Thermal Integration Guide

For all OS0, OS1, and OS2 lidar sensors

Ouster

Feb 25, 2022

Contents

1 Thermal Integration Guide

1.1 Overview

The Ouster lidar sensors offers an industry-leading combination of price, performance, reliability, size, weight, and power. It is designed for indoor/outdoor all-weather environments and a long operating lifetime.

The Ouster family of sensors consist of three models, the OS0, OS1, and OS2, with differing beam configuration and vertical resolution, but identical mechanical dimensions.

The contents of this manual are applicable only to Rev 06 sensors. Please contact support@ouster.io with the sensor serial number to find out your sensor Rev information. For all other sensor hardware revisions, please refer to the respective hardware user manual found Here.

Terminology

For the purposes of this document, let us first establish some common terminology that will be used in this guide.

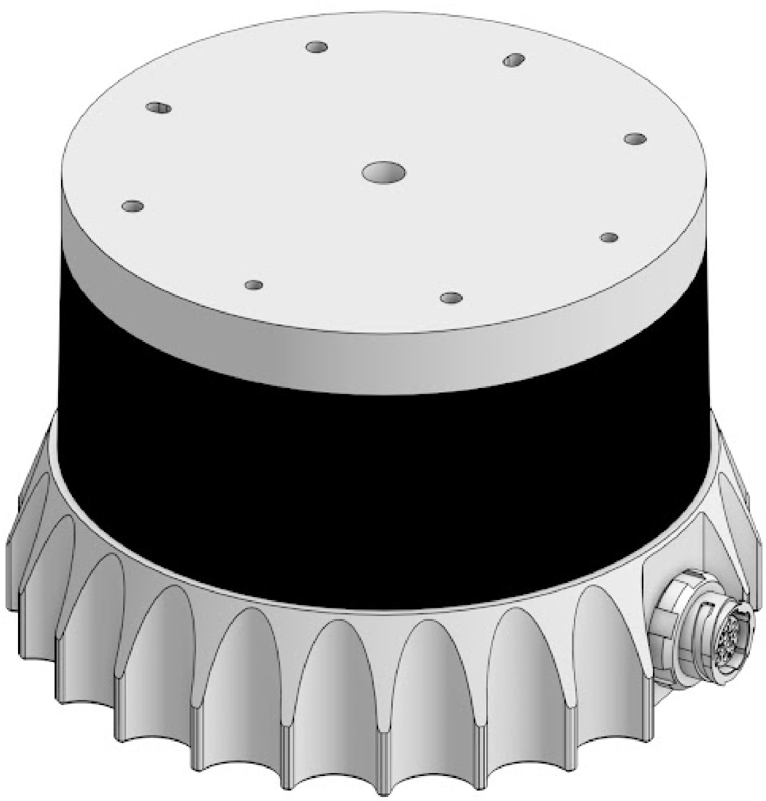

Figure1: **The Sensor** without any heatsink or mounting plates

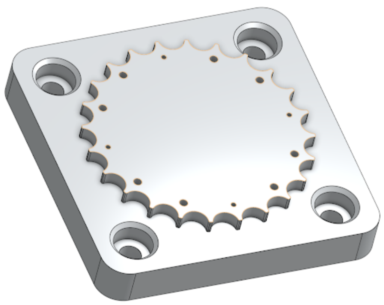

Fig. 2: **Heatsink Base** which doubles as the standard mounting plate.

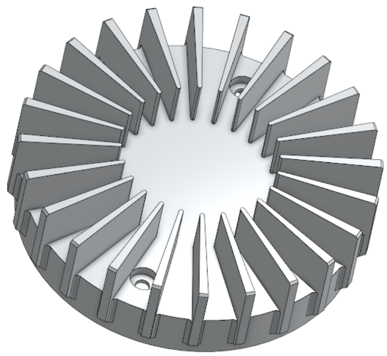

Fig. 3: **Heatsink Radial** is the radial finned heatsink modular cap.

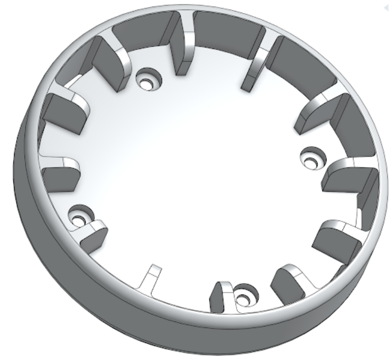

Fig. 4: **Heatsink Halo** The halo finned heatsink modular cap. *Preferred* when application needs to reduce sharp edges.

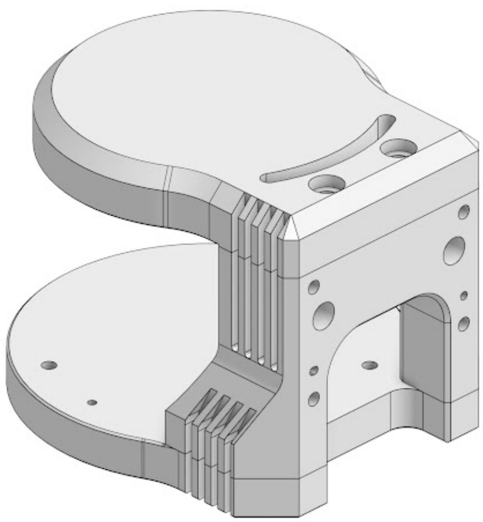

Fig. 5: **Heatsink Clamshell** Is a reference heatsink for integrating into vehicles in locations that require tighter integration.

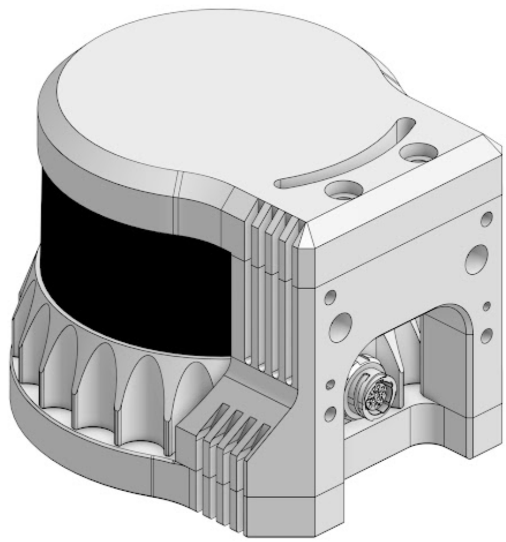

Fig. 6: **Heatsink Clamshell** with an Ouster Sensor.

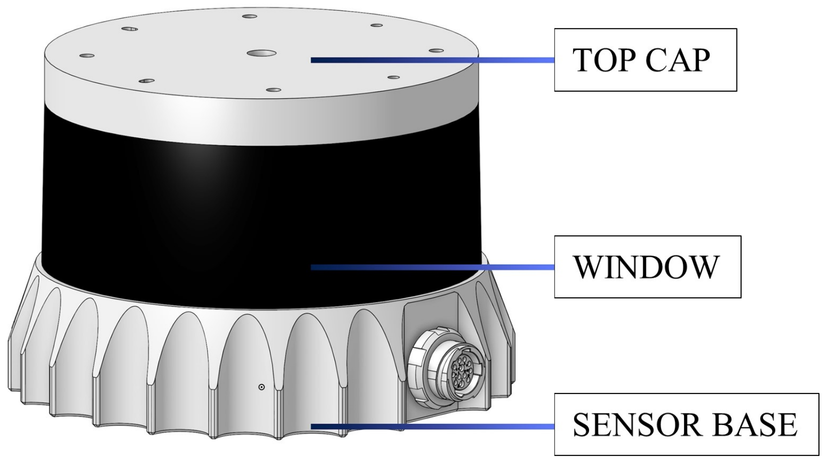

Figure7: Top Cap, Window and Sensor Base

- **Top Cap** The top of the sensor, which accepts modular heatsinks such as the Heatsink-Radial, Heatsink-Halo and has mounting features for seamless integrations.
- **Window** The window through which the lasers are emitted.
- **Sensor Base** The base of the sensor which has the connector mounted to it.

Free Convection The movement caused within a fluid by the tendency of hotter and therefore less denser material to rise, and colder, denser material to sink under the influence of gravity, which consequently results in transfer of heat.
Stagnant Air Air that is not moving other than by Free Convection.
Forced Convection The transfer of heat due to the bulk movement of fluid molecules over an object. The bulk movement can be due to wind, fan, vehicle motion, etc.

For the following reference tests in the Thermotron SE-1000-6-6 Environmental Chamber, our **FORCED CONVECTION** flow rate is 1000 cubic feet per minute (CFM). This is approximately 0.5 m/s or 1.8 km/h of air speed. The air in this chamber flows from top to bottom.

2 Performance Of Standard Design

2.1 Where does the heat come from?

There are two primary heat-dissipating assemblies in the sensor.

- The **Optical Turret** - containing the lasers and receivers.
- The **Base Assembly** - containing the computing, communication, and power.

The **Optical Turret** dissipates heat to both the `TOP CAP` and the `SENSOR BASE`. While, the `BASE ASSEMBLY` conducts most of its heat to the `SENSOR BASE`.

It is important in any sensor mounting integration design to accept heat from both the `TOP CAP` and `SENSOR BASE`.

Another important heat source factor to consider is the Sun. If the sensor will be operating in full sun you will need to account for the solar load (~1000 W/m2). In our testing, solar load reduces the maximum operating temperature by approximately 8ºC.

Please see the *Sunshade Concept Design* for inspiration on possible solutions.

2.2 Where does the heat go?

Standard Heatsinks

The sensor comes with two standard heatsinks attached to it.

- The base heatsink and mounting plate. (referred to as **HEATSINK-BASE**)
- The radial finned or halo heatsink modular caps. (referred to as **HEATSINK-RADIAL**, **HEATSINK-HALO**)

Note: Both have the same thermal performance.

It is also possible to create your own custom heatsinks for your specific integration, given that it adequately dissipates the heat from the sensor. For more information contact our Support team.

In the reference test conducted in the thermal chamber under **FORCED CONVECTION** (0.5 m/s) with the standard heatsinks, 38% of the heat is conducted into the **HEATSINK-BASE**.

While the remaining 62% of the heat convects to the air through the **HEATSINK-RADIAL**, **SENSOR BASE**, and **WINDOW**. Refer to *Forced Convection With Standard Heatsink Heat Path*.

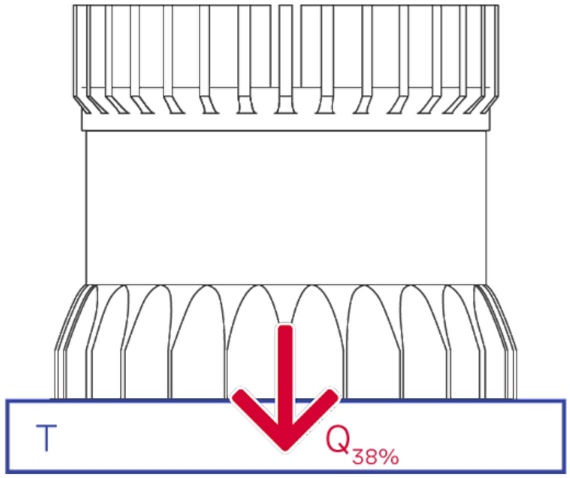

Figure8: Forced Convection With Standard Heatsink Heat Path

Similarly, for **FREE CONVECTION** (Stagnant Air) in the thermal chamber with the standard heatsinks, 45% of the heat is conducted into the **HEATSINK-BASE**.

While the remaining 55% of the heat convects to the air through the **HEATSINK-RADIAL**, **SENSOR BASE**, and **WINDOW**. Refer to *Stagnant Air with standard heatsink heat path*.

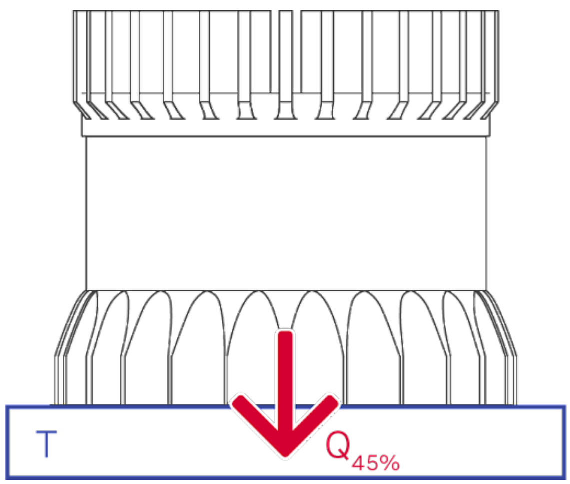

Figure9: Stagnant Air with standard heatsink heat path

Clamshell heatsink

The clamshell design was created to give you a reference of an integrated installation where heat dissipation is accomplished primarily through conduction into a vehicle chassis.

In the reference test conducted in the thermal chamber under **FREE CONVECTION** (Stagnant Air) with the clamshell heatsink, 87% of the heat is conducted into the **HEATSINK-CLAMSHELL**. While the remaining 13% of the heat convects to the air through the **HEATSINK-CLAMSHELL**, **SENSOR BASE** and **WINDOW**. Refer to *Clamshell Heat Path*.

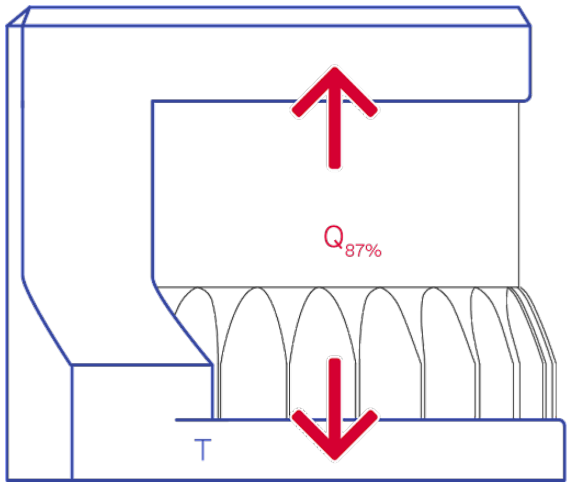

Figure10: Clamshell Heat Path

Now that you have a good understanding of where the heat goes, we will discuss some best practices when designing your own heatsinks and integrations.

3 Thermal Integration Best Practices

There are a few considerations when designing your heatsink integrations for your application.

1- Choose a material that has a high thermal conductivity to ensure the heat is efficiently conducted away from the sensor.

- If possible, the sensor should not share an interface with materials with low thermal conductivities. Materials such as wood (~0.12 W/m-K), glass (~0.935 W/m-K), and rubber (~0.140 W/m-K) have low thermal conductivities. In general, Aluminum alloys are best both for their thermal conductivity and mass properties.
- Below is a list of recommended Aluminum alloys and their thermal conductivities:
  - 6061: 167 W/m-K
  - 7075: 130 W/m-K
  - 2024: 151 W/m-K

2- Ensure that all interfaces are clean and free from debris. Debris and contaminants can reduce the thermal conductivity at an interface.

3- Torque bolts appropriately for the mount material and bolts specified. This will ensure the best thermal conductivity at an interface without damaging the threads. Below is a list of torque values for the sensor by screw size:

- 2 N-m: M3-0.5 mm
  - **HEATSINK-BASE** to **SENSOR BASE**
  - **HEATSINK-RADIAL** or **-HALO** to sensor **TOP CAP**
- 4 N-m: M4-0.7 mm
  - **HEATSINK-CLAMSHELL** top to clamshell riser
- 7 N-m: M6-0.8 mm
  - **HEATSINK-CLAMSHELL** base to sensor **TOP CAP**
  - **HEATSINK-CLAMSHELL** base to clamshell riser

4- Use Thermal Interface Material (TIM) for any irregular or non machined surfaces. TIM usually comes in a paste or pad form; it works to increase the surface area that heat can be conducted through at an interface.

5- Ensure that the sensor is not over constrained if mounting to both **SENSOR BASE** and **TOP CAP**. If the sensor is clamped between the surfaces that attach to the **SENSOR BASE** and **TOP CAP**, the **WINDOW** will experience deflection which will negatively affect the optical performance.

- To ensure this does not occur we recommend using a TIM pad to ensure good conductivity while not over-constraining.

6. Ensure your implementation maintains the base and top of the sensor below the maximum chassis temperatures listed in *Sensor Max Operating Temperature - Gen 1 OS1 with Legacy Cap*.

7. To maximize **FREE** and **FORCED CONVECTION**, the area around the sensor should be unobstructed.

8. Design the shape of any heatsinks to maximize the surface area for **FREE** and **FORCED CONVECTION** while being thick enough to allow the heat to conduct through the material. Below are some recommended features:

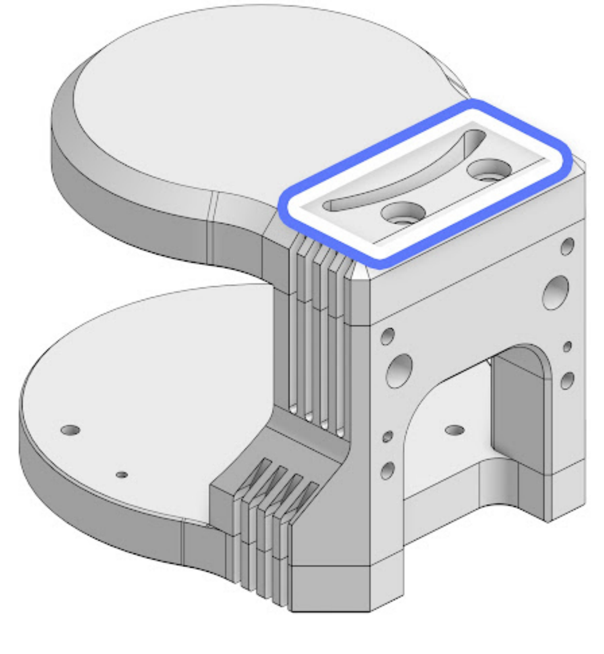

Fig. 11: Air Flow Paths

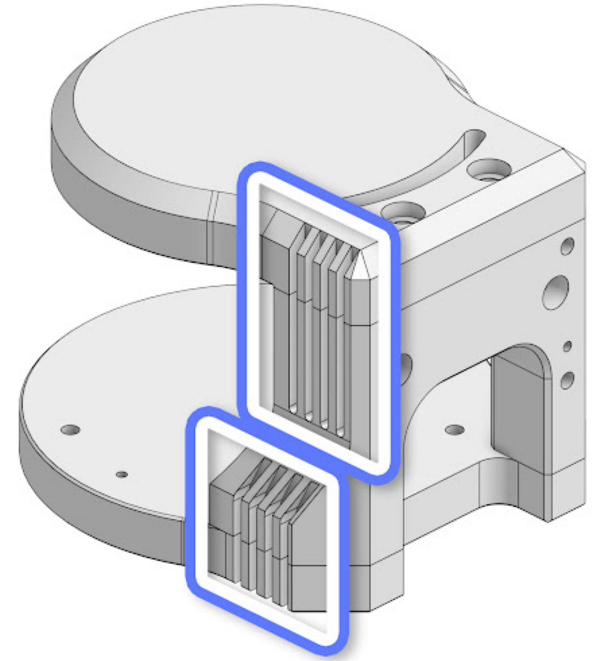

Fig. 12: Fins

9- Whenever possible it is highly recommended to use heatsinks. For special integrations where the **HEATSINK-RADIAL** and **HEATSINK-BASE** are both removed, such as drone integrations, it is critical that the thermal alerts are monitored closely. For these types of integrations it is required to use the `STANDBY` operating mode until adequate **FORCED CONVECTION** (e.g. from flying) is provided. Without heatsinks, if any thermal alerts are triggered, the sensor should immediately be put into `STANDBY` mode or shut off until adequate heatsinking is provided.

> **Warning:** If the sensor is consistently receiving thermal alerts due to the removal of the heatsinks, this will **void** the **warranty**.

Now that you have some best practices for your integration, we will discuss how to monitor your integration with *Thermal Alerts*.

4 Max Operating Temperatures

Max operating temperatures were calculated through reference tests conducted in Ouster's thermal chambers. OS0, OS1, and OS2 are tested on **HEATSINK-BASE** is as shown below:

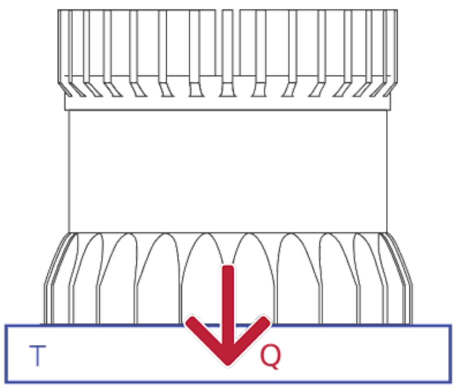

Fig. 13: OS0, OS1 Mounting Image

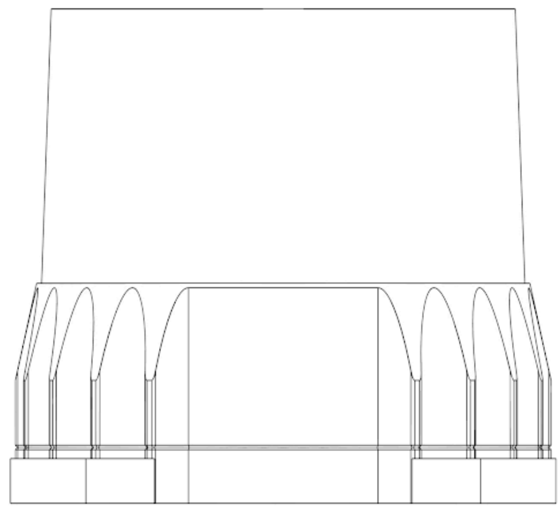

Fig. 14: OS2 Mounting Image

The results may vary slightly depending on test conditions such as air temperature, air flow, and sensor mounting.

Table 1: Sensor Max Operating Temperature - **Gen 1 OS1 with Legacy Cap**

Sensor Part Number		**Convective Air**	**Stagnant Air**
840-101396-03 (with Push-Pull Connector)	Start of Shot Limiting Active (Performance 100% - 70%)	$T_{chassis}$ = 55ºC T_{air} = 50ºC	$T_{chassis}$ = 56ºC T_{air} = 40ºC
840-101855-02 (with Locking Bayonet Connector)	Max Temp Sensor Shutdown	$T_{chassis}$ = 65ºC T_{air} = 60ºC	$T_{chassis}$ = 60ºC T_{air} = 50ºC

Table 2: Sensor Max Operating Temperature - **OS1 Gen 1/ OS0/1 Rev C with Modular Cap**

Sensor Part Number		Convective Air	Stagnant Air
840-101855-03 (Gen1 OS1 with Locking Bayonet Connector) **840-102144-C** (Gen2 OS0 with Locking Bayonet Connector)	Start of Shot Limiting Active (Performance 100% - 70%)	$T_{chassis}$ = 52ºC T_{air} = 47ºC	$T_{chassis}$ = 52ºC T_{air} = 37ºC
840-102145-C (Gen2 OS1 with Locking Bayonet Connector)	Max Temp Sensor Shutdown	$T_{chassis}$ = 65ºC T_{air} = 60ºC	$T_{chassis}$ = 60ºC T_{air} = 45ºC

Table 3: Sensor Max Operating Temperature - **OS0/1 Rev D/05/06 with Modular Cap**

Sensor Part Number		Convective Air	Stagnant Air
840-102144-D (Gen2 OS0 with Locking Bayonet Connector) **840-102145-D** (Gen2 OS1 with Locking Bayonet Connector) **840-102144-05** (Gen2 OS0 with Locking Bayonet Connector)	Start of Shot Limiting Active (Performance 100% - 70%)	$T_{chassis}$ = 58ºC T_{air} = 53ºC	$T_{chassis}$ = 58ºC T_{air} = 45ºC
840-102145-05 (Gen2 OS1 with Locking Bayonet Connector) **840-102144-06** (Gen2 OS0 with Locking Bayonet Connector) **840-102145-06** (Gen2 OS1 with Locking Bayonet Connector)	Max Temp Sensor Shutdown	$T_{chassis}$ = 65ºC T_{air} = 60ºC	$T_{chassis}$ = 60ºC T_{air} = 50ºC

Note: Without a HEATSINK-BASE, thermal performance decreases by an estimated 4ºC

Table 4: Sensor Max Operating Temperature - **OS2 Rev D/05/06 with Modular Cap**

Sensor Part Number		Convective Air	Stagnant Air
840-102146-D (Gen2 OS2 with Locking Bayonet Connector) **840-102146-05** (Gen2 OS2 with Locking Bayonet Connector) **840-102146-06** (Gen2 OS2 with Locking Bayonet Connector)	Start of Shot Limiting Active (Performance 100% - 70%)	$T_{chassis}$ = 62ºC T_{air} = 52ºC	$T_{chassis}$ = 62ºC T_{air} = 50ºC
840-102146-D (Gen2 OS2 with Locking Bayonet Connector) **840-102146-05** (Gen2 OS2 with Locking Bayonet Connector) **840-102146-06** (Gen2 OS2 with Locking Bayonet Connector)	Max Temp Sensor Shutdown	$T_{chassis}$ = 75ºC T_{air} = 62ºC	$T_{chassis}$ = 71ºC T_{air} = 60ºC

Note: In our testing, solar load reduces the maximum operating temperature by approximately 8ºC. Please see the Appendix: Sunshade concept design for inspiration on possible solutions.

5 Thermal Alerts

The sensor alert system and thermal management are designed to ensure safe and robust operation in demanding environments. As the environment temperature gets higher the sensor will selectively reduce the amount of power consumed to ensure continued operation in temperatures approaching the maximum listed in *Sensor Max Operating Temperature - Gen 1 OS1 with Legacy Cap*.

Note: 50% shot limiting means 50% of the signal not 50% of the range.

The sensor has four stages of operation related to high-temperature environments as shown in the *High Temperature Operating Modes*.

1- Normal Operation - This stage is the default when the temperatures are between the minimum and maximum specified in the datasheet.

- In this stage, the sensor operates at full performance.

2- Shot Limiting Zone Entered - This stage is entered when the chassis temperature is within ~2ºC of the maximum specified temperature.

- In this stage, the sensor continues to operate at full performance and produces an alert to notify you that the sensor may soon enter a reduced performance mode.

3- Shot Limiting Active - This stage is entered when the chassis temperature is at the maximum operating temperature listed in *Sensor Max Operating Temperature - Gen 1 OS1 with Legacy Cap*.

- In this stage, the sensor continues to operate but at reduced performance. The number of shots will gradually decrease from 100% down to 50% until reaching the saturation temperature.

4- Shot Limiting Saturated - This stage is entered when the shots have been limited by 50%.

- In this stage, the sensor will continue to limit the number of shots at 50% until the temperature rises approximately 5ºC.

5- Sensor Shutdown - This stage is entered when the chassis temperature reaches the sensor shutoff temperature listed in *Sensor Max Operating Temperature - Gen 1 OS1 with Legacy Cap*.

- In this stage, the sensor will shut itself down to prevent damage.

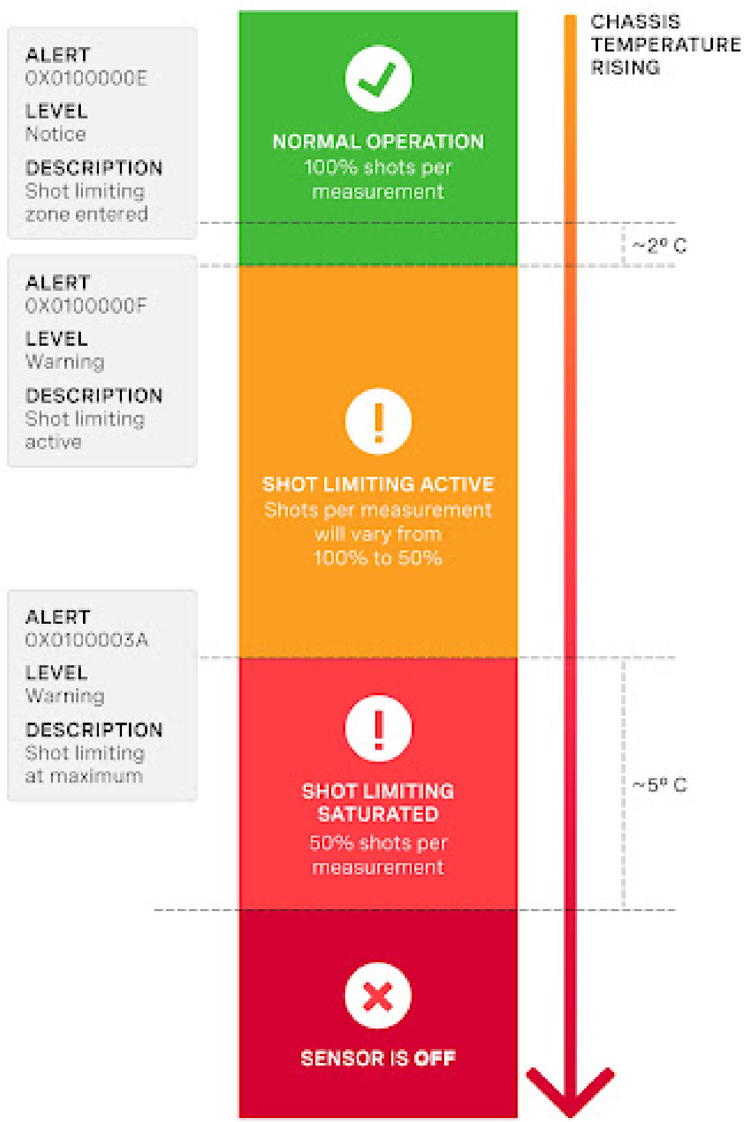

Figure15: High Temperature Operating Modes

6 Appendix

6.1 Simple Thermal Model

- Use the sensor CAD from the Downloads page to define the control volume
- Simulate the sensor as a conductive material, such as aluminum, with a single power source.
- Using the sensor product line data sheet to determine the power dissipated inside the control volume.

Note: The power dissipation varies during startup, nominal operation, and in cold ambient temperatures.

6.2 OS0/1 Detailed Thermal Model

Thermal Model Specifications and *OS0/1 Thermal Model Cross Section* detail the specifications of the Thermal Model. Assumptions for Thermal Model are as follows:

- Use case is to add the Thermal Model to CAD/simulation software to conduct CFD simulation.
- Simulation is not transient, so thermal capacitance of materials and soak times do not need to be accurately estimated.
- Simulation needs to estimate the power dissipation at the sensor's three external components: **HEATSINK-RADIAL**, **WINDOW**, and **SENSOR BASE** enclosure given various external constraints.
- Internal temperatures of the sensor do not need to be simulated.
- Temperatures and heat fluxes need to be simulated at the control volume surface.
- There is no contact resistance between components of the Thermal Model.
- The Thermal Model assumes 18W power dissipation. This is a conservative assumption for a sensor at steady state conditions at higher temperatures. Sensor power draw is higher during startup and colder ambient conditions. Reference the relevant sensor datasheet for the power draw at startup and cold ambient temperatures.

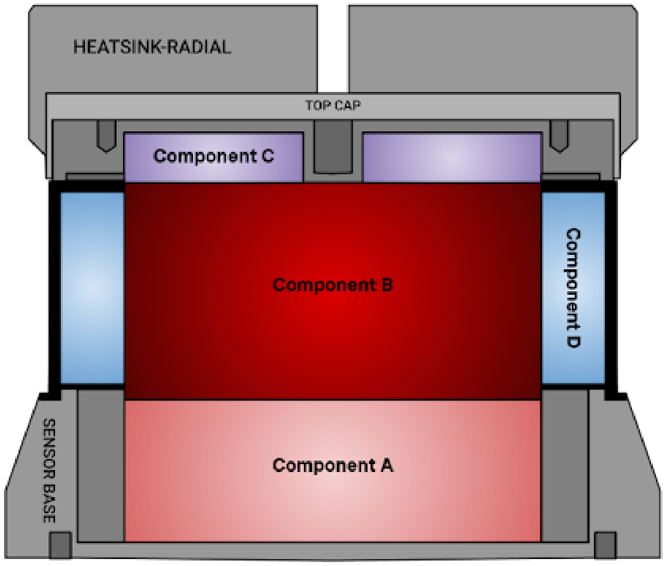

Figure16: OS0/1 Thermal Model Cross Section

Table 5: Thermal Model Specifications

	Shape	Material/ Conductivity	Heat Dissipation
Simplified **SENSOR BASE**	Cylindrical Bowl	Aluminum 6061-T6 with clear anodize	·
Simplified **TOP CAP**	Cylindrical Bowl	Aluminum 6061-T6 with clear anodize	·
WINDOW	Tube	Polycarbonate	·
Component A	Cylinder	2.68 W* m^{-1}* K^{-1}	6 W (at SENSOR BASE interface)
Component B	Cylinder	Perfect conductor	12 W
Component C	Tube / Donut	0.401 W* m^{-1}* K^{-1}	·
Component D	Tube / Donut	0.209 W* m^{-1}* K^{-1}	·

6.3 Sunshade Concept Design

We have created a simple *Sunshade Concept Design* that may help mitigate the solar load. It attaches on top of the modular cap using the existing mounting holes in the modular cap.

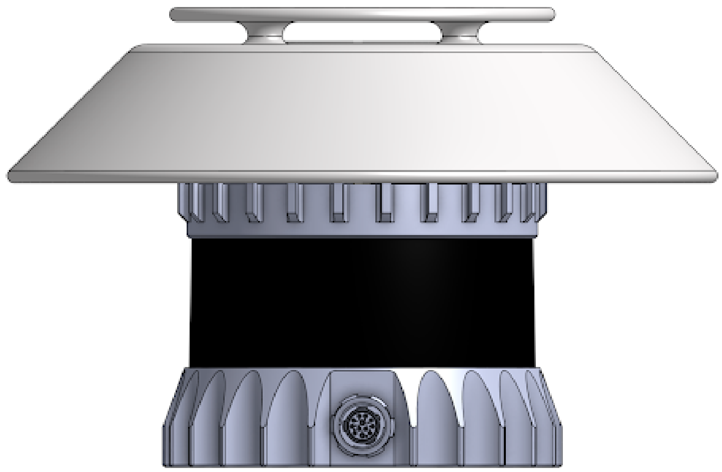

Figure17: Sunshade Concept Design

Note: The modular cap (**HEATSINK-RADIAL** or -**HALO**) must remain attached to the **TOP CAP** of the sensor. The original M3-0.5x5 mm modular cap screws would need to be replaced with longer M3-0.5x30 mm standoffs.

Note: This concept design is only for sensors with the modular cap that has the four mounting holes to interface with the **TOP CAP**. * 840-101855-03 - Gen1 OS1 with Locking Bayonet Connector * 840-102144-A/B/C/D/5/6 - Gen2 OS0 with Locking Bayonet Connector * 840-102145-A/B/C/D/5/6 - Gen2 OS1 with Locking Bayonet Connector

Note: This version is designed not to occlude any beams on a Gen2 OS1-128 with 45º VFOV. Design should be modified to accommodate wider VFOVs (90º) or more shade.

Warning: This design is meant to be an inspiration for your design and has not been validated.

The CAD model is available *HERE* for you to iterate and fabricate.

7 Supported Products

The current firmware is supported on the following Ouster products:

→

OS0 , OS1, OS2:

- GEN1: P/N 840-101-XXX-XX
- Rev C: P/N 840-102-XXX-C
- Rev D: P/N 840-102-XXX-D
- Rev 05: P/N 840-102xxx-05
- Rev 06: P/N 840-102xxx-06

Note: Dual Return mode is only supported with Rev 06 and above sensors.