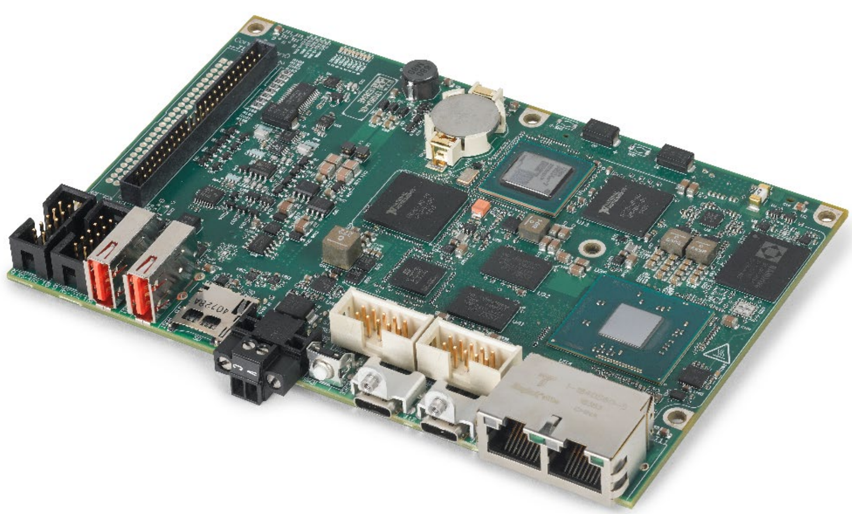
Cooling NI Single-Board RIO Systems

Appendix: Reference Examples
NI sbRIO-9609/29

1/2/2020



1. Introduction

The NI sbRIO-9609/29 product typically operates as a component in a higher-level system in which the thermal performance of the sbRIO is greatly influenced by several factors including resource utilization, mounting, and adjacent power dissipation. It is the responsibility of the system integrator to consider enclosure size, materials, heat spreading or sinking solutions, and other mounting conditions when designing a system to ensure the sbRIO remains within maximum allowed temperature ranges.

The following document is intended to provide high-level examples of the thermal limits for an sbRIO-9609/29 product when integrated into a few example system configurations, and assuming maximum achievable thermal dissipation. These thermal reference examples explore enclosure choice, RMC expansion board power dissipation, and LVDS output as factors in the overall thermal performance of the NI sbRIO-9609/29.

It will be shown that integrating an sbRIO into an enclosure introduces self-heating around the sbRIO, resulting in a lower achievable external ambient for the system, and further, that the enclosure material can play a role in the magnitude of the self-heating. Additional RMC expansion board power dissipation adjacent to the sbRIO-9609/29, or use of advanced features such as LVDS output, can further increase the self-heating and further reduce the achievable external ambient.

It is important to note the sbRIO-9609/29 products possess a powerful quad-core CPU intended for high demand applications. With significantly higher thermal dissipation compared to other sbRIO models, the sbRIO-9609/29 will require a more robust thermal solution if operating at a high resource utilization. To protect itself, the CPU reduces its operating frequency when the die temperature reaches 108 °C. Testing has shown that without a thermal solution present, a fully utilized sbRIO-9609/29 CPU will reduce its operating frequency in many room temperature or below environments. For optimum performance, it is highly recommended that the sbRIO-9609/29 always be used with a properly designed thermal solution, such as the NI Thermal Kit for CompactRIO Single Board Controller with DAQmx. Unlike the thermal reference example documents for other sbRIO models this document will only cover installations which include a thermal solution.

When comparing the most favorable test results to the least favorable, an sbRIO-9609/29 mounted with a heat spreader but otherwise with little consideration to thermals may induce a 24 °C, or greater, penalty to the system's achievable external ambient when compared to an sbRIO-9609/29 integrated in an ideal manner.

It is important to acknowledge the following results are specific to the enclosure size, enclosure material, mounting orientation, and resource utilization used for testing. The system integrator should weigh these considerations when determining how relevant the reference examples may be to any additional system configurations.

2. NI sbRIO-9629 General Setup

Device Under Test (DUT): NI sbRIO-9629

Equipment and Testing Supplies:

Test Equipment:

- Power Supply
- I/O Connectors and Cables
- RMC Resistor Load Test Board (used to simulate added power from an RMC)
- Thermal Kit for sbRIO-9603/08/09/28/29/38 (NI P/N 787331-01)

Enclosures:

- Large Fiberglass Enclosure – 12.0"x10.0"x6.34"
- Aluminum Panel (To mount the NI sbRIO-9629 for open air and inside the large enclosure)

- Small Metal Enclosure – 10.2"x6.3"x3.6"

NI sbRIO-9629 DUT Preparation:

- Thermocouples were mounted to critical IC cases.
- Six local ambient thermocouples were mounted approximately 0.2" away from the PCB on either side of the NI sbRIO-9629
- Wires were connected in order to measure the power dissipated by the DUT

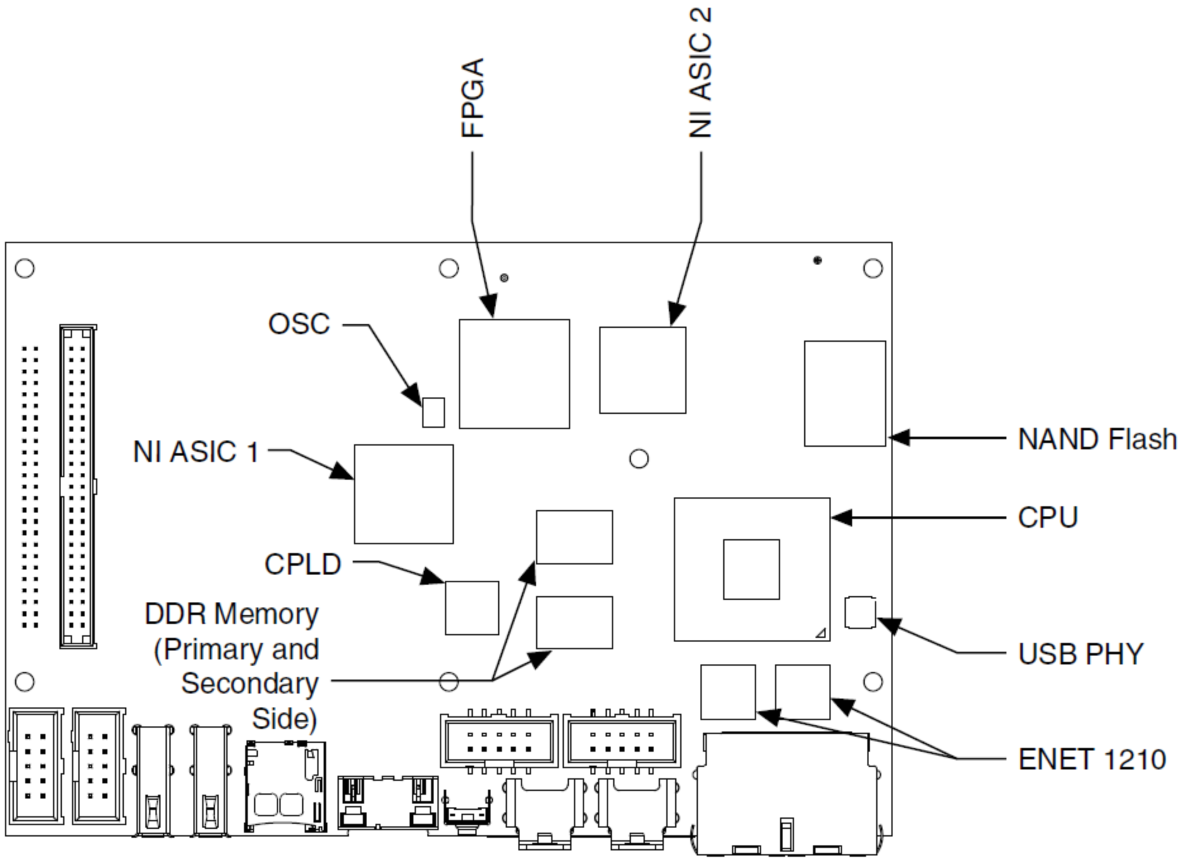


Figure 1: Thermally relevant component designation on NI sbRIO-9609/29

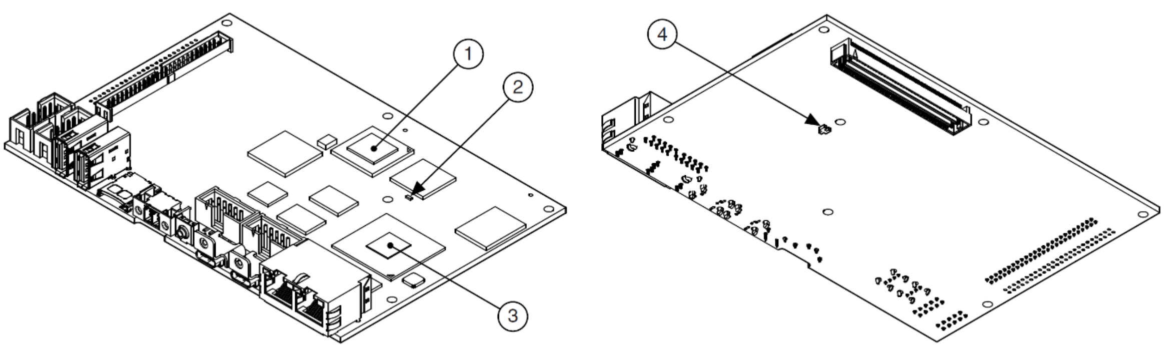


Figure 2: Digital thermal sensors designation on NI sbRIO-9609/29

Designation	Components
1	FPGA Sensor, U11
2	Primary System Sensor, U18
3	CPU Sensor, U36

4	Secondary System Sensor, Q24

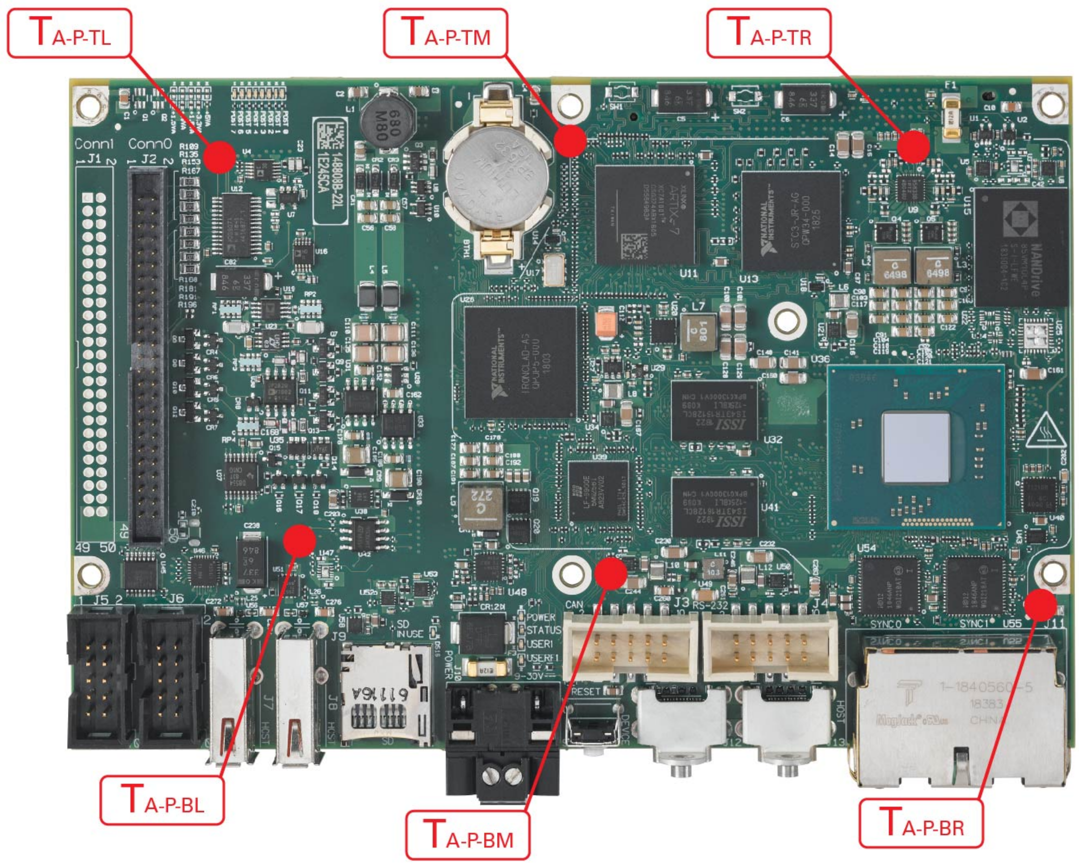


Figure 3: Thermocouple locations for Local Ambient temperature measurement, Primary Side shown. Measurements repeated on secondary side.

RMC Resistor Load Test Board Preparation:

- 4.05"x6.05" PCB
- Load resistors to provide even power distribution on both sides of PCB (e.g. 3W RMC test board is 1.5W on each side)

Software:

- A system stress-and-verify VI is run
  - Stresses the CPU and FPGA to max achievable power*
  - Performs write, read back, and verify tests to USB Flash drives, microSD card, DDR memory, and the NAND flash
  - Stresses and verifies all I/O

*The power dissipation of the FPGA is drastically increased when utilizing LVDS outputs. Utilization of all 45 channels of LVDS outputs is a rare use case and could have substantial impacts on the achievable external ambient of an sbRIO installation. For this reason, Examples 1 – 2 below only exercised the FPGA to max achievable power without any channels of LVDS output. Example 3 below explores the additional impact to achievable external ambient when adding LVDS output to an installation. Due to Artix 7 FPGA technology used, LVDS inputs have a near negligible effect on thermal performance when compared to LVDS outputs.

Measurements:
The following table provides the channel, name, and description of the thermocouples that were measured during the tests, as well as the maximum allowed temperature for critical ICs and ambient locations for the NI sbRIO-9629 as defined in the user manual.

NI recommends using digital validation. The sbRIO-9629 includes four onboard temperature monitoring sensors to simplify validation of a thermal solution. The sensors measure the CPU and FPGA junction temperatures as well as printed circuit board temperatures that can be used to approximate the primary and secondary side local ambient temperatures. This approach is called digital validation.

The digital approach is more accurate for determining the performance of the CPU/FPGA but is more conservative for determining the local ambient temperatures. If the reported Primary System temperature or reported Secondary System temperature exceed the maximum temperatures listed in this document, then analog validation using thermocouples may be used for further verification.

Table 1: Monitored components on sbRIO-9629

Name	Description	Max Allowed (°C)	Comments
$T_{SEN\text{-}CPU\text{-}0}$	CPU Core 0 On-Chip Temperature Reading	108	Use digital approach to ensure the on-chip temperature reading is below 108°C*
$T_{SEN\text{-}CPU\text{-}1}$	CPU Core 1 On-Chip Temperature Reading	108	Use digital approach to ensure the on-chip temperature reading is below 108°C*
$T_{SEN\text{-}CPU\text{-}2}$	CPU Core 2 On-Chip Temperature Reading	108	Use digital approach to ensure the on-chip temperature reading is below 108°C*
$T_{SEN\text{-}CPU\text{-}3}$	CPU Core 3 On-Chip Temperature Reading	108	Use digital approach to ensure the on-chip temperature reading is below 108°C*
$T_{SEN\text{-}FPGA}$	FPGA On-Chip Temperature Reading	98	Use digital approach to ensure the on-chip temperature reading is below 98°C
$T_{C\text{-}DDR\text{-}1}$	DDR Case, First Primary Side Chip	95	One of two DDR chips located on primary side
$T_{C\text{-}DDR\text{-}2}$	DDR Case, Second Primary Side Chip	95	One of two DDR chips located on primary side
$T_{C\text{-}NAND}$	NAND Flash Case	91	
$T_{C\text{-}CPLD}$	CPLD Case	94	
$T_{C\text{-}USB}$	USB PHY Case	120	
$T_{C\text{-}ENET\text{-}1}$	ENET I210 Case, First Chip	95	
$T_{C\text{-}ENET\text{-}2}$	ENET I210 Case, Second Chip	95	
$T_{C\text{-}ASIC\text{-}1}$	NI ASIC 1 Case	120	
$T_{C\text{-}ASIC\text{-}2}$	NI ASIC 2 Case	116	
$T_{C\text{-}OSC}$	OSC Case	112	
$T_{C\text{-}SD}$	microSD Card Case	85	Industrial temperature rated, such as NI P/N 786913-01 or 786989-01.
$T_{A\text{-}P\text{-}SEN}$	Digitally Reported Primary Side Local Ambient	85	Conservative approximation of the local ambient temperature

$T_{A\text{-}S\text{-}SEN}$	Digitally Reported Secondary Side Local Ambient	85	Conservative approximation of the local ambient temperature
$T_{A\text{-}P\text{-}TL}$	Primary Side, Top Left Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}P\text{-}TM}$	Primary Side, Top Middle Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}P\text{-}TR}$	Primary Side, Top Right Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}P\text{-}BL}$	Primary Side, Bottom Left Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}P\text{-}BM}$	Primary Side, Bottom Middle Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}P\text{-}BR}$	Primary Side, Bottom Right Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}TL}$	Secondary Side, Top Left Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}TM}$	Secondary Side, Top Middle Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}TR}$	Secondary Side, Top Right Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}BL}$	Secondary Side, Bottom Left Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}BM}$	Secondary Side, Bottom Middle Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}S\text{-}BR}$	Secondary Side, Bottom Right Local Ambient	85	Mounted 0.2" off PCB
$T_{A\text{-}Ext}$	External Ambient (Room Ambient)	NA	Average of two thermocouple measurements

* The CPU reduces its operating frequency when the die temperature reaches 108 °C. NI recommends keeping the die temperature below 108 °C to guarantee optimal performance. Refer to the *CompactRIO Single Board Controller with DAQmx Hardware Installation Manual* for information about monitoring the CPU die temperature.

Note: IC case temperatures were either obtained from manufacturer's datasheets or calculated using the formula:

$T_J = T_C + P \times \Theta_{J\text{-}C}$

Where:

T_J – Junction Temperature

T_C – Case Temperature

P – Power Dissipation (From Datasheet, Measured or Estimated)

$\Theta_{J\text{-}C}$ – Junction-Case Thermal Resistance

Test Procedure:

- Testing was conducted at room temperature
- The NI sbRIO-9629 was mounted as described by the examples in the following sections
- The NI sbRIO-9629 was powered at 30V
- The system stressing VI was configured and run
- The system was allowed to reach steady state
- Temperature measurements were logged

3. Example 1 – NI sbRIO-9629, Open Air vs. Enclosure Size, With Thermal Solution

3.1. *Test Description*

In this example, the NI sbRIO-9629 was configured with a heat spreader and installed in open air and with varying enclosure sizes/materials to show how the enclosure affects the self-heating around the circuit card. This Example does not exercise the LVDS features of the FPGA. See Example 3 for more information on the additional thermal impacts of using LVDS.

3.2. *Test Results Summary*

The self-heating around the NI sbRIO-9629 is increased by adding an enclosure, resulting in a lower achievable external ambient.

In this set of examples, with the heat spreader present, the digitally reported primary side local ambient has the lowest margin for configurations A and B, in the open air and the large fiberglass enclosure, respectively. The lowest margin component in configuration C, using the small metal enclosure, was the microSD card. Extrapolating to the maximum allowed component temperatures of the sbRIO-9629, the estimated maximum achievable external ambient for each configuration is shown in the following table.

Table 2: Maximum achievable ambient – open air vs. enclosure size with thermal solution

Configuration	**A** (Open Air)	**B** (Large Fiberglass Enclosure)	**C** (Small Metal Enclosure)
Max Achievable $T_{A\text{-}Ext}$ (°C)	63.1	52.4	60.2

Comparing configuration A to configuration C, the addition of a large fiberglass enclosure around the sbRIO-9629 results in an approximate 11 °C decrease in the achievable external ambient for the system. The small metal enclosure, being more thermally conductive, provides some improvement in self-heating and only reduces the achievable ambient by 3 °C compared to open air.

3.3. *Test Setup*

- In this example, the NI sbRIO-9629 was installed with a heat spreader attached (NI P/N 787331-01). No RMC was installed (i.e. controller only).
- The NI sbRIO-9629 was mounted such that the heat spreader directly contacted the metal mounting surface.
- (A) Open Air Configuration – The NI sbRIO-9629 was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9629 was mounted to a metal panel and installed into a large fiberglass enclosure. The enclosure was oriented such that the PCB was vertical during testing, as shown in the following images.
- (C) Small Metal Enclosure – The NI sbRIO-9629 was mounted directly to the side wall of a small aluminum enclosure. The enclosure was oriented such that the PCB was vertical during testing, as shown in the following images.

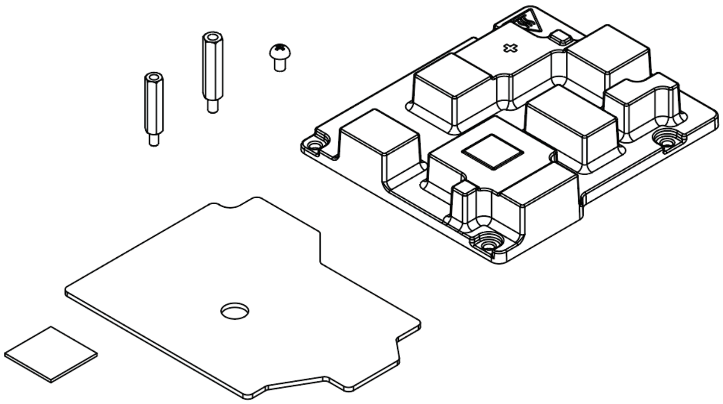


Figure 4: Thermal Kit (NI P/N 787331-01)

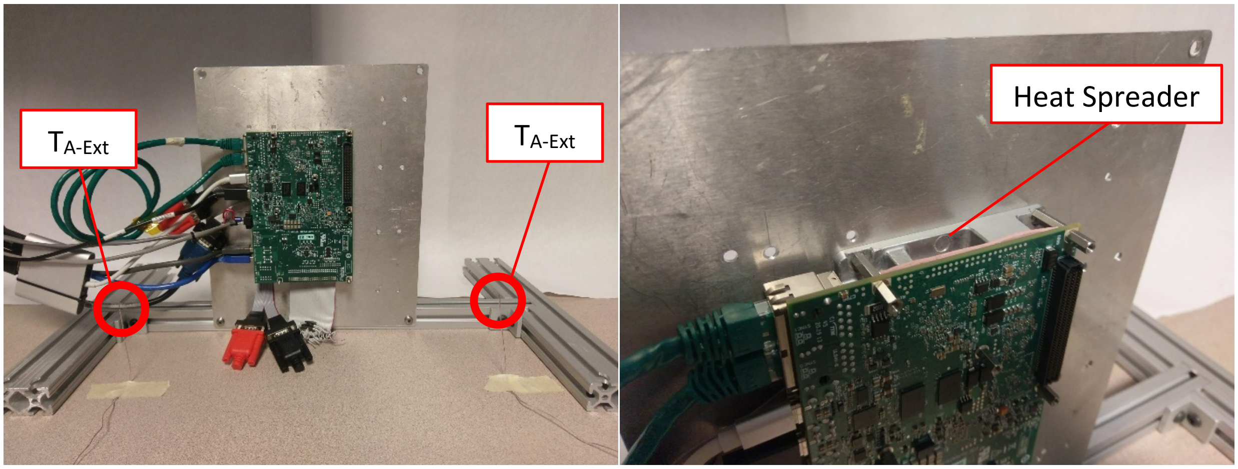


Figure 5: Configuration A – NI sbRIO-9629 with heat spreader in open air

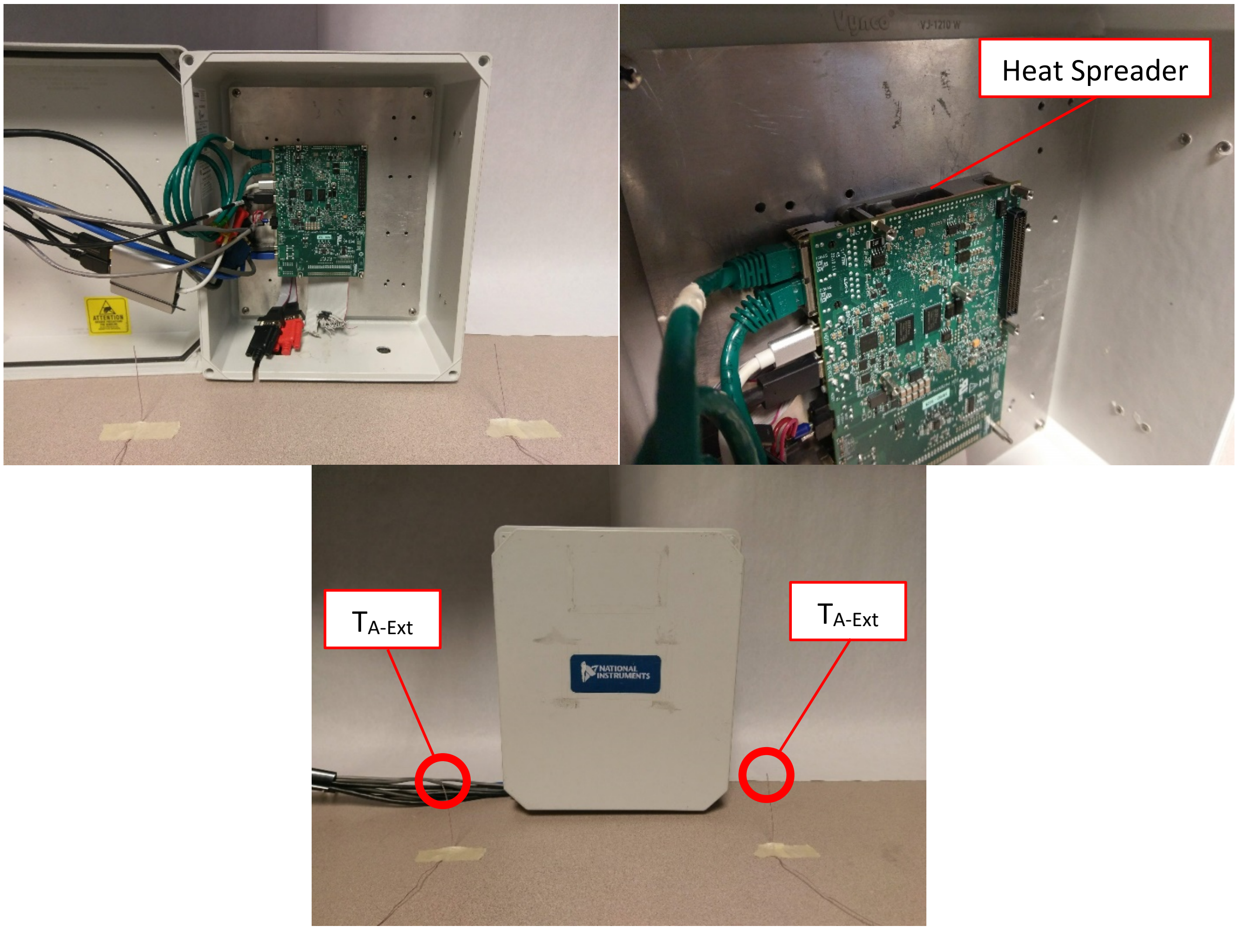


Figure 6: Configuration B – NI sbRIO-9629 with heat spreader in a large fiberglass enclosure

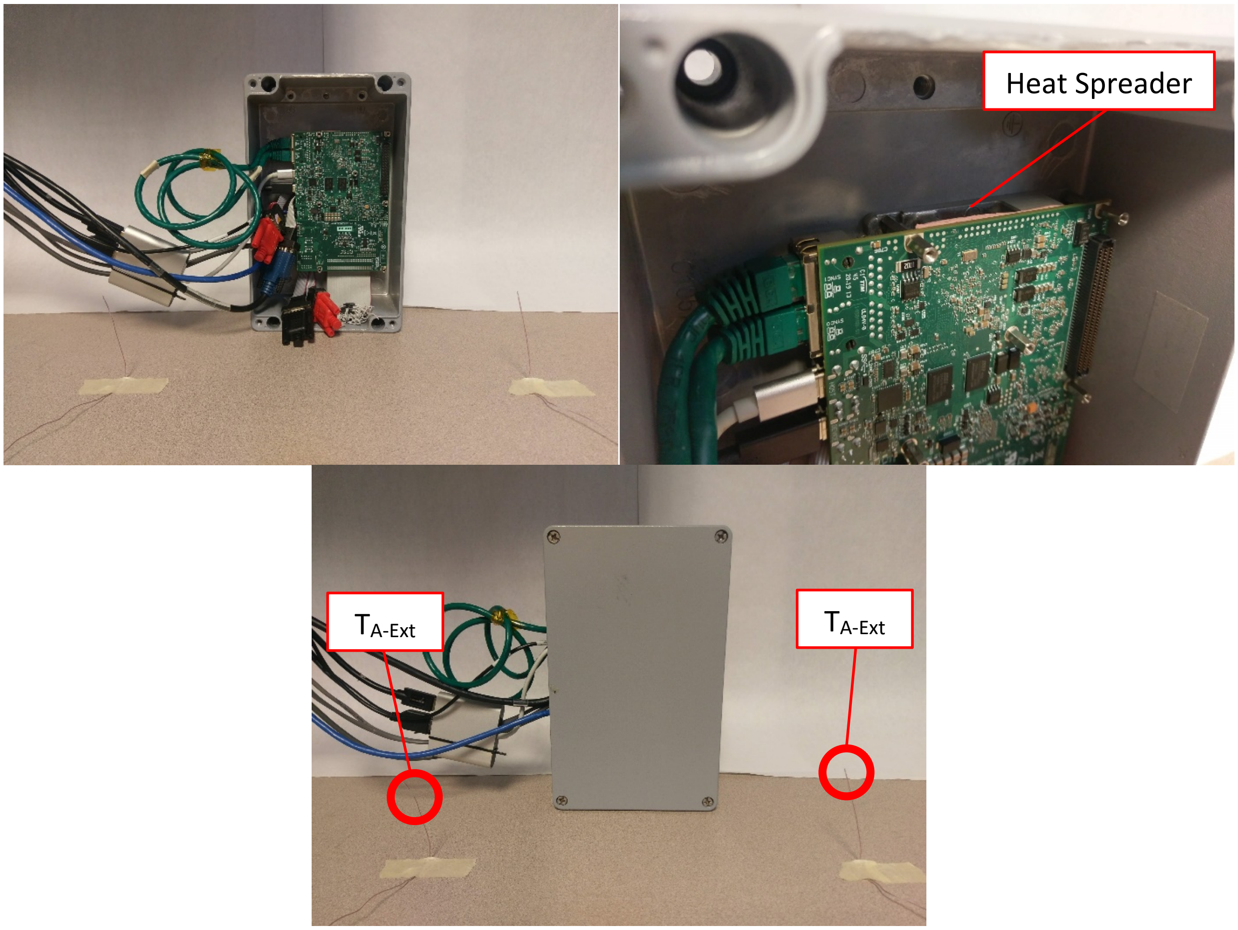


Figure 7: Configuration C – NI sbRIO-9629 with heat spreader in a small metal enclosure

3.4. *Results*

The following table shows the test results normalized to $T_{A\text{-}Ext}$=25°C. In addition, it includes the margin of the temperature reading compared to the maximum allowed values for each component or ambient measurement. In the "margin" column, the lowest margin component is highlighted.

Table 3: sbRIO-9629 component measurements and margin – open air vs. enclosure size with thermal solution

	A Open Air		**B Large Fiberglass Encl.**		**C Small Metal Encl.**	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{SEN\text{-}CPU\text{-}0}$	53.6	54.4	64.7	43.3	50.6	57.4
$T_{SEN\text{-}CPU\text{-}1}$	53.9	54.1	64.7	43.3	50.6	57.4
$T_{SEN\text{-}CPU\text{-}2}$	54.1	53.9	65.6	42.4	51.6	56.4
$T_{SEN\text{-}CPU\text{-}3}$	55.1	52.9	66.1	41.9	52.0	56.0
$T_{SEN\text{-}FPGA}$	49.1	48.9	60.1	37.9	47.0	51.0
$T_{C\text{-}DDR\text{-}1}$	44.4	50.6	55.6	39.4	42.2	52.8
$T_{C\text{-}DDR\text{-}2}$	44.7	50.3	55.9	39.1	42.6	52.4
$T_{C\text{-}NAND}$	44.3	47.2	55.4	36.1	41.6	49.9
$T_{C\text{-}CPLD}$	44.4	49.5	55.6	38.4	42.9	51.0

$T_{C\text{-}USB}$	45.4	74.3	56.3	63.3	42.5	77.1
$T_{C\text{-}ENET\text{-}1}$	45.8	49.2	57.0	38.0	43.5	51.5
$T_{C\text{-}ENET\text{-}2}$	46.3	48.7	57.4	37.6	43.9	51.1
$T_{C\text{-}SD}$	46.1	38.9	56.4	28.6	49.8	35.2
$T_{C\text{-}ASIC\text{-}1}$	45.3	74.6	56.5	63.4	43.9	76.0
$T_{C\text{-}ASIC\text{-}2}$	46.3	70.0	57.5	58.9	44.2	72.1
$T_{C\text{-}OSC}$	44.6	67.8	55.8	56.6	43.3	69.1
$T_{A\text{-}P\text{-}SEN}$	46.9	38.1	57.6	27.4	45.1	39.9
$T_{A\text{-}S\text{-}SEN}$	45.3	39.7	56.1	28.9	43.7	41.3
$T_{A\text{-}P\text{-}TL}$	36.7	48.3	46.8	38.2	43.1	41.9
$T_{A\text{-}P\text{-}TM}$	43.0	42.0	54.9	30.1	42.6	42.4
$T_{A\text{-}P\text{-}TR}$	44.8	40.2	55.7	29.3	43.5	41.5
$T_{A\text{-}P\text{-}BL}$	39.5	45.5	49.6	35.4	43.0	42.0
$T_{A\text{-}P\text{-}BM}$	43.9	41.1	55.6	29.4	45.7	39.3
$T_{A\text{-}P\text{-}BR}$	43.3	41.7	54.8	30.2	42.7	42.3
$T_{A\text{-}S\text{-}TL}$	34.0	51.0	42.8	42.2	40.9	44.1
$T_{A\text{-}S\text{-}TM}$	41.8	43.2	50.0	35.0	43.9	41.1
$T_{A\text{-}S\text{-}TR}$	42.8	42.2	53.4	31.6	44.5	40.5
$T_{A\text{-}S\text{-}BL}$	35.2	49.8	46.2	38.8	41.3	43.7
$T_{A\text{-}S\text{-}BM}$	37.6	47.4	49.4	35.6	44.1	40.9
$T_{A\text{-}S\text{-}BR}$	41.1	43.9	53.0	32.0	43.6	41.4
$T_{A\text{-}Ext}$	25.0	-	25.0	-	25.0	-

The measured system power draw of the NI sbRIO-9629 was approximately 22.7 W for each configuration.

In configurations A and B, the digitally reported primary side local ambient is the lowest margin component. For configuration C, the lowest margin component is the microSD card.

The microSD card used for testing has an industrial temperature rating of 85 °C, such as NI P/N 786913-01 (16 GB) or 786989-01 (32 GB). Using a microSD card with a lower temperature rating will further reduce the achievable external ambient. Removing the microSD card would allow for an additional 4 °C rise in achievable external ambient and make the primary side bottom middle ambient ($T_{A\text{-}P\text{-}BM}$) the lowest margin measurement for configuration C.

Extrapolating to the maximum allowed temperature of the lowest margin measurements, the estimated maximum achievable external ambient for each configuration is shown in the following table.

Table 2: Maximum achievable ambient – open air vs. enclosure size with thermal solution

Configuration	**A** (Open Air)	**B** (Large Fiberglass Enclosure)	**C** (Small Metal Enclosure)
Max Achievable $T_{A\text{-}Ext}$ (°C)	63.1	52.4	60.2

4. Example 2 – NI sbRIO-9629, Open Air vs. Enclosure Size, With Thermal Solution and RMC

4.1. *Test Description*

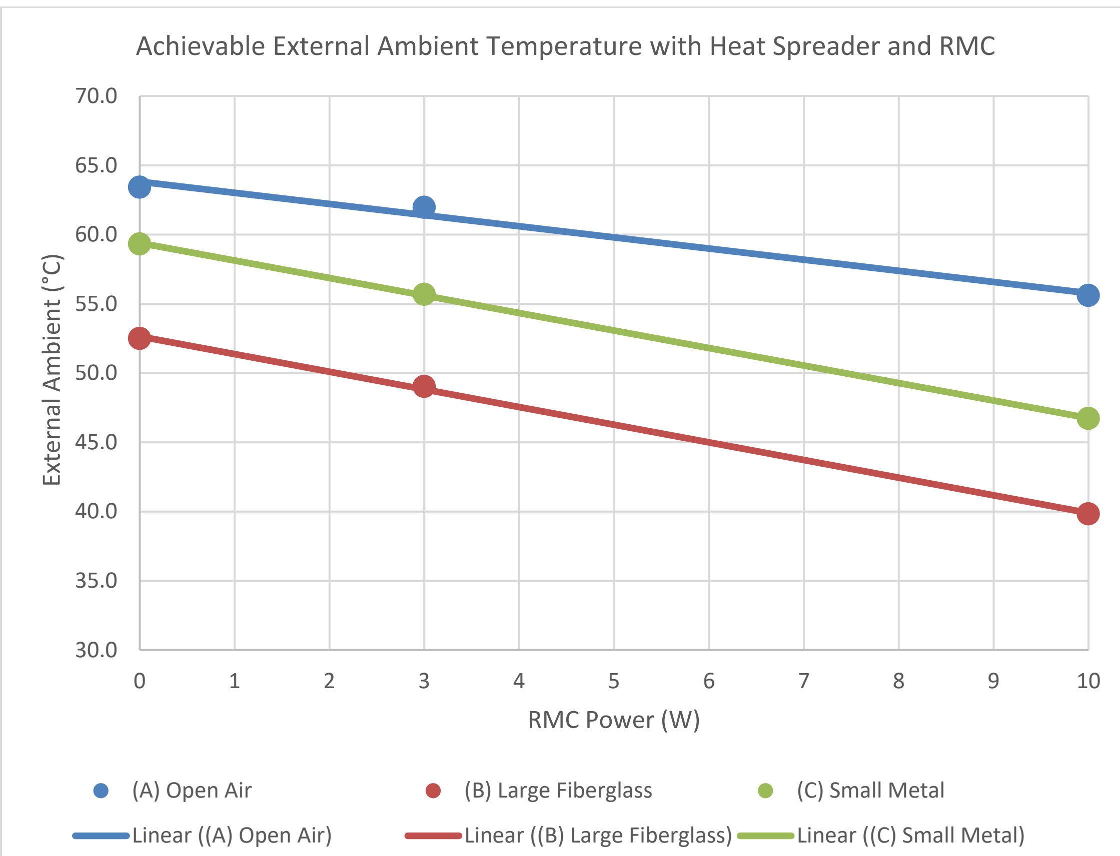
In this example, the NI sbRIO-9629 was configured with a heat spreader and an RMC loaded at varying power levels to show the impact of adding an expansion card. The same open air and enclosure configurations from Example 1 were used. This Example does not exercise the LVDS features of the FPGA. See Example 3 for more information on the additional thermal impacts of using LVDS.

4.2. *Test Results Summary*

The self-heating around the NI sbRIO-9629 is increased within an enclosure, resulting in a lower achievable external ambient. In addition, the rate of self-heating increases with increasing RMC power, resulting in a larger change in the achievable external ambient between the 0W RMC and 10W RMC within an enclosure.

In this set of examples, the digitally reported primary side local ambient has the lowest margin when in the open air or the large fiberglass enclosure. When inside the small metal enclosure, the microSD card has the lowest margin only when the RMC load is small. At higher RMC loads the secondary side bottom right ambient ($T_{A\text{-}S\text{-}BR}$) becomes the lowest margin component. Extrapolating to the maximum allowed local ambient or microSD card case temperature, the estimated maximum achievable external ambient for each configuration is shown in the following chart.

Chart 1: sbRIO-9629 achievable ambient vs. RMC power – open air vs. enclosure size with thermal solution and RMC



These configurations did not include a thermal solution on the RMC thermal load board. Adding a thermal solution to the RMC or less stressful applications may result in additional improvements in the max achievable external ambient temperature.

4.3. *Test Setup*

In this example, the NI sbRIO-9629 was installed with a heat spreader (NI P/N 787331-01) and a resistor load RMC test board.

- The circuit cards were mounted such that the heat spreader on the NI sbRIO-9629 directly contacted the metal mounting surface.
- The RMC was mounted to the NI sbRIO-9629 using 9.65mm tall standoffs. No thermal solution was attached to the RMC load board.
- The same open air and enclosure configurations as in Example 3 were used.
- Tests were performed with the RMC load at 0W, 3W, and 10W. In the test results, the subscript number for each test configuration corresponds to the RMC power load used for that test. So, A_0 corresponds to the 0W RMC, A_{10} corresponds to the 10W RMC, and so on.
- (A) Open Air Configuration – The NI sbRIO-9629 with RMC was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9629 with RMC was mounted to a metal panel and installed into a large fiberglass enclosure. The enclosure was oriented such that the PCBs were vertical during testing, as shown in the following images.
- (C) Small Metal Enclosure – The NI sbRIO-9629 was mounted directly to the side wall of a small aluminum enclosure. The enclosure was oriented such that the PCBs were vertical during testing, as shown in the following images.

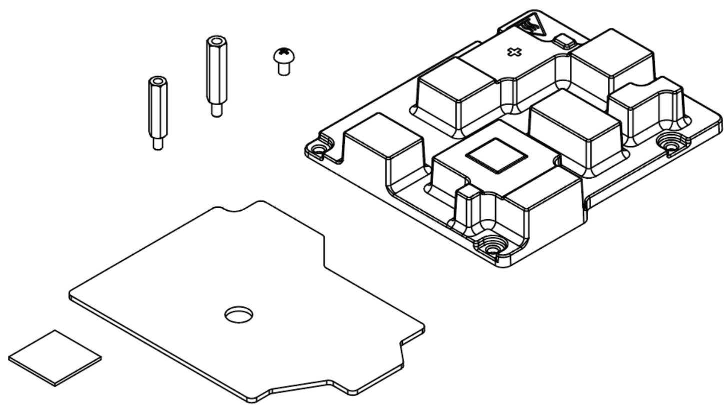


Figure 8: Thermal Kit (NI P/N 787331-01)

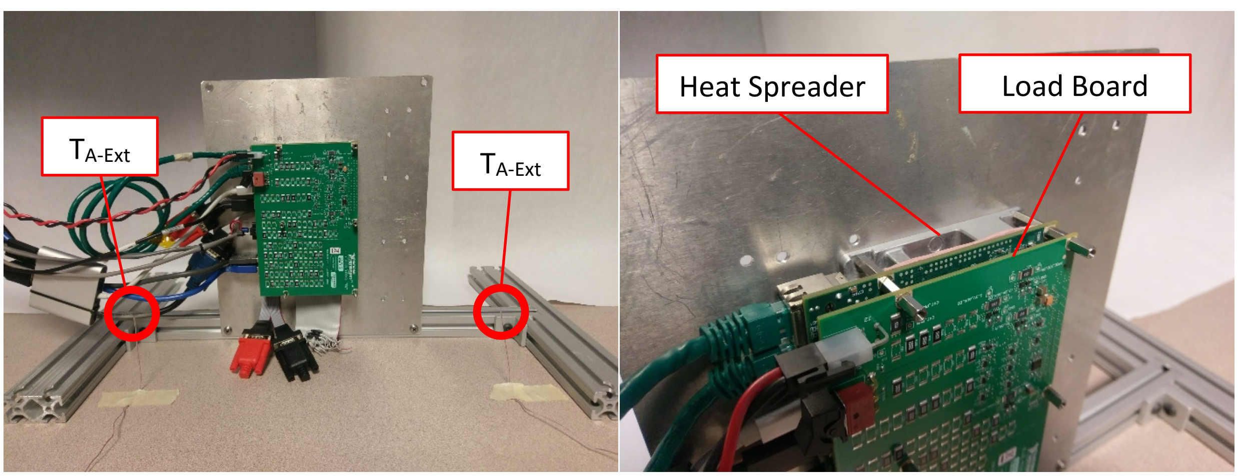


Figure 9: Configuration A – NI sbRIO-9629 with RMC load board and heat spreader in open air

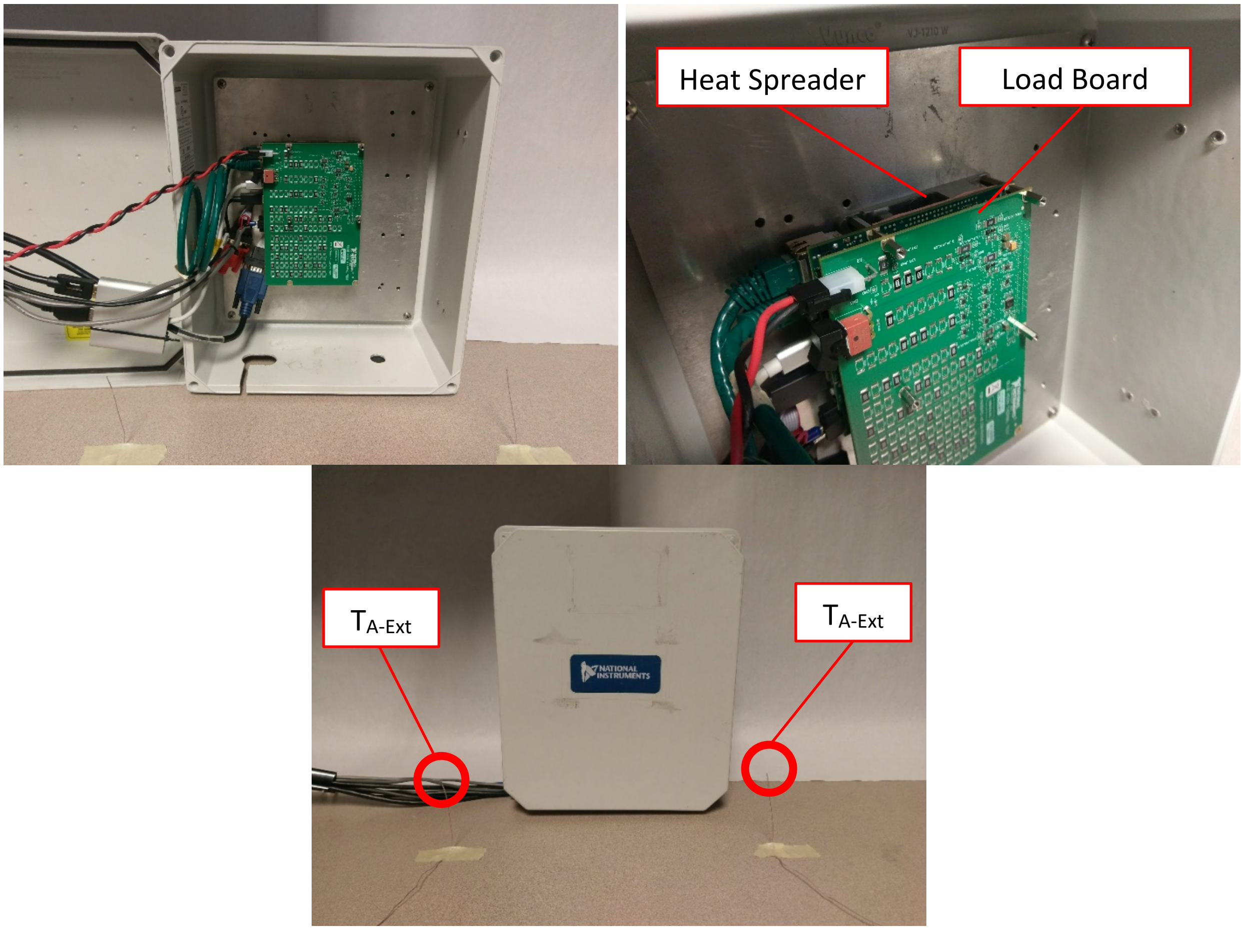


Figure 10: Configuration B – NI sbRIO-9629 with RMC load board and heat spreader in a large fiberglass enclosure

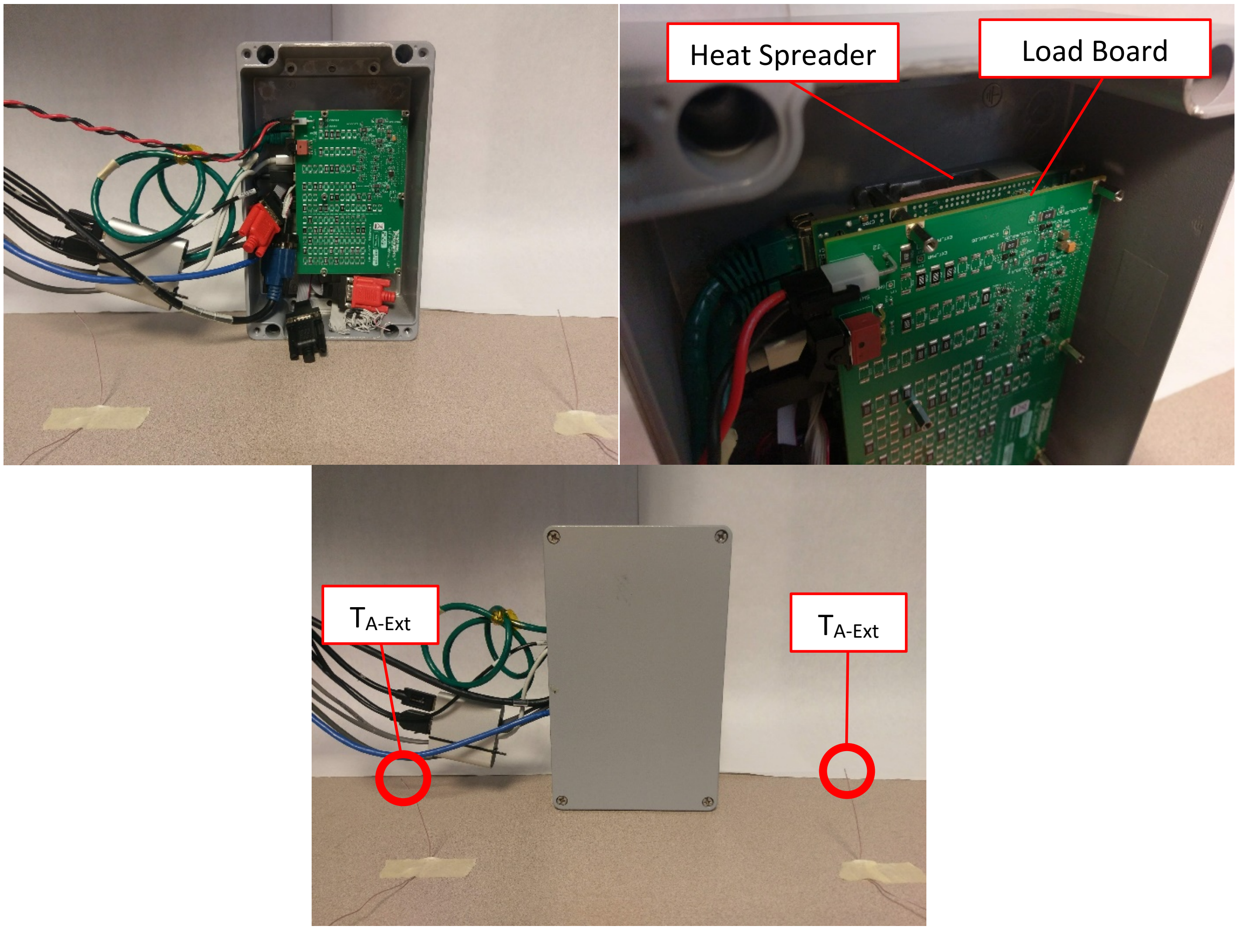


Figure 11: Configuration C – NI sbRIO-9629 with RMC load board and heat spreader in a small metal enclosure

4.4. *Results*

The following table shows the test results normalized to $T_{A\text{-}Ext}$=25°C. It includes the power draw measured by both the sbRIO board and the RMC test board, along with the margin of the temperature reading compared to the maximum allowed values for each component or ambient measurement. In the "margin" column, the lowest margin component is highlighted.

Table 4: sbRIO-9629 component measurements and margin – configuration A with thermal solution and RMC

Open Air with Heat Spreader and RMC						
Configuration	**A_0**		**A_3**		**A_{10}**	
NI sbRIO-9629 Power (W)	23.8		23.8		24.4	
RMC Power (W)	0.0		3.0		10.0	
Total System Power (W)	23.8		26.8		34.4	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{SEN\text{-}CPU\text{-}0}$	53.8	54.2	54.8	53.2	60.5	47.5
$T_{SEN\text{-}CPU\text{-}1}$	53.9	54.1	55.0	53.0	60.5	47.5
$T_{SEN\text{-}CPU\text{-}2}$	54.1	53.9	55.7	52.3	61.2	46.8

$T_{SEN-CPU-3}$	55.1	52.9	56.6	51.4	61.5	46.5
$T_{SEN-FPGA}$	48.9	49.1	50.1	47.9	56.7	41.3
$T_{C-DDR-1}$	44.6	50.4	45.7	49.3	50.8	44.2
$T_{C-DDR-2}$	44.9	50.1	46.1	48.9	51.3	43.7
T_{C-NAND}	44.2	47.2	45.4	46.1	50.5	41.0
T_{C-CPLD}	44.7	49.2	45.9	48.1	51.4	42.6
T_{C-USB}	45.3	74.3	46.5	73.2	51.5	68.2
$T_{C-ENET-1}$	46.0	49.0	47.2	47.8	52.3	42.7
$T_{C-ENET-2}$	46.5	48.5	47.7	47.3	52.7	42.3
T_{C-SD}	46.5	38.5	48.0	37.0	53.1	31.9
$T_{C-ASIC-1}$	45.6	74.3	46.7	73.2	52.0	67.9
$T_{C-ASIC-2}$	46.2	70.1	47.4	68.9	52.9	63.4
T_{C-OSC}	44.8	67.6	46.0	66.5	51.3	61.1
$T_{A-P-SEN}$	46.6	38.4	48.0	37.0	54.4	30.6
$T_{A-S-SEN}$	45.4	39.6	46.9	38.1	53.4	31.6
T_{A-P-TL}	37.6	47.4	38.5	46.5	42.8	42.2
T_{A-P-TM}	43.7	41.3	44.9	40.1	50.3	34.7
T_{A-P-TR}	44.2	40.8	45.5	39.5	51.9	33.1
T_{A-P-BL}	39.2	45.8	40.5	44.5	44.8	40.2
T_{A-P-BM}	44.9	40.1	46.5	38.5	53.0	32.0
T_{A-P-BR}	43.5	41.5	45.1	39.9	49.3	35.7
T_{A-S-TL}	34.8	50.2	36.2	48.8	39.4	45.6
T_{A-S-TM}	42.2	42.8	44.2	40.8	51.9	33.1
T_{A-S-TR}	43.6	41.4	45.5	39.5	53.0	32.0
T_{A-S-BL}	35.8	49.2	37.1	47.9	40.6	44.4
T_{A-S-BM}	40.9	44.1	44.1	40.9	50.4	34.6
T_{A-S-BR}	43.5	41.5	46.1	38.9	51.6	33.4
T_{A-Ext}	25.0	-	25.0	-	25.0	-

Table 5: sbRIO-9629 component measurements and margin – configuration B with thermal solution and RMC

Large Fiberglass Enclosure with Heat Spreader and RMC						
Configuration	**B_0**		**B_3**		**B_{10}**	
NI sbRIO-9629 Power (W)	23.0		23.3		24.4	
RMC Power (W)	0.0		3.0		10.0	
Total System Power (W)	23.0		26.3		34.4	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{SEN-CPU-0}$	64.1	43.9	67.9	40.1	76.7	31.3
$T_{SEN-CPU-1}$	64.9	43.1	68.0	40.0	76.8	31.2

$T_{SEN-CPU-2}$	65.5	42.5	69.1	38.9	77.8	30.2
$T_{SEN-CPU-3}$	66.0	42.0	69.3	38.7	78.6	29.4
$T_{SEN-FPGA}$	60.0	38.0	63.2	34.8	71.6	26.4
$T_{C-DDR-1}$	55.6	39.4	58.7	36.3	66.8	28.2
$T_{C-DDR-2}$	55.9	39.1	59.1	35.9	67.3	27.7
T_{C-NAND}	55.2	36.3	58.4	33.1	66.5	25.0
T_{C-CPLD}	55.7	38.2	58.9	35.1	67.4	26.6
T_{C-USB}	56.3	63.4	59.5	60.2	67.6	52.0
$T_{C-ENET-1}$	57.0	38.0	60.2	34.8	68.4	26.6
$T_{C-ENET-2}$	57.4	37.6	60.7	34.3	68.9	26.1
T_{C-SD}	56.9	28.1	60.7	24.3	69.4	15.6
$T_{C-ASIC-1}$	56.6	63.3	59.7	60.2	67.9	52.0
$T_{C-ASIC-2}$	57.3	59.1	60.4	55.9	68.7	47.6
T_{C-OSC}	55.8	56.6	58.9	53.5	67.0	45.4
$T_{A-P-SEN}$	57.5	27.5	61.0	24.0	70.2	14.8
$T_{A-S-SEN}$	56.4	28.6	59.9	25.1	69.4	15.6
T_{A-P-TL}	46.8	38.2	49.8	35.2	56.6	28.4
T_{A-P-TM}	54.6	30.4	57.7	27.3	65.8	19.2
T_{A-P-TR}	55.0	30.0	58.4	26.6	67.6	17.4
T_{A-P-BL}	49.7	35.3	53.1	31.9	60.9	24.1
T_{A-P-BM}	55.8	29.2	59.4	25.6	69.3	15.7
T_{A-P-BR}	53.9	31.1	57.9	27.1	66.1	18.9
T_{A-S-TL}	44.6	40.4	47.7	37.3	54.0	31.0
T_{A-S-TM}	52.9	32.1	57.0	28.0	67.1	17.9
T_{A-S-TR}	54.5	30.5	58.5	26.5	69.3	15.7
T_{A-S-BL}	45.8	39.2	49.5	35.5	56.5	28.5
T_{A-S-BM}	51.5	33.5	56.8	28.2	67.9	17.1
T_{A-S-BR}	54.6	30.4	59.3	25.7	70.1	14.9
T_{A-Ext}	25.0	-	25.0	-	25.0	-

Table 6: sbRIO-9629 component measurements and margin – configuration C with thermal solution and RMC

Small Metal Enclosure with Heat Spreader and RMC						
Configuration	C_0		C_3		C_{10}	
NI sbRIO-9629 Power (W)	23.2		23.1		25.2	
RMC Power (W)	0.0		3.0		10.0	
Total System Power (W)	23.2		26.1		35.2	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{SEN-CPU-0}$	51.5	56.5	54.0	54.0	60.8	47.2

$T_{SEN-CPU-1}$	51.6	56.4	54.1	53.9	60.9	47.1
$T_{SEN-CPU-2}$	52.2	55.8	54.8	53.2	61.5	46.5
$T_{SEN-CPU-3}$	52.5	55.5	55.3	52.7	61.8	46.2
$T_{SEN-FPGA}$	47.7	50.3	50.5	47.5	57.3	40.7
$T_{C-DDR-1}$	42.9	52.1	45.5	49.5	51.8	43.2
$T_{C-DDR-2}$	43.4	51.6	46.0	49.0	52.4	42.6
T_{C-NAND}	42.3	49.2	44.8	46.6	51.2	40.2
T_{C-CPLD}	43.7	50.3	46.3	47.6	53.2	40.8
T_{C-USB}	43.3	76.4	45.8	73.8	52.1	67.5
$T_{C-ENET-1}$	44.3	50.7	46.9	48.1	53.3	41.7
$T_{C-ENET-2}$	44.7	50.3	47.3	47.7	53.8	41.2
T_{C-SD}	50.7	34.3	54.3	30.7	62.8	22.2
$T_{C-ASIC-1}$	44.7	75.2	47.3	72.6	54.0	65.9
$T_{C-ASIC-2}$	44.9	71.4	47.5	68.8	54.2	62.1
T_{C-OSC}	44.0	68.4	46.6	65.8	53.3	59.1
$T_{A-P-SEN}$	45.8	39.2	48.8	36.2	56.5	28.5
$T_{A-S-SEN}$	44.6	40.4	47.7	37.3	55.7	29.3
T_{A-P-TL}	44.0	41.0	47.5	37.5	55.4	29.6
T_{A-P-TM}	43.2	41.8	45.9	39.1	52.6	32.4
T_{A-P-TR}	44.0	41.0	47.1	37.9	55.3	29.7
T_{A-P-BL}	43.8	41.2	47.4	37.6	55.6	29.4
T_{A-P-BM}	46.6	38.4	49.8	35.2	58.6	26.4
T_{A-P-BR}	43.5	41.5	46.3	38.7	53.3	31.7
T_{A-S-TL}	41.1	43.9	45.2	39.8	53.2	31.8
T_{A-S-TM}	45.6	39.4	50.2	34.8	61.2	23.8
T_{A-S-TR}	45.5	39.5	49.6	35.4	60.2	24.8
T_{A-S-BL}	41.8	43.2	45.6	39.4	53.9	31.1
T_{A-S-BM}	45.7	39.3	51.2	33.8	62.7	22.3
T_{A-S-BR}	44.9	40.1	50.5	34.5	63.3	21.7
T_{A-Ext}	25.0	-	25.0	-	25.0	-

The tests above shown with a 0W RMC had the RMC board installed but not powered. The measured power draw of the NI sbRIO-9629 increases slightly as the RMC power increases due to the added load on the power supply. With a 10W RMC, this results in approximately 1.3W additional power being dissipated on the sbRIO board.

The first thing to note is that additional loads nearby to the sbRIO-9628 can both impact the component margins and cause the lowest margin component to change. Also, the self-heating caused by the addition of an enclosure results in an additional temperature rise within the system.

The digitally reported primary side local ambient had the lowest margin in configurations A and B, and the microSD card the lowest margin in configuration C, when the RMC power was low. At the highest RMC power the limiting measurement for configuration C changed to the secondary side bottom right ambient (T_{A-S-BR}).

The microSD card used for testing has an industrial temperature rating of 85 °C, such as NI P/N 786913-01 (16 GB) or 786989-01 (32 GB). Using a microSD card with a lower temperature rating will further reduce the achievable external ambient. Removing the microSD card may allow for an additional 3 - 4 °C rise in achievable external ambient and make one of the local ambient temperatures the lowest margin measurement, depending on the RMC power.

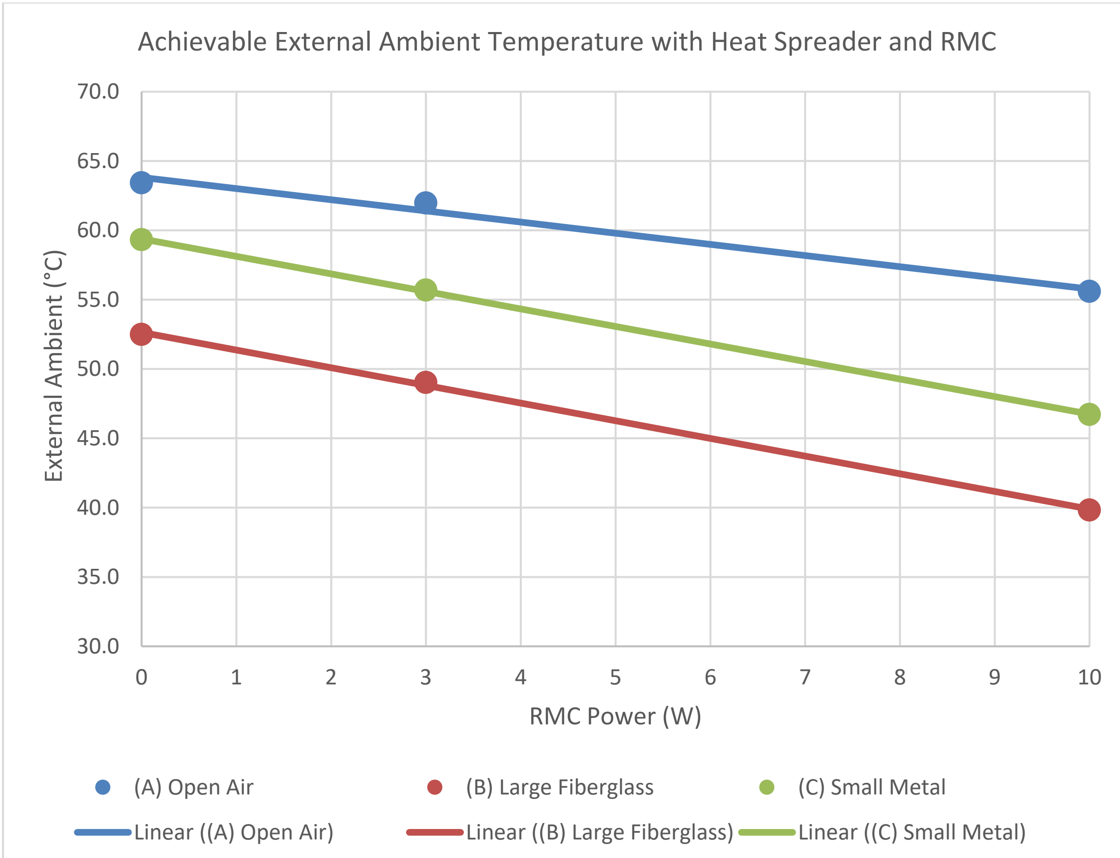
Using this data, the maximum achievable external ambient for each configuration is estimated, as shown in the following table.

Table 7: Maximum achievable ambient – open air vs. enclosure size with thermal solution and RMC

RMC Power (W)	Max Achievable T_{A-Ext} (°C)		
	A	B	C
0.0	63.4	52.5	59.3
3.0	62.0	49.0	55.7
10.0	55.6	39.8	46.7

The following chart plots the achievable external ambient compared with RMC power levels for each configuration. The results may be approximated with a linear extrapolation to estimate the ambient at different RMC power levels within the different enclosures.

Chart 1: sbRIO-9629 achievable ambient vs. RMC power – open air vs. enclosure size with thermal solution and RMC


Achievable External Ambient Temperature with Heat Spreader and RMC
External Ambient (°C)
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
0
1
2
3
4
5
6
7
8
9
10
RMC Power (W)
(A) Open Air
(B) Large Fiberglass
(C) Small Metal
Linear ((A) Open Air)
Linear ((B) Large Fiberglass)
Linear ((C) Small Metal)

5. Example 3 – NI sbRIO-9629, LVDS Output Impact

5.1. *Test Description*

The power dissipation of the FPGA is drastically increased when utilizing LVDS outputs. In this example, the NI sbRIO-9629 was configured in the same manner as configuration C from Example 2. Configuration C included both a thermal solution and the RMC load powered at 3W. The power consumption of the FPGA was adjusted to simulate varying channel counts of LVDS output in order to explore the impact of LVDS output on achievable external ambient.

5.2. *Test Results Summary*

In this Example the lowest margin component remains the microSD card regardless of the LVDS utilization. Extrapolating to the maximum allowed local ambient temperature of the lowest margin component, the estimated maximum achievable external ambient for each LVDS utilization is shown in the following chart.

Table 8: Maximum achievable ambient – with LVDS output

LVDS Channel Count	Max Achievable T_{A-Ext} (°C)
	C
0	55.7
17	55.4
45	54.1

Compared to Example 2, adding 45 channels of LVDS output to an sbRIO operating in a small metal enclosure with a thermal solution (configuration C) and 3W of RMC power results in approximately a 1.6°C reduction in the achievable external ambient.

5.3. *Test Setup*

In this example, the NI sbRIO-9629 was installed with a heat spreader (NI P/N 787331-01) and a resistor load RMC test board for configuration C only.

- The circuit cards were mounted such that the heat spreader on the NI sbRIO-9629 directly contacted the metal mounting surface.
- The RMC was mounted to the NI sbRIO-9629 using 9.65mm tall standoffs. No thermal solution was attached to the RMC load board.
- The same open air and small metal enclosure configurations as in Example 1 and D, respectively, were used.
- Tests were performed with the RMC load at 3W for configuration C only.
- Power consumption of the FPGA was adjusted to represent max achievable load assuming either 0, 17, or 45 channels of LVDS. In the test results, the subscript number for each test configuration corresponds to the channel count used for that test. So, A_0 corresponds to 0 channels of LVDS, A_{45} corresponds to the 45 channels of LVDS, and so on.
- (A) Open Air Configuration – The NI sbRIO-9629 with no thermal solution or RMC was mounted to a metal panel and oriented vertically, as shown in the following images.
- (C) Small Metal Enclosure – The NI sbRIO-9629 was mounted directly to the side wall of a small aluminum enclosure, along with the heat spreader and RMC. The enclosure was oriented such that the PCBs were vertical during testing, as shown in the following images.

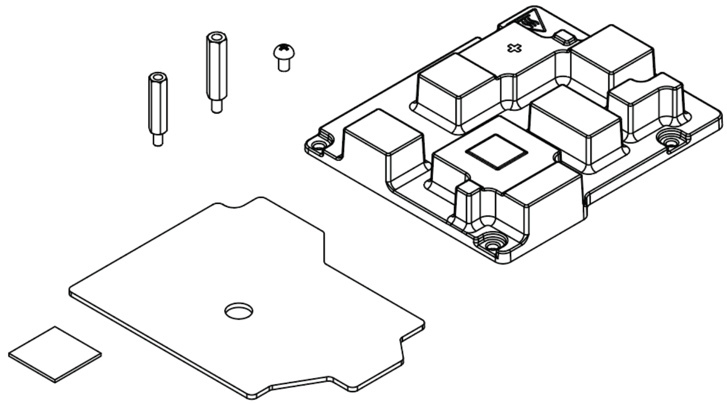


Figure 12: Thermal Kit (NI P/N 787331-01)

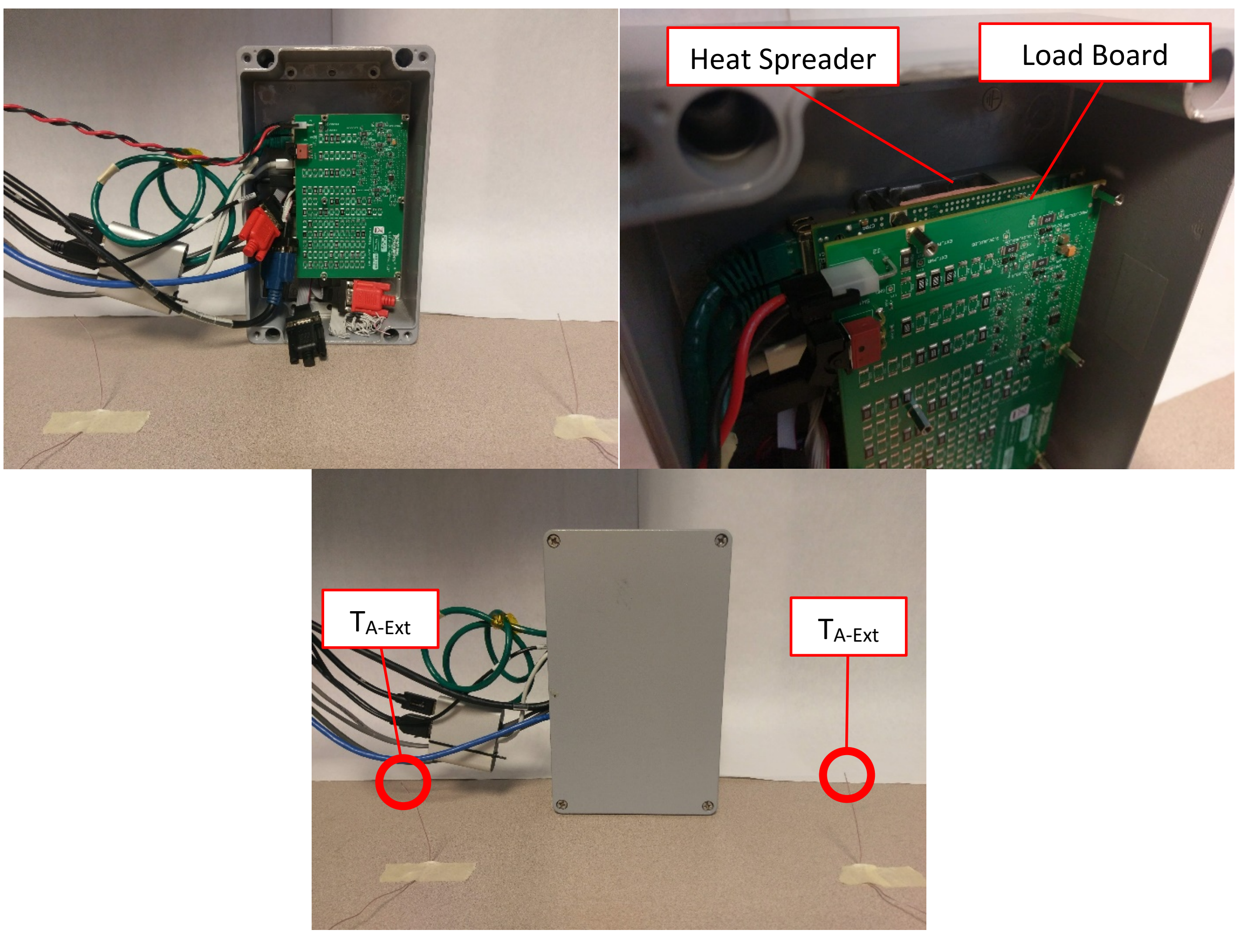


Figure 13: Configuration C – NI sbRIO-9629 with RMC load board and heat spreader in a small metal enclosure

5.4. Results

The following table shows the test results normalized to $T_{A\text{-}Ext}$=25°C. It includes the power draw measured, along with the margin of the temperature reading compared to the maximum allowed values for each component or ambient measurement. In the "margin" column, the lowest margin component is highlighted.

Table 9: sbRIO-9629 component measurements and margin – configuration C with thermal solution, RMC, and LVDS output

Small Metal Enclosure with Heat Spreader, RMC, and LVDS						
Configuration	**C_0**		**C_{17}**		**C_{45}**	
NI sbRIO-9629 Power (W)	23.1		24.0		25.2	
RMC Power (W)	3.0		3.0		3.0	
Total System Power (W)	26.1		27.0		28.2	
Component	**Measurement (°C)**	**Measurement (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{\text{SEN-CPU-0}}$	54.0	54.0	54.5	53.5	55.7	52.3
$T_{\text{SEN-CPU-1}}$	54.1	53.9	54.7	53.3	56.1	51.9
$T_{\text{SEN-CPU-2}}$	54.8	53.2	55.0	53.0	56.4	51.6
$T_{\text{SEN-CPU-3}}$	55.3	52.7	55.8	52.2	57.4	50.6
$T_{\text{SEN-FPGA}}$	50.5	47.5	51.8	46.2	54.6	43.4
$T_{\text{C-DDR-1}}$	45.5	49.5	45.9	49.1	47.6	47.4
$T_{\text{C-DDR-2}}$	46.0	49.0	46.4	48.6	48.0	47.0
$T_{\text{C-NAND}}$	44.8	46.6	45.2	46.3	46.8	44.7
$T_{\text{C-CPLD}}$	46.3	47.6	46.8	47.2	48.4	45.5
$T_{\text{C-USB}}$	45.8	73.8	46.2	73.4	47.7	71.9
$T_{\text{C-ENET-1}}$	46.9	48.1	47.2	47.8	48.8	46.2
$T_{\text{C-ENET-2}}$	47.3	47.7	47.7	47.3	49.2	45.8
$T_{\text{C-SD}}$	54.3	30.7	54.6	30.4	55.9	29.1
$T_{\text{C-ASIC-1}}$	47.3	72.6	47.9	72.0	49.6	70.3
$T_{\text{C-ASIC-2}}$	47.5	68.8	48.1	68.2	49.9	66.4
$T_{\text{C-OSC}}$	46.6	65.8	47.3	65.1	49.2	63.2
$T_{\text{A-P-SEN}}$	48.8	36.2	49.5	35.5	51.4	33.6
$T_{\text{A-S-SEN}}$	47.7	37.3	48.4	36.6	50.3	34.7
$T_{\text{A-P-TL}}$	47.5	37.5	47.8	37.2	49.3	35.7
$T_{\text{A-P-TM}}$	45.9	39.1	46.6	38.4	48.6	36.4
$T_{\text{A-P-TR}}$	47.1	37.9	47.6	37.4	49.2	35.8
$T_{\text{A-P-BL}}$	47.4	37.6	47.7	37.3	49.0	36.0
$T_{\text{A-P-BM}}$	49.8	35.2	50.3	34.7	51.9	33.1
$T_{\text{A-P-BR}}$	46.3	38.7	46.6	38.4	48.1	36.9
$T_{\text{A-S-TL}}$	45.2	39.8	45.7	39.3	47.0	38.0
$T_{\text{A-S-TM}}$	50.2	34.8	50.9	34.1	52.7	32.3
$T_{\text{A-S-TR}}$	49.6	35.4	50.1	34.9	51.9	33.1
$T_{\text{A-S-BL}}$	45.6	39.4	45.7	39.3	47.0	38.0
$T_{\text{A-S-BM}}$	51.2	33.8	51.4	33.6	52.8	32.2
$T_{\text{A-S-BR}}$	50.5	34.5	50.7	34.3	52.1	32.9
$T_{\text{A-Ext}}$	25.0	-	25.0	-	25.0	-

The measured power draw of the NI sbRIO-9629 increases slightly as the LVDS output channel count increases due to the added load on the FPGA. With 45 channels of LVDS output, this results in roughly 2W additional power being dissipated on the sbRIO board.

The impact of the additional 2W of thermal dissipation in the FPGA is largely mitigated by the heat spreader, which has provided a direct conductive path from the FPGA to the enclosure body. In this Example the microSD card remained the lowest margin component despite the added load to the FPGA.

While not directly witnessed here, it is shown in the reference examples of other lower power sbRIO models that the presence of the heat spreader greatly reduces the impact of the LVDS output load on the FPGA temperature. Due to the quad-core CPU's high thermal dissipation, it is not recommended to operate the sbRIO-9629 at full CPU utilization without a thermal solution installed, so a comparison on the affects of removing the heat spreader was not possible here.

Using this data, the maximum achievable external ambient for each configuration is estimated, as shown in the following table.

Table 8: Maximum achievable ambient – with LVDS output

LVDS Channel Count	Max Achievable $T_{A\text{-}Ext}$ (°C)
	C
0	55.7
17	55.4
45	54.1