Acromag, Incorporated
30765 S Wixom Rd, PO Box 437, Wixom, MI 48393-7037 USA
Tel: 248-295-0310 • Fax: 248-624-9234 • www.acromag.com

White Paper:

How to Select an Industrial PC with I/O for a Wide Temperature Application

Thermal management considerations when integrating I/O modules within a small, fanless box computer

High Temp in small spaces: Thermal management for the small box

As more embedded customers move from large rack based systems, such as VME and cPCI, into small boxes, designers need to take heat inside and outside the box into consideration.

Today's industrial and military customers are demanding computer systems that have the ability to operate in a wider array of applications than traditional industrial and commercial products were designed to survive. This includes not only the need for extended operating temperatures (-40 to +75^{o}C) but also the ability to survive in high shock and vibration environments.

At the same time, many of the systems used in these projects have been reduced to a CPU board and specialized I/O. This has led system designers to question the need for the expensive infrastructure of a VME or CompactPCI based system. To meet this need, they have started to look to small, box type computer packages – specifically the Industrial PC.

Industrial PC

The Industrial PC offers an assembled box, typically based on an Intel processor, with a fixed set of PC type I/O (Ethernet, USB, audio, video and serial I/O). At first glance, the Industrial PC would seem to offer the easiest path to a fully ruggedized, extended temperature design, since most of the key elements are controlled by the manufacturer. The container can be designed from the outset to control the internal temperature of the components with the use of vents, fans or conduction cooling. Internal cabling can be eliminated or reduced by moving the connectors on to the printed circuit board, thus minimizing shock and vibration issues. Finally, the components can be selected by the vendor to meet the design criteria of the expected application.

Figure 2: Acromag's I/O Server Industrial PC

What appears to be the strength of the Industrial PC can also turn into its weakness – expandability. If the user's application requires I/O (i.e. analog, digital or specialized serial I/O) beyond the limited set of I/O offered on the Industrial PC, the user is typically forced to add secondary devices to provide this I/O. This means added costs in hardware, cabling, power and, of course, space. Some manufacturers have tried to accommodate I/O needs by adding a PC/104 expansion slot inside their package. At first glance, this would appear to solve the problem, but now the work that went into designing a temperature controlled environment is now compromised by an uncontrolled element. How will the heat from the

Figure 3: I/O modules on an integrated carrier

expansion boards be dispersed? Can the power supply provide the required extra power needed by the expansion board? And finally, how is the added cabling/connector to the field handled?

To address this need, Acromag has introduced the I/O Server Industrial PC featuring an internal carrier card to interface a wide selection of related plug-in I/O modules. Designed specifically to work together, this combination of a rugged, fanless box computer and conduction-cooled I/O modules provides a truly integrated system for high-performance measurement and control projects. The I/O Server's enclosure, power supply and internal cooling are designed to allow the addition of up to four I/O modules without compromising the ruggedness or operational temperature range of the product.

Overcoming the Heat

When designing these smaller, flexible packages, product designers must take into consideration the full thermal management of the design. This means understanding where hotspots are located, how heat can be moved away from the electronics and where heat will travel before exiting the enclosure. If printed circuit boards are to be stacked, will heat rising from lower boards be captured and dispersed before it can affect boards above? Finally, the designer must consider how customers will use the finished product. Will the product always be oriented in an upright position or will some customers attach the device sideways on a wall or even upside down in a vehicle? All in all, accounting for these aspects can be a daunting task for the product's designers.

Designing the product's electronics must start with the selection and placement of components. To ensure proper operation across the full temperature range, components used in the design should be industrial rated (-40 to 85^{o}C). The designer must then carefully consider each component's location and how much heat it generates. When placing the hottest components, one has to consider how heat generated from that component will affect other components around it. The goal, of course, is to draw heat away from the component to outside the enclosure as quickly as possible. While even the best cooling techniques cannot prevent some heat from migrating across the board, the goal should be to minimize its affect on other components.

Cooling techniques

A wide range of techniques have been developed over the years to transfer heat out of the computer enclosure. These techniques include vents, fans and conduction cooling techniques. All work with varying level of success.

<u>Natural Convection</u>

Natural convection relies on the natural movement of heat from the hottest location to the coolest. The most common natural convection method is the use of vent holes. Vents holes are usually configured as a set of holes on at least two sides of the enclosure, thus allowing air to move through the enclosure cooling the electronics. The technique relies on heat rising off the electronics and moving out one vent, causing cool air to be drawn in through the other (referred to as the Stack Effect). Due to a vent's limited ability to provide sufficient air movement, it is generally restricted to cooling low power devices in benign environments. Natural convection also has a number of other drawbacks, particularly in applications where contaminants such as moisture, dust or corrosive gasses are an issue. For vents to work properly they must draw air from outside the enclosure, which allows contaminants to enter the enclosure and potentially damage the electronics.

Forced Convection

While natural convection relies on the heat source to create air movement, forced convection uses a mechanical movement to force a coolant across the components to draw heat away. In box-based designs, this typically means a fan blowing outside air through the box and out a vent. Although forced convection can cool more effectively than vents alone, they share similar problems. Both methods allow moisture, dust and contaminants to enter the enclosure, threatening the electronics. Concern also has to be given to what happens if/when the fan fails or becomes blocked; this could quickly lead to over heating and possibly failure of the electronics.

Conduction Cooling

Conduction cooling techniques used in Industrial PC type box designs typically fall into two categories – heat sinks and heat pipes. Both provide a mechanism to quickly move the heat to the body of the enclosure allowing the outside ambient air to draw the heat away. It is not uncommon to see both techniques used within the same enclosure depending on the placement of the electronics.

In box-based designs, one of the most efficient methods for cooling hot electronics is to use the body of an aluminum enclosure as a heat sink. This is done by bringing the electronics into contact with the body of the aluminum enclosure. This technique works both by absorbing the heat from a individual hot spot and dissipating heat over a large area (the enclosure) then transferring the heat to the cooler air on the outside of the enclosure. Cooling fins added to the outside of the enclosure further improve the efficiency. Fins provide both more surface area and a means of disrupting the air flow across the box, thereby improving thermal transfer. Figure 4 shows a typical heat sink example. A crucial heat sink design component is the thermal gap pad. This thermally conductive material efficiently transfers heat from electronic components to the heat sink by filling any gaps that may form. The thermal gap pad also prevents components from shorting to the metal enclosure when the product vibrates. It is crucial that the pad is of appropriate thickness to prevent compression or separation in high shock and vibration environments.

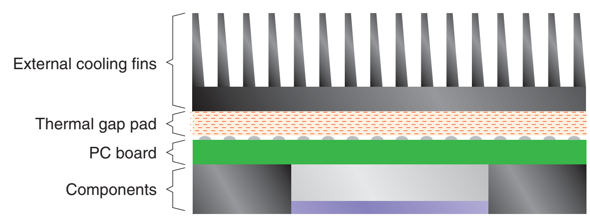

Figure 4: Cooling fins dissipate heat from the board

When electronics are stacked, one row above the other, a variation on the previous technique can be used. A heat spreader is added across the middle of the enclosure and connected to the enclosure's outside wall. The electronics on lower circuit boards then contact this heat spreader to move the heat to the enclosure body (heat sink). This method has the secondary benefit of capturing rising heat before it can affect electronics placed above. In designs that require customer access to the electronics, a friction plate allows the electronics to slide in and out without damaging the thermal gap pad (see Figure 5).

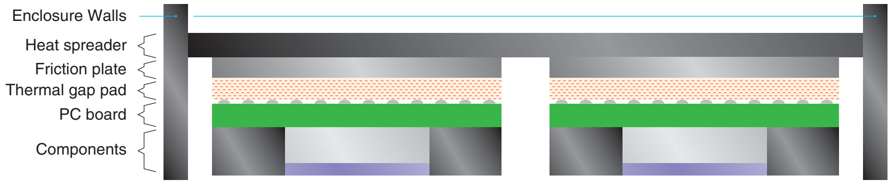

Figure 5: A friction plate and heat spreader use conduction to wick heat away from components to the external enclosure walls

Heat pipes rely on evaporative cooling effects caused by a temperature differential between two ends of the pipe. A fluid at the hot end of the pipe turns to a vapor; this vapor then flows naturally to the cool end of the pipe and condenses (see Figure 6). When particularly hot components are located away from the heat sink created by the enclosure, a heat pipe can be added to transfer that heat to the enclosures wall. Using heat pipes in a high shock or vibration environment requires care to prevent flexing that could create stress fractures. A vacuum is required for the heat pipe to operate efficiently. If the heat pipe cracks or a hole forms the vacuum can be lost, substantially lowering the effectiveness of the heat pipes. To help prevent potential damage, designers often encapsulate heat pipes in an aluminum block.

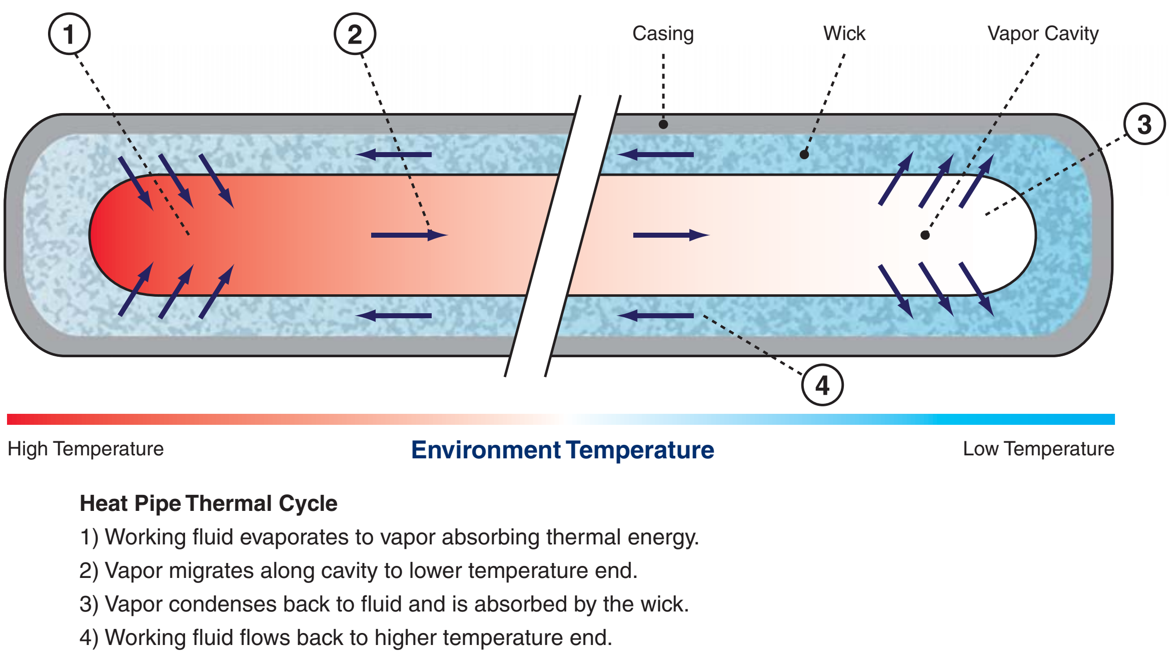

Figure 6: Diagram of a heat pipe

What happens when it gets cold outside?

Heat is often seen as the main culprit in failed electronics, but operating electronics below their rated operating temperature can also cause failures. This is particularly true in newer CPU designs. Product designers therefore must use care is selecting components that can specifically operate at the device's rated temperature. One would think that with all the heat generated within the enclosure that the designer could stretch the specification due to "self heating". Unfortunately, in a product that is designed to effectively move heat from inside the enclosure to the outside, there is very little self heating.

Summary

Well-designed box-based Industrial PC, offer a reliable solution to a wide array of applications. They can be used wherever the environment will permit. In industrial applications, a box's rugged design may allow placement on or near machinery without concern for the effect of heat, shock or vibration caused by the machinery. In addition to typical industrial applications, box-based designs are often well-suited for mobile application such as heavy moving equipment, trains and ships. The extended temperature specifications of these products mean they are also suitable for remote outdoor application where it is cost-prohibitive to build a climate controlled structure to protect sensitive electronics. When properly designed for wide temperature operation, box-based computer solutions can offer a rugged, reliable solution for a wide range of military, industrial and scientific applications.

About the Author:

Acromag is an international corporation that has been manufacturing and developing measurement and control products for more than 50 years. Acromag offers a complete line of industrial I/O products including process control instruments, distributed I/O systems, embedded I/O modules, and data acquisition boards.

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