

Thermal Management Techniques for VME Systems

Introduction

The VMEbus specification, when first introduced in the early 1980s, allowed for power dissipation of about 35 watts per card, depending upon ambient temperature. Throughout the 1990s, the trend has been toward packaging more compute power, I/O and storage functions per card cage slot. Indeed, device technology has advanced to give us lower power implementation of functions that would not have been possible 10 years ago.

One consequence of the trend towards miniaturization (known as scaling) is that it has also allowed us to package enough of these devices to approach and even exceed the 35W limit with increasing regularity. Exacerbating this trend, dense packaging has restricted airflow, making thermal management of critical importance in building high-reliability VMEbus systems.

Miniaturization can impact component reliability in several ways. First, it allows greater current densities and higher chip temperatures. Faster IC clock rates add to the increased currents. In addition, as package sizes are decreased, gate oxide thickness is also decreased. These thinner gates are more prone to electrostatic discharge and wear-out from hot electron bombardment. Although manufacturers incorporate protection from these effects in their chip designs, pushing the temperature limits on these parts can result in reduced reliability and shorter component life. Studies have proven thermal overload to be the leading cause of equipment failure.

This document details techniques for thermal management in VME systems. Topics we will cover include different VME rack cooling methods and their effectiveness, temperature measurement, power distribution, and maximizing air flow.

Section 1: Thermal Considerations

In an air-cooled VME system, there are many factors that can contribute to degradation of the cooling system's performance. Some of these are:

1.1 Thermal Shadows

Thermal shadows occur when a tall component sits ahead of a short component in the air stream. In this case, the stream flows over the tall component, never making laminar contact with the short component. In fact, a turbulent eddy often forms over the short component, trapping the heated air and causing severe overheating.

Resolution: This is a PCB level problem which can only be resolved by the board manufacturer. Its effects can be minimized, however, by designing for best possible air flow in the VMEbus system.

1.2 Open Front Panels

One cause of degradation in system cooling that many VMEbus card cage users are unaware of is uncovered VMEbus slots. Air leakage through the front panel disrupts the laminar flow of air inside the card cages, reducing the effective velocity of the airflow over the installed cards.

Resolution: This problem can easily be resolved by installing blank front panels to cover any unused VME slots. It is also helpful to redirect the air in the unused slot. Various card cage manufacturers make convenient baffle boards that can be installed in an unused slot to both close the front panel and block the airflow to the unused slot. Some of these boards also function as daisy-chain boards, containing jumpers for VME bus grants (BG01-3 in/out) and interrupt acknowledge (IACK in/out).

1.3 Heat Soak

Most of today's VMEbus designs are subject to a phenomenon known as Heat Soak. The unit operates within maximum temperature limits while power is applied to the fans, but when power is removed and the fans stop, the temperature rises for a few minutes even though the components are no longer under power. This is because the component density is too great to allow normal convection to remove the remaining heat. This residual heat build up can last from 10 to 20 minutes before it starts to ramp down in temperature. The elevated temperature can cause damage at the IC die level, and stress to the IC packages and solder joints.

Resolution: Fortunately the solution to the heat soak problem is straightforward: simply wire the fans in the card cage to the AC mains through a power switch independent of the switch used for the DC power supply. Allow the fans to remain in operation for at least 15 minutes after power is turned off. Note that separate switches for the power supply and fans are not standard in most VME chassis, but can usually be provided on special order.

1.4 VME Board Power Ratings

When configuring a system, power ratings of each board used should always be considered. While some boards may push the 35 watt limit per VMEbus slot, other boards may have low power ratings. Placing multiple high-power boards in adjacent slots will increase temperature in that part of the system.

Resolution: Alternate between high and lower power boards so that heat is more evenly distributed over the system.

1.5 VME Rack Power Supply Voltage Settings

VMEbus voltage limits are 4.875 volts minimum to 5.25 volts maximum. Most ICs have a minimum voltage rating of 4.75 volts, and many actually require a higher voltage for operation. If the VME rack is run at minimum backplane voltage, it may not be enough for some of these ICs. In addition, there is some improvement in noise margin at higher voltages. Power dissipation is approximately 13% higher at 5.25 volts as compared to 4.875 volts.

Unfortunately, running at maximum voltage rating (supply voltage 5.25V) will increase power dissipation to the overall system by approximately 7%, therefore causing system temperature to rise. Also, if the power supply is mounted ahead of the card cage in the air stream this effect is amplified. Alternately, the power supply itself can be affected if it is at the end of the air stream. Most power supplies are rated for room temperature, and begin to derate at around 50°C. Their output wattage derates as temperature increases since power supply components are less able to dissipate heat at higher temperatures.

Resolution: In most cases, operating at 5 volts will be enough to power all ICs, while not producing excess power to the system. The best setting will vary from system to system. Checking the backplane voltage for dynamic step response under load will help you to choose the lowest voltage setting that is efficient for your system. This should be checked from the VME backplane to the farthest VME board point from the power supply connection. It is also important to verify that backplane voltage is within spec over all of the slots.

1.6 Board Temperatures

Although manufacturers' board power ratings are a good starting point, they do not provide enough information to determine how hot a board is running. There is no way of knowing whether a manufacturer's power rating is conservative, or even accurate. In addition, other factors can add to board temperature.

Resolution: Air flow must be maintained in the three air paths through each VME board: the solder side of the board, the center path (inside) and the top side of any attached mezzanine module. The best way to determine how hot boards are running is to measure their exhaust temperature. Instructions and guidelines are provided in the next section.

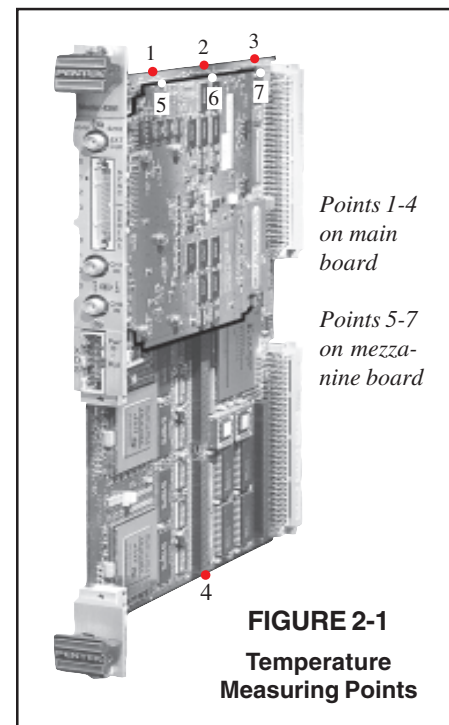
Section 2: Measuring Exhaust Temperature

A good way to know how well your VME board is being cooled is to measure temperature directly above the VMEbus slot in which it resides. Although most commercial grade products allow for maximum exhaust temperatures of 40 to 50°C, it is best to keep your system operating temperature below these maximum limits. Adding this safety margin will not only reduce the risk of thermal overload, but also help to extend the life of your system. Ideal operating temperatures are as follows:

Desired Target Exhaust Temperature: 35 to 40°C.

Maximum Exhaust Temperature with safety margin: 40 to 45°C.

Exhaust temperature can be measured with a temperature probe positioned as close as possible to the top card edge. For the most accurate reading, measure the temperature in three different places along this edge, from front to rear (Fig. 2-1, points 1-3 for main board or 5-7 for mezzanine board). An intake temperature measurement should be taken at the bottom of the main board (Fig. 2-1, point 4). A large difference (greater than 10°C) between the intake and exhaust temperatures indicates the need for more air flow.



Section 3: Cooling Methods

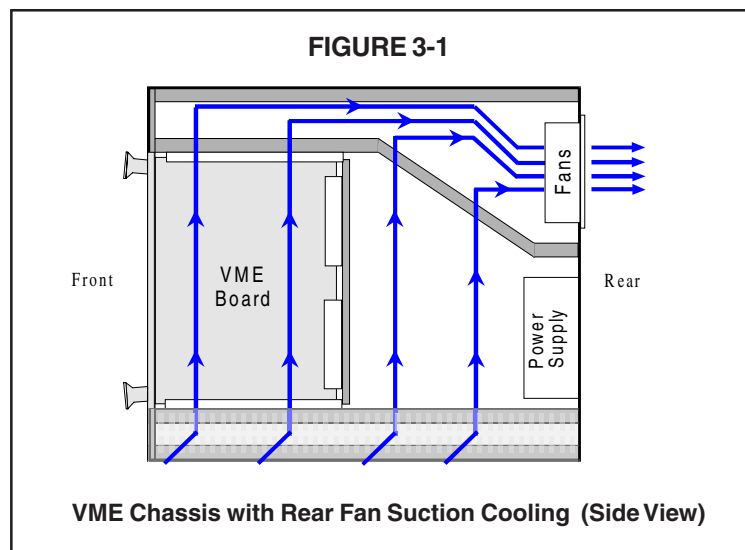
One of the first steps in putting together a VME system is choosing a chassis. There are several cooling methods available in VME chassis, each having different cooling capabilities and effectiveness. The most common of these methods are outlined below, starting with the least effective:

3.1 Convection Cooling

Convection cooling provides the least air flow possible. There are no fans in the VME chassis to release hot air from the system, so boards will inevitably run hot. This method is not recommended for any Pentek products, or most other VME applications.

3.2 Suction Cooling

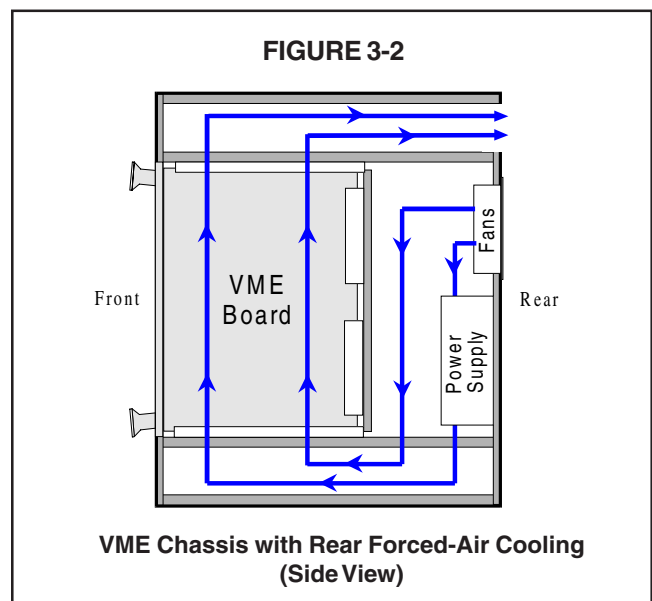
Suction cooling is featured in some VME chassis. Figure 3-1 illustrates a stand-alone version. Fans are mounted on either the back or top of the card cage, usually in racks of 3 with ratings of at least 70 CFM (cubic feet per minute) each. The fans draw hot air out of the system. Filters can be used to prevent dirt from being brought into the system, but this will decrease the effectiveness of the fans. Since fans can push more air than they can draw in, this method provides minimal cooling. It is also important to note that as the air restriction increases, the volume of moving air falls off faster than in a forced-air system. While it may be acceptable for small systems containing a few low-power VME boards, it is not recommended for most requirements.



3.3 Forced-Air Cooling

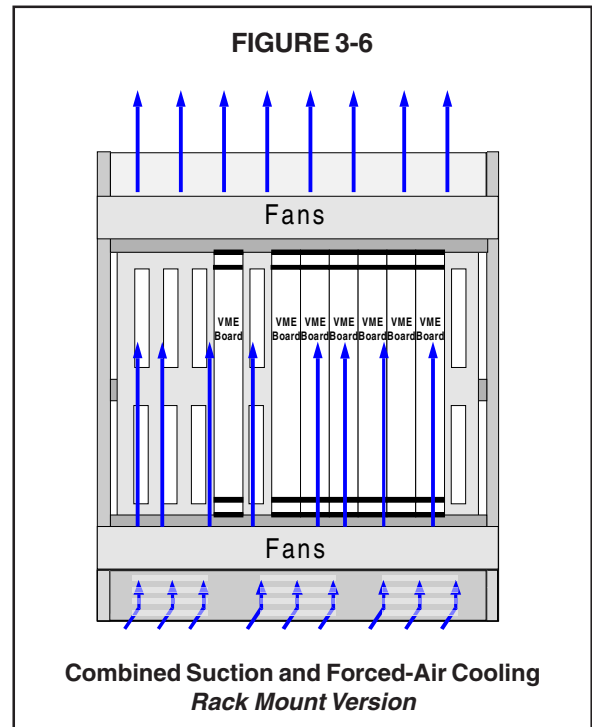
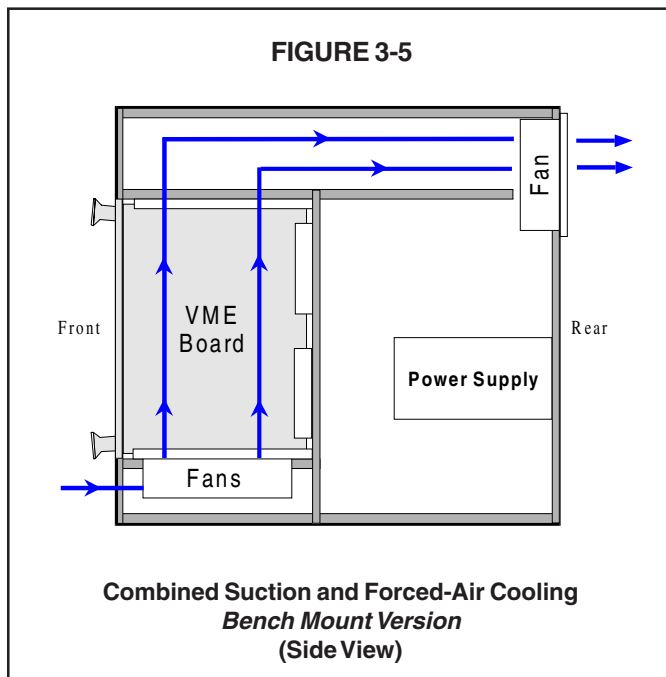
Forced-air cooling is more effective than suction cooling. It features fans mounted on either the rear or bottom of the card cage, pushing air out of the system. Fans vary in CFM rating, depending upon the size and power rating of the chassis.

Figure 3-2 shows a stand-alone system containing forced-air cooling by fans mounted in the rear of the chassis. Note that one drawback to this configuration is that the power supply is in the path of the incoming air flow. This means that air is actually heated by the power supply before reaching the VME boards. While the fans still will provide cooling for the system, the heat added by the power supply will somewhat diminish their effect.



3.4 Combined Suction and Forced-Air Cooling

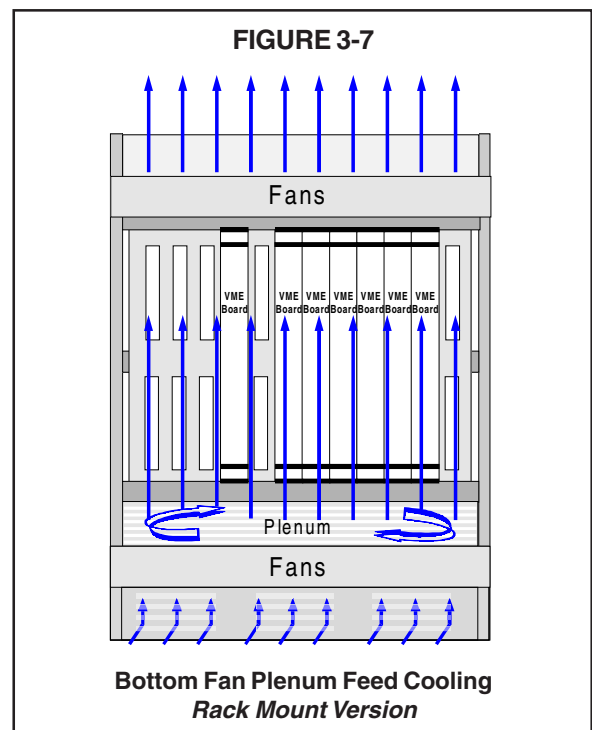
Some rack and chassis enclosures use both suction and forced-air cooling, therefore combining the effectiveness of both methods. Figure 3-5 shows a bench version with a chassis mounted in an enclosure, while Figure 3-6 shows a rack mount configuration. In the bench configuration, air is pushed through a set of 3 fans at the bottom of the chassis, and a rear fan is used to suck the air out. In addition, power supplies in this configuration are sometimes available with their own fan. In the rack configuration, a set of fans is placed at the bottom of the system pushing air through, while another set of fans at the top pulls air out. The rack configuration is more effective since it allows a direct air path, and more fans are used for suction; however, it requires extra rack space on the top and bottom. The enclosure in Figure 3-5 is preferable if you are short on space.



3.5 Bottom and Rear Fan Plenum Feed Cooling

In all of the configurations we've discussed featuring forced-fan cooling, there is always an uneven distribution of air through the fans. One way of solving this problem is to use a bottom or rear fan plenum feed. Figure 3-7 shows the same combined suction/forced-air rack system as Figure 3-6, but with plenum feed at the bottom. In this configuration, extra space is added between the fans and the VME boards, surrounded on all four sides by gasketing material such as rubber. This enclosed space allows the air to build up some pressure, and then flow through the system more evenly. As you can see, air is more evenly distributed over all of the VME slots.

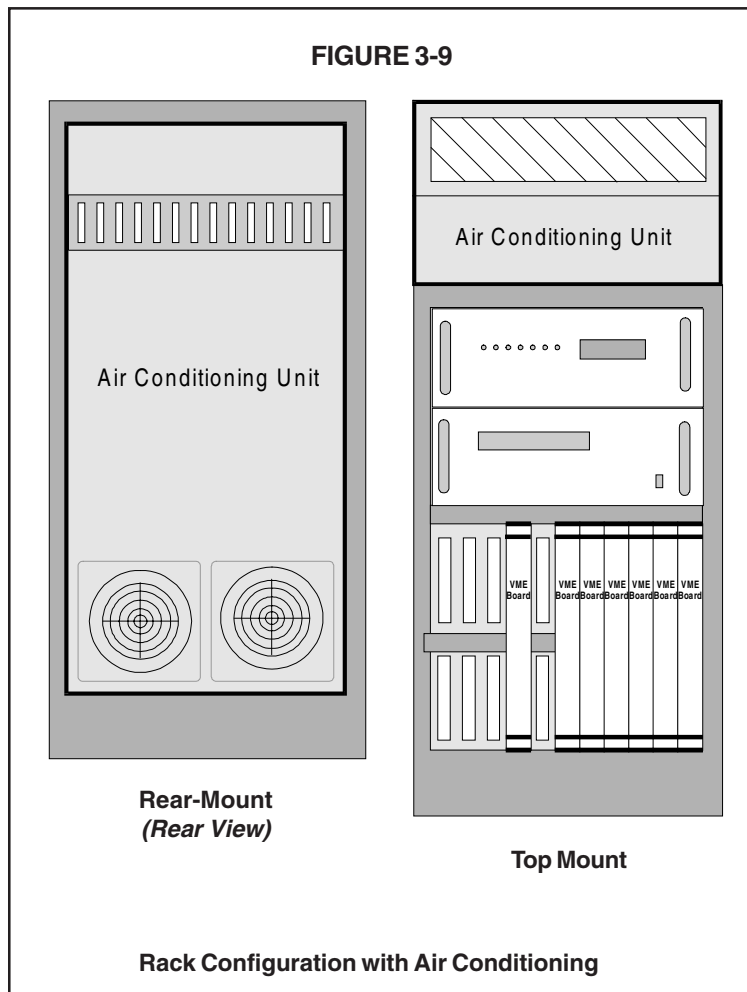
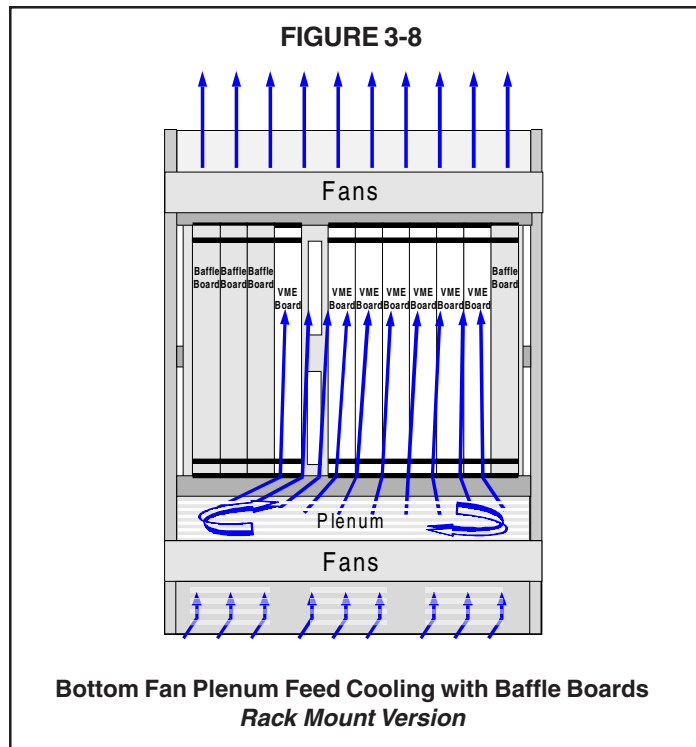
The bottom fan plenum feed cooling method shown in Figure 3-7 can be configured using standard racks and rack-mountable fans. Gasketing material will generally need to be purchased separately and installed by the user, although some chassis and rack manufacturers will build custom units based on customer requirements.



Baffle boards described in Section 3.3 are most effective with plenum feed configuration. When unused slots are blocked off, not only is air forced to go to the occupied slots, but air pressure to those slots is increased. Figure 3-8 shows how adding baffle boards to the same configuration increases air pressure to the VME boards.

While plenum feed is one of the most desirable cooling methods, it is generally not used as much as standard forced-air or combined forced-air/suction system. One reason for this is that it requires more rack space (height) than non-plenum systems; it is also not as easily available in bench-mount chassis configurations.

While plenum feed configurations are more efficient, a standard forced-air or combined system can suffice for most applications provided that proper steps are taken to make the maximize the efficiency of the cooling system.



3.6 Plenum Feed Cooling with Rack Fan Assist

In rack configurations, plenum feed cooling can be taken a step further by adding rack fans. These fans are usually located on the back, towards the bottom. They draw air into the rack, which in turn is drawn in by the plenum feed in each chassis. This is usually used in large rack systems which contain multiple stacked chassis.

3.7 Plenum Feed Cooling with Air-Conditioning Assist

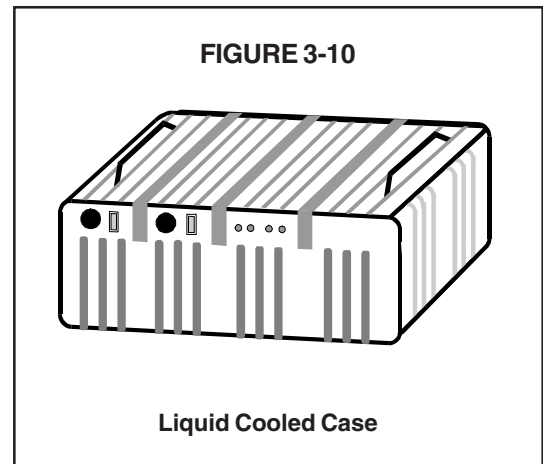
Rack cooling can be maximized by adding air conditioning. These are mounted on either the top or rear of the rack, maintaining constant internal temperature regardless of the ambient temperature.

This configuration occupies even more space, and is much more expensive than the others. It is usually used in large rack systems which are packed tight with boards, or contain boards which are extra-sensitive to changes in temperature and humidity. See Figure 3-9 for illustration.

3.8 Ruggedized Applications: Liquid Cooling

Liquid cooling is a very expensive, specialized cooling method in which boards are placed in an environmentally sealed case (usually aluminum), and VME cards are conductively cooled using heat sinks with liquid circulating through them. The casing provides full environmental, RFI/EMI and tempest protection, and is usually submersible up to approximately 15 feet.

When designing a system using liquid cooling, it is important to allow a long lead time since liquid cooling systems are made-to-order. It is also important to remember that once boards are mounted in the case, the user no longer has access to their front panels. Any front panel functions needed by the user should be accessible via external computer control.



Section 4: Fans

When selecting a VME chassis, there are usually different fans available. Some things to keep in mind when choosing fans and chassis configurations:

- Specifications to look for are cooling in CFM (cubic feet per minute) or LFM (linear feet per minute) and high static head pressure. A good fan cooling rating is approximately 100 CFM.
- The higher the CFM/LFM specification, the better.
- Ball bearing type fans have less drag than sleeved versions
- Fans last longer when they are mounted ahead of a heat source
- Fans move more air under pressure than in a vacuum
- Fans run best in the vertical position since there is less drag on end thrust bearings
- Having multiple fans in the system increases the safety margin if one fails.
- A dirty filter will diminish the fans' cooling effect on the system
- Dust and dirt on components (unfiltered system) will diminish the fans' cooling effect on the system

Section 5: The Future - Making Thermal Management Easier

Thermal management should be a priority in manufacturing VME boards. Pentek is taking several steps to help customers measure and manage temperature in their system. In the near future, you will begin to see new technology added to Pentek boards for thermal management including:

- Boards using new IC's which contain die mounted base/emitter junctions on the output pins for measuring temperature on the die directly.
- On-board voltage and temperature measurement and monitoring
- Front panel LED indicators for overheating.
- On board interrupt and status registers with environmental status indication for voltages and temperatures.

References:

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2. Krishna Seshan, Timothy J. Maloney, Kenneth J. Wu, "The Quality and Reliability of Intel's Quarter Micron Process," *Intel Technology Journal Q3 1998*
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