TI Designs
High Temperature Touch Through Glass Reference Design

Design Overview

The human machine interface (HMI) is an essential part of process plants because it is one of the major ways through which humans and machines interact. The TIDA-00464 reference design offers an HMI solution for harsh and hazardous area applications. In process plants, operators are required to interact with explosion-proof displays or controllers, which are housed in screw-on metallic enclosures with thick glass windows to display local readout and programming functions.
The TIDA-00464 TI Design, which uses the capacitive sensing technology integrated in the FDC2214, allows the operator to interact with a controller without requiring them to open the enclosure, which saves time by avoiding a work permit or plant shutdown.

Design Resources

TIDA-00464	Design Folder
FDC2214	Product Folder
FDC2214EVM	Tool Folder

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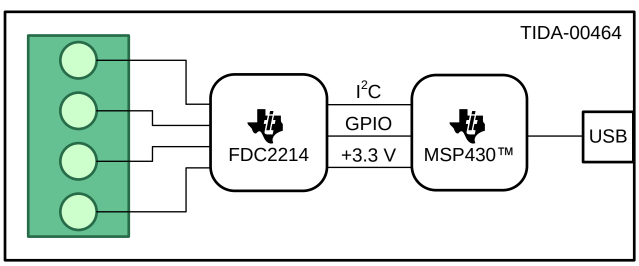
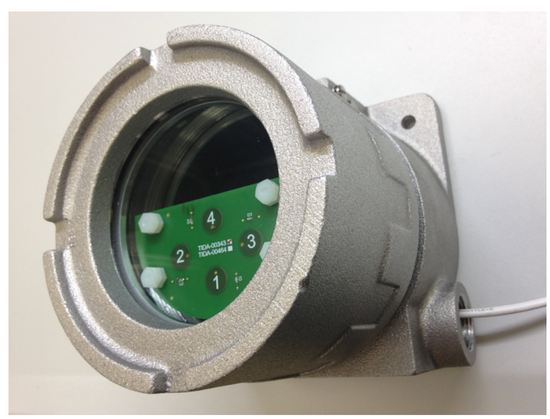
Design Features

- Single and Multistep Button Press
- Four Robust Buttons Option Implemented
- Variable Air Gap Between Buttons and Glass (1 mm to 2 mm)
- Touch Detection Through 10-mm Thick Glass
- Work With Gloves and in Harsh Environment (Water, Oil, Dust, and So Forth)
- Temperature Range: –40°C to 125°C

Featured Applications

- HMI
- Process Control
- Field Transmitters
- Field Actuators





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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Glass thickness	9.5 mm	See Section 3.2
Glass diameter	80 mm	See Section 3.2
Air gap	1 mm to 2 mm	See Section 3.3
Number of buttons	Four	See Section 3.3
Work with gloves	—	See Section 8.2
Harsh environment resistant	—	See Section 8
SNR	—	See Section 8
Crosstalk	—	See Section 8
Temperature range	–40°C to 125°C	—

2 System Description

The TIDA-00464 design combines a button board with the FDC2214EVM, which processes the inputs given by an operator.

The complete system offers an HMI solution for harsh or difficult hazardous area applications in process plants that require operators to interact with an explosion-proof display or controller. Displays and controllers are housed in screw-on metallic enclosures with thick glass windows to display local readout and programming functions.

The FDC2214 device allows the operator to interact with the controller without requiring them to open the enclosure, which saves time by avoiding a work permit or plant shutdown.

The FDC2214 device also provides high-resolution capacitive-touch sensing, which allows plant operators to touch buttons through the thick glass window while offering high reliability and noise immunity at the lowest power (see Figure 1).

Figure 1. Touch Through-Glass Application

3 System Design Theory

This section focuses on the design theory of the electrode board. For more information on the FDC2214EVM, consult the following *FDC2114 and FDC2214 EVM User's Guide* (SNOU138).

3.1 Mechanical Design

Designing the electrode board requires attention to a few key mechanical details. Note that the board is to be housed in a screw-on metallic enclosure (see Section 3.2), which can be removed by unscrewing the unit. To prevent any interference with the electronics when the user removes the enclosure, the electrode board must not be in direct contact with the glass window. The distance between the window glass and the electrode board can vary depending on the application.

The typical placement of the electrode board is in the lower part of the glass window to leave space for a liquid-crystal display (LCD) on the upper part of the glass window for a local readout of the sensor parameters.

3.2 Explosion-Proof Enclosure

The TIDA-00464 design uses an explosion-proof enclosure made of stainless steel with a 9.5-mm thick glass window. Figure 2 shows the mechanical specifications of this enclosure.

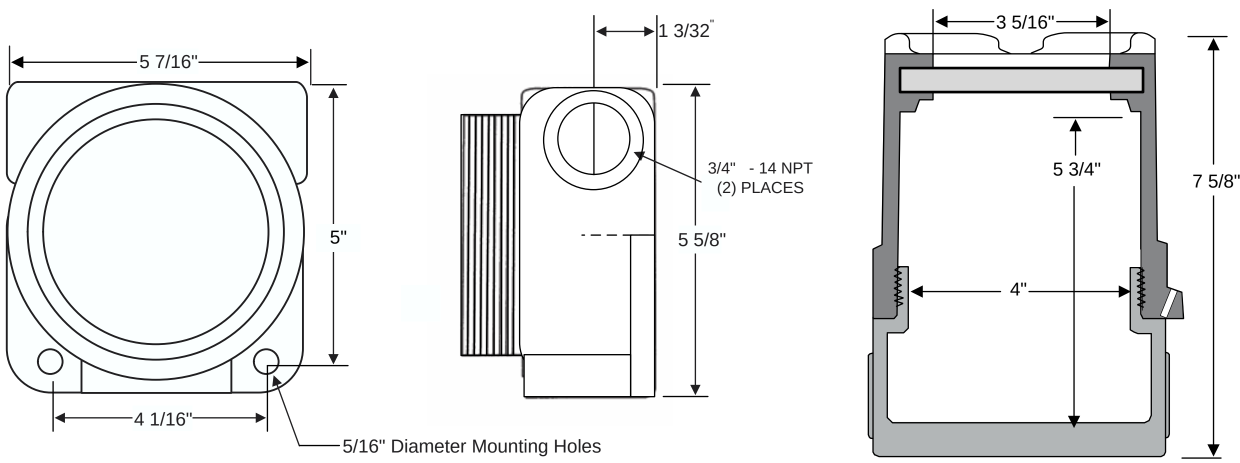

Figure 2. Explosion-Proof Enclosure (XIHLDGCX From Adalet)

The enclosure is big enough to contain the electronics and has a hole on the bottom side that allows the user to wire the USB cable, which is used to connect to the PC and acquire data from the sensors.

The enclosure must be grounded. If the enclosure is floating, a touch on it may couple together all of the buttons and cause a false detection.

However, the buttons closer to the enclosure or any conductive surface that is tied at a fixed potential are less sensitive than the other buttons because the grounded enclosure pulls in the electric field, which limits the field above the glass in the desired area of interaction.

3.3 Electrode Design

The diameter and shape of the electrodes are defined by a tradeoff between obtaining the maximum sensitivity (Equation 1) and the mechanical constraints of the application (see Figure 3).

$$C = \epsilon_r \times \epsilon_0 \times \frac{A}{d} \qquad (1)$$

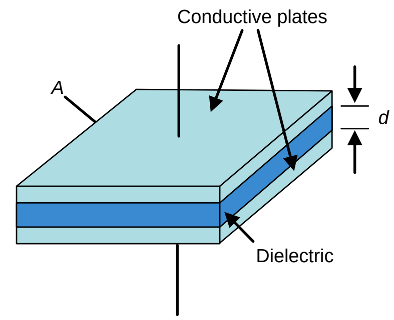

Figure 3. Parallel Plate Capacitor

The area of the button must be as big as possible or at least the same size of the average finger press for a higher sensitivity. The button diameter of the TIDA-00464 is equal to 10 mm, which is a bit smaller than the average finger press of an operator and is limited by the mechanical constraints of the application.

This application typically requires the use of a glass window with a diameter that spans from 4 cm up to 12 cm and contains three to six buttons, which are placed behind the glass on the lower section. In this setup, the space for each button is approximately 1 cm to 2 cm without accounting for the minimum distance required between the buttons, which is fundamental to avoiding crosstalk, and the space occupied by the microcontroller (MCU), light-emitting diode (LED), and passives in the printed circuit board (PCB).

A medium-sized enclosure has an 8-cm glass window diameter and a four-button application. To account for the application requirements of this design, the TIDA-00464 has four buttons with 10-mm diameters.

Section 3.1 explains the importance of placing the buttons a certain distance from the metallic enclosure. Additionally, the buttons must be placed as far as possible from each other to avoid crosstalk, which increases as the air gap between the glass and buttons increase. Note that the dielectric of this application is not negligible (see Figure 4).

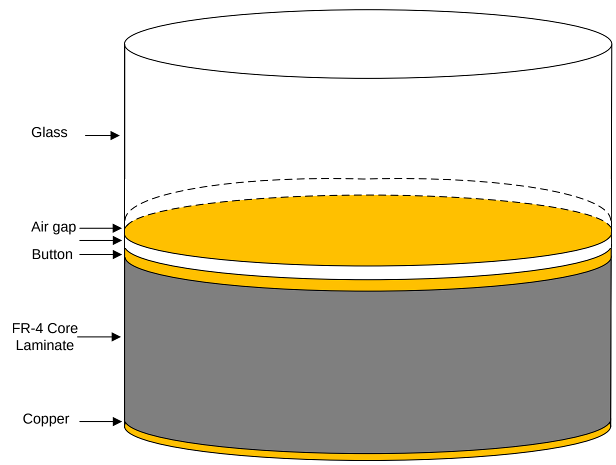

Figure 4. Application Stackup

Every 1 mm of air gap is equivalent to 7 mm to 8 mm of glass (see Table 2). So with a glass thickness of 10 mm, the actual stackup consists of approximately 25 mm to 30 mm of glass. This ratio of material affects the sensitivity of the buttons, too.

Table 2. Dielectric Material

MATERIAL	DIELECTRIC CONSTANT (Er)
Air	1.0
FR-4	4.8
Glass	7.6 to 8.0
Gorilla and regular glass	7.2 to 7.6
Polycarbonate	2.9 to 3.0
Acrylic	2.8
ABS	2.4 to 4.1

Figure 5 shows the configuration of the buttons.

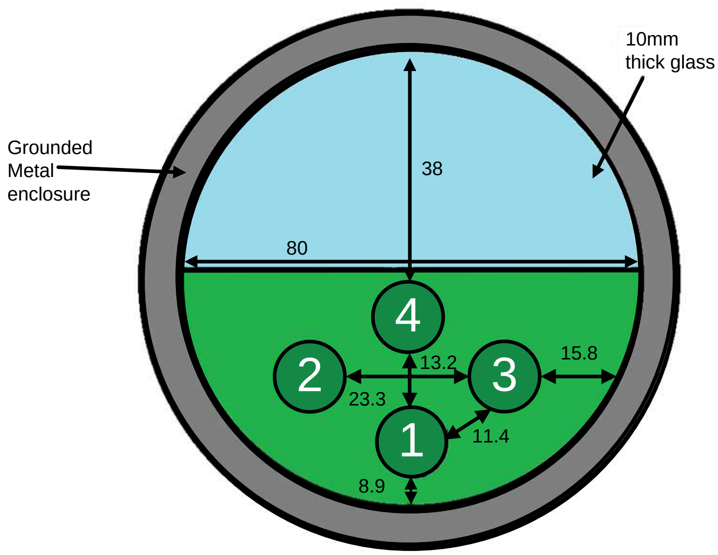

Figure 5. Button Configuration

This configuration allows the user to test how the crosstalk varies among the buttons and how the metal enclosure influences the different buttons.

The TIDA-00464 design utilizes buttons known as self-capacitance buttons.

3.4 Self-Capacitive Buttons

A self-capacitive button sensor is a single electrode. Self-capacitive buttons are simple to lay out and each button is assigned to only one pin on the MCU (see Figure 6). Self-capacitive buttons provide greater sensitivity as compared to a mutual capacitive button, but are more influenced by parasitic capacitances to ground.

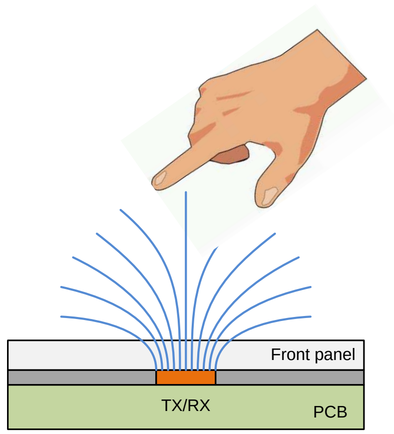

Figure 6. Example Diagram—Self-Capacitive Button Design

Table 3 shows the basic specifications of self-capacitive buttons.

Table 3. Self-Capacitive Button Properties

PARAMETER	GUIDANCE
Radiation pattern	Between electrode and ground
Size	Equivalent to interaction
Shape	Various: typically round or square
Spacing	0.5 × overlay minimum thickness

3.4.1 Self-Capacitive Button Shapes

The electrode shape is typically rectangular or round with common sizes of 10 mm and 12 mm. Ultimately, the size depends on the required touch area. A good design practice is to keep the size of the button as small as possible, which minimizes the capacitance and helps with the following:

- Reduce susceptibility to noise
- Improve sensitivity
- Lower power operation as a result of smaller capacitance and reduced electrode scan time

Figure 7 shows an example of a silkscreen-button outline pattern.

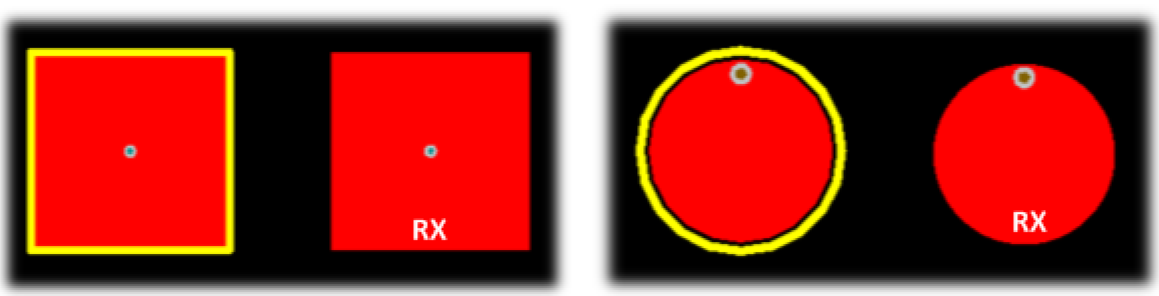

Figure 7. Silkscreen-Button Outline Pattern

The goal of the button area is to provide a sufficient signal when the user touches the overlay above the button electrode. Typically, a nonconductive decal or ink is used to identify the touch area above the electrode. The relationship between the decal and the electrode can be varied so that contact with the outer edge of the decal registers a touch. Conversely, the electrode can also be small to ensure that the button only activates after touching the center of the decal. The following Figure 8 and Figure 9 show how the effective touch area is a function of the electrode size and the size of the finger making contact.

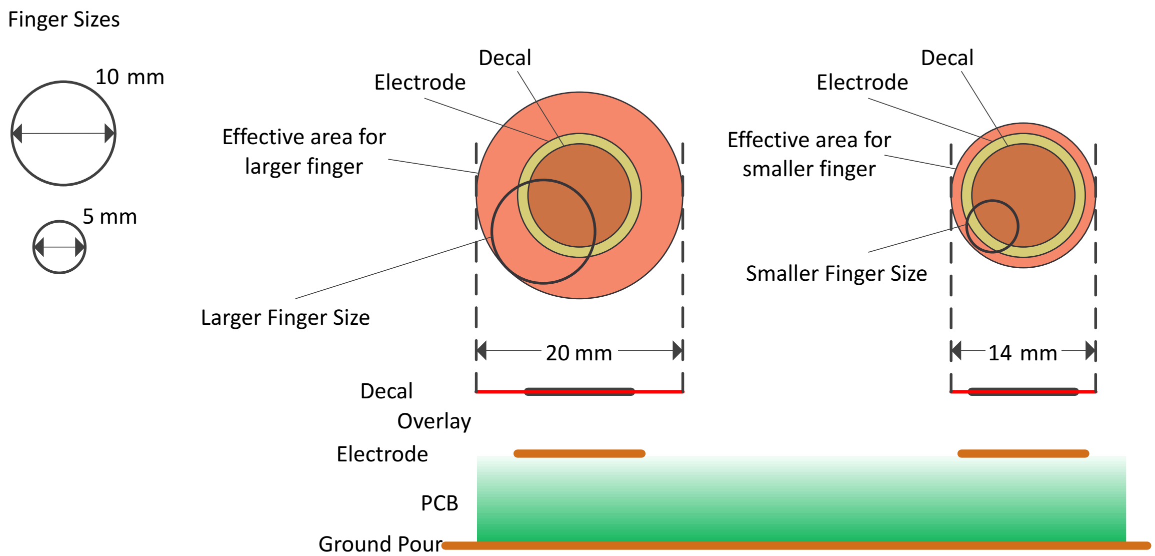

Figure 8. Effective Area Example for Electrodes Larger Than Decal

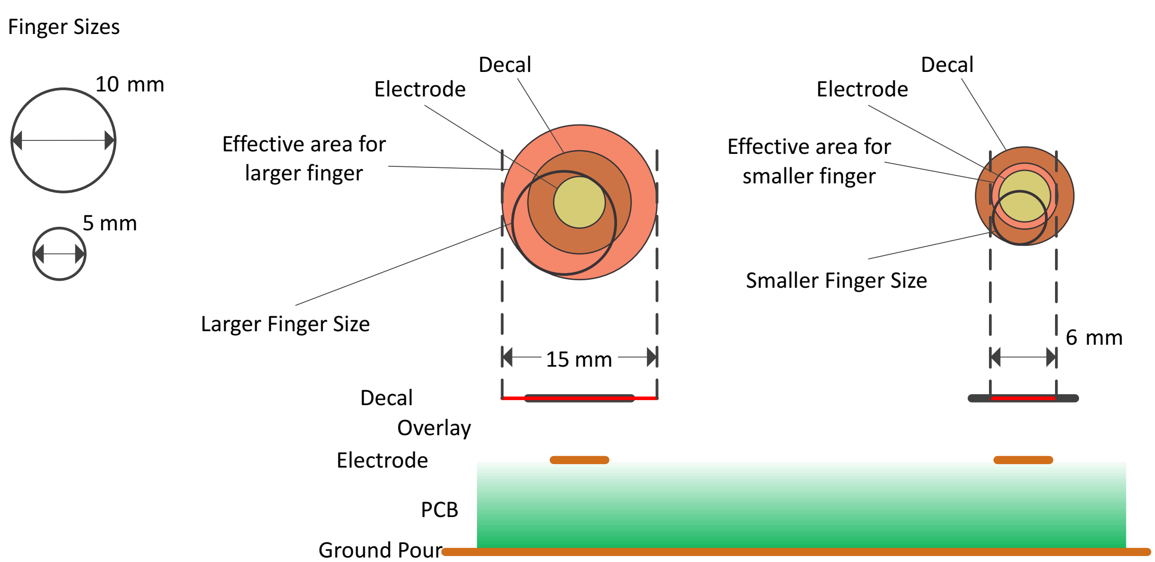

Figure 9. Effective Area Example for Electrode Smaller Than Decal

One common mistake is to make the electrode the same shape as the icons printed (in nonconductive ink) on the overlay. As Figure 10 shows, this action can lead to electrodes with odd shapes that create discontinuities and reduce surface area.

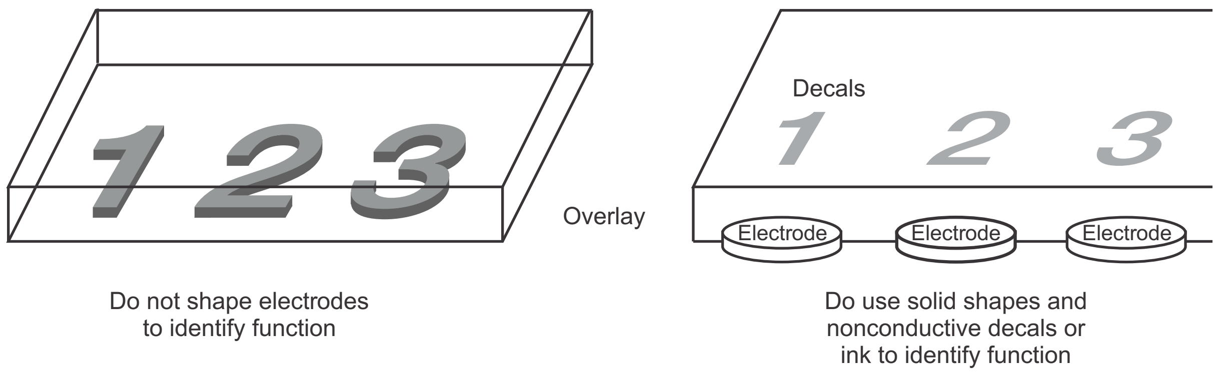

Figure 10. Button Shape Examples—Dos and Don'ts

As the distance of the overlay increases, the effective area decreases; therefore, it is important to keep the button electrode diameter at least three times the laminate thickness.

4 Block Diagram

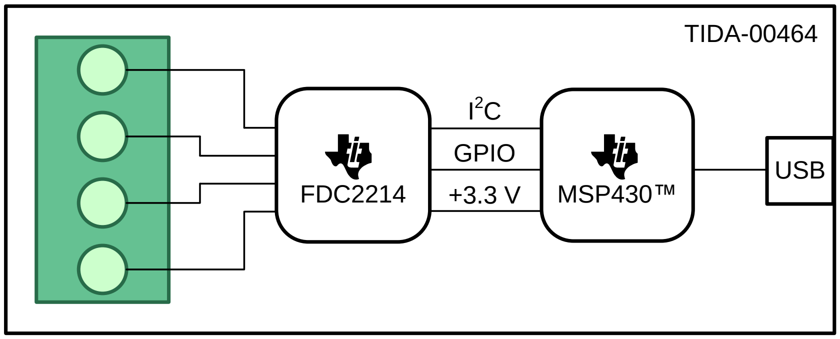

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Figure 11. TIDA-00464 Block Diagram

4.1 Highlighted Products

The key part of the TIDA-00464 system design is the FDC2214, which allows capacitive sensing by pressing a button. The touch of this button registers, even through layers, such as a screen of thick glass.

4.1.1 FDC2214

Features:

- EMI-resistant architecture
- Maximum output rates (one active channel):
  - 13.3 ksps (FDC2112, FDC2114)
  - 4.08 ksps (FDC2212, FDC2214)
- Maximum input capacitance: 250 nF (at 10 kHz with 1 mH inductor)
- Sensor excitation frequency: 10 kHz to 10 MHz
- Number of channels: 2, 4
- Resolution: up to 28 bits
- System noise floor: 0.3 fF at 100 sps
- Supply voltage: 2.7 V to 3.6 V
- Power consumption: Active: 2.1 mA
- Low-power sleep mode: 35 uA
- Shutdown: 200 nA
- Interface: I^2C
- Temperature range: -40 ° C to +125 ° C

Applications:

- Proximity sensor
- Gesture recognition
- Level sensor for liquids, including conductive ones such as detergent, soap, and ink
- Collision avoidance
- Rain, fog, ice, and snow sensor
- Automotive door and kick sensors
- Material size detection

Description:

Capacitive sensing is a low-power, low-cost, high-resolution contactless sensing technique that can be applied to a variety of applications ranging from proximity detection and gesture recognition to remote liquid level sensing. The sensor in a capacitive sensing system is any metal or conductor, allowing for low cost and highly flexible system design.

The main challenge limiting sensitivity in capacitive sensing applications is noise susceptibility of the sensors. With the FDC2x1x innovative electromagnetic interference (EMI) resistant architecture, performance can be maintained even in presence of high-noise environments.

The FDC2x1x is a multi-channel family of noise and EMI-resistant high-resolution, high-speed capacitance-to-digital converters for implementing capacitive sensing solutions. The devices employ an innovative narrow-band based architecture to offer high rejection of noise and interferers while providing high resolution at high speed. The devices support a wide excitation frequency range, offering flexibility in system design. A wide frequency range is especially useful for reliable sensing of conductive liquids such as detergent, soap, and ink.

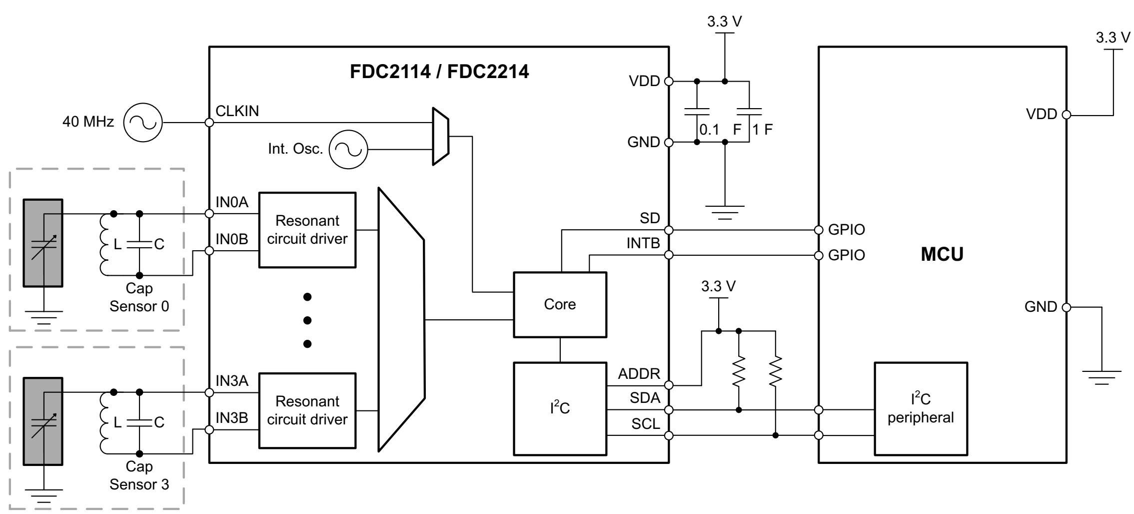

Figure 12. FDC2114 Simplified Schematic

5 Getting Started Hardware

Implement the following steps to set up the hardware:

1. Connect the two example PCB sensors from the FDC2214EVM. For more information about the FDC2214EVM, visit the tool folder at: www.ti.com/tool/fdc2214evm.
2. Connect the electrode board to the FDC2214EVM through wires. A helpful tip is to solder the connectors in the four input channels of the FDC2214EVM. The following Table 4 shows the corresponding connections:

Table 4. Electrode Board to FDC2214EVM Connections

CONNECTOR ELECTRODE BOARD (J1)	CONNECTOR FDC2214EVM (J10)
B1	CH0
B2	CH1
B3	CH2
B4	CH3
L1	NC
L2	NC
L3	NC
L4	NC
GND	GND
GND	Enclosure

3. Use plastic spacers to elevate the board from the floor up to the glass. The length of the spacers depends on the used enclosure.
4. Use screws, nuts, spacers, or bumpers to establish a defined air gap between the glass window and the board.
5. Place the board inside the enclosure with the electrode board facing the glass window, as Figure 13 shows.
6. Connect the FDC2214EVM to the PC through a micro-USB cable.

6 Getting Started Firmware

Follow these steps to get started with the firmware. For more information, refer to the *FDC2114 and FDC2214 EVM User's Guide* (SNOU138):

1. Download the Sensing Solutions EVM GUI Tool v1.8.8.
2. Start the *SensingSolutions GUI*.

7 Test Setup

The electrode board and the FDC2214EVM must be connected as outlined in Section 5 and then contained in an explosive-proof enclosure. A USB wire is the only object that is allowed to protrude from the enclosure and this USB must be connected to a laptop, which uses the Sensing Solutions EVM GUI Tool v1.8.8 to acquire the sensor data. Figure 13 shows an image of the final test setup.

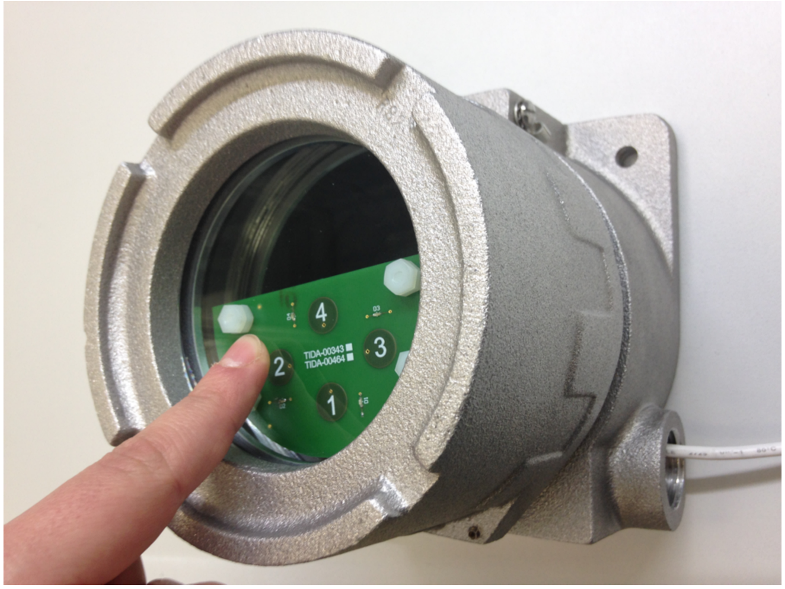

Figure 13. Test Setup

Adjusting certain parameters in the Sensing Solutions EVM GUI Tool v1.8.8 is important for obtaining the best performance using the TIDA-00464.

Navigate to the *Input Deglitch Filter* setting in the *Configuration* page of the GUI. Select the lowest setting that exceeds the oscillation tank oscillation frequency, which is set to 10 MHz for the TIDA-00464. Enable the four channels in the *Measurement Settings* tab of the *Configuration* page to retrieve the samples from the four buttons. Increase the amplitude of oscillation by increasing the I*drive* in the *Current Drive and Power* tab. The amplitude of oscillation has been increased to 1.2 V for the TIDA-00464 by increasing the I*drive* of the four channels to 20.

Increase the value for the *Divider Code* to 2 in the *Measurement Settings* tab and then play with the *Parallel Inductance* values in the *Sensor Properties and Input Adjustments* tab to ensure the same total capacitance for the four buttons.

Be sure to set the RCOUNT registers (08-0B) to xFFFF in the registers page.

The following tests were performed:

- Touch
- Touch with gloves
- False touch

In each test, 1000 samples were taken while pressing a button (touch) and 1000 samples were taken without performing any action (untouched). The sampling was followed by a calculation of the SNR and crosstalk among the buttons.

The diagram in Figure 14 can be used to show the results if considering a normal distribution for the touch event and untouched event:

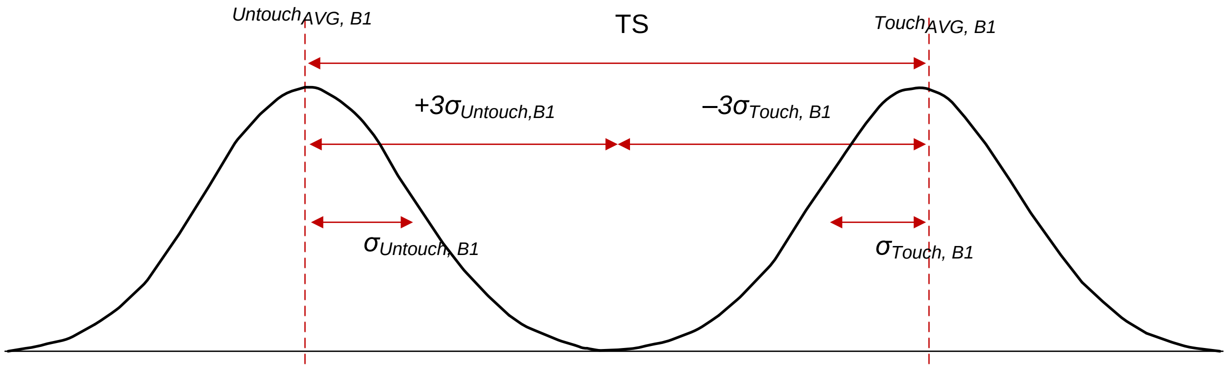

Figure 14. Event Distribution (SNR) With Touch and Untouched

$Touched_{AVG\_B1}$ is the average of 1000 sample while pressing button 1 (see Equation 2).

$$Touched_{AVG\_B1} = \frac{\sum_{n=0}^{Sample\ Size} Touched_{B1}[n]}{Sample\ Size} \quad (2)$$

$Untouched_{AVG\_B1}$ is the average of 1000 samples without any button presses (see Equation 3).

$$Untouched_{AVG\_B1} = \frac{\sum_{n=0}^{Sample\ Size} Untouched_{B1}[n]}{Sample\ Size} \quad (3)$$

Table 5 shows the SNR and the probability of a false event as a function of the number of σ.

Table 5. SNR and Probability of False Event in Function of Number of σ

zσ	SNR	PROBABILITY OF FALSE EVENT
1σ	0 dB	31.73%
2σ	6 dB	4.55%
3σ	9.5 dB	0.27%
4σ	12 dB	60 ppm
5σ	14 dB	0.57 ppm

To achieve a 0.27% probability of a false event, the user must ensure that the value for the $Touched_{AVG\_B1}$ is calculated as follows in Equation 4:

$$T_{AVG\_B1} - 3\sigma_{Touch\_B1} > U_{AVG\_B1} + 3\sigma_{Untouch\_B1} \quad (4)$$

where:

$$\sigma_{Touch\_B1} = \sqrt{\left(\frac{\sum_{n=0}^{Sample\ Size} \left(Touched_{B1}[n] - Touched_{AVG\_B1}\right)^2}{Sample\ Size}\right)} \quad (5)$$

$$\sigma_{Untouch\_B1} = \sqrt{\left(\frac{\sum_{n=0}^{Sample\ Size} \left(Untouched_{B1}[n] - Untouched_{AVG\_B1}\right)^2}{Sample\ Size}\right)} \quad (6)$$

The calculations from Equation 4 can be further simplified in Equation 7:

$$T_{AVG\_B1} - U_{AVG\_B1} > 3\left(\sigma_{Untouch\_B1} + \sigma_{Touch\_B1}\right) \rightarrow \frac{T_{AVG\_B1} - U_{AVG\_B1}}{\sigma_{Untouch\_B1} + \sigma_{Touch\_B1}} > 3 \tag{7}$$

Define the touch strength (TS) in Equation 8 using the previous calculations from Equation 7:

$$\text{Touch Strength}\ (TS) = \text{Untouched}_{AVG\_B1} - \text{Touched}_{AVG\_B1} \tag{8}$$

Calculate the SNR in dB in Equation 9:

$$SNR(dB) = 20 \times \log\left(\frac{\text{Touch Strength}\ (TS)}{\sigma_{Untouch\_B1} + \sigma_{Touch\_B1}}\right) > 9.5\ dB \tag{9}$$

To ensure that the probability of a button being touched is equal to 99.73%, the SNR must be greater than 9.5 dB (see Table 5).

The method for calculating the crosstalk is similar to that of the SNR; however, this method considers the average of 1000 samples of a button while touching a nearby button (see Figure 15).

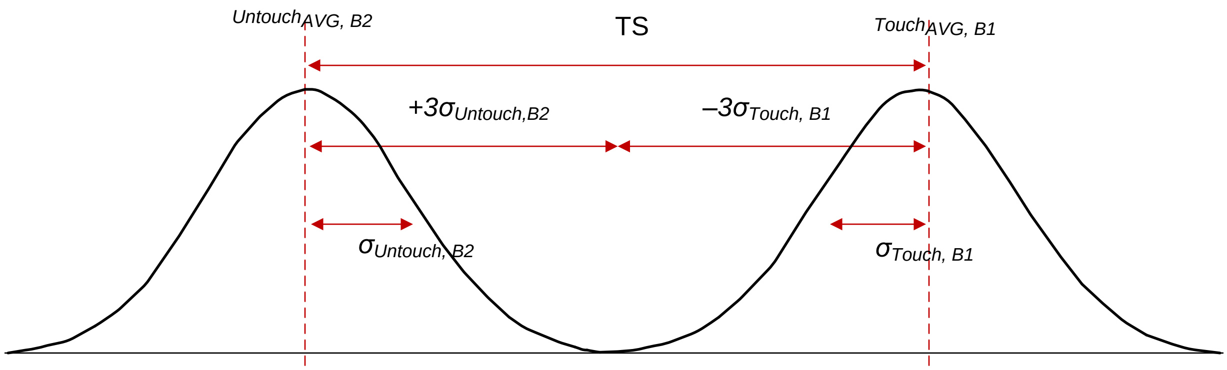

Figure 15. Event Distribution (Crosstalk) With Touch and Untouched

In Figure 15, Touch_{AVG_B1} is equal to the average of 1000 samples while button 1 is pressed and Untouch_{AVG_B2} is equal to the average of 1000 samples of button 2 while button 1 is pressed.

Equation 10 shows how to calculate the crosstalk:

$$\text{Crosstalk}_{B1\_B2}(dB) = 20 \times \log\left(\frac{\text{Touch Strength}\ (TS)}{\sigma_{Untouch\_B2} + \sigma_{Touch\_B1}}\right) > 9.5\ dB \tag{10}$$

To ensure that the probability of an unintentional button touch is equal to 0.27%, the crosstalk must be greater than 9.5 dB (see Figure 15). Refer to Equation 5, Equation 6, and Equation 8 for calculating the touch strength, $\sigma_{Untouch\_B2}$, and $\sigma_{Untouch\_B1}$.

The air gap between the glass window and the buttons varies in each test from 1 mm to 2 mm and no air gap. Decrease the proximity and touch threshold in the *Tuning* tab of the *ButtonGroupSensor* properties as the air gap increases.

8 Test Data

8.1 Touch

This test measures the SNR and crosstalk for each button while using a human finger to press the button. The following Table 6 and Figure 16 show how the SNR decreases as the air gap increases.

Table 6. Touch—SNR

AIR GAP (mm)	SNR (dB)			
	B1	B2	B3	B4
0	33	36	38	33
1	23	22	24	20
2	20	19	20	17

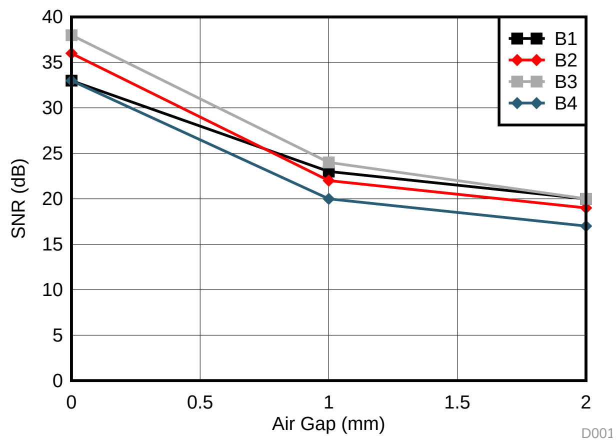

Figure 16. Touch—SNR

The SNR is still greater than 9.5 dB at a 2-mm air gap for all the buttons, which ensures that the application is robust. The crosstalk has a similar behavior to that of the SNR: the crosstalk decreases as the air gap increases. Table 7 shows the obtained results:

Table 7. Touch—Crosstalk

AIR GAP (mm)	CROSSTALK (dB)				
	UNTOUCHED BUTTONS	B1	B2	B3	B4
0	B1	—	32	35	31
	B2	30	—	37	32
	B3	31	37	—	31
	B4	29	33	35	—
1	B1	—	25	24	23
	B2	21	—	25	22
	B3	24	26	—	23
	B4	22	23	23	—
2	B1	—	19	16	14
	B2	17	—	16	16
	B3	19	18	—	13
	B4	18	17	17	—

The crosstalk is measured for each button pressed. The best crosstalk results are obtained between button 3 and button 2 because they have the most distance between each other with respect to the other buttons (see Figure 5).

Figure 17 shows the crosstalk results:

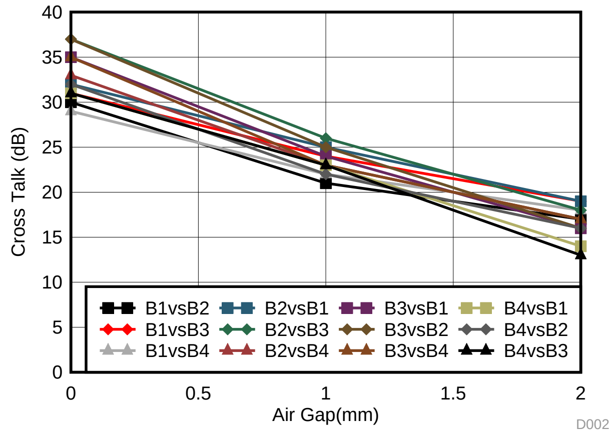

Figure 17. Touch—Crosstalk

8.2 Touch With Gloves

This test measures the SNR and crosstalk for each button while a human finger wearing a thick glove is used to press the button (see Figure 18).

Figure 18. Example Firefighting Glove

This test shows a significant decrease in the measured SNR and crosstalk in comparison to the test results without a glove, which is a result of the thick fabric of the glove and its resistance to harsh environments.

However, the SNR values are still fairly satisfactory, with only two cases of values below 9.5 dB (button 1 and button 3) and recognition of button touches 95.45% of the time (see Table 8).

Table 8. Touch With Gloves—SNR

AIR GAP (mm)	SNR (dB)			
	B1	B2	B3	B4
0	21	20	22	19
1	11	12	13	11
2	8	10	6	10

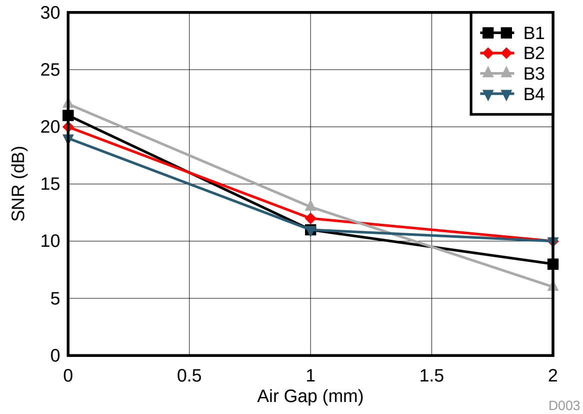

Figure 19. Touch With Gloves—SNR

Table 9 shows the crosstalk values. Some of the resulting crosstalk values are less than 9.5 dB when measuring at the 2-mm air gap. These results indicate that a touch of the button while wearing gloves can influence nearby buttons.

However, the results can be improved by implementing a data processing algorithm. One such example is to increase the sample rate, which also effectively increases the sample averaging (see Figure 20).

Table 9. Touch With Gloves—Crosstalk

AIR GAP (mm)	CROSSTALK (dB)				
	UNTOUCHED BUTTONS	B1	B2	B3	B4
0	B1	—	24	22	23
	B2	20	—	23	20
	B3	23	22	—	23
	B4	20	21	20	—
1	B1	—	14	15	13
	B2	10	—	15	10
	B3	12	16	—	12
	B4	11	12	13	—
2	B1	—	8	6	9
	B2	4	—	7	5
	B3	5	11	—	8
	B4	3	6	6	—

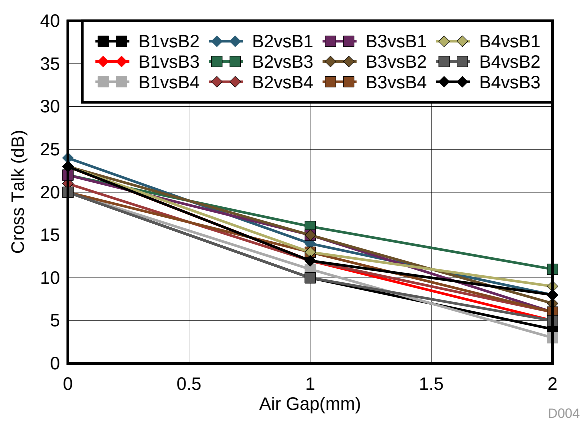

Figure 20. Touch With Gloves—Crosstalk

8.3 False Touch

This test measures the SNR of the two buttons that are the closest to the false touch position and is performed by touching the point between two buttons, as Figure 21 shows.

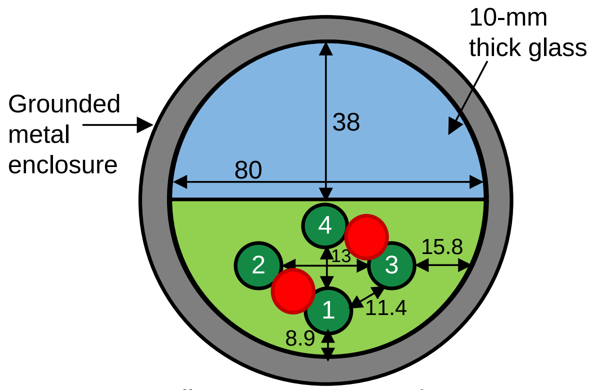

Figure 21. .False Touch Example

Table 10 shows the results of the false touch test:

Table 10. False Touch—SNR

AIR GAP (mm)	SNR (dB)				
	B1–B2	B2–B4	B4–B3	B3–B1	B3–B2
0	20–24	25–23	22–25	18–21	16–17
1	8–13	14–9	12–13	7–13	9–13
2	8–8	7–6	9–6	11–11	10–12

In the false touch example, the measured SNR on button 1 and button 2 is 8 dB and 13 dB, respectively, when measuring with a 1-mm air gap. These values show that the SNR of button 1 and button 2 is lower during a false-touch event in comparison to the values in Table 6 during a normal button touch event. The minimum SNR difference between a false and true event is 7 dB. This difference is enough to set a proper threshold to exclude the false touch event from the true event. Another way to address false touch events is to exclude them from the true events when the SNR of the two buttons is simultaneously high.

The same false touch test has been performed while wearing the firefighter glove, for which Table 11 shows the results.

Table 11. False Touch With Gloves—SNR

AIR GAP (mm)	SNR (dB)				
	B1–B2	B2–B4	B4–B3	B3–B1	B3–B2
0	11–11	13–8	9–9	10–12	8–12
1	0–5	0–7	7–3	5–7	2–0
2	0–0	5–4	5–1	0–3	0–5

9 Design Files

9.1 Schematics

To download the schematics, see the design files at TIDA-00464.

9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00464.

9.3 Layout Guidelines

9.3.1 PCB Layout Recommendations

The use of a hatched ground plane on the bottom side reduces the parasitic capacitance associated with both trace and electrode capacitance, reducing the susceptibility of the traces to capacitive touch events (see Figure 22).

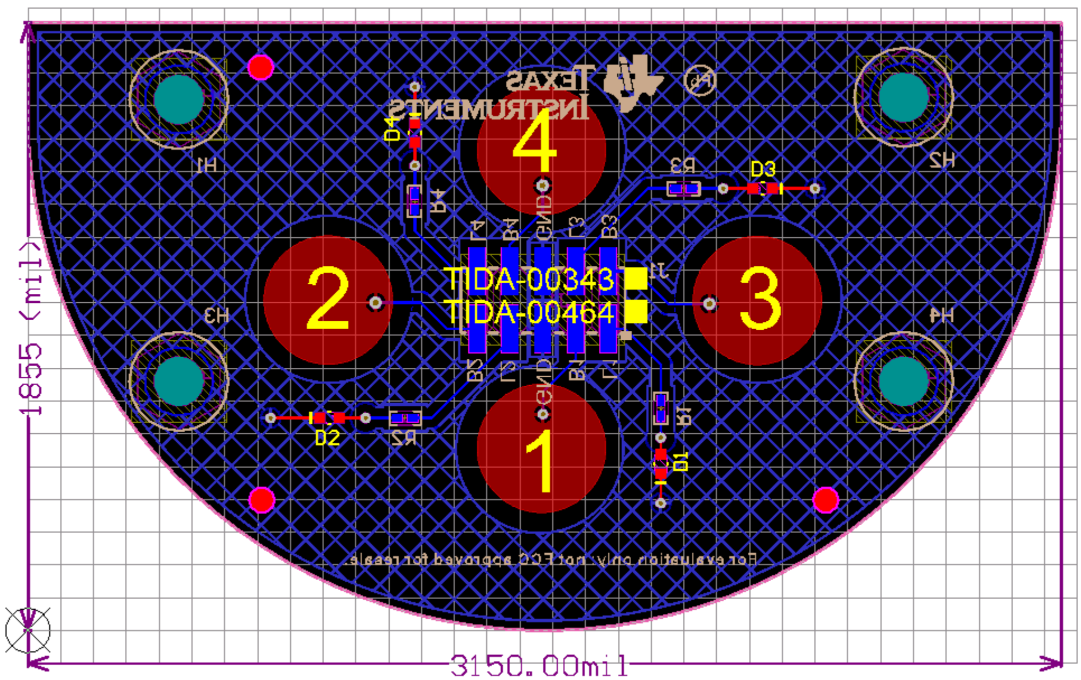

Figure 22. TIDA-00464 Layout

TI recommends to keep the traces as short as possible. Increasing the distance of the trace increases the parasitic capacitance associated with the trace. Increasing the trace length can also increase susceptibility to noise.

9.4 Layout Prints

To download the layer plots, see the design files at TIDA-00464.

9.5 Altium Project

To download the Altium project files, see the design files at TIDA-00464.

9.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00464.

9.7 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00464.

10 Software Files

To download the software files, see the design files at TIDA-00464.

11 References

1. Texas Instruments, *Noise-immune Capacitive Proximity Sensor System Reference Design*, TIDA-00466 Design Guide (TIDUAF9)
2. Texas Instruments, *FDC2114 and FDC2214 EVM User's Guide*, (SNOU138)

12 About the Author

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