Application Report
SLLA355–March 2015

Ice Buildup Detection Using TI's Capacitive Sensor Technology

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ABSTRACT

Ice buildup can cause problems in many different environments and applications. The ability to sense ice buildup on enclosures and surfaces in harsh environments can initiate countermeasures at the proper time. Countermeasures can increase the usability and durability in a variety of applications. In some applications, ice detection is beneficial. It is even more helpful to be able sense ice buildup when not exposed to the harsh environmental changes that are being measured, such as a hermetically sealed container or enclosure. The FDC1004 can sense ice buildup through various non-conductive substances. If further customization is needed, such as logging temperature outside the hermetically sealed enclosure, the TMP007 sensor can be housed inside the enclosure to sense the outside temperature.

This application report provides an overview of the test setup and sensor results of the FDC1004 ice detection experiment.

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1 Background

In cold environments, data about ice buildup can be useful if a counter measure needs to be activated. Testing for ice buildup can be a difficult problem to solve and for that matter also hard to test. A test was devised to contain water and ice inside a uniform test platform to determine how well Texas Instruments' FDC1004 could detect ice buildup. A temperature chamber set below freezing point was the method used for customizing how and when the ice froze to the test platform. Tests and procedures are discussed starting in Section 3.

2 Theory

Various sensor configurations can be used for sensing ice buildup, but for this experiment an isolated sensor configuration was chosen. The isolated sensor configuration is very similar to a parallel plate capacitor, except instead of the ground plate there is a shield plate. The isolated sensor works well for detecting ice buildup for a couple reasons. The isolated sensor configuration is the simplest design because it can be small and only requires two signal wires to sensor configuration. With a fixed distance and dielectric between each "plate" of the sensor, a baseline capacitance can be established when none of the electric field around the sensor is disturbed. The field lines of the isolated sensor configuration model the field lines of a parallel plate capacitor in that the e-field lines will go to the nearest ground source. For example, the ground could be an enclosure or a grounded conductive material.

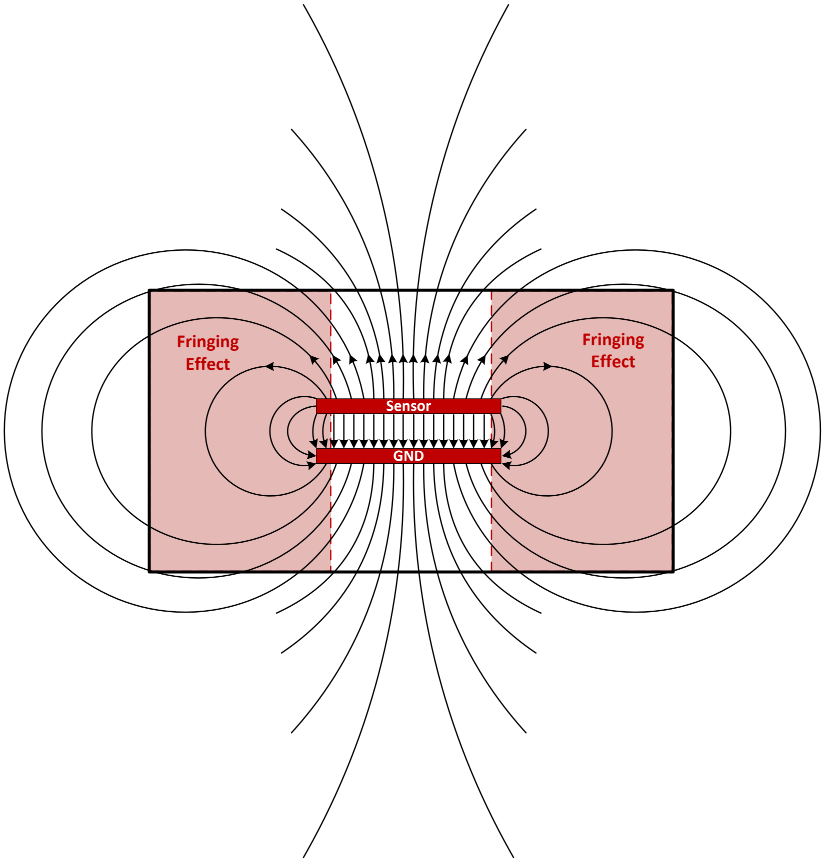

Figure 1. Electric Fields of a Parallel Plate Capacitor

Electric field disturbances such as materials with a higher dielectric constant than air near the capacitor results in a higher capacitance reading. Ice has a dielectric constant 3 times that of air and water is even greater. When ice and water are positioned near the parallel plate capacitor, the capacitance increases.

Other sensor configurations may also be suitable for sensing ice buildup; the configurations and their applications are covered in *FDC1004: Basics of Capacitive Sensing and Applications* (SNOA927).

3 Setup

This section discusses the materials used and how the test setup was put together to model an environment where ice buildup would be measured. A ring like structure was created and attached onto a sheet of polycarbonate to contain the water during freezing.

3.1 Materials

A majority of the non-semiconductor materials were acquired from a home improvement store. Table 1 lists the materials and a basic use of the material.

Table 1. Basic List of Materials

Material	Use
8”diameter 3D printed ring (1 inch high)	Wall to contain water on Lexan sheet
Lexan Polycarbonate sheet (0.1 inch thick)	Transparent backplane to attach sensor (metal strips)
Acrylic cement	Glue printed ring onto Lexan
FDC1004EVM	Measurement IC to measure capacitance
1”x 1” of 2 layer copper sheet	Create a parallel plate capacitor sensor
Thermocouple	Verify temperature of Lexan sheet
Temperature Chamber	Control environment temperature of test platform
Spray bottle	Spray small amount of water onto test platform

3.2 Putting It All Together

The following setup is quite simple:

1. Cut the sheet of the Lexan into squares large enough to comfortably fit the 8 inch ring, about 9.5 inches.
2. Design and print the ring on the 3D printer and use the acrylic cement to glue the 3D printed ring down onto the Lexan.
3. Make sure there is enough adhesive to ensure a waterproof joint between the two plastics. ABS plastic was used to print the ring, but other types of plastic will also work, just be sure to get the correct plastic adhesive for your setup.
4. When cutting the copper sheet down to size, make sure not to short circuit the two layers of copper.
5. Check with the continuity checker before continuing. One side of the copper square is CIN1 and the other is SHLD1.
6. Solder a wire to each side of the copper square and attach them to the correct signals on the EVM.
7. Attach the sensor and thermocouple to the backside of the Lexan (the opposite side of the 3D printed ring). The final product looks like Figure 2.

Figure 2. Test Platform Closeup

A different size setup would also work; this size platform enabled other tests to be completed on the same platform with more sensors. Other materials could be utilized as well to contain the water and ice to see how different material affects results.

4 Sudden Ice Introduction Test

The first of the tests completed (with the test platform) introduced a lot of ice at the same time to see how the FDC1004 would react.

4.1 Sudden Ice Introduction Procedure

1. Place the test platform in the temperature chamber with the FDC1004; make sure that the metal floor of the chamber is not in contact with the capacitive sensor. The sudden ice introduction test temperature range is 10°F to 50°F (-12°C to 10°C), the ideal range for ice build-up and melting.
2. Baseline measurements were collected the same way as the test measurements. The baseline measurements are taken with no ice or water on the test platform. For each temperature data point, approximately every 10°F, the temp chamber is set to the desired temperature. Once at the desired temperature, the test platform soaks for 5 minutes in the chamber before recording temperatures and time stamps. The results are taken by using the continuous data collection mode of the FDC1004EVM. The results are shown in Section 4.2.
3. After taking baseline measurements with the test platform in the same location in the test chamber, the test is done again starting at 10°F (-12°C). However, when 30°F is reached, the door is opened and crushed ice is quickly added to the test platform. The crushed ice looks like the ice in Figure 3.

Figure 3. Crushed Ice

4.2 Sudden Ice Introduction Results

As seen in the results, the baseline test with no ice or water on the test platform, reads a pretty constant 4 pF. When the crushed ice is added during the functional test, the sensor reads 7 pF.

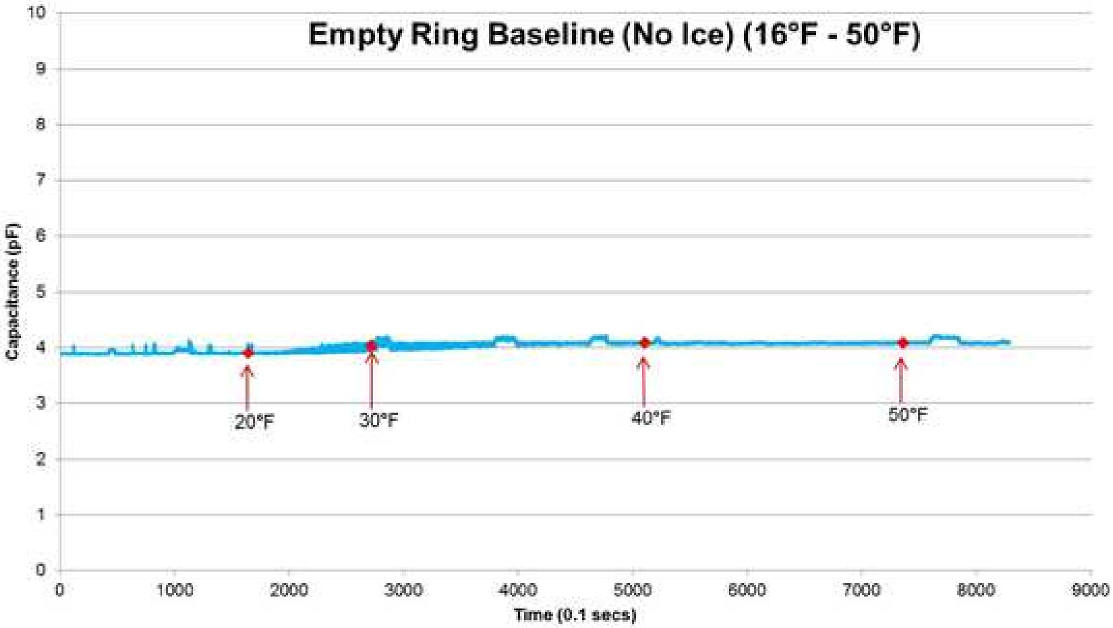

Figure 4. Baseline Graph

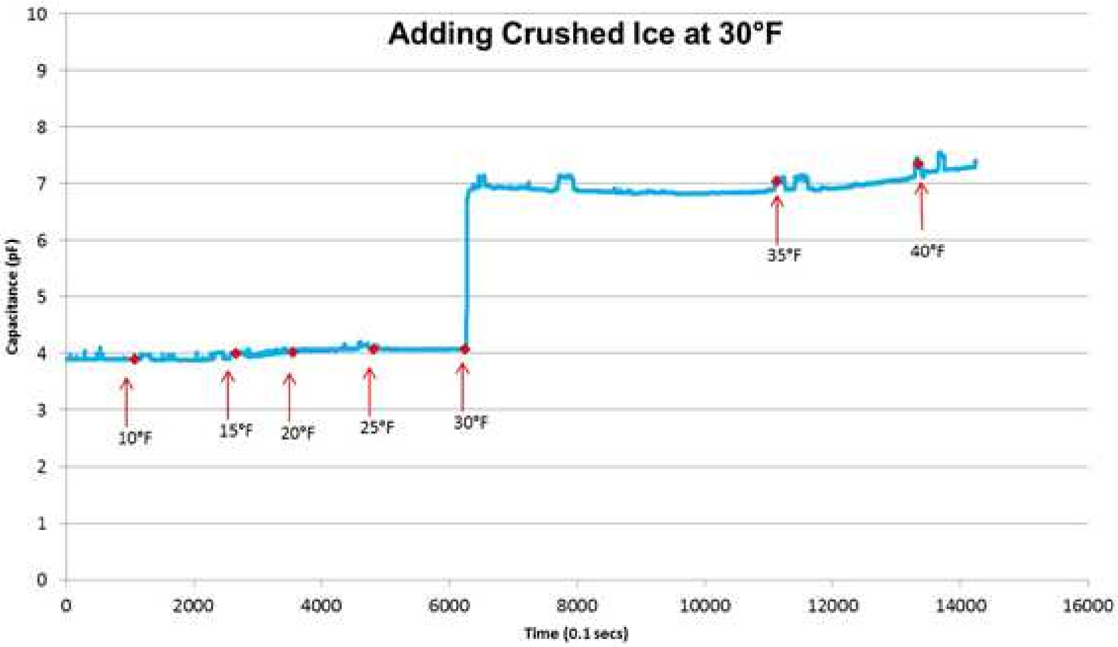

Figure 5. Sudden Ice Introduction Graph

5 Slow Ice Build-Up Test

The next test more closely models what happens in most environments. The ice gradually builds up on the surface; this test is difficult because the water may not freeze over the sensor with the same shape each time.

5.1 Slow Ice Buildup Procedure

1. A slight modification was made to the test platform before the slow ice build test was completed. The thickness of the Lexan has doubled to further test the sensitivity of the FDC1004. Now the distance between the ice and the capacitive copper sensor is approximately 0.2 inches. The test platform and FDC1004 are positioned in the temperature chamber set to 25°F (-4°C). The test platform soaked for 5 minutes to allow an even temperature. A baseline reading was taken for approximately 90 minutes in order to compare the gradual ice buildup to the baseline reading.
2. Using the spray bottle, water is sprayed onto the test platform while aiming at the center of the sensor. With the current tools available, the temperature chamber door had to be opened each time water was sprayed. Water was sprayed onto the sensor about every 4 to 5 minutes; this allowed time for the previous spray of water to freeze on to the Lexan.

Figure 6 shows how the water froze onto the Lexan.

Figure 6. Slow Water Buildup

5.2 Slow Ice Buildup Results

During the baseline testing, there was some interference during the cooling process within the temperature chamber. The interference could be caused from extra air currents, or something nearby in the environment, such as the temp chamber’s fan. The baseline measurements were taken first and then directly after the water sprays were being added.

Each spike in the red waveform represents when the temperature chamber was opened and the water was sprayed onto the test platform. This occurs because of the quick temp fluctuation and the introduction of water before it froze. The dielectric constant for water is around 80 while the constant for ice is closer to 3. This is the main reason for the spikes when the water is sprayed. Absolute mass, point where there is enough ice to be detected reliably can be reached relatively quickly to correctly sense the ice. This happens around sample 23,000. Sample rate is 10 samples per second, so about 23 minutes into the experiment. Ice thickness at absolute mass was approximately 1 mm thick. At the end of the experiment 0.5 ounces (15 cc) of water was frozen to the Lexan test platform.

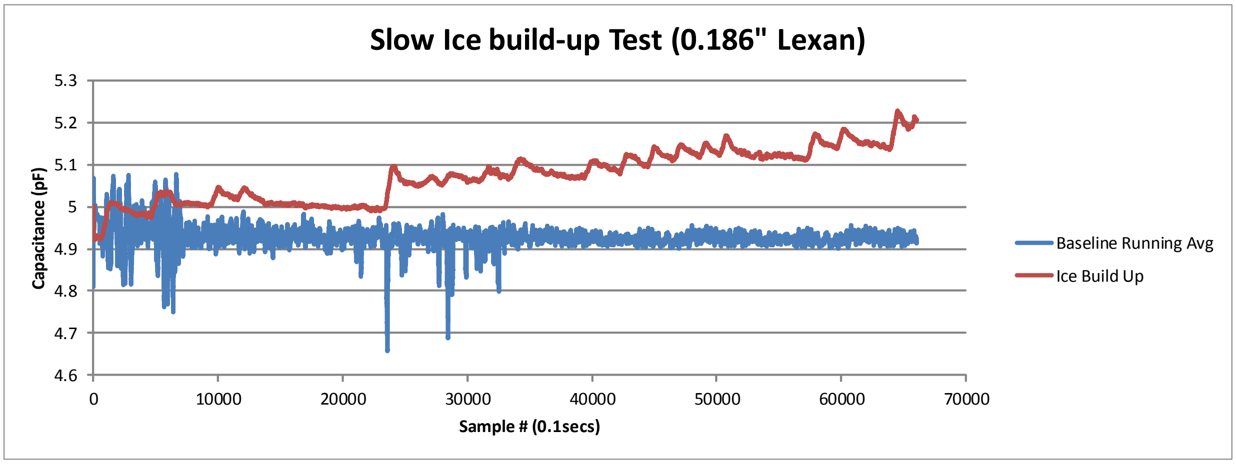

Figure 7. Slow Ice Buildup Graph

6 Summary

The instant ice detection is a success. If a large amount of ice gets frozen to the material in question, a small 1 inch square sensor located behind the non-conductive material can in fact sense this instant change. The slow ice buildup also showed promising results. With only about 1mm of ice a definite change was seen in the output. The change is big enough to be able to accurately set a threshold interrupt for an embedded system. A small sensor was used, but a larger sensor with different geometries could be researched and tested to get even better results.

7 About the Author

Jarrod Krebs is a systems designer at Texas Instruments, where he is responsible for developing reference designs in the industrial segment. Jarrod has experience with software and embedded applications implemented on ARM based microcontrollers and TI's MSP430 platforms. Jarrod earned his Bachelor of Science in Computer Engineering from Kansas State University in Manhattan, KS. Jarrod is also a member of the Institute of Electrical and Electronics Engineers (IEEE).

8 References

- *FDC1004: Basics of Capacitive Sensing and Applications* (SNOA927)

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