Cooling NI Single-Board RIO Systems

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1. Objective

Because of challenges meeting the thermal requirements of newer processors and FPGA's, system designers need to understand how to develop embedded single-board systems for their environment and have a degree of certainty knowing it will meet the thermal constraints when deployed. Different environmental and design factors can make this particularly challenging in still air (natural convection) environments or within sealed enclosures, even with today's lower power processors and FPGA's.

The objective of this white paper is to discuss some of the environmental and design factors that can impact the thermal performance of an NI Single-Board RIO system, and provide a few reference design examples that empirically demonstrate the impact with some common system configurations.

2. Problem Description

NI Single-Board RIO systems provide system engineers with the freedom to develop custom embedded solutions targeted to their specific needs. With this design freedom comes the challenge of determining what maximum ambient temperature a system may operate within, while still operating within the maximum local ambient around the circuit board and maximum case or junction temperature of critical components on the circuit card assembly.

3. Factors Impacting System

There are many factors developers must consider when designing their single-board system. These factors can be classified as environmental or design factors. Environmental factors are based on the location the system will be deployed. The developer may not have much, if any, control over these factors, but they must be considered, as they can impact the system design. Design factors are those controlled by the system engineer with the design, selection, or configuration of components within the system. The following environmental and design factors are typically the most common factors to consider when developing an embedded single-board system.

3.1. <u>Environmental Factors</u>

3.1.1. Ambient temperature

Ambient temperature can be confusing to describe depending on one's interpretation. It is always a good idea to clarify what is meant. There is the local ambient temperature around the circuit card assembly, inside the enclosure (away from the circuit card), outside the enclosure, and, if the enclosure is part of a larger system, around the system itself. Self-heating caused by the circuit card or other equipment in the system can affect ambient temperatures at these various locations. For example, the ambient temperature in a room will not be the same ambient temperature around the circuit card when it is installed in an enclosure.

3.1.2. Moisture, particles, dust, corrosive chemicals, etc.

These embedded systems are also commonly deployed in harsh environments where moisture, airborne particles or dust, or corrosive chemicals are of concern. These types of environments can affect the IP rating and materials required for an enclosure. When ventilation is not allowed, the circuit card must rely heavily on heat transfer via conduction or convection to the enclosure case. Heat transfer through the air inside the enclosure is not very effective because air is a thermal insulator. This may not be a problem if the ambient temperature around the enclosure is low enough to allow for the self-heating. However, the heat transfer may be improved with the addition of a heat spreader that conducts heat directly from the circuit card to the enclosure.

3.1.3. Airflow

Single-board systems are commonly deployed in rugged environments without fans or other forced air movement; therefore, they must rely on natural convection to cool the system. Component temperatures can differ significantly depending on still or moving air.

3.1.4. Physical space constraints

The physical space constraints of a system can impact the amount of self-heating around a circuit card or enclosure. The more restrictive the space, the more self-heating may increase the local ambient around the circuit card or enclosure.

3.1.5. External heat sources (surrounding components or equipment)

Embedded control systems are commonly deployed around or near other heat generating equipment or machinery. The heat generated by these external sources can directly affect the ambient temperature around the enclosure or circuit card. In addition, when installed in a suitable enclosure, these systems may also be deployed in outdoor applications where they may be exposed to the sun. The added affect from the solar radiation can significantly increase the ambient temperature inside the enclosure. Special considerations should be taken to reduce this impact, such as shading the system or choosing an enclosure that has appropriate radiation absorptivity, reflectivity, and emissivity properties.

3.2. Design Factors

3.2.1. Enclosures

The enclosure requirements can be heavily dictated by the environmental factors of the installation location. In addition, systems engineers may be either selecting an off-the-shelf enclosure, choosing from a myriad of types and options for one that meets their requirements, or designing a custom enclosure specifically suited to their needs. In either case, the enclosure material and size can greatly impact the system's thermal performance.

3.2.1.1. Enclosure Material

The enclosures will typically be a conductive metal, such as steel or aluminum, or an insulating material, such as plastic or fiberglass. Metals can allow for a better ability to conduct heat away from the circuit card if heat spreaders or heat sinks are used to create a conduction path between the circuit card and enclosure. An insulating enclosure material could help thermally isolate the circuit board from the surrounding environment which could result in substantially increased temperatures inside the enclosure.

3.2.1.2. Enclosure Size

A smaller enclosure may create more self-heating around the circuit cards due to the restricted air space, resulting in a higher temperature rise between the air inside and outside the enclosure. A larger enclosure can reduce some of the self-heating effects, but could also increase the length of the conduction path between the circuit card and enclosure.

3.2.2. Thermal Solutions

There are many types of thermal solutions to consider when designing a system. Most commonly, system designers may consider adding heat spreaders or heat sinks directly to the circuit card, but may also consider adding vents or fans to their enclosure.

3.2.2.1. Heat Spreaders and Heat Sinks

When properly designed, the addition of heat spreaders or heat sinks can help improve the thermal performance of a system by conducting heat away from the circuit card or hot components, spreading the heat load to reduce or eliminate hot spots, or increasing the convection of heat away from the circuit card into the surrounding air. This can reduce the local ambient temperatures and lower the component temperatures on the circuit card. To reduce surface resistivity, thermal interface materials, such as gap pads or thermal greases should be used between circuit card components and heat sinks or heat spreaders. When using a heat spreader inside an enclosure, greater thermal performance can be achieved by sinking the spreader to the enclosure wall.

It is recommended to use the available NI thermal kit which includes a heat spreader and gap pad designed to optimize heat transfer from the circuit card. This heat spreader may already be pre-attached for SOM cards. Alternatively, the thermal pedestal and gap pad features of the thermal kit could be designed into the geometries of the enclosure or custom heat spreader/sink.

3.2.2.2. Vents

Adding vents to the enclosure helps reduce the internal ambient temperature by allowing air to escape to the surrounding environment, thus reducing some of the self-heating effect. In natural convection environments, vents may only have a minimal impact on internal ambient temperatures or component case temperatures.

3.2.2.3. Airflow

Adding airflow into the system or enclosure by the use of fans or blowers can greatly improve the thermal performance of the system. Convection is improved, reducing component and surface temperatures. Typically, ambient specifications are defined in still air. With the addition of forced air, the ambient temperature measurements are generally less reliable as a measure of thermal performance. Surface and/or component case temperature measurements are more reliable to compare between still and forced air configurations.

3.2.3. Mounting

The ways in which a circuit card or enclosure are mounted can impact the thermal performance of the system. In particular, the type of surface being mounted to and the orientation of the circuit card or enclosure should be considered.

3.2.3.1. Mounting Surface

The surface a circuit card or enclosure is mounted to could vary from a flat mounting panel, a wall, or a piece of machinery. Similar to the enclosure materials, mounting the enclosure or circuit card to a conductive surface, such as a steel or aluminum panel, can aid in conduction from the enclosure or card to the surface, thus reducing temperatures on or around the circuit card. The surface finish can impact the resistivity of the thermal interface between parts. Rough, textured, or painted surfaces will be more resistive than smooth or uncoated surfaces.

3.2.3.2. Orientation

Mounting orientation can impact how well heat dissipates from an enclosure or circuit card. Typically, mounting such that the PCB is oriented vertically will improve the convection of heat away from the card. When the system is rotated, local ambient temperatures, component temperatures, and hot spots may change.

3.2.4. Carrier or RIO Mezzanine Cards

Many NI Single-Board RIO systems contain expansion connectors that provide direct access to digital or analog I/O lines, or other processor-specific functions or I/O. System designers may use these expansion connectors to develop custom daughter cards to fit their specific applications. The NI Single-Board RIO will be capable of supplying and/or receiving a specified maximum electrical power through the expansion connectors, but the thermal dissipation of this power must be considered, as it can impact the achievable ambient temperature of the system. A system engineer must consider the total power being dissipated on the expansion card, the power density on the expansion card (i.e. local high power "hot spots"), and where the power is being dissipated (all on the expansion card, or distributed to other parts of the system via cables, for example). In particular, the local ambient in the region between circuit cards can be significantly hotter than the air on the opposite sides of the circuit cards or other areas within the enclosure, even on lower power expansion boards.

3.2.5. System Stressing and Software Applications

Each user's application may stress the system differently; therefore, dissipating different power. In order to validate the thermal performance of a system, National Instruments tests our products by maximizing the I/O, processor, and FPGA utilization in order to dissipate the maximum power reasonably achievable. It is recommended for systems designers to thermally validate their systems while running applications consistent with their final deployment.

4. Summary

When system engineers perform thermal validation of their system, it is recommended to use the real software applications, hardware configurations, and enclosures in an environment that closely mimics the deployed location. When possible, testing in the actual final deployed environment is preferred. When these environmental and design factors are considered and appropriately accounted for in a system design, system engineers will have a much higher level for a successful deployment of their system and improved long-term reliability.

5. Appendix – Reference Examples

See supplemental documents for examples of various sbRIO systems.