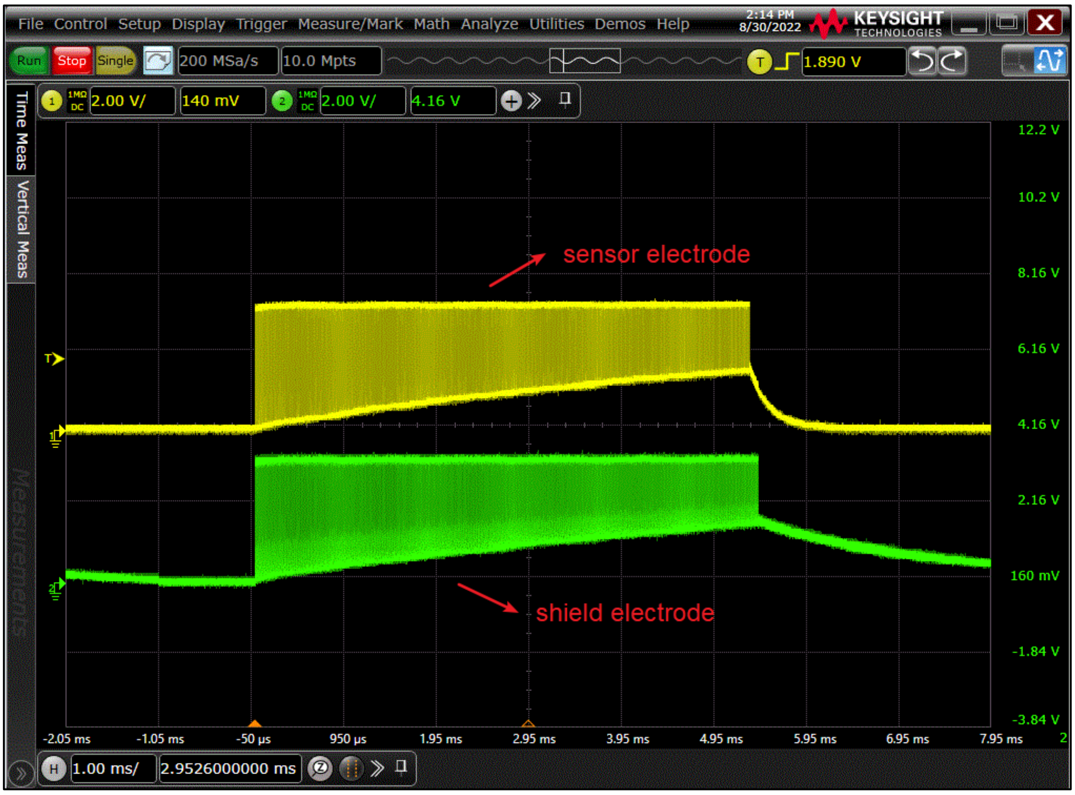
The use of active shield may cause excessive RF interference (fast charge and discharge of large-area shield electrodes), so in special occasions, it is necessary to reduce the area of active shield to reduce RF interference, as shown in ***Figure 6-3. Reduce active shield area***. Power consumption can be effectively reduced by increasing the serial resistance on the shield electrode.

Figure 6-3. Reduce active shield area



When using active shield, it is necessary to adjust $C_{SSHIELD}$ and $R_{SSHIELD}$ so that the charging and discharging process of the sensor electrode is consistent with the charging and discharging process of the shield electrode, as shown in ***Figure 6-4. Waveforms with active shield***.

Figure 6-4. Waveforms with active shield



7. Revision history

Table 7-1. Revision history

Revision No.	Description	Date
1.0	Initial Release	Dec.16, 2022