Cooling NI Single-Board RIO Systems

Appendix: Reference Examples
NI sbRIO-9627/37

11/17/2016

1. **NI sbRIO-9627 General Setup**

Device Under Test (DUT): NI sbRIO-9627

Equipment and Testing Supplies:
Test Equipment:
- NI sbRIO-9627 Power Cable (NI P/N: 152834-01)
- I/O Connectors and Cables
- RMC Resistor Load Test Board (used to simulate added power from an RMC)
- Heat spreader (NI P/N 153901-02)

Enclosures:
- Large Fiberglass Enclosure (NI P/N: 153253A-01 from WSN-3295 IP Enclosure)– 12.0"x10.0"x6.34"
- Aluminum Panel (To mount the NI sbRIO-9627 for open air and inside the large enclosure)
- Small Plastic Enclosure with plastic mounting panel – 9.5"x6.3"x2.5"
- Small Metal Enclosure – 10.2"x6.3"x3.6"

NI sbRIO-9627 DUT Preparation:
- Thermocouples were mounted to critical ICs per user manual
- Six local ambient thermocouples were mounted approximately 0.2" away from the PCB on both sides of the NI sbRIO-9627
- Wires for close loop feedback were connected in order to measure and control the power dissipated by the CPU/FPGA

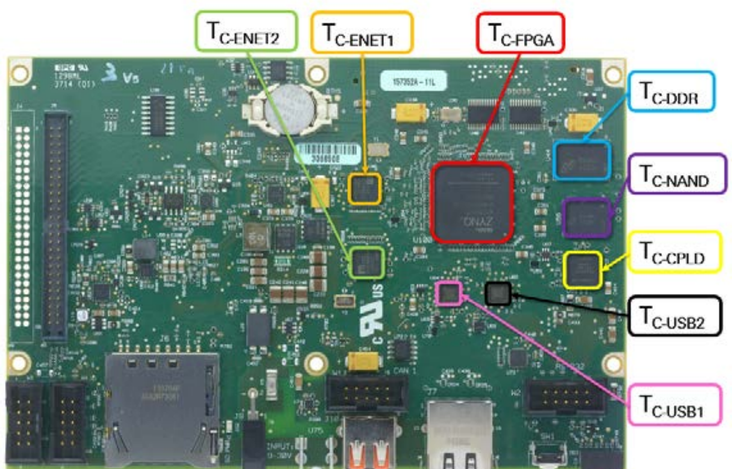


Figure 1: Thermally relevant component designation on NI sbRIO-9627/37

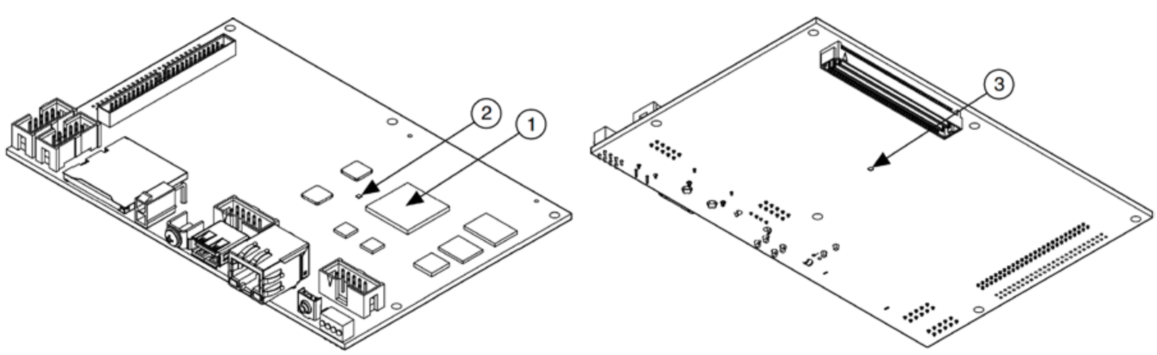


Figure 2: Digital thermal sensors designation on NI sbRIO-9627/37

Designation	Components
1	CPU/ FPGA Sensor, U100
2	Primary System sensor, U54
3	Secondary System sensor, U8

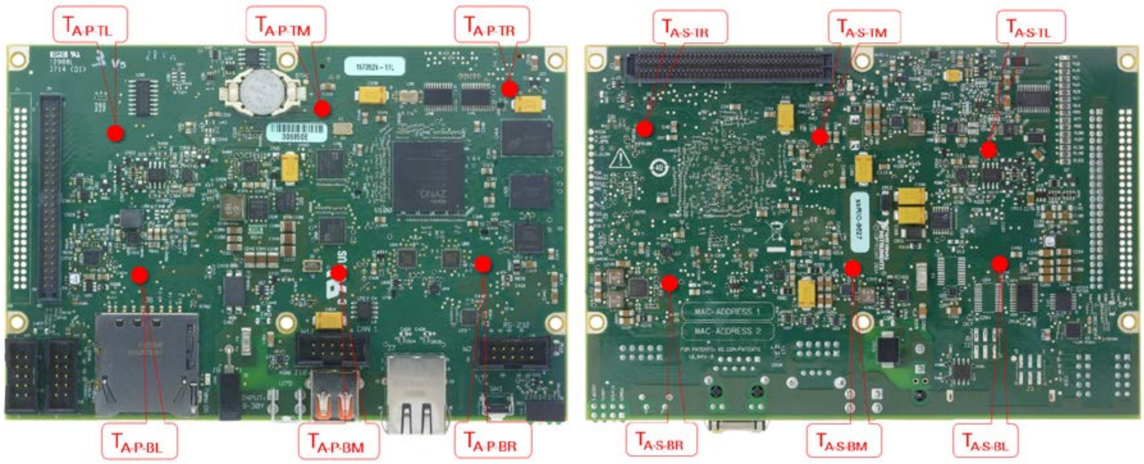


Figure 3: Thermocouple locations for Local ambient temperature measurement

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
  - o Stresses the processor and CPU/FPGA to max achievable power
  - o Performs write, read back, and verify tests to a USB Flash drive, DDR memory, and the NAND flash
  - o Stresses and verifies I/O

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-9627 as defined in the user manual.

NI recommends using digital validation. The sbRIO-9627 includes three onboard temperature monitoring sensors to simplify validation of a thermal solution. The sensors measure the CPU/FPGA junction temperature and 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.

Channel	Name	Description	Max Allowed (°C)	Comments

1	$T_{C\text{-}FPGA}$	CPU/FPGA Case	NA	Use digital approach to ensure the on-chip temperature reading ($T_{SEN\text{-}FPGA}$) is below 98°C
2	$T_{C\text{-}DDR}$	DDR Case	95	
3	$T_{C\text{-}NAND}$	NAND Case	89	
4	$T_{C\text{-}CPLD}$	CPLD Case	94	
5	$T_{C\text{-}USB}$	USB PHY Case	120	
6	$T_{C\text{-}ENET}$	ENET PHY Case	120	
7	$T_{SEN\text{-}FPGA}$	CPU/FPGA Die Junction Temperature	98	
8	$T_{A\text{-}P\text{-}SEN}$	Digitally Reported Primary Side Local Ambient	85	Conservative approximation of the local ambient temperature
9	$T_{A\text{-}S\text{-}SEN}$	Digitally Reported Secondary Side Local Ambient	85	Conservative approximation of the local ambient temperature
10	$T_{A\text{-}P\text{-}TL}$	Primary Side, Top Left Local Ambient	85	Mounted 0.2" off PCB
11	$T_{A\text{-}P\text{-}TM}$	Primary Side, Top Middle Local Ambient	85	Mounted 0.2" off PCB
12	$T_{A\text{-}P\text{-}TR}$	Primary Side, Top Right Local Ambient	85	Mounted 0.2" off PCB
13	$T_{A\text{-}P\text{-}BL}$	Primary Side, Bottom Left Local Ambient	85	Mounted 0.2" off PCB
14	$T_{A\text{-}P\text{-}BM}$	Primary Side, Bottom Middle Local Ambient	85	Mounted 0.2" off PCB
15	$T_{A\text{-}P\text{-}BR}$	Primary Side, Bottom Right Local Ambient	85	Mounted 0.2" off PCB
16	$T_{A\text{-}S\text{-}TL}$	Secondary Side, Top Left Local Ambient	85	Mounted 0.2" off PCB
17	$T_{A\text{-}S\text{-}TM}$	Secondary Side, Top Middle Local Ambient	85	Mounted 0.2" off PCB
18	$T_{A\text{-}S\text{-}TR}$	Secondary Side, Top Right Local Ambient	85	Mounted 0.2" off PCB
19	$T_{A\text{-}S\text{-}BL}$	Secondary Side, Bottom Left Local Ambient	85	Mounted 0.2" off PCB
20	$T_{A\text{-}S\text{-}BM}$	Secondary Side, Bottom Middle Local Ambient	85	Mounted 0.2" off PCB
21	$T_{A\text{-}S\text{-}BR}$	Secondary Side, Bottom Right Local Ambient	85	Mounted 0.2" off PCB
22	$T_{A\text{-}Ext}$	External Ambient (Room Ambient)	NA	Average of two thermocouple measurements

Table 1: Temperature Designation and Description

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-9627 was mounted as described by the examples in the following sections
- The NI sbRIO-9627 was powered at 30V
- The system stressing VI was configured and run
- The system was allowed to reach steady state
- Temperature measurements were logged

2. Example A – NI sbRIO-9627, Open Air vs. Enclosure Size

2.1. *Test Description*

In this example, the NI sbRIO-9627 was configured in open air and with varying enclosure sizes to show how the enclosure size affects the self-heating around the circuit card.

2.2. *Test Results Summary*

The self-heating within an enclosure increases as the enclosure size decreases, resulting in a lower achievable external ambient.

In this set of examples, without a thermal solution, the CPU/FPGA has the lowest margin. Extrapolating to the maximum allowed case temperature of the CPU/FPGA, the estimated maximum achievable external ambient for each configuration is shown in the following table.

Configuration	**A** (Open Air)	**B** (Large Fiberglass Enclosure)	**C** (Small Plastic Enclosure)
Max Achievable $T_{A\text{-}Ext}$ (°C)	36.8	32.0	27.6

In addition, because there was a large difference between the margin of the CPU/FPGA and the next lowest margin temperature measurement, less stressful applications or the addition of a thermal solution such as a heat sink or heat spreader may improve the max achievable external ambient. Later in this document, examples showing the impact of adding a thermal solution will be examined. See Examples C and D for more information.

2.3. *Test Setup*

In this example, the NI sbRIO-9627 was installed without an RMC (i.e. controller only).

- The NI sbRIO-9627 was mounted to the panel using 9.65mm standoffs.
- (A) Open Air Configuration – The NI sbRIO-9627 was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9627 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 Plastic Enclosure – The NI sbRIO-9627 was mounted to a plastic panel and installed into a small plastic enclosure. The enclosure was oriented such that the PCB was vertical during testing, as shown in the following images.

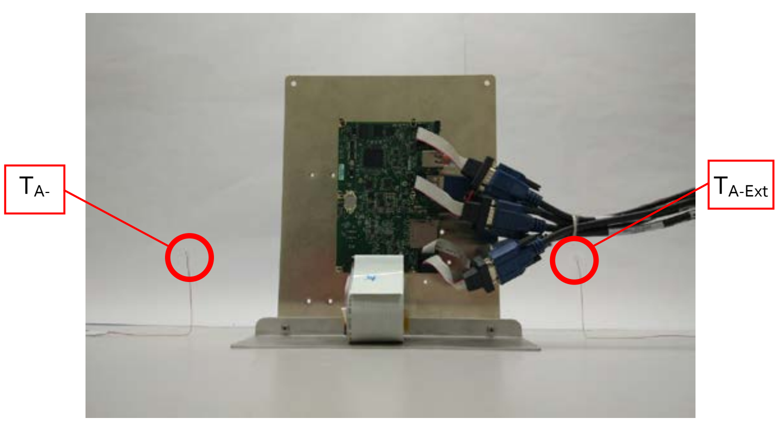


Figure 4: Configuration A – NI sbRIO-9627 in open air

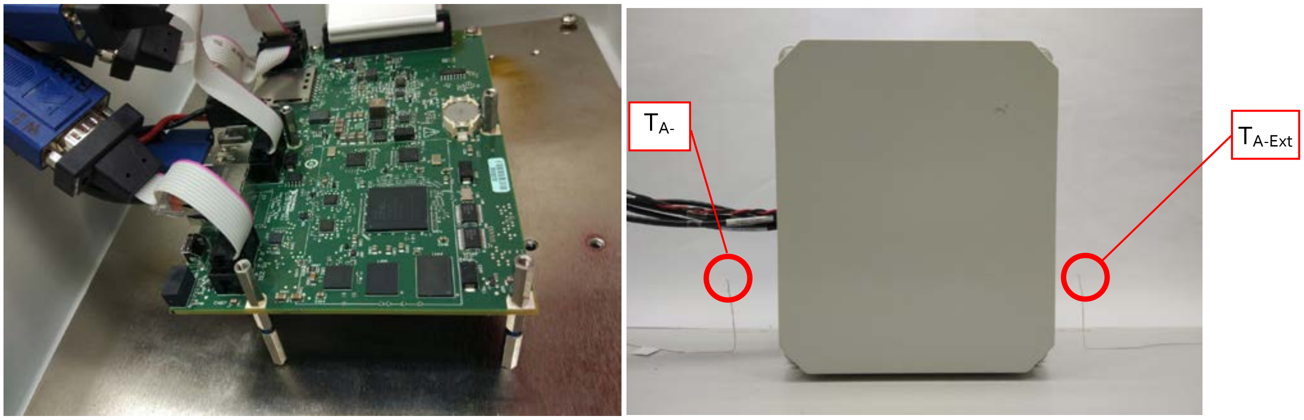


Figure 5: Configuration B – NI sbRIO-9627 in a large fiberglass enclosure

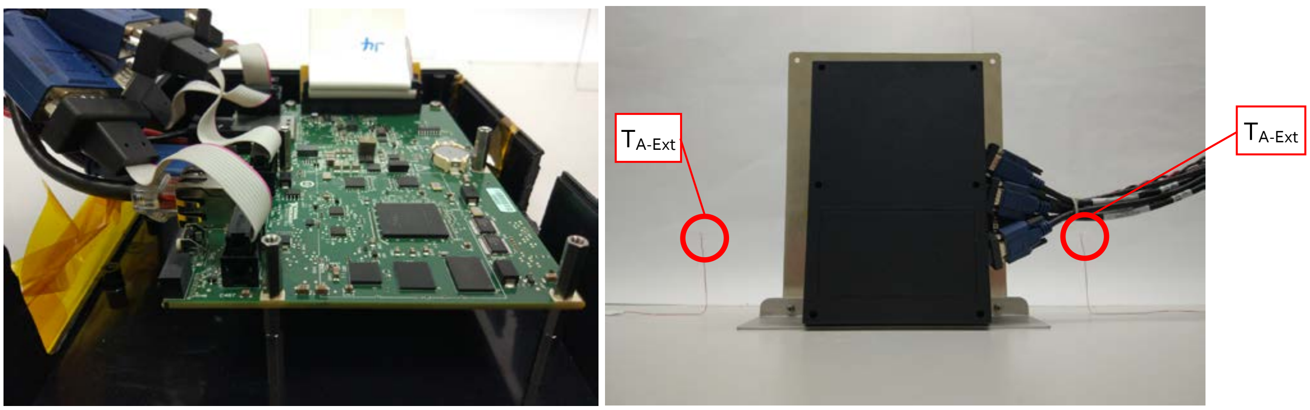


Figure 6: Configuration C – NI sbRIO-9627 in a small plastic enclosure

2.4. *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.

	A Open Air		B Large Fiberglass Encl.		C Small Plastic Encl.	
Component	Measurement (°C)	Margin (°C)	Measurement (°C)	Margin (°C)	Measurement (°C)	Margin (°C)
$T_{C\text{-}ENET1}$	51.4	68.4	55.9	63.9	59.9	59.8
$T_{C\text{-}ENET2}$	53.5	66.3	58.0	61.7	62.0	57.7
$T_{C\text{-}USB1}$	50.1	70.1	55.0	65.2	59.3	60.9
$T_{C\text{-}USB2}$	51.0	69.2	56.0	64.2	60.4	59.8
$T_{C\text{-}CPLD}$	49.8	44.6	54.8	39.5	59.4	35.0
$T_{C\text{-}NAND}$	49.8	45.2	54.8	40.2	59.5	35.5
$T_{C\text{-}DDR}$	51.4	38.4	56.3	33.6	61.0	28.8
$T_{C\text{-}FPGA}$	76.5	-	81.2	-	85.6	-
$T_{S\text{-}FPGA}$	82.2	15.8	87.0	11.0	91.5	6.5
$T_{A\text{-}P\text{-}SEN}$	52.4	32.6	56.9	28.1	61.3	23.7
$T_{A\text{-}S\text{-}SEN}$	52.7	32.3	57.1	27.9	61.6	23.4
$T_{A\text{-}P\text{-}TL}$	29.8	55.2	35.2	49.8	39.5	45.5

T_{A-P-TM}	35.2	49.8	40.0	45.0	46.2	38.8
T_{A-P-TR}	38.4	46.6	42.9	42.1	50.7	34.3
T_{A-P-BL}	29.9	55.1	36.4	48.6	39.0	46.0
T_{A-P-BM}	34.6	50.4	39.1	45.9	46.3	38.7
T_{A-P-BR}	32.3	52.7	42.9	42.1	48.2	36.8
T_{A-S-TL}	33.6	51.4	38.1	46.9	41.8	43.2
T_{A-S-TM}	35.9	49.1	41.4	43.6	46.7	38.3
T_{A-S-TR}	37.8	47.2	43.2	41.8	50.1	34.9
T_{A-S-BL}	31.1	53.9	35.4	49.6	38.6	46.4
T_{A-S-BM}	36.9	48.1	41.3	43.7	45.3	39.7
T_{A-S-BR}	36.4	48.6	41.3	43.7	49.3	35.7
T_{A-Ext}	25.0		25.0		25.0	

The measured system power draw of the NI sbRIO-9627 was 7.7W for each configuration.

The first thing to note is that the CPU/FPGA has the lowest margin in all three configurations. Also, the self-heating caused by the addition of an enclosure results in an additional temperature rise within the system.

Comparing B to A, the added self-heating temperature rise of the larger fiberglass enclosure is approximately 4 to 5 °C. Comparing C to A, the added self-heating of the small plastic enclosure is approximately 9 to 10°C.

Using this data, we can estimate the maximum achievable external ambient for each configuration, as shown in the following table.

Configuration	**A** **(Open Air)**	**B** **(Large Fiberglass Enclosure)**	**C** **(Small Plastic Enclosure)**
Max Achievable T_{A-Ext} (°C)	40.8	36.0	31.5

3. **Example B – NI sbRIO-9627, Open Air vs. Enclosure Size, With RMC**

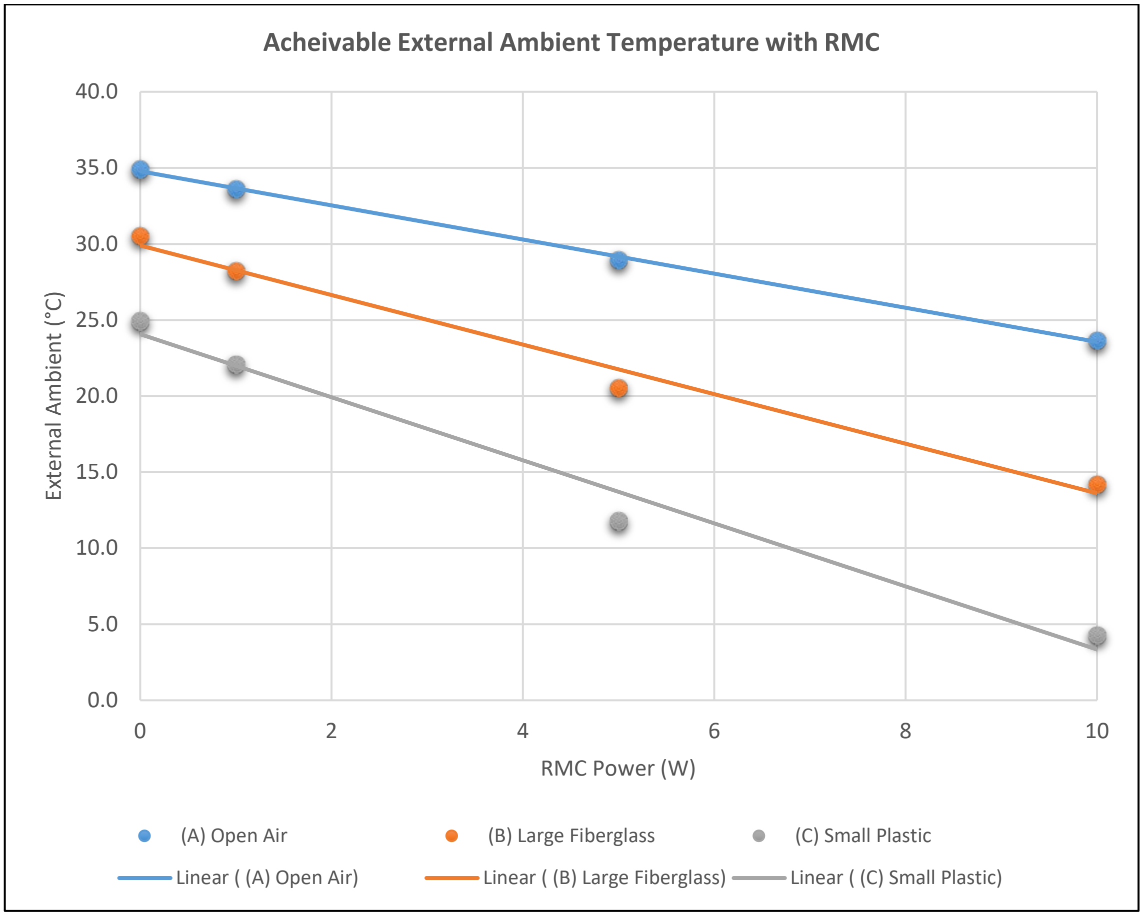
3.1. Test Description

In this example, the NI sbRIO-9627 was configured with 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 A were used.

3.2. Test Results Summary

The self-heating within an enclosure increases as the enclosure size decreases, resulting in a lower achievable external ambient. In addition, the rate of self-heating increases with increasing RMC power as the enclosure size decreases, resulting in a larger change in the achievable external ambient between the 0W RMC and 10W RMC with a smaller enclosure.

In this set of examples, without a thermal solution, the CPU/FPGA has the lowest margin. Extrapolating to the maximum allowed case temperature of the CPU/FPGA, the estimated maximum achievable external ambient for each configuration is shown in the following chart.



In addition, because there was a large difference between the margin of the CPU/FPGA and the next lowest margin temperature measurement, less stressful applications or the addition of a thermal solution such as a heat sink or heat spreader may improve the max achievable external ambient. Later in this document, examples showing the impact of adding a thermal solution will be examined. See Examples C and D for more information.

3.3. *Test Setup*

In this example, the NI sbRIO-9627 was installed with a resistor load RMC test board.

- The circuit cards were mounted such that the RMC was between the mounting panel and the NI sbRIO-9627.
- The RMC was mounted to the panel using standoffs. The standoffs were doubled to clear test connectors underneath the RMC test board, resulting in a total standoff distance of 19.3mm between the RMC and panel.
- The NI sbRIO-9627 was mounted to the RMC using 9.65mm standoffs.
- The same open air and enclosure configurations as in Example A were used.
- Tests were performed with the RMC load at 0W, 1W, 5W, 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 unpowered, 0W RMC, A_1 corresponds to the 1W RMC, as so on.
- (A) Open Air Configuration – The NI sbRIO-9627 with RMC was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9627 with RMC 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 Plastic Enclosure – The NI sbRIO-9627 with RMC was mounted to a plastic panel and installed into a small plastic enclosure. The enclosure was oriented such that the PCB was vertical during testing, as shown in the following images.

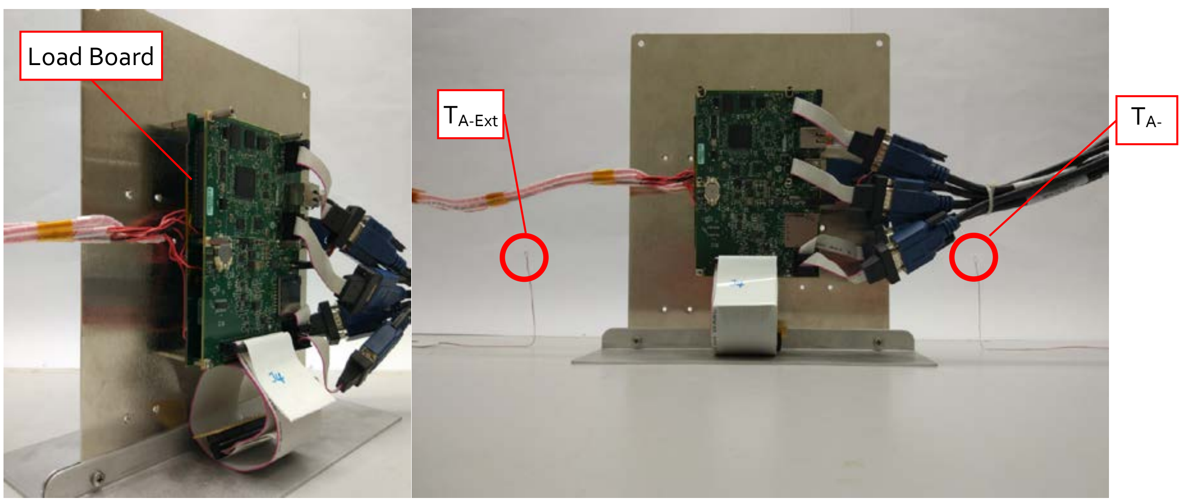


Figure 7: Configuration A – NI sbRIO-9627 with RMC test board in open air

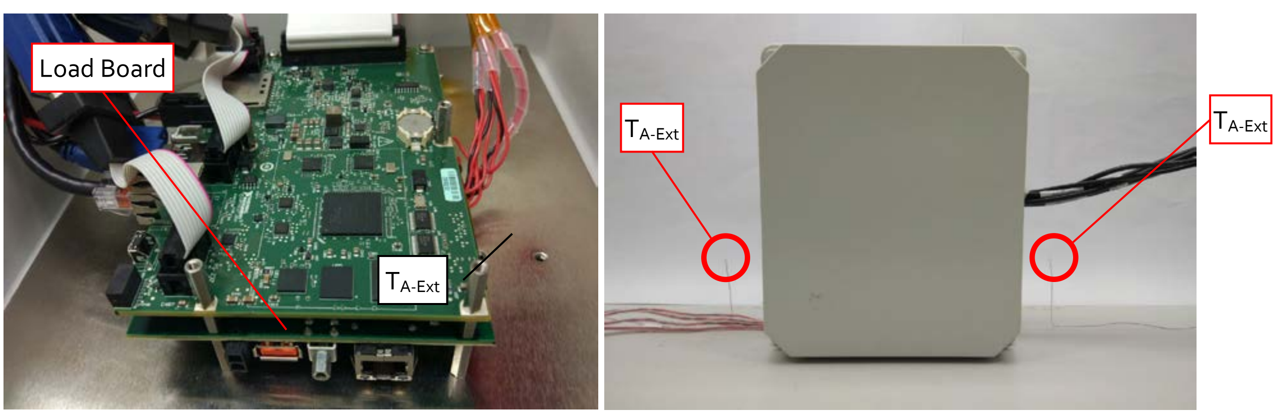


Figure 8: Configuration B – NI sbRIO-9627 with RMC test board in a large fiberglass enclosure

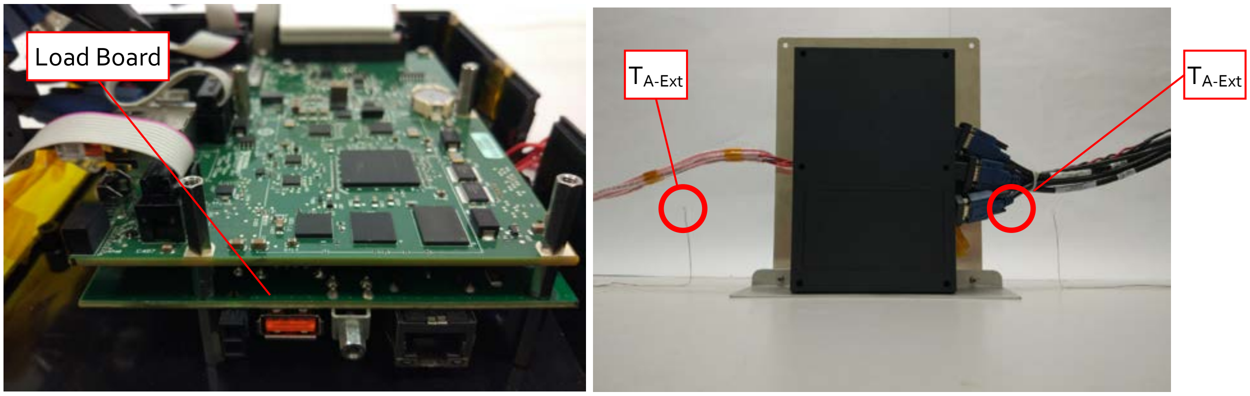


Figure 9: Configuration C – NI sbRIO-9627 with RMC test board in a small plastic enclosure

3.4. <u>Results</u>

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.

Configuration A – Open Air with RMC

Open Air with RMC								
Configuration	**A_0**		**A_1**		**A_5**		**A_{10}**	
NI sbRIO-9627 Power (W)	9.5		9.8		10.5		10.7	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.5		20.7	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C\text{-}ENET1}$	57.8	62.0	59.3	60.5	64.4	55.4	69.1	50.6
$T_{C\text{-}ENET2}$	57.2	62.6	58.7	61.1	64.0	55.8	68.7	51.1
$T_{C\text{-}USB1}$	54.1	66.1	55.5	64.7	60.1	60.1	64.2	56.0
$T_{C\text{-}USB2}$	54.1	66.1	55.4	64.8	59.9	60.3	63.9	56.3
$T_{C\text{-}CPLD}$	52.6	41.8	53.9	40.5	58.3	36.1	62.2	32.2
$T_{C\text{-}NAND}$	52.2	42.8	53.5	41.5	57.9	37.1	61.8	33.2
$T_{C\text{-}DDR}$	53.3	36.5	54.7	35.1	59.3	30.6	63.4	26.5
$T_{C\text{-}FPGA}$	82.4	-	83.8	-	88.5	-0.2	92.9	-
$T_{S\text{-}FPGA}$	88.1	9.9	89.4	8.6	94.0	4.0	99.3	-1.3
$T_{A\text{-}P\text{-}SEN}$	56.6	28.4	58.0	27.0	63.0	22.0	68.6	16.4
$T_{A\text{-}S\text{-}SEN}$	56.8	28.2	58.3	26.7	63.4	21.6	69.2	15.8
$T_{A\text{-}P\text{-}TL}$	30.7	54.3	31.2	53.8	32.7	52.3	32.8	52.2
$T_{A\text{-}P\text{-}TM}$	36.3	48.7	36.8	48.2	39.1	45.9	40.3	44.7
$T_{A\text{-}P\text{-}TR}$	38.4	46.6	39.1	45.9	41.1	43.9	42.5	42.5
$T_{A\text{-}P\text{-}BL}$	32.0	53.0	32.3	52.7	34.6	50.4	34.9	50.1
$T_{A\text{-}P\text{-}BM}$	35.6	49.4	36.4	48.6	38.9	46.1	40.0	45.0

$T_{A\text{-}P\text{-}BR}$	39.3	45.7	40.1	44.9	42.7	42.3	44.5	40.5
$T_{A\text{-}S\text{-}TL}$	36.8	48.2	38.1	46.9	42.8	42.2	46.5	38.5
$T_{A\text{-}S\text{-}TM}$	42.4	42.6	44.3	40.7	51.5	33.5	57.8	27.2
$T_{A\text{-}S\text{-}TR}$	46.1	38.9	48.0	37.0	54.4	30.6	60.5	24.5
$T_{A\text{-}S\text{-}BL}$	35.7	49.3	37.8	47.3	46.0	39.0	53.4	31.6
$T_{A\text{-}S\text{-}BM}$	39.6	45.4	41.6	43.4	49.1	35.9	56.5	28.5
$T_{A\text{-}S\text{-}BR}$	42.2	42.8	44.7	40.3	52.8	32.2	61.8	23.2
$T_{A\text{-}Ext}$	25.0		25.0		25.0		25.0	

Configuration B – Large Fiberglass Enclosure with RMC

Fiberglass with RMC								
Configuration	**A_0**		**A_1**		**A_5**		**A_{10}**	
NI sbRIO-9627 Power (W)	9.5		9.8		10.6		10.8	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.6		20.8	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C\text{-}ENET1}$	62.1	57.7	64.5	55.3	72.7	47.1	78.8	40.9
$T_{C\text{-}ENET2}$	61.5	58.2	64.0	55.8	72.4	47.3	78.6	41.2
$T_{C\text{-}USB1}$	58.5	61.7	60.8	59.4	68.4	51.8	74.3	45.9
$T_{C\text{-}USB2}$	58.5	61.7	60.8	59.4	68.1	52.1	74.0	46.2
$T_{C\text{-}CPLD}$	57.4	37.0	59.6	34.7	66.8	27.5	72.8	21.5
$T_{C\text{-}NAND}$	56.9	38.1	59.2	35.8	66.3	28.7	72.4	22.6
$T_{C\text{-}DDR}$	57.8	32.0	60.2	29.7	67.5	22.4	73.7	16.2
$T_{C\text{-}FPGA}$	86.3	-	88.6	-	96.1	-	102.2	-
$T_{S\text{-}FPGA}$	92.5	5.5	94.8	3.2	102.4	-4.4	108.8	-10.8
$T_{A\text{-}P\text{-}SEN}$	61.0	24.0	63.3	21.7	71.4	13.6	77.8	7.2
$T_{A\text{-}S\text{-}SEN}$	61.3	23.7	63.6	21.4	72.1	12.9	78.8	6.2
$T_{A\text{-}P\text{-}TL}$	36.0	49.0	37.1	47.9	40.3	44.7	42.7	42.3
$T_{A\text{-}P\text{-}TM}$	40.7	44.3	42.2	42.8	46.7	38.3	50.3	34.7
$T_{A\text{-}P\text{-}TR}$	43.5	41.5	45.2	39.8	50.4	34.6	54.6	30.4
$T_{A\text{-}P\text{-}BL}$	37.7	47.3	39.0	46.0	43.1	41.9	46.3	38.7
$T_{A\text{-}P\text{-}BM}$	40.9	44.1	42.5	42.5	47.6	37.4	51.9	33.1
$T_{A\text{-}P\text{-}BR}$	47.6	37.4	49.5	35.5	55.3	29.7	60.0	25.0
$T_{A\text{-}S\text{-}TL}$	40.9	44.1	43.1	41.9	50.2	34.8	56.3	28.7
$T_{A\text{-}S\text{-}TM}$	46.7	38.3	49.6	35.4	59.7	25.3	68.2	16.8
$T_{A\text{-}S\text{-}TR}$	50.9	34.1	53.8	31.2	63.0	22.0	71.4	13.6
$T_{A\text{-}S\text{-}BL}$	39.6	45.4	42.6	42.4	53.2	31.8	62.9	22.1
$T_{A\text{-}S\text{-}BM}$	43.8	41.2	46.7	38.3	57.0	28.0	66.4	18.6
$T_{A\text{-}S\text{-}BR}$	47.1	37.9	50.5	34.5	61.5	23.5	72.2	12.8

T_{A-Ext}	25.0		25.0		25.0		25.0	

Configuration C – Small Plastic Enclosure with RMC

Plastic with RMC								
Configuration	**C_0**		**C_1**		**C_5**		**C_{10}**	
NI sbRIO-9627 Power (W)	9.5		9.8		10.6		10.8	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.6		20.8	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C-ENET1}$	67.4	52.3	70.4	49.4	81.4	38.4	88.9	30.9
$T_{C-ENET2}$	66.8	52.9	69.8	49.9	81.1	38.7	88.7	31.1
T_{C-USB1}	64.2	56.0	67.1	53.1	77.5	42.7	85.0	35.2
T_{C-USB2}	64.5	55.7	67.4	52.8	77.6	42.6	85.1	35.1
T_{C-CPLD}	63.2	31.1	66.1	28.3	76.1	18.2	83.9	10.5
T_{C-NAND}	62.8	32.2	65.7	29.3	75.6	19.4	83.1	11.9
T_{C-DDR}	63.6	26.2	66.5	23.4	76.4	13.4	84.0	5.9
T_{C-FPGA}	92.4	-	95.3	-	105.6	-	113.2	-
T_{S-FPGA}	98.1	-0.1	100.9	-2.9	111.2	-13.2	118.7	-20.7
$T_{A-P-SEN}$	66.2	18.8	69.1	15.9	80.0	5.0	87.7	-2.7
$T_{A-S-SEN}$	66.6	18.4	69.5	15.5	80.6	4.4	88.7	-3.7
T_{A-P-TL}	40.6	44.4	42.4	42.6	48.8	36.2	53.7	31.3
T_{A-P-TM}	47.7	37.3	50.0	35.0	58.7	26.3	65.1	19.9
T_{A-P-TR}	51.5	33.5	54.1	30.9	63.6	21.4	70.3	14.7
T_{A-P-BL}	39.6	45.4	41.1	43.9	47.3	37.7	51.2	33.8
T_{A-P-BM}	47.7	37.3	50.0	35.0	58.6	26.4	64.3	20.7
T_{A-P-BR}	55.6	29.4	58.3	26.7	67.6	17.4	74.9	10.1
T_{A-S-TL}	45.8	39.2	48.6	36.4	58.6	26.4	66.6	18.4
T_{A-S-TM}	51.6	33.4	55.1	29.9	68.1	16.9	78.1	6.9
T_{A-S-TR}	52.3	32.7	56.0	29.0	67.9	17.1	78.2	6.8
T_{A-S-BL}	43.4	41.6	46.7	38.3	58.6	26.4	68.4	16.6
T_{A-S-BM}	48.5	36.5	52.0	33.0	64.6	20.4	75.0	10.1
T_{A-S-BR}	53.2	31.8	57.3	27.7	70.8	14.2	82.8	2.2
T_{A-Ext}	25.0		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-9627 increases slightly as the RMC power increases due to the added load on the power supply. With a 5W or 10W RMC, this results in 1.3W additional power being dissipated on the sbRIO board.

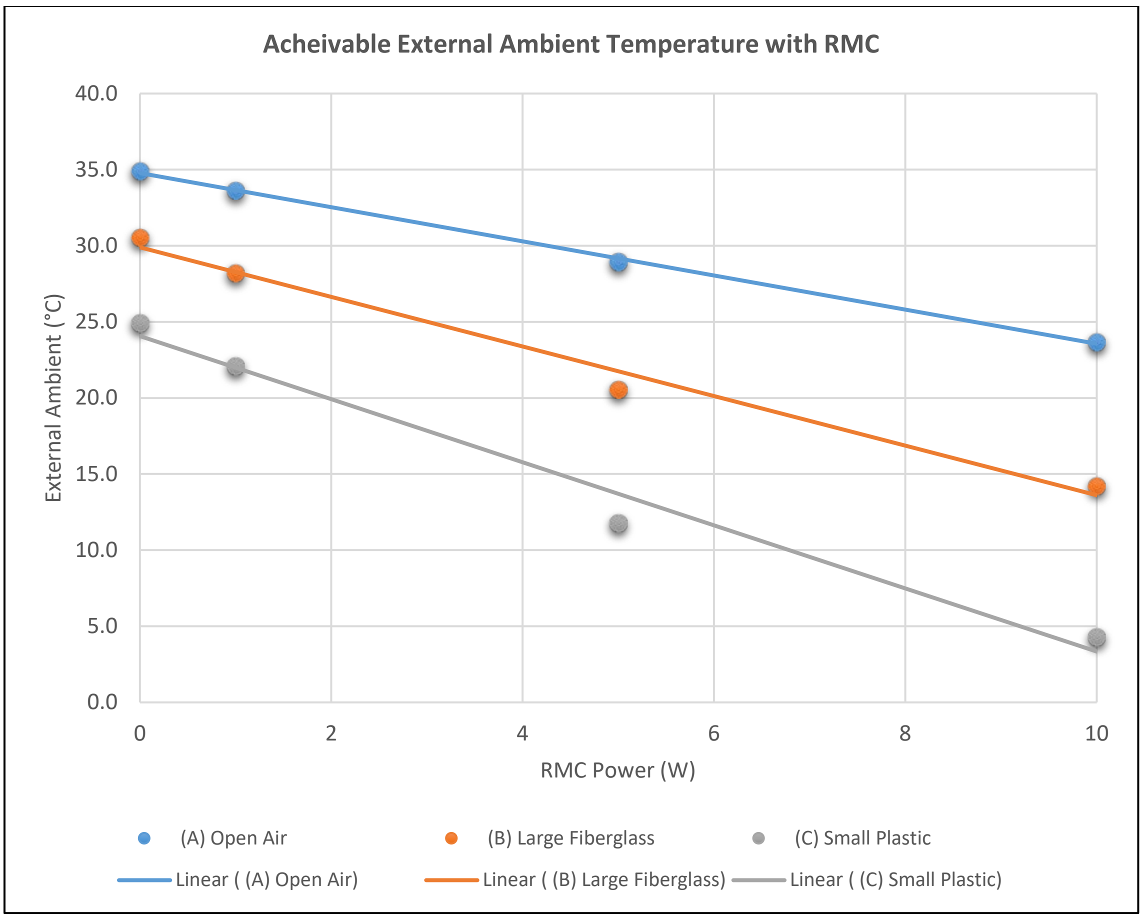
The first thing to note is that the CPU/FPGA has the lowest margin in all three configurations. Also, the self-heating caused by the addition of an enclosure results in an additional temperature rise within the system.

It is also seen that the local ambient temperatures on the secondary side of the sbRIO board, between the sbRIO and RMC ($T_{A\text{-}S\text{-}TL}$, $TA_{\text{-}S\text{-}TM}$, $T_{A\text{-}S\text{-}TR}$, $T_{A\text{-}S\text{-}BL}$, $T_{A\text{-}S\text{-}BM}$, and $T_{A\text{-}S\text{-}BR}$) are typically hotter than the local ambient temperature measurements on the primary side. This becomes more noticeable as the RMC power increases.

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

RMC Power (W)	Max Achievable $T_{A\text{-}Ext}$ (°C)		
	A	B	C
0.0	34.9	30.5	24.9
1.0	33.6	28.2	22.1
5.0	29.0	20.6	11.8
10.0	23.7	14.2	4.3

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.



4. Example C – NI sbRIO-9627, Open Air vs. Enclosure Size, With Thermal Solution

4.1. *Test Description*

In this example, the NI sbRIO-9627 was configured with a heat spreader and installed in open air and with varying enclosure sizes/materials to show how a heat spreader can improve the thermal performance.

4.2. *Test Results Summary*

With the addition of a heat spreader, the impact of self-heating is greatly reduced compared to the tests in Example A. In addition, the heat spreader greatly reduces the junction temperature of the CPU/FPGA and case temperature of other critical ICs, resulting in a higher external ambient temperature. Extrapolating to the maximum allowed local ambient temperature of the die junction temperature of the CPU/FPGA, the estimated maximum achievable external ambient for each configuration is shown in the following table.

Configuration	**A** (Open Air)	**B** (Large Fiberglass Enclosure)	**D** (Small Metal Enclosure)
Max Achievable $T_{A\text{-}Ext}$ (°C)	59.9	55.4	59.1

Comparing to Example A, configurations A and B result in approximately 19°C increase in the achievable external ambient. Comparing configuration C (Example A) to configuration D in this example there is approximately 27°C increase in the achievable external ambient by changing from a small plastic enclosure to a small metal enclosure with a heat spreader.

4.3. *Test Setup*

- In this example, the NI sbRIO-9627 was installed with a heat spreader attached (NI P/N 153901-02). No RMC was installed (i.e. controller only).
- The NI sbRIO-9627 was mounted such that the heat spreader directly contacted the metal mounting surface.
- (A) Open Air Configuration – The NI sbRIO-9627 was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9627 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.
- (D) Small Metal Enclosure – The NI sbRIO-9627 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.

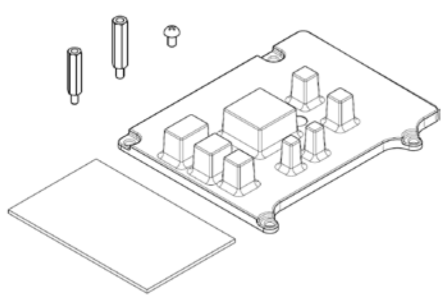


Figure 10: Thermal Kit (NI P/N 153901-02)

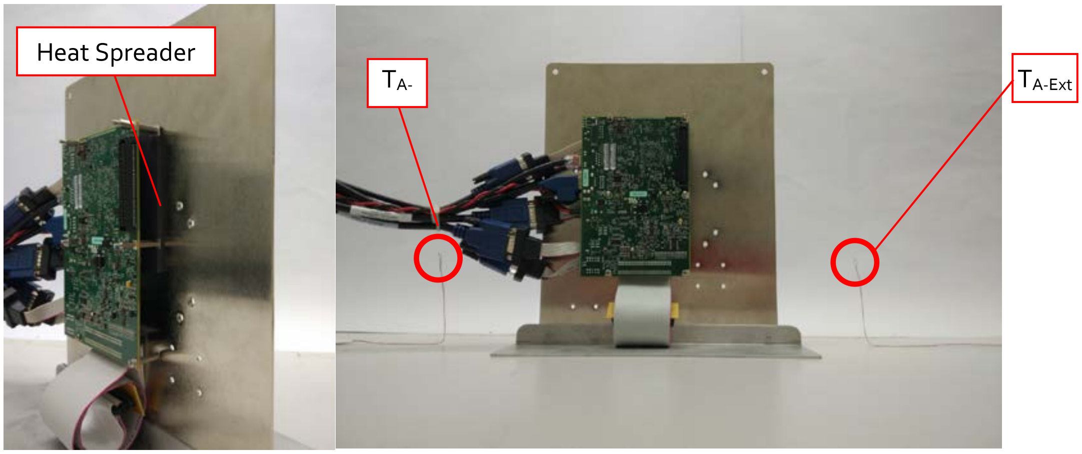


Figure 11: Configuration A – NI sbRIO-9627 in open air

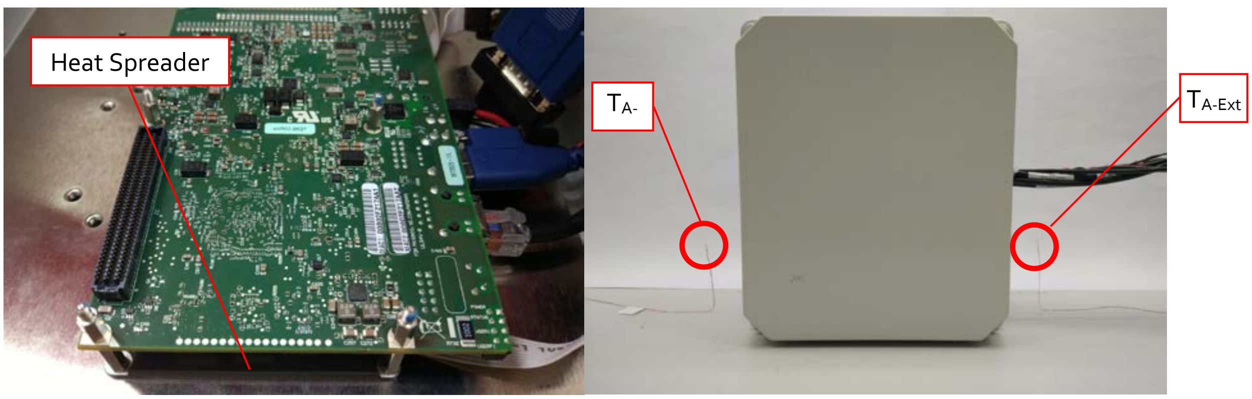


Figure 12: Configuration B – NI sbRIO-9627 in a large fiberglass enclosure

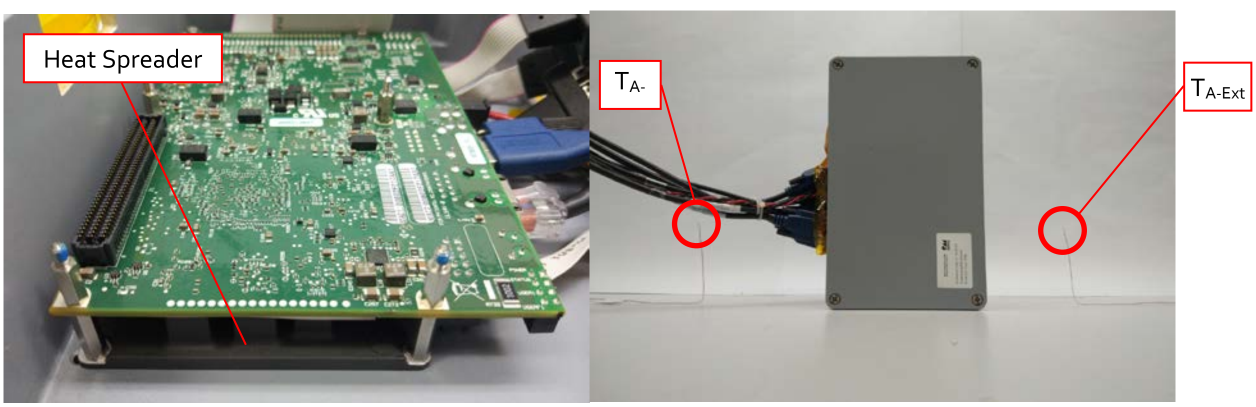


Figure 13: Configuration C – NI sbRIO-9627 in a small metal enclosure

4.4. *Results*

The following table shows the test results normalized to T_{A-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.

	A Open Air		B Large Fiberglass Encl.		D Small Metal Encl.	
Component	Measurement (°C)	Margin (°C)	Measurement (°C)	Margin (°C)	Measurement (°C)	Margin (°C)
$T_{C-ENET1}$	39.3	80.4	43.6	76.1	39.7	80.1
$T_{C-ENET2}$	40.6	79.1	44.9	74.9	41.2	78.5
T_{C-USB1}	38.7	81.4	43.1	77.1	38.8	81.3
T_{C-USB2}	38.9	81.3	43.3	76.9	39.1	81.1
T_{C-CPLD}	37.5	56.9	41.9	52.5	37.2	57.2
T_{C-NAND}	37.2	57.8	41.5	53.5	36.6	58.4
T_{C-DDR}	37.4	52.5	41.8	48.1	36.9	52.9
T_{C-FPGA}	47.4	-	52.0	-	47.8	-
T_{S-FPGA}	63.1	34.9	67.6	30.4	63.9	34.1
$T_{A-P-SEN}$	43.7	41.3	47.9	37.1	44.9	40.1
$T_{A-S-SEN}$	44.0	41.0	48.2	36.8	45.7	39.3
T_{A-P-TL}	32.4	52.6	35.5	49.5	36.3	48.7
T_{A-P-TM}	38.6	46.4	43.0	42.0	40.4	44.6
T_{A-P-TR}	37.7	47.3	42.1	42.9	37.5	47.5
T_{A-P-BL}	34.5	50.5	38.7	46.3	36.0	49.0
T_{A-P-BM}	38.0	47.0	42.1	42.9	39.6	45.4
T_{A-P-BR}	36.1	48.9	40.6	44.4	36.5	48.5
T_{A-S-TL}	32.1	52.9	36.7	48.3	37.0	48.0
T_{A-S-TM}	33.3	51.7	38.3	46.7	38.5	46.5
T_{A-S-TR}	32.9	52.1	38.7	46.3	38.5	46.5
T_{A-S-BL}	30.1	54.9	34.2	50.8	34.4	50.6
T_{A-S-BM}	34.5	50.5	38.8	46.2	38.1	46.9
T_{A-S-BR}	32.4	52.6	38.0	47.0	38.2	46.8
T_{A-Ext}	25.0		25.0		25.0	

The measured system power draw of the NI sbRIO-9627 was approximately 7.7W for each configuration.

With the addition of a heat spreader, the die junction temperature of the CPU/FPGA and case temperature of other critical ICs are greatly reduced, resulting in the die junction temperature of the CPU/FPGA becoming the lowest margin. Extrapolating to the maximum allowed local ambient temperature of the lowest margin of CPU/FPGA junction temperature, the estimated maximum achievable external ambient for each configuration is shown in the following table.

Configuration	**A** (Open Air)	**B** (Large Fiberglass Enclosure)	**D** (Small Metal Enclosure)
Max Achievable $T_{A\text{-}Ext}$ (°C)	59.9	55.4	59.1

The achievable external ambient temperatures are close together, showing that the addition of a heat spreader greatly reduces the impact of self-heating.

Finally, the heat spreader improved the thermal performance of the CPU/FPGA and other critical ICs such that less stressful applications will only see minimal additional improvements to the max achievable external ambient.

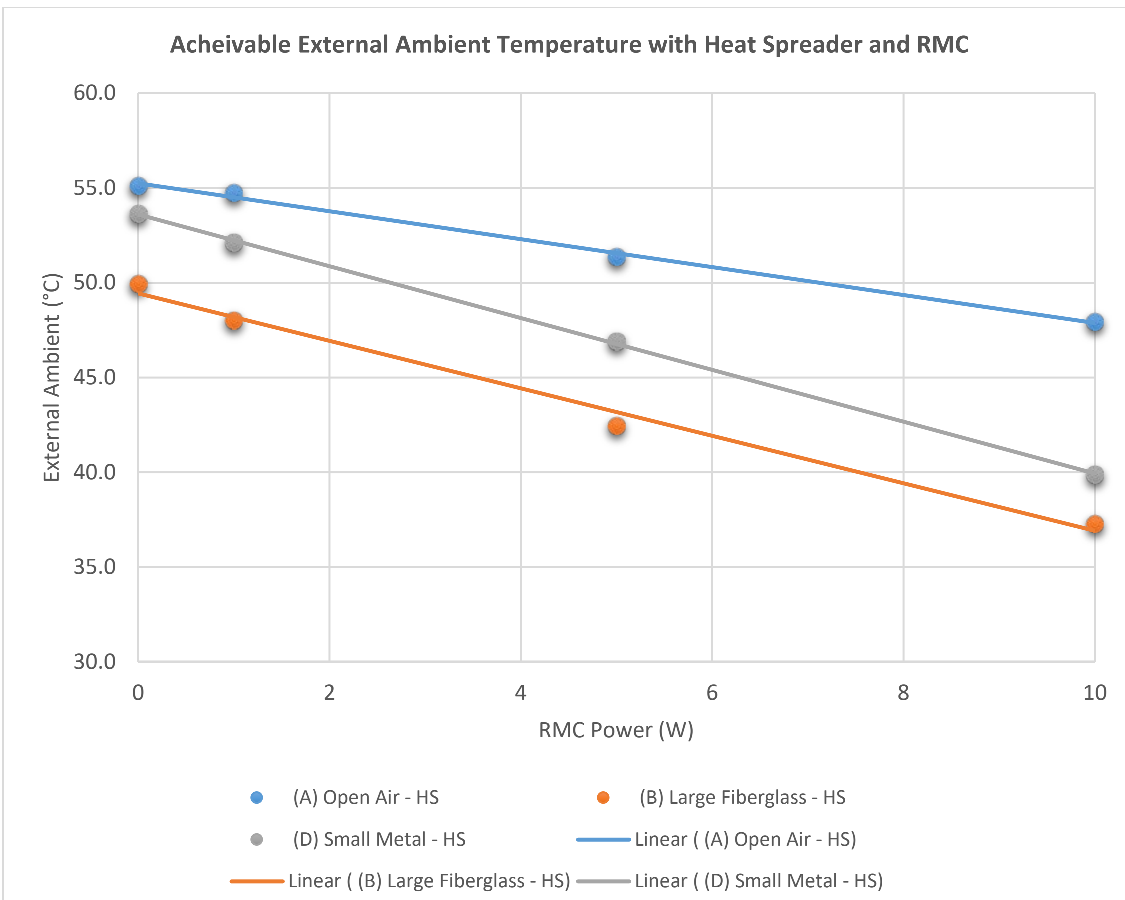
5. Example D – NI sbRIO-9627, Open Air vs. Enclosure Size, With Thermal Solution and RMC

5.1. *Test Description*

In this example, the NI sbRIO-9627 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 C were used.

5.2. *Test Results Summary*

With the addition of a heat spreader, the impact of self-heating is greatly reduced compared to the tests in Example B. In addition, the enclosure size has much less effect, as the max achievable ambient of configurations B (large fiberglass enclosure) and D (small metal enclosure) are very close to each other and only minimally different from configuration A (open air). The heat spreader greatly reduces the die junction temperature of the CPU/FPGA and case temperature of other critical ICs, while making the die junction temperature of the CPU/FPGA and local ambient temperature around the PCB the lowest margin, the use of heat spreader results in a higher external ambient temperature. Extrapolating to the maximum allowed local ambient temperature of the lowest margin component, the estimated maximum achievable external ambient for each configuration is shown in the following chart.



Compared to Example B, configurations A and B result in approximately 19-22°C increase in the achievable external ambient. Comparing configuration C (example B) to configuration D in this example there is approximately 28-35°C increase in the achievable external ambient by changing from a small plastic enclosure to a small metal enclosure with a heat spreader, depending on the RMC power.

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

5.3. *Test Setup*

In this example, the NI sbRIO-9627 was installed with a heat spreader (NI P/N 153901-02) and a resistor load RMC test board.

- The circuit cards were mounted such that the heat spreader on the NI sbRIO-9627 directly contacted the metal mounting surface.
- The RMC was mounted to the NI sbRIO-9627 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 C were used.
- Tests were performed with the RMC load at 0W, 1W, 5W 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_1 corresponds to the 1W RMC, A_{10} corresponds to the 10W RMC, as so on.
- (A) Open Air Configuration – The NI sbRIO-9627 with RMC was mounted to a metal panel and oriented vertically, as shown in the following images.
- (B) Large Fiberglass Enclosure – The NI sbRIO-9627 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.
- (D) Small Metal Enclosure – The NI sbRIO-9627 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.

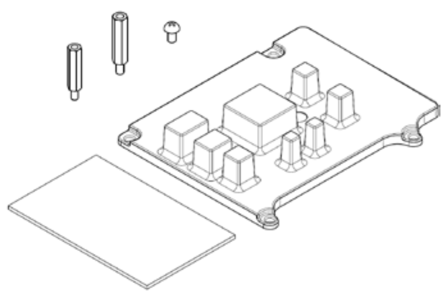


Figure 14: Thermal Kit (NI P/N 153901-02)

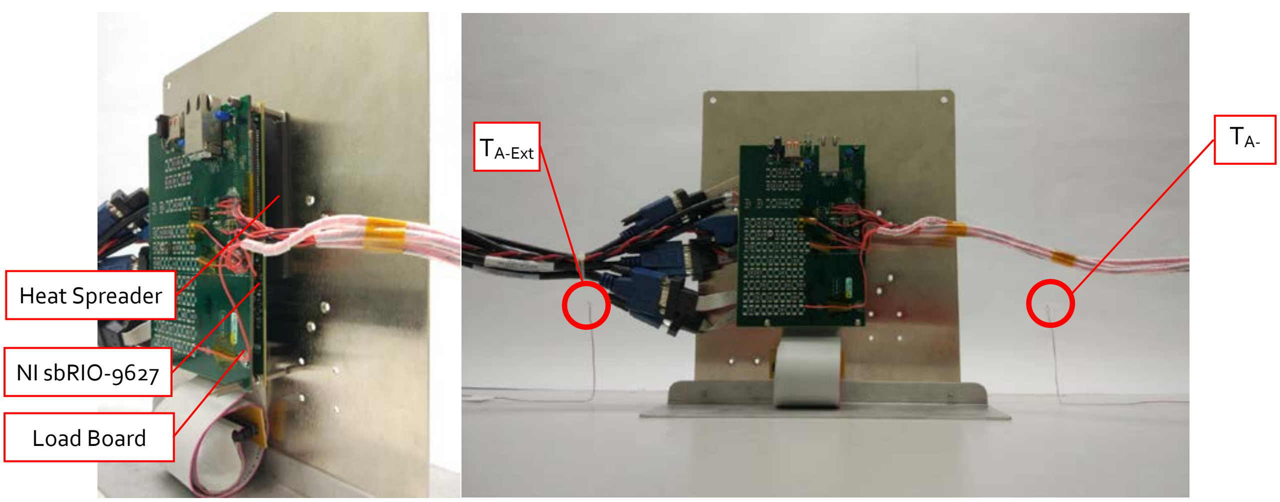


Figure 15: Configuration A – NI sbRIO-9627 with RMC test board in open air

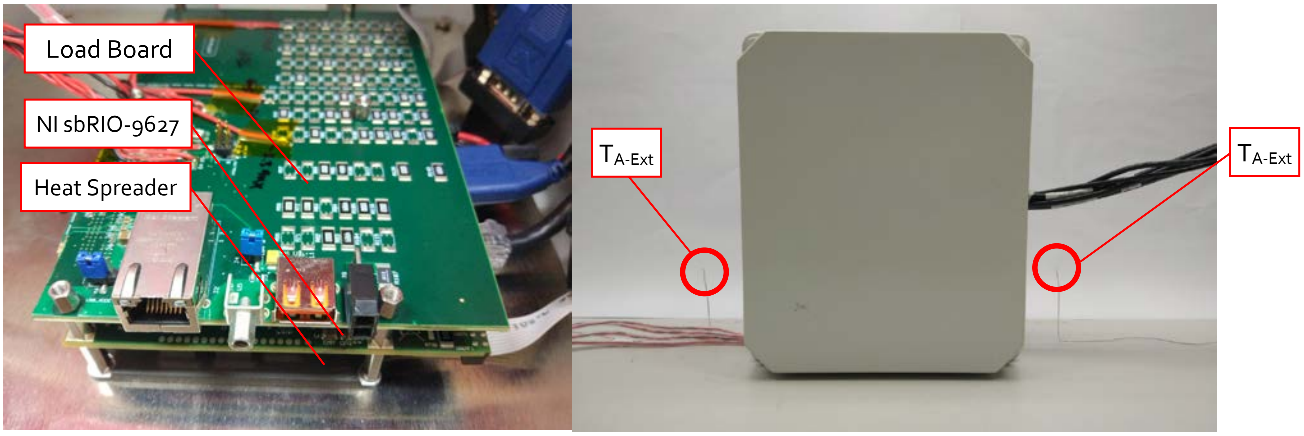


Figure 16: Configuration B – NI sbRIO-9627 with RMC test board in a large fiberglass enclosure

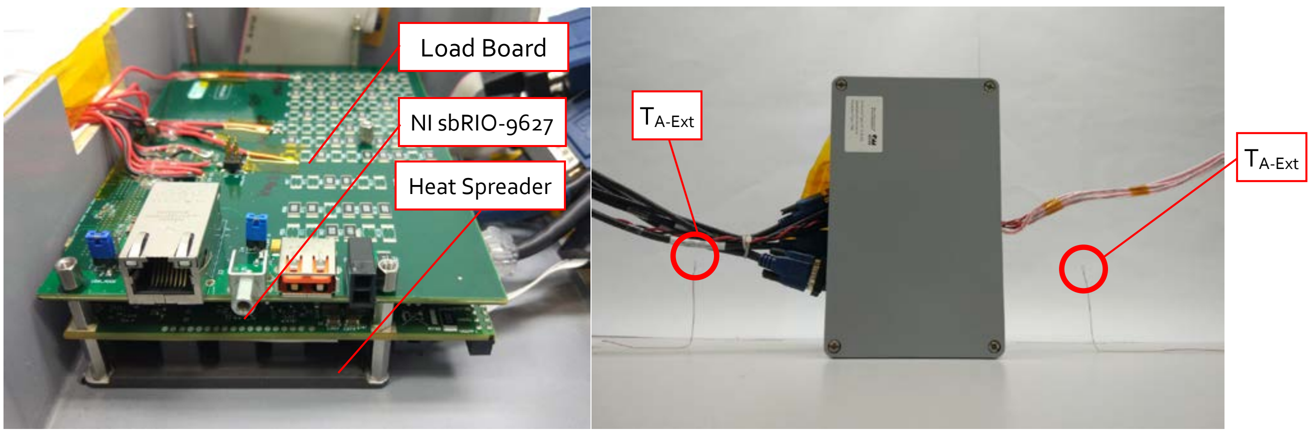


Figure 17: Configuration D – NI sbRIO-9627 with RMC test board in a small metal enclosure

5.4. *Results*

The following table shows the test results normalized to $T_{A\text{-}Ext}$=25°C. It includes the power draw measured 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.

Configuration A – Open Air with RMC

Open Air with RMC								
Configuration	A_0		A_1		A_5		A_{10}	
NI sbRIO-9627 Power (W)	9.5		9.8		10.5		10.7	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.5		20.7	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C\text{-}ENET1}$	43.3	76.5	43.3	76.4	46.4	73.3	49.7	70.1
$T_{C\text{-}ENET2}$	43.5	76.3	43.6	76.2	46.8	72.9	50.2	69.5
$T_{C\text{-}USB1}$	41.5	78.7	41.5	78.7	44.2	76.0	47.4	72.8

T_{C-USB2}	41.4	78.8	41.3	78.9	44.0	76.2	47.3	72.9
T_{C-CPLD}	39.6	54.7	39.6	54.8	41.9	52.4	44.8	49.6
T_{C-NAND}	39.2	55.8	39.2	55.8	41.5	53.5	44.4	50.6
T_{C-DDR}	39.3	50.6	40.1	49.7	42.6	47.2	44.3	45.5
T_{C-FPGA}	51.0	-	51.2	-	53.7	-	56.7	-
T_{S-FPGA}	67.9	30.1	68.2	29.8	71.6	26.4	75.0	23.0
$T_{A-P-SEN}$	47.8	37.2	48.2	36.8	52.9	32.1	57.3	27.7
$T_{A-S-SEN}$	48.3	36.7	48.7	36.3	53.8	31.2	58.4	26.6
T_{A-P-TL}	33.0	52.0	34.1	50.9	34.9	50.1	34.9	50.1
T_{A-P-TM}	41.1	43.9	40.3	44.7	43.1	41.9	47.7	37.3
T_{A-P-TR}	39.4	45.6	39.2	45.8	41.3	43.7	44.5	40.5
T_{A-P-BL}	36.1	48.9	35.9	49.1	38.7	46.3	40.8	44.2
T_{A-P-BM}	40.8	44.2	40.8	44.2	44.9	40.1	48.3	36.7
T_{A-P-BR}	38.2	46.8	39.3	45.7	42.0	43.0	43.1	41.9
T_{A-S-TL}	36.4	48.6	36.5	48.5	41.0	44.0	45.6	39.4
T_{A-S-TM}	39.5	45.5	40.4	44.6	47.4	37.6	54.0	31.0
T_{A-S-TR}	40.0	45.0	41.1	43.9	47.1	37.9	54.0	31.0
T_{A-S-BL}	35.3	49.7	36.1	48.9	43.9	41.1	54.6	30.4
T_{A-S-BM}	38.7	46.3	39.0	46.0	46.5	38.5	54.8	30.2
T_{A-S-BR}	38.8	46.2	39.9	45.1	48.3	36.7	57.6	27.4
T_{A-Ext}	25.0		25.0		25.0		25.0	

Configuration B – Large Fiberglass Enclosure with RMC

Fiberglass with RMC								
Configuration	**A_0**		**A_1**		**A_5**		**A_{10}**	
NI sbRIO-9627 Power (W)	9.5		9.8		10.6		10.8	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.6		20.8	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C-ENET1}$	47.9	71.8	50.1	69.7	55.5	64.2	60.1	59.6
$T_{C-ENET2}$	48.2	71.6	50.3	69.4	56.0	63.7	60.8	59.0
T_{C-USB1}	46.2	74.0	48.4	71.8	53.6	66.6	58.0	62.1
T_{C-USB2}	46.2	74.0	48.4	71.8	53.5	66.7	58.0	62.2
T_{C-CPLD}	44.4	49.9	46.4	47.9	51.2	43.2	55.5	38.8
T_{C-NAND}	44.1	50.9	46.0	49.0	50.8	44.2	55.1	39.9
T_{C-DDR}	44.1	45.8	46.1	43.8	50.8	39.1	55.0	34.8
T_{C-FPGA}	56.0	-	58.1	-	63.1	-	67.6	-
T_{S-FPGA}	73.1	24.9	75.0	23.0	80.5	17.5	85.7	12.3
$T_{A-P-SEN}$	52.6	32.4	54.9	30.1	61.8	23.2	67.6	17.4

$T_{A-S-SEN}$	53.4	31.6	55.5	29.5	63.0	22.0	68.8	16.2
T_{A-P-TL}	36.1	48.9	38.6	46.4	41.8	43.2	43.2	41.8
T_{A-P-TM}	46.1	38.9	46.8	38.2	52.3	32.7	58.7	26.3
T_{A-P-TR}	44.4	40.6	46.3	38.7	51.3	33.7	55.6	29.4
T_{A-P-BL}	40.8	44.2	42.6	42.4	47.2	37.8	50.5	34.5
T_{A-P-BM}	45.2	39.8	47.9	37.1	54.1	30.9	58.2	26.8
T_{A-P-BR}	43.0	42.0	45.5	39.5	50.4	34.6	53.8	31.2
T_{A-S-TL}	40.4	44.6	43.3	41.7	50.2	34.8	55.5	29.5
T_{A-S-TM}	44.0	41.0	47.2	37.8	56.6	28.4	64.2	20.8
T_{A-S-TR}	44.6	40.4	47.8	37.2	56.3	28.7	64.0	21.0
T_{A-S-BL}	39.2	45.8	42.5	42.5	52.9	32.1	62.8	22.2
T_{A-S-BM}	43.5	41.5	46.0	39.0	55.8	29.2	65.0	20.0
T_{A-S-BR}	43.8	41.2	47.6	37.4	58.0	27.0	68.4	16.6
T_{A-Ext}	25.0		25.0		25.0		25.0	

Configuration D – Small Metal Enclosure with RMC

Plastic with RMC								
Configuration	C_0		C_1		C_5		C_{10}	
NI sbRIO-9627 Power (W)	9.5		9.8		10.6		10.8	
RMC Power (W)	0.0		1.0		5.0		10.0	
Total System Power (W)	9.5		10.8		15.6		20.8	
Component	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**	**Measurement (°C)**	**Margin (°C)**
$T_{C-ENET1}$	44.1	75.7	45.5	74.3	50.5	69.2	56.1	63.7
$T_{C-ENET2}$	44.5	75.3	46.0	73.8	51.3	68.4	56.9	62.8
T_{C-USB1}	41.9	78.2	43.3	76.9	48.0	72.2	53.3	66.9
T_{C-USB2}	41.9	78.3	43.3	76.9	47.9	72.3	53.2	67.0
T_{C-CPLD}	39.6	54.7	40.8	53.6	44.8	49.5	49.7	44.6
T_{C-NAND}	38.9	56.1	40.1	54.9	44.0	51.0	48.9	46.1
T_{C-DDR}	39.0	50.8	40.2	49.7	44.2	45.7	48.9	40.9
T_{C-FPGA}	51.7	-	53.0	-	57.3	-	62.4	-
T_{S-FPGA}	69.4	28.6	70.9	27.1	76.1	21.9	82.0	16.0
$T_{A-P-SEN}$	49.9	35.1	51.8	33.2	58.7	26.3	65.6	19.4
$T_{A-S-SEN}$	50.8	34.2	52.8	32.2	60.3	24.7	67.4	17.6
T_{A-P-TL}	38.5	46.5	39.6	45.4	43.5	41.5	48.0	37.0
T_{A-P-TM}	43.9	41.1	45.7	39.3	52.0	33.0	58.4	26.6
T_{A-P-TR}	40.0	45.0	41.2	43.8	45.4	39.6	50.1	34.9
T_{A-P-BL}	37.9	47.1	39.1	45.9	43.5	41.5	48.5	36.5
T_{A-P-BM}	43.1	41.9	44.7	40.3	50.9	34.1	56.8	28.2
T_{A-P-BR}	39.0	46.0	40.2	44.8	44.4	40.6	49.1	35.9

$T_{A\text{-}S\text{-}TL}$	41.5	43.5	43.8	41.2	52.0	33.0	60.6	24.4
$T_{A\text{-}S\text{-}TM}$	44.0	41.0	46.8	38.2	57.3	27.7	67.8	17.2
$T_{A\text{-}S\text{-}TR}$	43.6	41.4	46.3	38.7	55.1	29.9	64.7	20.3
$T_{A\text{-}S\text{-}BL}$	39.7	45.3	42.9	42.1	54.9	30.1	67.8	17.2
$T_{A\text{-}S\text{-}BM}$	42.8	42.2	45.9	39.1	56.9	28.1	68.7	16.3
$T_{A\text{-}S\text{-}BR}$	43.0	42.0	46.5	38.5	57.5	27.5	70.1	14.9
$T_{A\text{-}Ext}$	25.0		25.0		25.0		25.0	

The measured power draw of the NI sbRIO-9627 increases slightly as the RMC power increases due to the added load on the power supply. With a 10W RMC, this results in 1.3W additional power being dissipated on the sbRIO board.

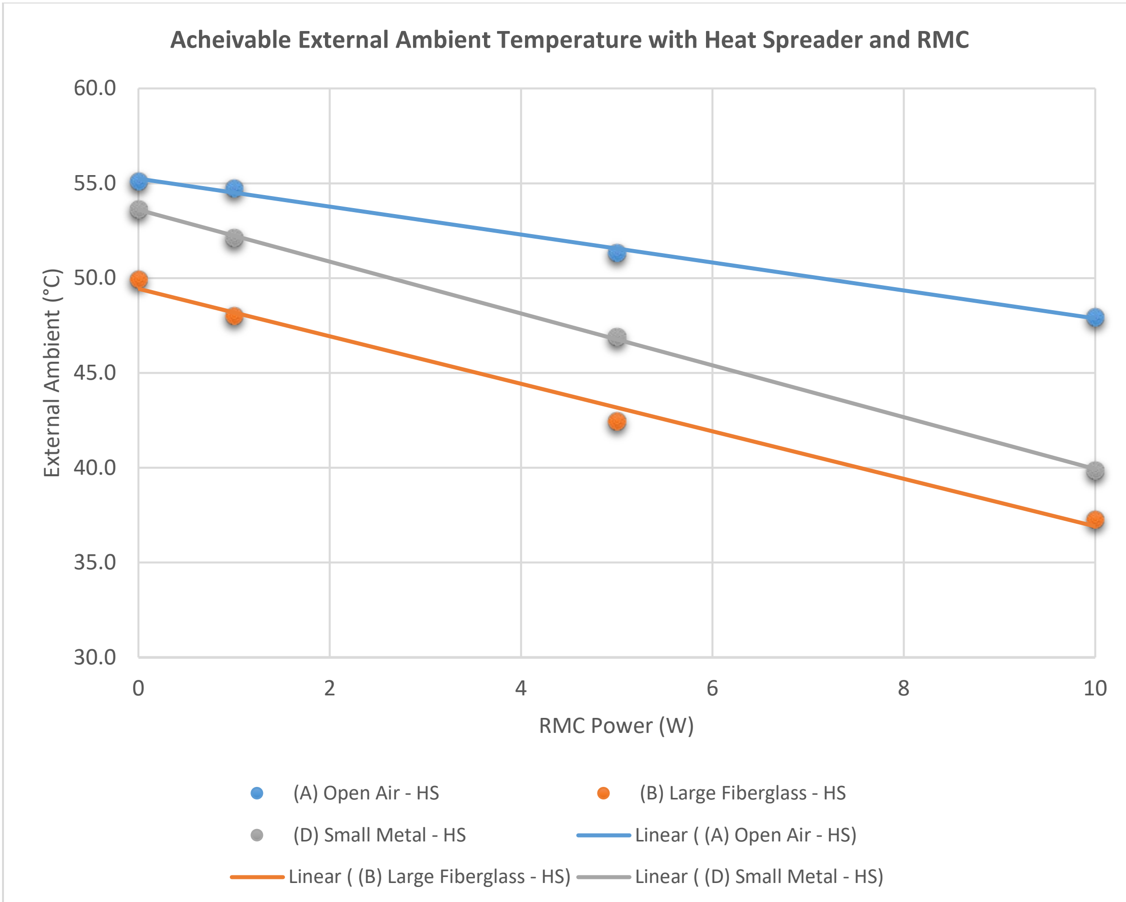
The heat spreader greatly reduces the die junction temperature of the CPU/FPGA and other case temperature of other critical ICs, making the CPU/ FPGA has the lowest margin in Open Air, Fiberglass and Small Metal Enclosure except local ambient temperature ($T_{A\text{-}S\text{-}BR}$) around the PCB in Small Metal enclosure with RMC dissipating 10W .

It is also seen that the local ambient temperatures on the secondary side of the sbRIO board, between the sbRIO and RMC ($T_{A\text{-}S\text{-}TL}$, $T_{A\text{-}S\text{-}TM}$, $T_{A\text{-}S\text{-}TR}$, $T_{A\text{-}S\text{-}BL}$, $T_{A\text{-}S\text{-}BM}$ and, $T_{A\text{-}S\text{-}BR}$) are typically hotter than the local ambient temperature measurements on the primary side. This becomes more noticeable as the RMC power increases.

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

RMC Power (W)	**Max Achievable $T_{A\text{-}Ext}$ (°C)**		
	A	**B**	**D**
0.0	55.1	49.9	53.6
1.0	54.8	48.0	52.1
5.0	51.4	42.5	46.9
10.0	48.0	37.3	39.9

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.


Acheivable External Ambient Temperature with Heat Spreader and RMC
60.0
55.0
50.0
45.0
40.0
35.0
30.0
External Ambient (°C)
0
2
4
6
8
10
RMC Power (W)
(A) Open Air - HS
(B) Large Fiberglass - HS
(D) Small Metal - HS
Linear ((A) Open Air - HS)
Linear ((B) Large Fiberglass - HS)
Linear ((D) Small Metal - HS)