WHITE PAPER

Defeating Extreme Cold with an Intelligent Heating Solution

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Summary

Industrial field sites in the petroleum industry are more and more often in remote, distant places exposed to the most extreme cold the earth has to offer, and the computer systems which serve them must be capable of reliably tolerating these extreme environments. Unfortunately, industrial-grade panel PCs that are used in extremely low temperatures will typically have serious problems. Freezing cold causes display distortions like white spots and LCD motion blur, and corrupts the output of onboard components in unpredictable ways. For most platforms, system stability can't be guaranteed until the average temperature rises to 0°C. In many ocean and winter environments, however, reaching this baseline temperature cannot occur without mechanical help of some sort, and makeshift workarounds invariably leave operators frustrated and impatient. For this reason, an onboard, automated heating system is a key improvement for systems built to withstand outdoor temperature extremes.

Figure 1: Display distortions: White spots appear at 0°C

A Heating Solution for Reliable Operations in Extreme Cold

From an embedded computing perspective, temperature extremes are among the most difficult natural conditions to manage, particularly freezing cold. For a variety of reasons manufacturers have, over the years, focused more on overcoming the effects of heat. Yet today, with so

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many methods of accelerating heat dissipation without fans or other failure-prone devices, extremely low temperatures have become the next engineering challenge to overcome. In extreme cold well below 0°C, the performance of components such as hard drives and display panels can be dramatically affected, up to and including system failure; with many industrial sites now being rapidly pushed into inhospitably frigid environments, the need for cold-tolerant machines is increasing apace.

With industrial panel computers increasingly used as HMIs, maintaining the reliability of these systems in extreme cold is a crucial issue for many industries. However, heating a cold system is a far more thorny challenge than cooling a hot one. The basic engineering goal is to raise the system to a specific temperature range that guarantees reliable operation—typically somewhere around 0°C, which is the lowest limit for most computer components. If the average temperature of the computer falls much below 0°C, most systems will begin to experience subsystem failures and/or signal corruption. The elementary solution is to include a heater that turns on once the system temperature falls below 0°C. Yet this is easier said than done: this heater must also evaluate ambient temperatures, maintain the temperature at an optimal threshold when the system itself cannot, and not overheat the system once the internal temperature begins to climb. Hence, this heating solution must be "intelligent."

How to Build an Effective, Efficient, Intelligent Heating Solution

To build an intelligent heating system, more than just a sensor and a heater are needed. While the most fundamental hardware components of a heating subsystem are a heating element and a temperature sensor (thermistor), it is not enough to simply set a target temperature and turn the heater on or off when that temperature is reached. Control loops of this sort are commonly called bang-bang controls, and they are notorious for imprecision and waste. A much more efficient approach is a proportional control loop, where the system temperature is intelligently evaluated, and continuous adjustments are made relative to the system state.

Proportional control loops deliver the greatest power and output efficiency available, but their engineering is by no means straightforward. With a heating element, output is controlled according to the amount of power supplied. Proportional heating controls, therefore, use pulse-width modulation (or PWM) to deliver a spectrum of wattage rather than just a full on / full off switch. A sensor, of course, is also needed to monitor heat output, and finally two or three software subsystems are needed to intelligently manage and monitor system temperature. Each of these elements brings with it its own design challenges, increasing the complexity of proportional control systems far beyond simple bang-bang controls.

In contrast to the proportional controller described above, past heating solutions have generally used bang-bang (or hysteresis) controllers, turning the heater on or off at some target threshold. Yet bang-bang controllers introduce a host of undesirable side effects or potential points of failure. Beyond being vastly less efficient, heating solutions using bang-bang controllers can diminish power supply stability (leaving the platform prone to crashes) or unnecessarily overheat the computer's internal components, reducing the computer's MTBF (and increasing total cost of ownership). For sensitive applications requiring a high measure of reliability and efficiency, bang-bang control loops are too prone to premature system failures, hardware deterioration, and performance degradation to be of much use.

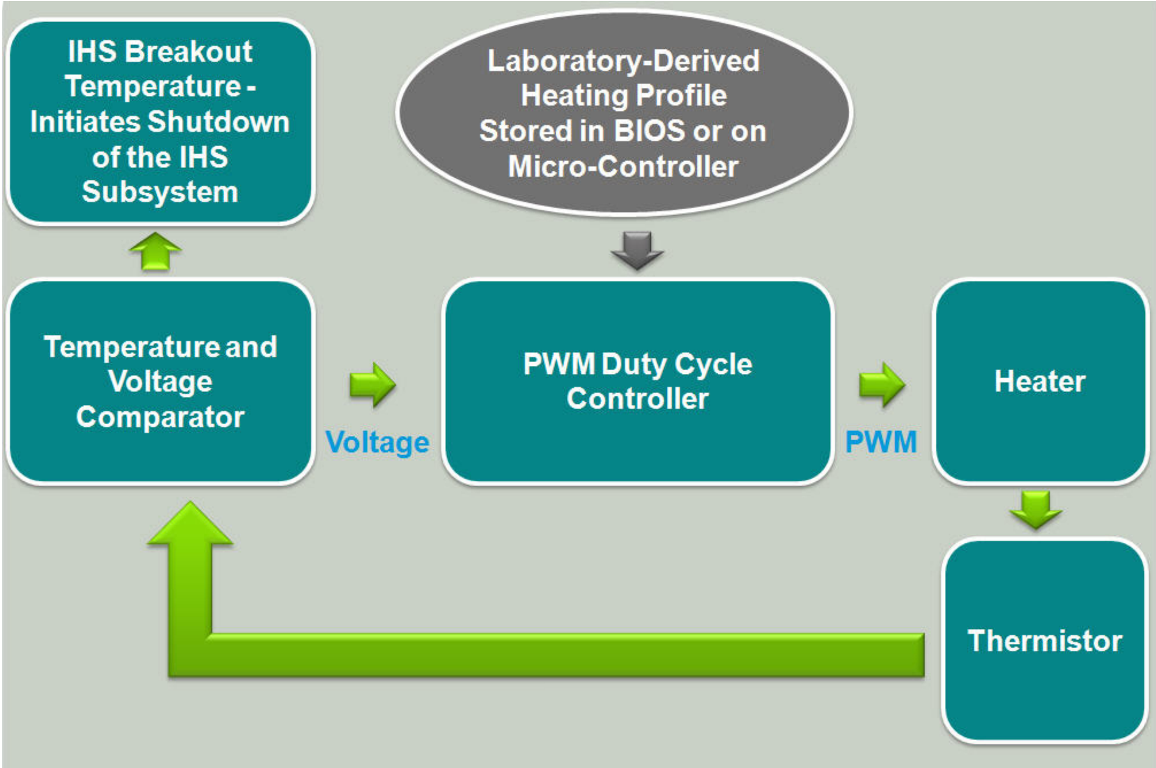

Figure 1: *Basic Proportional Control Feedback Loop*

In figure 1, above, we see the basic software components of a proportional feedback heating design. The temperature sensor feeds its output to a comparator, which then instructs the PWM controller to increase or decrease heat output. As power is altered the heat output increases or decreases, which is registered by the thermistor, which then feeds that information to the comparator. The comparator then either passes a command to the PWM controller or instructs the system to shut down. A control loop of this sort monitors and adjusts the system as a continuous cycle, and can only be said to end when it breaks out of the loop and turns itself off. For all of these reasons, even crude precision proportional controls can significantly increase the efficiency and safety of the system over a bang-bang approach, both conserving the power used while maintaining heat output within strict limits.

Engineering Proportional Controls

By using pulse-width modulation (PWM) to supply power to the heating element it is possible to deliver much finer responsiveness and precision than is capable with simple on-off feedback loops. Yet the relationship between power and heat is not a simple one-to-one correspondence. To design effective proportional controls, engineers must calibrate PWM output so that it results in a specific, predictable heat output at each temperature in the target range; this is not as easy as it sounds.

First, before engineers may address the power controls and heat values, they must first design the physical apparatus of the heating system itself. While it is possible to use independent heating elements and sensors, a more efficient design approach is to integrate the two, and—rather than mounting temperature sensors to take secondary external and internal measurements—to restrict the temperature sensors solely to the heating boards themselves. This eliminates several possible points of failure while also delivering the most accurate feedback possible regarding heat output. By combining a heating element and an integrated thermistor into PCB boards, the heating array may be safely and conveniently mounted to highly conductive radiators and then mounted within the display panel enclosure, giving the device a safe, unexposed, highly efficient heating element that provides constant feedback on its current temperature state.

Paring it Back to the Raw Essentials

However, because the temperature sensors (thermistors) of this system are integrated directly into the heater boards, the only temperature effectively measured will be the heat output at its source, on the element. This means that target temperature states must be defined not according to real time benchmarks taken from the current external temperature, but rather from the ratio of the element temperature to the current power input measured as a percentage of PWM. The formula used to derive this relationship is derived from the Electrical Power Equations:

$$\textbf{Heat Output}\ (Watts) = \chi \times \frac{V^2}{R}$$

χ = *Fraction of PWM duty cycles, by percentage (%)*

This is the governing equation at the heart of our intelligent heating system. The comparator uses it to decide whether to continue heating the system or to cut power and turn off the heater. The PWM controller uses it to evaluate how much power should be supplied to the heating element.

To make this arrangement work, every new platform design must be carefully analyzed in a lab to evaluate PWM output at various external temperatures. PWM output and ambient temperature form a two dimensional control domain, where an extremely wide array of data points must be measured and evaluated to establish the ratios where particular combinations of PWM output and the heater's temperature are able to maintain the system within the target temperature range (for our purposes, 0°C or above). To derive these ratios, temperatures are measured at various points within the computer (panel front, panel rear, enclosure front, and enclosure rear) as the two control values are manipulated across the full range of possible inputs. In this way, engineers are able to derive precisely what ratios of heat output to duty cycles produce the desired range of temperatures. Once these benchmarks have been established, the end result is that the system doesn't need to evaluate external temperatures. By reading only the current PWM output and the heating board's temperature, this heating solution is able to intelligently, efficiently maintain the system within a desired temperature range.

Building Conformity into Complex Systems: Resistors and Heat

Yet all of this is complicated by the peculiarities of hardware design. Each new hardware platform carries a unique heat profile, and behavior will change at different temperatures for different models. This is because heat is being generated not only by the heating element but also by the computer's internal components, and different platforms produce different heat profiles. Similarly, as components drop to very low temperatures unpredictable changes in performance occur at the component level, particularly among resistors. Through experimentation, Moxa has discovered that the changes in performance (Ω) that resistors experience as temperature drops will unpredictably alter PWM output at very low temperatures, distorting the relationship between PWM output and the heating element in unpredictable ways that can corrupt or even damage the heating system. For these reasons, an independent heat profile defined in terms of PWM duty cycles must be derived in the laboratory for each platform. This is the constant, labeled χ (chi) in the above formula.

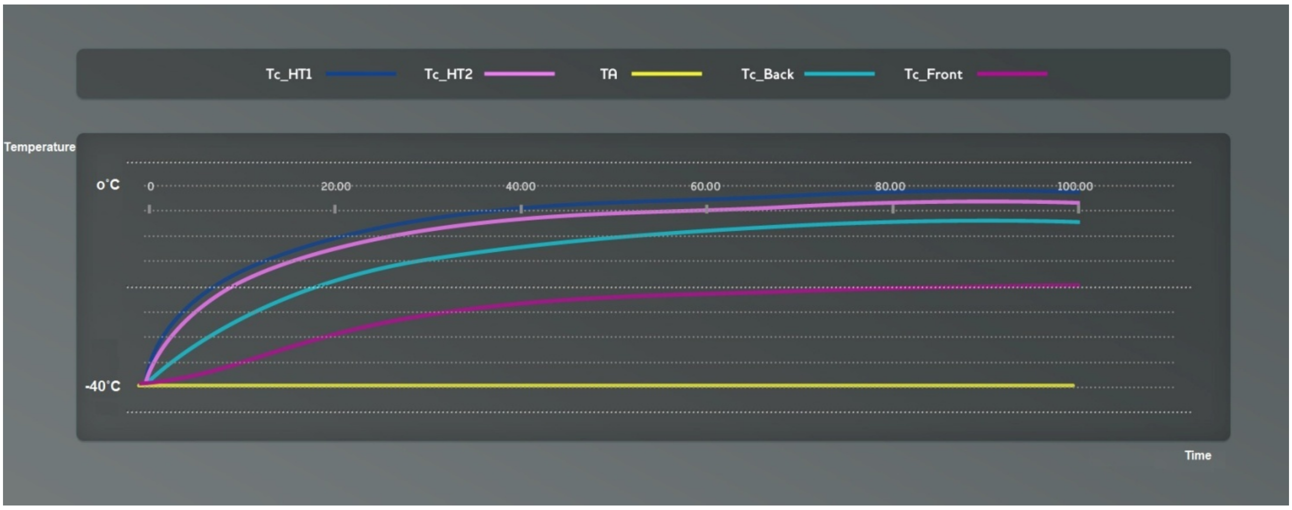

Figure 2: *The thermal curve of a computer heated from -40°C to 0°C over 40 minutes—notice its consistency.*
X-axis *is time (40 minutes),* ***Y-axis*** *is temperature.*

Tc_HT1 *= Heater Board A*
Tc_HT2 *= Heater Board B*
Tc_Back *= Temp. of enclosure's back panel (computer)*
Tc_Front *= Temp. of enclosure's front panel (LCD panel)*
TA *= Baseline environmental (ambient) temp.*

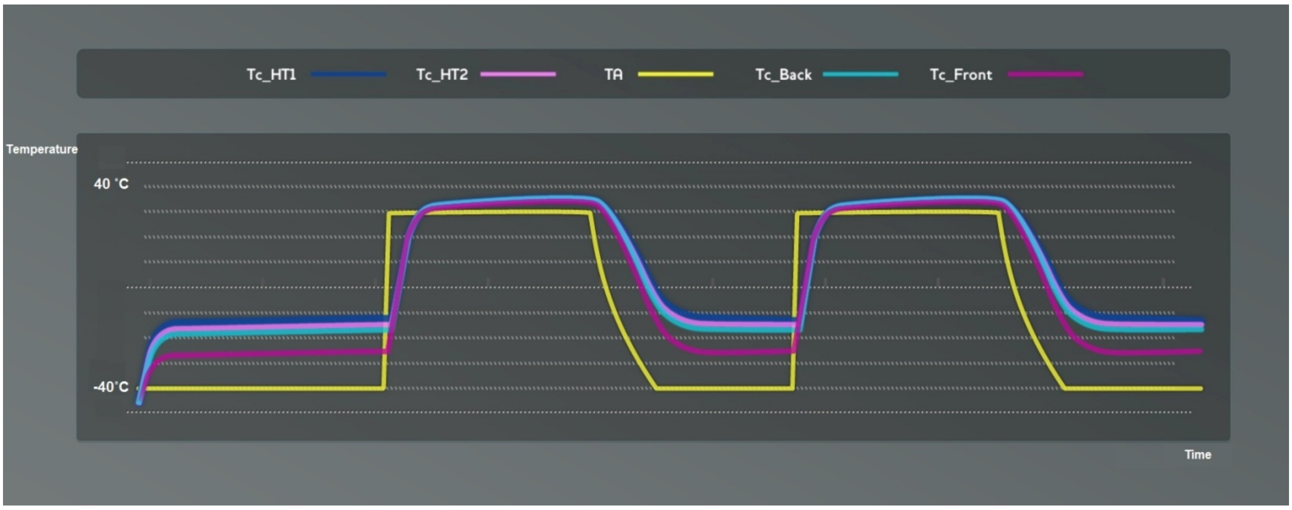

Figure 4: *Temperature response times over a period of two heat cycles totaling nearly 40 hours of continuous operation.*

This is a single test taken from late in the development of Moxa's Intelligent Heating System. ***X-axis*** *is time,* ***Y-axis*** *is temperature, in Celsius. Peaks are 30°C, lows are -40°C. Yellow line shows ambient temperature; the other lines represent benchmark locations within the platform. Rises in ambient temperature represent a period of about half an hour, decreases represent a period of about 2 hours.*

Showing How the System Works

By way of example, let us consider an automated heating system that has received a power-on signal. The heating system does not know that there are -40°C conditions outside; it is only aware that its thermistor (located on the same heating board as the heating element) is registering -40°C, so our heating solution automatically activates at full power. The heating subsystem continuously monitors PWM and heat output (via the thermistor), and as heating output rises these values are passed first through the comparator—which decides whether or not to continue powering the system—and then next, through the PWM duty cycle controller, which will decide how much power to cut (or add) depending on the ratio of PWM input to temperature output. Eventually, the system will heat to a temperature somewhere just beyond the 0°C point, whereupon the PWM controller will establish a state of equilibrium, supplying the heating element with a steady supply of power to maintain optimal thermal conditions. Now, our hypothetical computing platform may reliably operate with no worry of malfunction due to extreme cold. Later, should external temperatures heat up to 1°C, the heating boards will indicate to the comparator a temperature value that is out of the system's defined limits (~30°C), and the comparator will cut power to the heating system. The heat naturally generated by the system internals will keep the computer within reliable limits.

This is the sort of refinement and efficiency offered by proportional control; it is what puts the intelligence into an intelligent system.

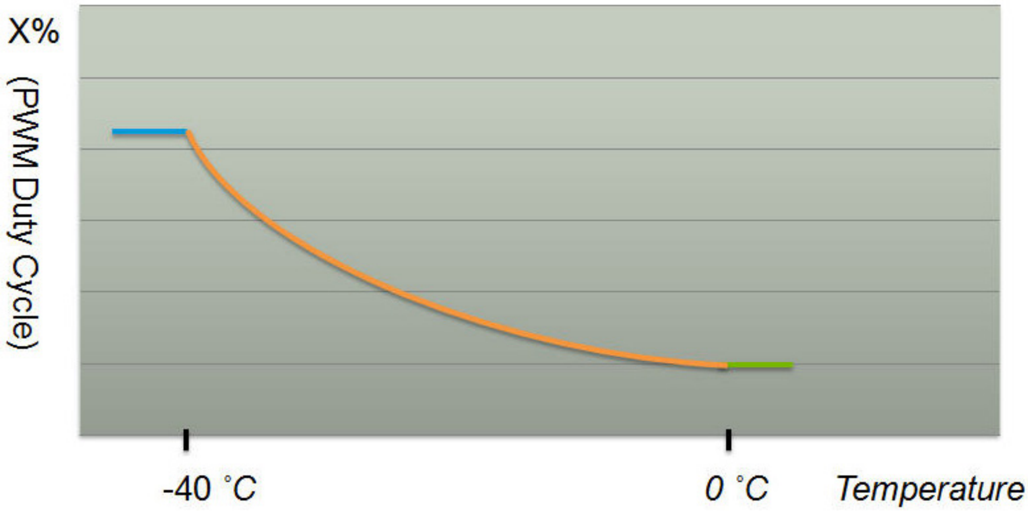

***Figure 3:** A curve showing power output relative to heat output, as a platform is heated from -40°C to 30°C*

One Final Failsafe

There is one last failsafe that an intelligent heating system requires, included not so much for the user as for the manufacturer: a fuse should be included, to safeguard against a heating system malfunction causing a full system burnout. While the likelihood of the heating element running out of control is extremely slim, to protect against the catastrophic consequences such an event might entail a fuse on the heater board is also provided, to provide a mechanical guarantee that whenever the heater's sensors rise to a temperature over 55°C the system will permanently disable itself.

By taking the time and care to select the right components, build effective system failsafes, and perform extensive testing and full platform profiling, a safe, reliable heating system will intelligently support computer operations over an extremely wide range of cold temperatures that would render other platforms useless.

Conclusion

Moxa's latest version of its Intelligent Heating Solution (IHS) is designed around a proportional controller, with careful attention paid to rigorous hardware specifications and thermal profiling. Utilizing two hardware patents developed specifically for IHS, Moxa's new heating solution makes our latest line of panel computers an ideal solution for outdoor applications that face the challenges posed by extremely low temperatures. Delivering the highest reliability and stability available even in low sub-zero temperatures (and an MTBF that compares to the best that industry has to offer), IHS allows our latest line of panel computers, the EXPC-1319, to be deployed in environments where computers were not feasible before.