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.

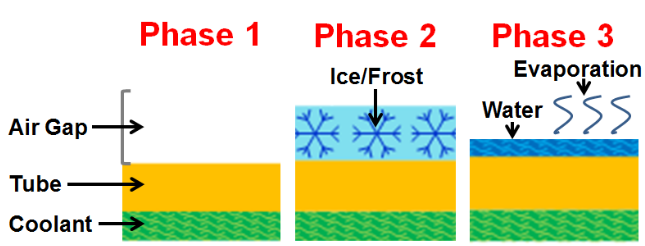

Figure 1. Ice and Frost Buildup Process

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 (εr)
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.

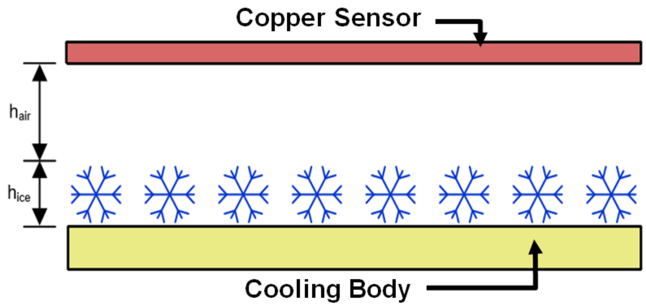

Figure 2. FDC Principle of Operation

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).

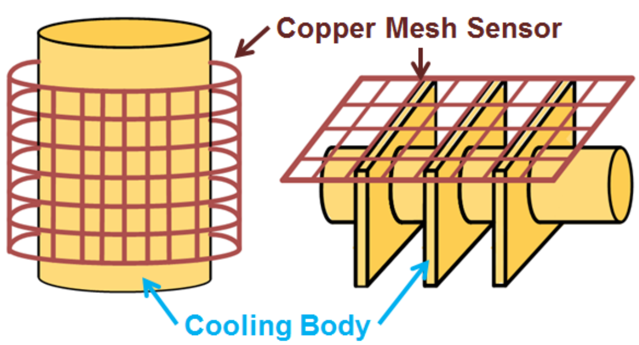

Figure 3. Capacitive Sensor on Cooling Body

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.

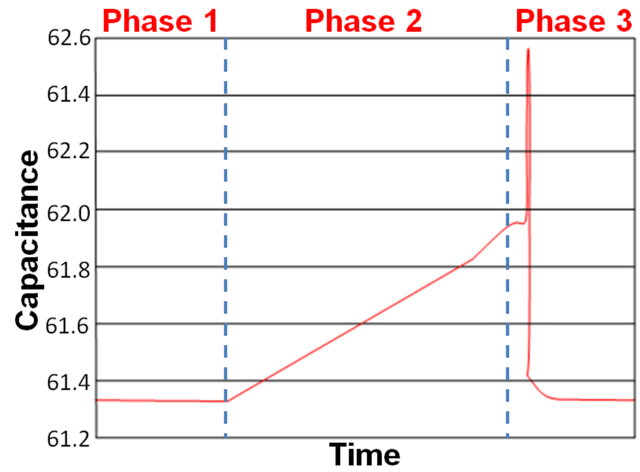

Figure 4. Capacitance Curve

[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