# Quantifying Ice and Frost Buildup Using Capacitive Sensors

TEXAS INSTRUMENTS

## [Introduction]

Ice and frost buildup is a common problem for many cooling systems in which conventional solutions do not efficiently solve. The accumulation of ice and frost can disrupt heat exchange in a system, resulting in excessive power consumption. Traditional methods for defrosting do not accurately quantify the amount of ice built up on a surface which may result in overheating the cooling system and therefore consume excessive power. This may also potentially spoil food in a refrigerator environment due to the lack of air circulation. Conversely, inaccurate defrosting methods may not heat the system enough to properly melt all of the ice, increasing the risk of disrupting the airflow of a cooling system.

One conventional solution seeks to melt ice and frost by turning on the heating elements after a predetermined time interval. This does not measure the amount of ice and frost collected and therefore assumes that it accumulates at a constant rate, which is seldom the case. Another traditional method uses a temperature sensor to defrost ice based on a detected change in temperature. However, this requires an extremely sensitive sensor and the measurement is not directly correlated to ice thickness or distribution so it is inherently inaccurate. Furthermore, more active ice monitoring systems exist that aim to detect the usage of the cooling system and actively decide when to initiate the heating elements. These methods are often complex, and ice buildup may not always be proportional to the amount of activity of the cooling system. Figure 1 shows the ideal ice frosting and defrosting process in which all of the ice melts after the heater is turned on.

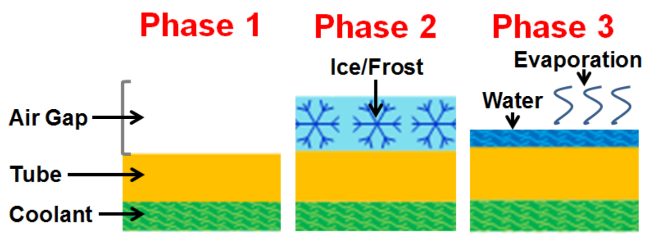


**Figure 1. Ice and Frost Buildup Process**

The capacitive sensing technique solves ambiguity issues concerning how much ice forms on the cooling surface in phase 2 by directly quantifying the amount of ice rather than following assumptions similar to the other methods. This approach measures the capacitance of the system which is unique at each phase due to the arrangement and thickness of materials and dielectric constants. As can be seen in Table 1, the dielectric constant varies significantly depending on the properties of the substance.

**Table 1. Material Dielectric Constants**

| MATERIAL | DIELECTRIC CONSTANT ($\varepsilon r$) |
|---|---|
| Air | 1 |
| Water (at 20°C) | 80 |
| Glass | 7.6-8.0 |
| Paper | 2.3 |
| Ice | 3.2 |

FDC devices operate with a narrowband resonant-based measurement which minimizes noise compared to the traditional broadband charge-based measurement. In an application where accuracy and noise rejection is important, such as the measurement of ice and frost, TI's EMI-resistant, capacitive sensing portfolio can provide resolution up to 28 bits and is reliable in temperatures as low as -40°C.

## [Theory of Operation]

The FDC1004 and FDC2x1x devices measure the capacitance between two parallel plates consisting of the metal surface of a cooling body and an added electrode at a fixed distance acting as the sensor. As the height of the ice formation begins to increase, the resonance in the LC tank also changes due to the change in capacitance, resulting from the dielectric change between the electrode and metal surface.

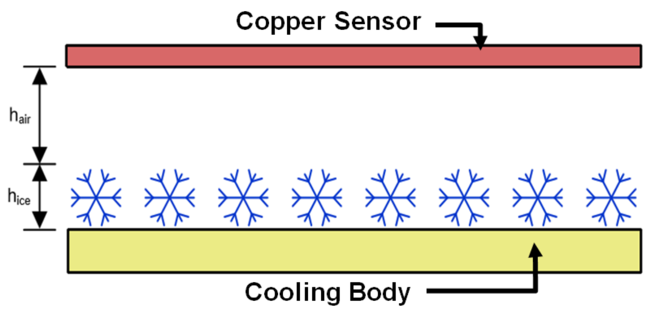


**Figure 2. FDC Principle of Operation**

The area of the sensor corresponds to the degree of sensitivity of the system—the larger the better. Sensors can simply be an electrode around a cooling tube or a sheet resting on top or side of a finned cooling body similar to the image on the right in Figure 3. TI recommends using a mesh electrode to ensure that the sensor does not impede the natural frost buildup between the electrode and cooling body because this could cause an inconsistent reading on the sensor compared to the rest of the system. Specific sensor design considerations can be found in Section 2.3.6 of the *TIDA-01465 Capacitive Frost or Ice Detection Reference Design* (TIDUD79).

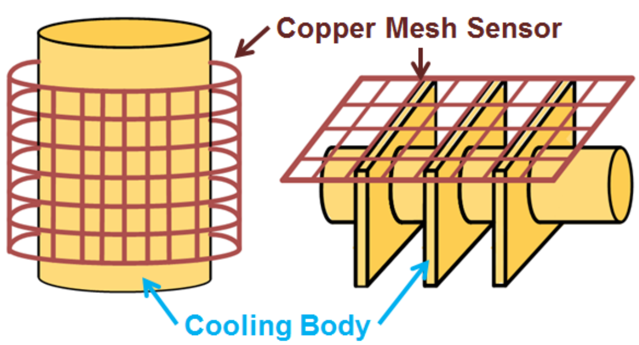


**Figure 3. Capacitive Sensor on Cooling Body**

The capacitance of the frost forming and defrosting process can be seen in Figure 4 as well as Figure 1. Observed in phase 1, capacitance stays constant until frost begins to form in phase 2. At this phase, the measured capacitance is proportional to the thickness of ice accumulated. Once the defrosting process begins in phase 3, water is introduced into the system that causes a spike in the capacitance before it begins to decrease rapidly as the water drains. Once all of the water drains or evaporates, the capacitance returns to the initial phase 1 value and the system is now free of ice.

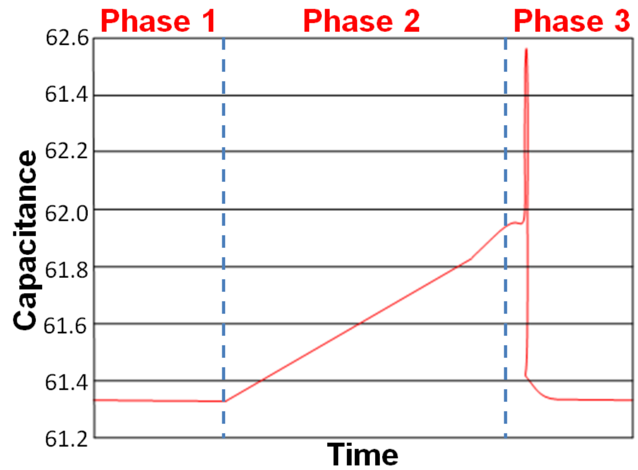


**Figure 4. Capacitance Curve**

**[FDC2214]**

The FDC2214 is an EMI-resistant, 28-bit, capacitance-to-digital converter. Unlike traditional capacitive sensing technologies, the narrowband architecture of the FDC2x1x series supports a wide range of excitation frequencies and maintains performance even in high-noise environments.

**[FDC1004]**

The FDC1004 is a 4-channel, high resolution, capacitance-to-digital converter. This device includes shield drivers for sensor shields that can reduce EMI interference and focus in on the sensing direction of the sensor.

**Table 2. Alternative Device Recommendations**

| DEVICE | OPTIMIZED PARAMETERS | PERFORMANCE TRADE-OFF |
|---|---|---|
| FDC2114 | High Speed | 12Bit resolution |

**Table 3. Recommended Collateral**

| COLLATERAL | DESCRIPTION |
|---|---|
| TIDA-01465 | *Capacitive Frost or Ice Detection Reference Design, Resolution of <1mm, Temperature Drift <0.25%* (TIDUD79) –FDC2214 |
| Application Report | *Ice Buildup Detection Using TI's Capacitive Sensor Technology* (SLLA355) – FDC1004 |

## IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265