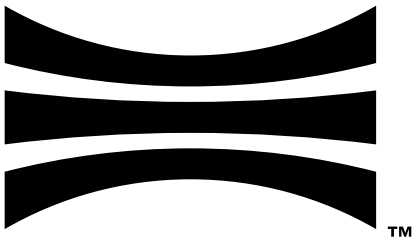


Ouster Firmware User Manual

Firmware v3.1.0 for all Ouster sensors

Ouster

May 02, 2024

Contents

1 Important Safety Information

1.1 Safety & Legal Notices

All Ouster sensors have been evaluated to be **Class 1 laser products** per **60825-1: 2014 (Ed. 3)** and operate in the 865nm band.

Tous les capteurs Ouster répondent aux critères des **produits laser de classe 1**, selon la norme **IEC 60825-1: 2014 (3ème édition)** et émettent dans le domaine de l'infrarouge, à une longueur d'onde de 865nm environ.

FDA 21CFR1040 Notice: All Ouster sensors comply with FDA performance standards for laser products except for deviations pursuant to Laser Notice No. 56, dated January 19, 2018.

Notice FDA 21CFR1040: Tous les capteurs Ouster sont conformes aux exigences de performances établies par la FDA pour les produits laser, à l'exception des écarts en application de l'avis nº56, daté du 19 janvier 2018.

Figure 1.1: Class 1 Laser Product

Figure 1.2: Caution "Sharp Edges"

The following symbols appear on the product label and in the user manual have the following meaning.

CAUTIONS

Figure 1.3: This symbol indicates that the sensor emits laser radiation.

Figure 1.4: This symbol indicates the presence of a hot surface that may cause skin burn.

- All Ouster sensors are hermetically sealed units, and are non user-serviceable.
- Use of controls, or adjustments, or performance of procedures other than those specified herein, may result in hazardous radiation exposure.
- Use of any Ouster sensor is subject to the Terms of Sale that you agreed and signed with Ouster or your distributor/integrator. Included in these terms are the prohibitions of:
  - Removing or otherwise opening the sensor housing
  - Inspecting the internals of the sensor
  - Reverse-engineering any part of the sensor
  - Permitting any third party to do any of the foregoing
- Operating the sensor without the attached mount that is shipped with the sensor, or attaching the sensor to a surface of inappropriate thermal capacity runs the risk of having the sensor overheat under certain circumstances.
- The Ouster sensor features a modular cap design to enable more flexible mounting and integration solutions for the sensor.
- The modular cap design increases design flexibility but it does not remove the need for thermal management on top of the sensor. The attached radial cap serves an important thermal management purpose and the sensor will not operate properly without a cap.
- Operation for extended periods of time without the cap will result in system errors and the sensor overheating. The cap can be replaced with alternative solutions but it cannot be left off altogether.
- If you wish to operate the sensor with a custom mounting solution, please contact our Field Application Team and we can answer your questions and provide guidance for achieving proper operations.
- This product emits Class 1 invisible laser radiation. The entire window is considered to be the laser aperture. While Class 1 lasers are considered to be "eye safe", avoid prolonged direct view-

ing of the laser and do not use optical instruments to view the laser.

- When operated in an ambient temperature >40 °C, the metallic surfaces of the sensor may be hot enough to potentially cause skin burn. Avoid skin contact with the sensor's base, lid and the heatsink when the sensor is operated under these conditions. The sensor should not be used in an ambient temperature above 60°C. The maximum safety certified ambient operating temperature is 60°C.

PRECAUTIONS:

- Tous les capteurs Ouster sont des unité hermétiquement scellée, qui ne peut être entretenue ou modifiée par l'utilisateur.
- L'utilisation de commandes, de réglages, ou l'exécution de procédures autres que celles spécifiées dans le présent document peuvent entraîner des rayonnements laser dangereux.
- L'utilisation d'un capteur Ouster est soumise aux conditions de vente signées avec Ouster ou le distributeur/intégrateur, incluant l'interdiction de:
    - Retirer ou ouvrir de quelque façon le boîtier du capteur
    - Analyser les composants internes du capteur
    - Pratiquer la rétro-ingénierie de toute ou partie du capteur
    - Autoriser une tierce personne à mener les actions listées ci-dessus
- L'utilisation du capteur sans le support (fourni avec les capteur) ou sans contact avec une surface ayant des capacités thermiques adéquates peut entraîner une surchauffe du capteur dans certaines conditions.
- Ce capteur présente une conception avec un dissipateur thermique supérieur modulaire, ceci pour apporter plus de flexibilité de montage et d'intégration au capteur.
- Cette conception modulaire augmente la flexibilité de conception mais ne supprime pas le besoin de dissipation thermique au-dessus du capteur. Le dissipateur thermique radial fourni est essentiel à une bonne gestion thermique. Le capteur ne fonctionnera pas correctement sans cette pièce.
- Une utilisation prolongée du capteur sans le dissipateur thermique supérieur peut résulter à des erreurs système ainsi qu'à une surchauffe du capteur pouvant aller jusqu'à son extinction. Le dissipateur thermique fourni peut être remplacé par une autre solution de dissipation thermique adéquate, mais ne doit pas être simplement retiré.
- Si vous souhaitez utiliser votre capteur avec une dissipation thermique personnalisée, merci de contacter notre Équipe Support qui pourra répondre à vos questions et vous apporter le support et le conseil nécessaire.
- Ce produit émet un rayonnement laser invisible de classe 1. L'ouverture de sortie du laser est constituée par la fenêtre du capteur dans sa totalité. Même si les lasers de classe 1 ne sont pas considérés comme dangereux pour les yeux, ne regardez pas directement le rayonnement laser de façon prolongée et n'utilisez pas d'instruments optiques pour observer le rayonnement laser.
- Lors d'une utilisation à température ambiante supérieure à 40°C, la surface métallique du cap-

teur peut présenter des risques de brûlures pour la peau. Dans ces conditions, il est important d'éviter tout contact avec la partie supérieure, la base ou le dissipateur thermique du capteur. Le capteur ne doit pas être utilisé à une température ambiante supérieure à 60˚C. 60˚C est la température maximale certifiée d'opération sûre du capteur.

Equipment Label: Includes model and serial number and a notice that states the unit is a Class 1 Laser Product, is affixed to the underside of the Sensor Enclosure Base. It is only visible after the attached mount with which the Sensor is shipped, is removed. For location details please refer to the hardware user manual.

L'étiquette de l'équipement, comprenant le modèle, le numéro de série, et la classification du produit laser (ici, classe 1), est apposée au-dessous de la base du boîtier du capteur. Il n'est visible qu'après avoir retiré le diffuseur de chaleur avec lequel le capteur est expédié. L'emplacement est décrit précisément dans le manuel d'utilisation du matériel.

Electromagnetic Compatibility: The Ouster sensors are an FCC 47 CfR 15 Subpart B device. This device complies with part 15 of the FCC Rules. Operation is subject to the following conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

"Ouster" and Ouster sensors are both registered trademarks of Ouster, Inc. They may not be used without express permission from Ouster, Inc.

If you have any questions about the above points, contact us at legal@ouster.io.

1.2 Proper Assembly, Maintenance and Safe Use

All Ouster sensors can be easily set up by following the instructions outlined in the hardware user manual. Any mounting orientation is acceptable. Each sensor is shipped with an attached mount that can be used for test or normal use within the specified operating conditions. The sensor may also be affixed to any other user specific mount of appropriate thermal capacity. Please contact Ouster for assistance with approving the use of user specific mounting arrangements.

Any attempt to utilize the sensor outside the environmental parameters delineated in the relevant data sheet for your Ouster sensor may result in voiding the warranty.

When power is applied, the sensor powers up and commences boot-up with the laser disabled. The boot-up sequence is approximately 30s in duration, after which the internal sensor optics subassembly commences spinning, the laser is activated, and the unit operates in the default 1024 x 10 Hz mode if no configuration is saved. When the sensor is running, and the laser is operating, a faint red flickering light may be seen behind the optical window.

Note: All Ouster sensors utilize an 865nm infrared laser that is only dimly discernible to the naked eye. The sensor is fully Class 1 eye safe, though Ouster strongly recommends against peering into the optical window at close range while the sensor is operating. Ouster sensors are equipped with a multi-layer series of internal safety interlocks to ensure compliance to Class 1 Laser Eye Safe limits.

All Ouster sensors are hermetically sealed units, and are not user-serviceable. Any attempt to unseal the enclosure has the potential to expose the operator to hazardous laser radiation.

The sensor user interface may be used to configure the sensor to a number of combinations of scan rates and resolutions other than the default values of 1024 x 10 Hz resolution. In all available combinations, the unit has been evaluated by an NRTL to remain within the classification of a Class 1 Laser Device as per IEC 60825-1:2014 (Ed. 3).

1.2.1 Assemblage correct et utilisation sûre

Tous les capteurs Ouster s'installe facilement en fixant la base sur un support percé de trous concordants, et en suivant les instructions d'interconnexion décrites dans le manuel d'utilisation du matériel. Toute orientation de montage est acceptable. Chaque capteur est expédié équipé d'un dissipateur de chaleur, utilisable en phase de test et en conditions normales. Néanmoins tout autre support présentant une capacité thermique appropriée pour l'application de l'utilisateur peut être utilisé. Veuillez contacter Ouster dans le cas où un montage spécifique à votre application serait nécessaire.

Toute tentative d'utilisation du capteur en dehors des paramètres environnementaux définis dans la fiche technique de votre capteur Ouster peut entraîner l'annulation de la garantie.

Lorsque le capteur est sous tension, celui-ci démarre et commence son initialisation avec le laser désactivé. Le temps de démarrage est d'environ 30s, après quoi le sous-système optique entre en rotation et le laser est activé, le capteur opère alors dans son mode par défaut de 1024 x 10 Hz. Lorsque le capteur est en marche et que le laser est activé, on peut apercevoir une faible lumière rouge vacillante derrière la vitre teintée. Tous les capteurs Ouster utilisent une longueur d'ondes infra-rouge de 865nm à peine perceptible pour l'œil humain, et le rayonnement laser IR émis est sans danger pour les yeux. Cependant, bien que les rayonnements laser de classe 1 soient sans danger dans des conditions raisonnablement prévisibles, Ouster recommande fortement de ne pas regard er fixement la vitre teintée pendant que le capteur est en marche. Tous les capteurs Ouster sont des unités hermétiquement scellées, qui ne peuvent pas être entretenues, modifiées ou réparées par l'utilisateur. Toute tentative d'ouverture du boîtier a pour risque d'exposer l'opérateur à un rayon-nement laser dangereux.

Les capteurs Ouster sont équipés d'une série de dispositifs de sécurité à plusieurs niveaux, de façon à assurer en toutes circonstances le respect des limites d'irradiance correspondant aux rayonnements lasers de classe 1, sans danger pour les yeux.

L'interface utilisateur du logiciel du capteur peut être utilisée pour configurer le capteur selon un certain nombre de combinaisons de vitesses de balayage et de résolutions autres que les valeurs utilisées par défaut, respectivement de 1024 x 10 Hz.

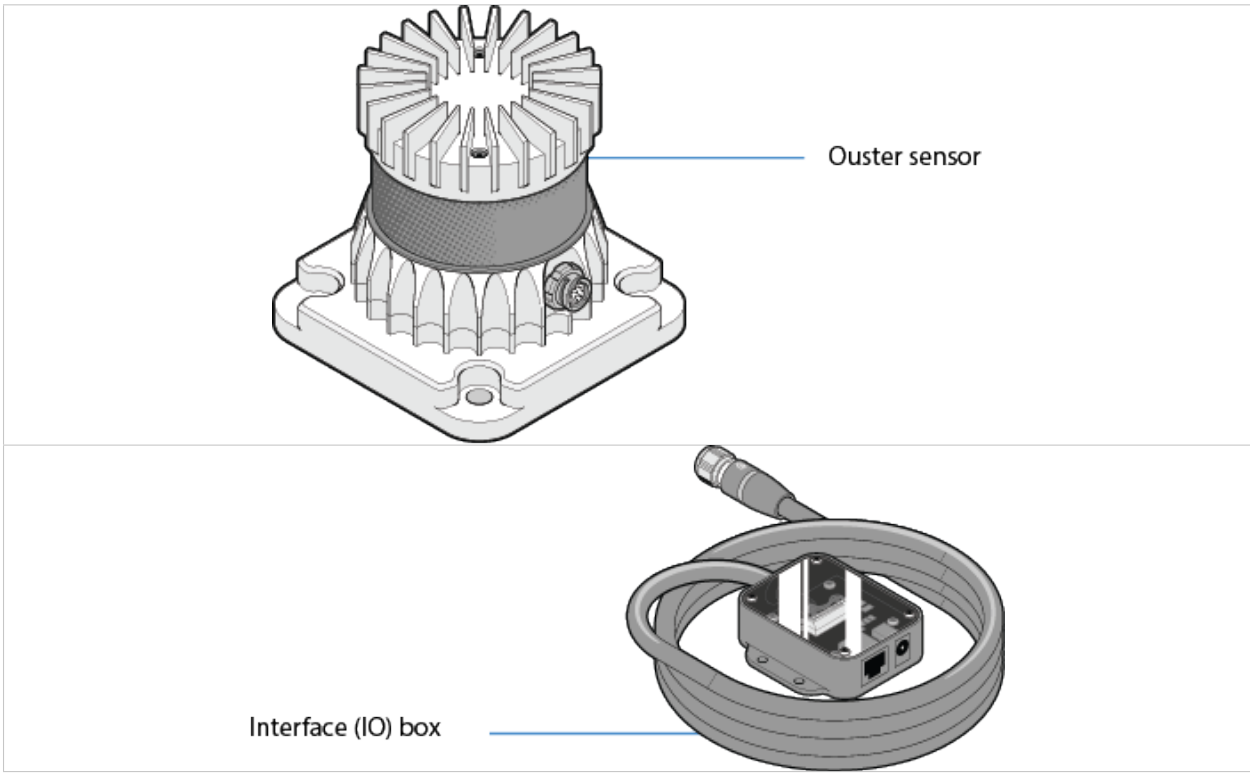
2 Quick Start Guide

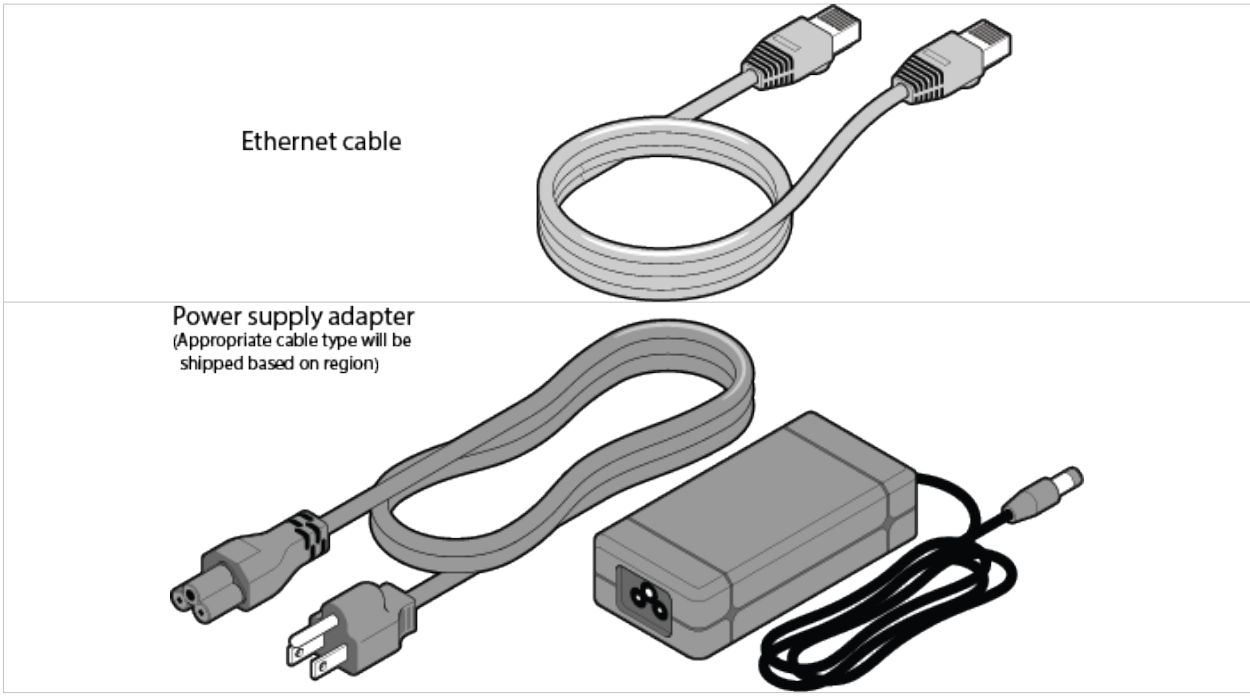
This **Firmware User Manual** is meant to allow the users to take advantage of all the features that are available with Ouster Sensors. Detailed Instructions regarding lidar operations, lidar data, API Guides and Troubleshooting guide are present in this user manual.

For information on the mechanical and electrical operations or the interface box, please refer to the Hardware User Manual.

To know more about Ouster sensors and their specifications please refer to the datasheets available on our Website.

2.1 What's in the box



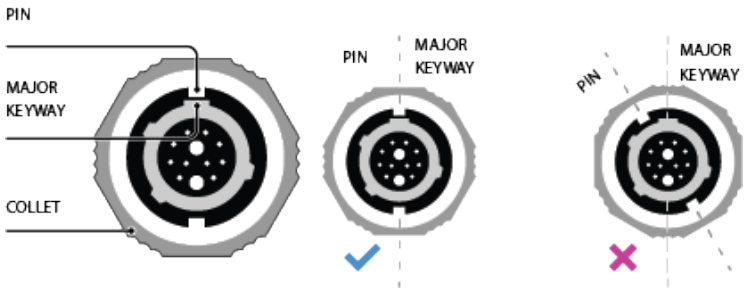


Note: Interface box is not always shipped with the sensor, based on customer requirement it could be a pig tail connector cable or a custom cable.

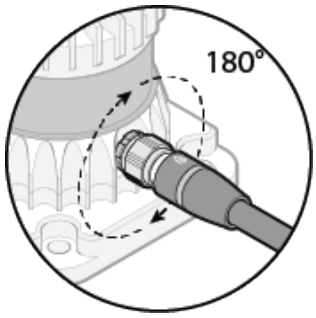
2.2 Sensor Setup

- Connect one end of the bayonet-style connector to the Ouster sensor as shown. Verify that the plug "UP" indicator is pointed up.

- Rotate the collet on the plug until one of its two pins is aligned with the major keyway. This will allow its two pins to enter the receptacle channel.



- Connect the plug to the sensor, then rotate the collet 180 degrees clockwise until it clicks. This indicates that it is fully seated.



- Connect one end of the power supply to the wall socket and the other end to the IO box.
- Connect one end of the ethernet cable provided to the IO box and the other end to a PC/LINUX/-MAC user interface.

2.3 Network Configuration

The sensor is designed to communicate with a host machine through a variety of different methods such as DHCP, IPv6/IPv4 link-local, and static IP.

On most systems you should be able to connect the sensor into your network or directly to a host machine and simply use the sensor hostname to communicate with it.

Your Ouster sensor requires a computer with a gigabit Ethernet connection and a 24V supply.

Optionally you may time synchronize the sensor through an external time source or through the computer via PTP.

The sensor hostname is `os-991234567890.local`, where `991234567890` is the sensor serial number. The sensor serial number can be found on a sticker affixed to the top of the sensor.

For more detailed guidance on communicating with the sensor on various operating systems and network settings please reference the *Networking Guide* in the Appendix.

Commands for *setting* and *deleting* a static IP address can be found in the *HTTP API Reference Guide* section.

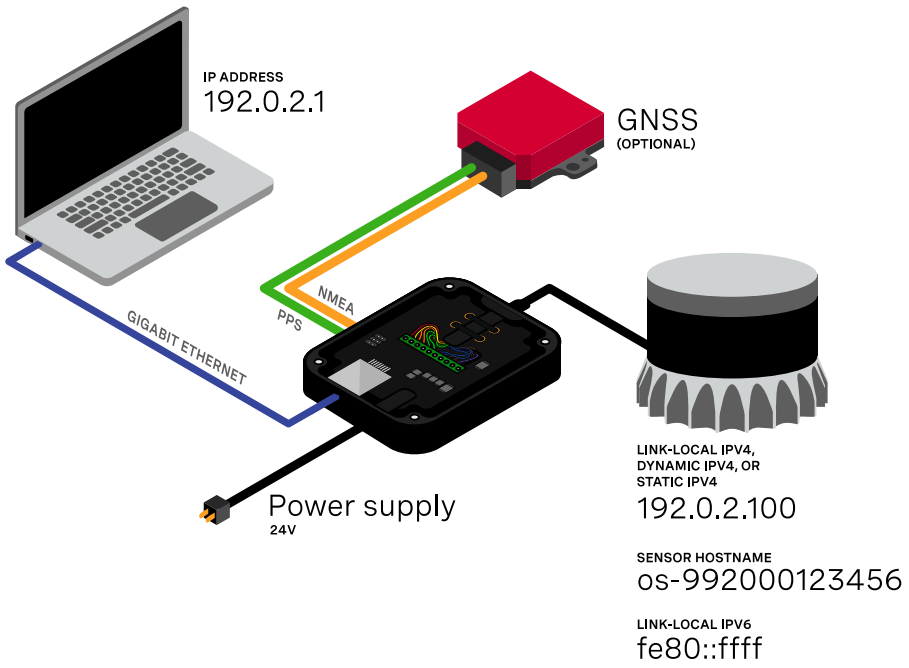


Figure 2.1: Network Configuration and Setup

Note: May be required to configure the firewall to connect with the sensor and access sensor data.

Open Google Chrome/Microsoft Edge/Firefox. Use the hostname in the format of `http://OS-99xxxxxxxxx.local` and click on "Enter/Character turn" to open Ouster Dashboard.

Note:

- The serial number of the sensor need not start with `99` and is only taken as an example in this document, the sensor serial number can be found on a sticker affixed to the top of the sensor.
- Please keep in mind **NOT** to use `https://` as it will result in an error, use without `s` as shown `http://OS-99xxxxxxxxx.local`.

2.4 Sensor Web Interface

The sensor homepage can be accessed by typing in the sensor's address (IPv4, IPv6, or hostname) in a web browser (http://os-991234567890.local/ where 991234567890 is the serial number). From here you can see information about the sensor, access documentation, and configure sensor settings.

Dashboard: Contains an overview of the sensor.

- **System Information**: This panel provides information regarding the network configuration and hardware details that are unique to each sensor
- **Firmware Update**: You can update firmware on this panel. See *Updating Firmware* for more details.
- **System Status**: This panel displays the status of the sensor and information regarding any Active Alerts. More information on the status of the sensor can be found by clicking the link, which will take the user to the Diagnostics tab.
- **Configuration**: An overview of the sensor configuration is available on this panel. The sensor configuration can also be edited by clicking on the link below, which will take the user to the Configuration tab.

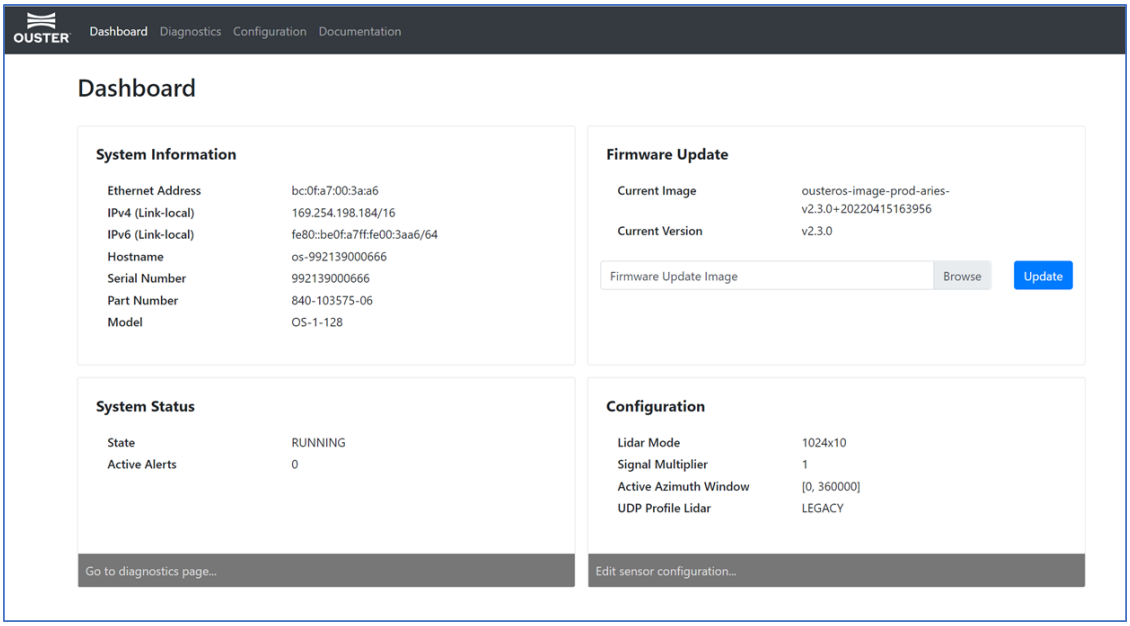


Figure 2.2: Ouster Dashboard

Diagnostics: Contains diagnostic alert and error information about the sensor for troubleshooting purposes. For a list of possible alerts and errors, see *Alerts and Errors*. Some Alerts require the user to reach out to Ouster support. Please include a copy of the System Diagnostics file which can be downloaded by clicking the blue tab on this page.

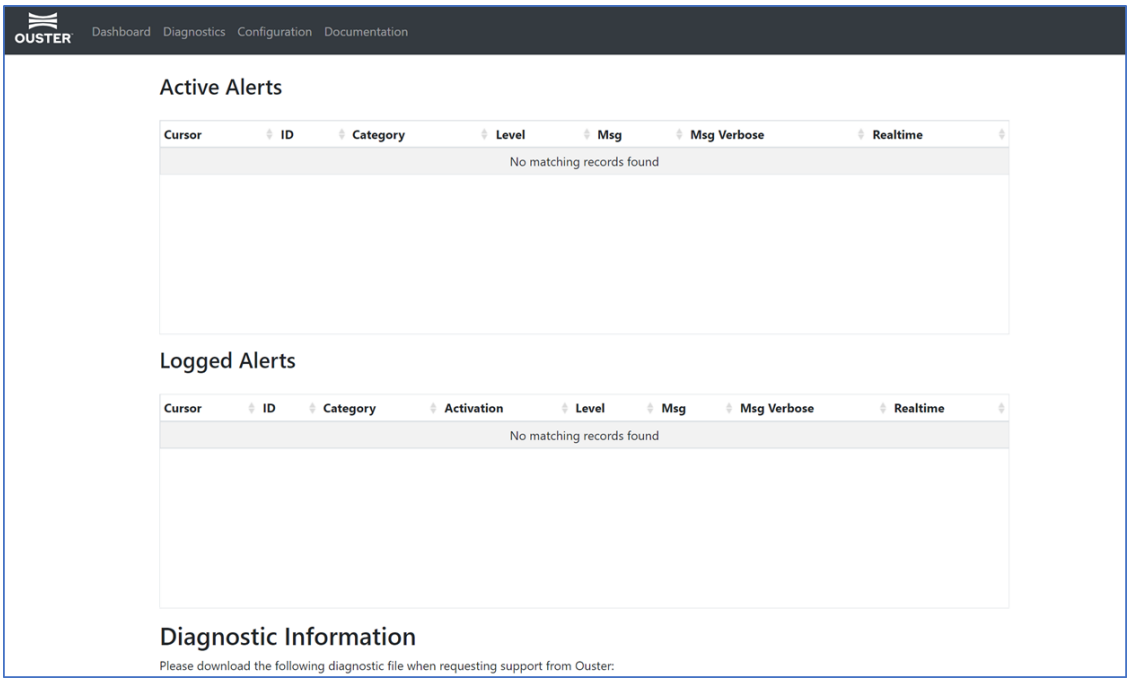


Figure 2.3: Ouster Alerts & Diagnostics

Configuration: This tab contains a user interface to change sensor configuration. If the sensor is in `STANDBY` mode, changes to configuration settings will not take effect until we switch the sensor back to `NORMAL` mode. Please refer to figure 3.4 for reference.

- **Reset Configuration**: Resets sensor to factory configurations and settings. Note that this resets any static IP address given to the sensor.
- **Persist Active Config**: Stores the currently active sensor configuration to persistent storage so it will be reloaded whenever the sensor starts up.
- **Apply Config (reinit)**: Allows the user to configure the sensor settings. This involves a reinitialization of the sensor, so that the sensor configuration settings can take effect.
- **Documentation**: Contains the HTTP and TCP API guides that are compatible with the version of the firmware on the sensor. Visit Ouster Sensor Documentation for latest hardware and software user manuals, along with integration guides and troubleshooting guides. Please refer to figure 3.5 for reference.

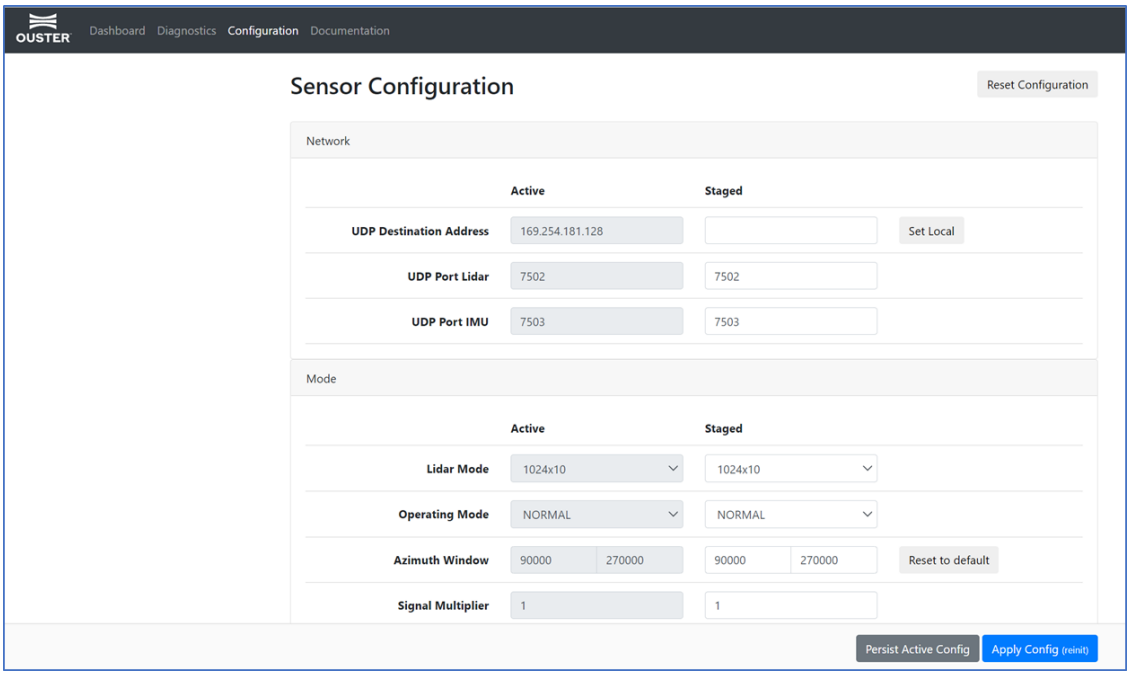


Figure 2.4: Sensor Configuration

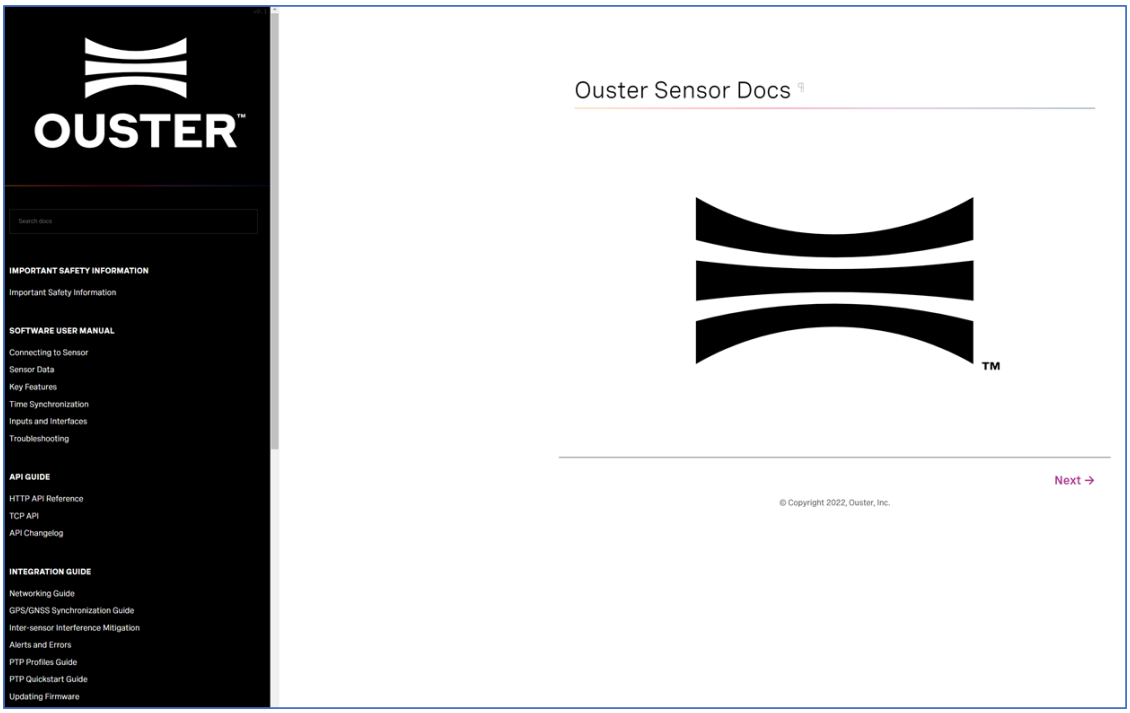


Figure 2.5: Ouster Documentation

2.5 Updating Firmware

Sensor firmware can be updated with an Ouster-provided firmware file from Ouster firmware by accessing the sensor over http - e.g., http://os-991900123456.local/ and uploading the file as prompted.

Note: User can also choose to do this step using an HTTP endpoint. Please refer to *POST /api/v1/system/firmware* in HTTP API section.

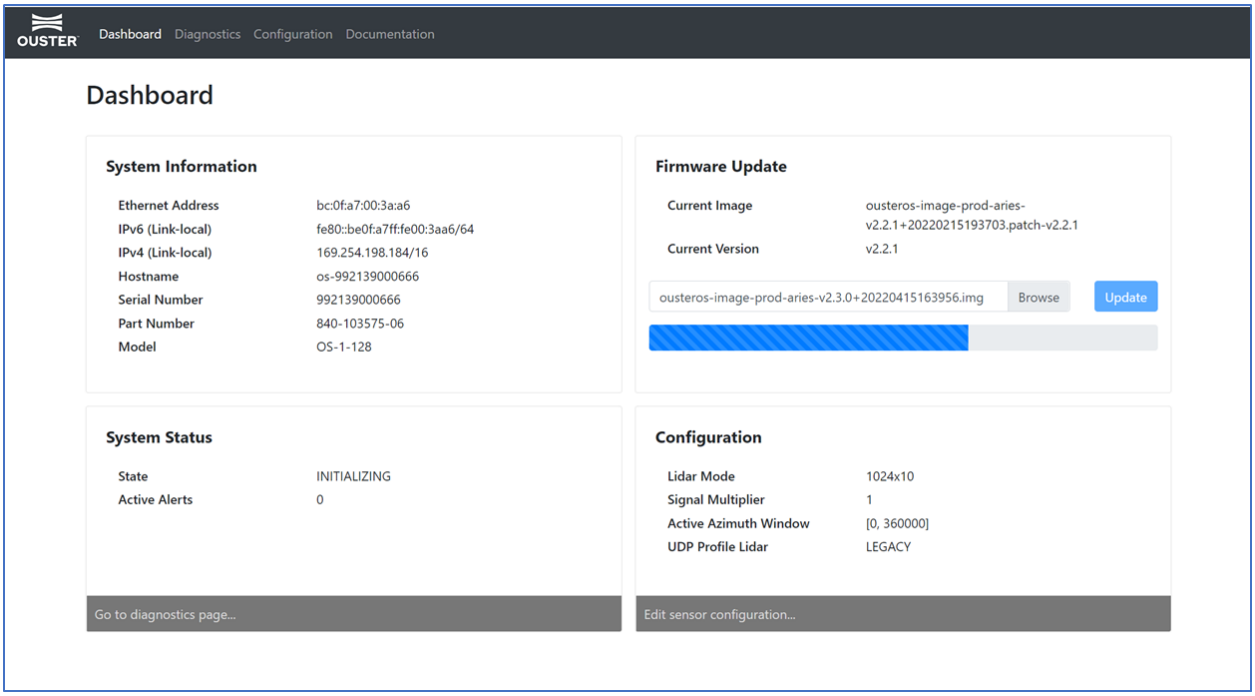


Figure 2.6: Uploading a new firmware image onto the sensor

Always check the firmware version running on the sensor before attempting to update. Only update to an equal or higher version number.

After the web UI confirms that the update is complete, please allow the sensor to reboot (about 2 minutes) and refresh your webpage to get access to the updated web UI.

3 Typical Sensor Operation

Described below is the typical sensor state machine operation. When the sensor is powered ON, the sensors start in the initialization phase.

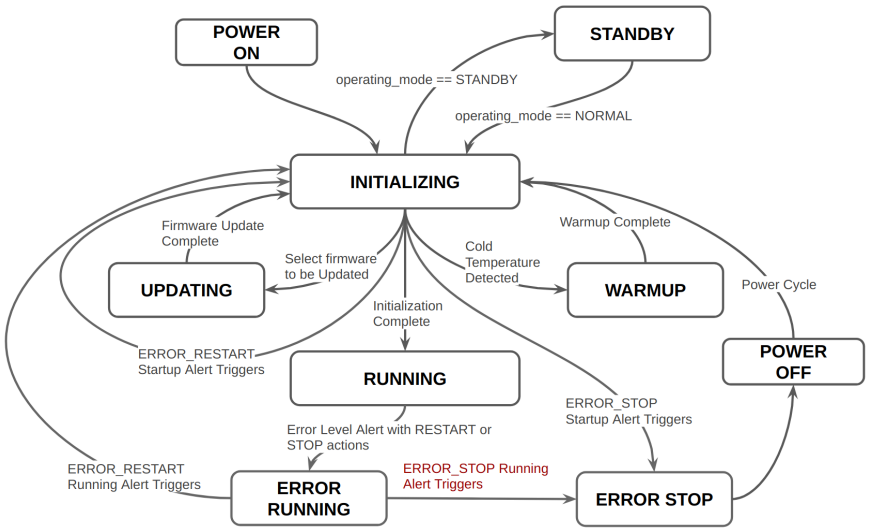


Figure 3.1: Sensor Operation Representation

Table 3.1: Sensor Operation Description

Operating State	**Description**
Power On	Ouster Lidar turned ON.
Initializing	Startup of Ouster Lidar.
Updating	Only remains in this state temporarily to update the firmware.
Warm-up	If the sensor detects that its environmental temperature is low it will attempt to self-heat in a warmup state (*Cold Start*) before entering a normal operating state.
Running	Sensor has completed initialization phase and is now running.
Error Running	An error has occurred and the sensor is deciding if it will restart or stop. No user action required.
Error Stop	If an exception is thrown during initialization or running state, the lidar logs the error and remains in Error until reconfigured or power cycled.
Standby	User enabled low power operating mode of the sensor.
Power OFF	Ouster Lidar shut off.

4 Sensor Data

4.1 Coordinate Frames and XYZ Calculation

Ouster defines two coordinate frames:

The **Lidar Coordinate Frame** follows the Right Hand Rule convention and is a point cloud-centric frame of reference that is the simplest frame in which to calculate and manipulate point clouds. The X-axis points backwards towards the external connector, which is an unintuitive orientation that was deliberately chosen to meet the following criteria:

- Data frames split at the back of the sensor i.e. the external connector
- Data frames start with the azimuth angle equal to 0º

All point cloud features including setting an azimuth window and phase locking are defined in the Lidar Coordinate Frame.

The **Sensor Coordinate Frame** follows the Right Hand Rule convention and is a mechanical housing-centric frame of reference that follows robotics convention with X-axis pointing forward. Ouster-provided drivers and visualizers represent data in the Sensor Coordinate Frame.

Note: All Ouster coordinate frames follow the Right Hand Rule, allowing for standard 3D transformation matrix math to convert between them. For multi-sensor systems that require calibration, this Linear Algebra-based approach can be convenient. However, customers with single-sensor systems may find it more intuitive to stay in the Lidar Coordinate Frame and take arithmetic shortcuts.

4.1.1 Lidar Coordinate Frame

The Lidar Coordinate Frame is defined at the intersection of the lidar axis of rotation and the lidar optical midplane (a plane parallel to Sensor Coordinate Frame XY plane and coincident with the 0º elevation beam angle of the sensor).

The Lidar Coordinate Frame axes are arranged with:

- positive X-axis pointed at encoder angle 0º and the external connector
- positive Y-axis pointed towards encoder angle 90º
- positive Z-axis pointed towards the top of the sensor

The Lidar Coordinate Frame is marked in both diagrams below with X_L, Y_L, and Z_L.

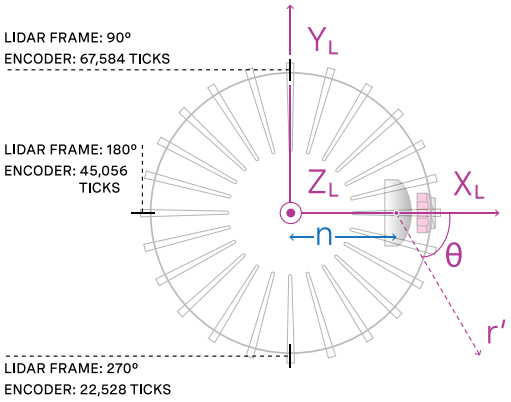


Figure 4.1: Top-down view of Lidar Coordinate Frame

4.1.2 Lidar Range to XYZ

Given the following information, range data may be transformed into 3D cartesian XYZ coordinates in the Lidar Coordinate Frame:

From a measurement block from the UDP packet:

- `Measurement ID` value can be found on the lidar data packet
- `scan_width` value of the horizontal resolution
- `r` or `range_mm`[1] value of the data block of the *i*-th channel
- `r'` or `range_to_beam_origin_mm`[2]

From the *GET /api/v1/sensor/metadata/beam_intrinsics* HTTP Command:

- `beam_to_lidar_transform`[3] value
- `beam_altitude_angles` array
- `beam_azimuth_angles` array

[1] `r` or `range_mm` is the sum of the magnitudes of vectors of r′ and n. This value is provided for each measurement in blocks [0-15] of the *i*-th channel.

[2] `r'` or `range_to_beam_origin_mm` is the magnitude of the distance vector from lidar front optics to the detected object. This value is **NOT** provided; It is only to help illustrate the concept.

[3] `beam_to_lidar_transform` is a translation matrix from the center of the lidar origin coordinate frame to lidar front optics. This value is provided from the *GET /api/v1/sensor/metadata/beam_intrinsics*, please refer to the API Guide for more information.

The corresponding 3D point can be computed by

$$
\begin{aligned}
r &= range\_mm \\
|\vec{n}| &= \sqrt{(beam\_to\_lidar[0,3])^2 + (beam\_to\_lidar[2,3])^2} \\
r &= |\vec{r'}| + |\vec{n}| \\
\theta_{encoder} &= 2\pi \cdot \left(1 - \frac{measurement\ \ ID}{scan\_width}\right) \\
\theta_{azimuth} &= -2\pi \frac{beam\_azimuth\_angles[i]}{360} \\
\phi &= 2\pi \frac{beam\_altitude\_angles[i]}{360}
\end{aligned}
$$

$$
\begin{aligned}
x &= (r - |\vec{n}|)\cos\left(\theta_{encoder} + \theta_{azimuth}\right)\cos(\phi) + (beam\_to\_lidar[0,3])\cos\left(\theta_{encoder}\right) \\
y &= (r - |\vec{n}|)\sin\left(\theta_{encoder} + \theta_{azimuth}\right)\cos(\phi) + (beam\_to\_lidar[0,3])\sin\left(\theta_{encoder}\right) \\
z &= (r - |\vec{n}|)\sin(\phi) + (beam\_to\_lidar[2,3])
\end{aligned}
$$

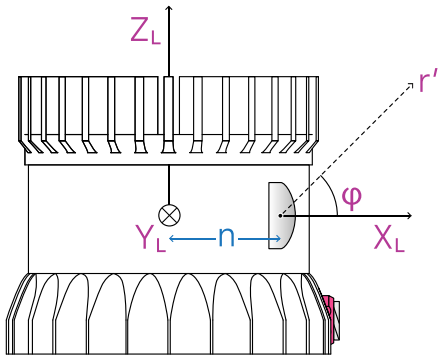


Figure 4.2: Side view of Lidar Coordinate Frame

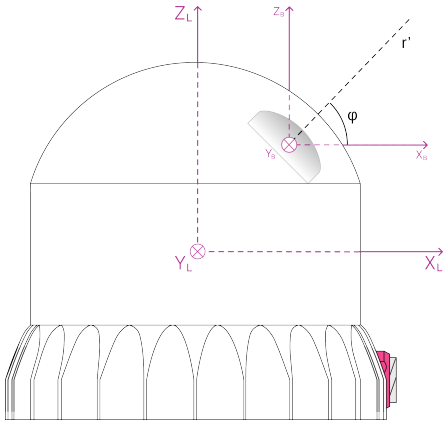


Figure 4.3: Side view of an OSDome Lidar Coordinate Frame

4.1.3 Sensor Coordinate Frame

The Sensor Coordinate Frame is defined at the center of the sensor housing on the bottom, with the X-axis pointed forward, Y-axis pointed to the left and Z-axis pointed towards the top of the sensor. The external connector is located in the negative x direction. The Sensor Coordinate Frame is marked in the diagram below with X_S, Y_S, Z_S.

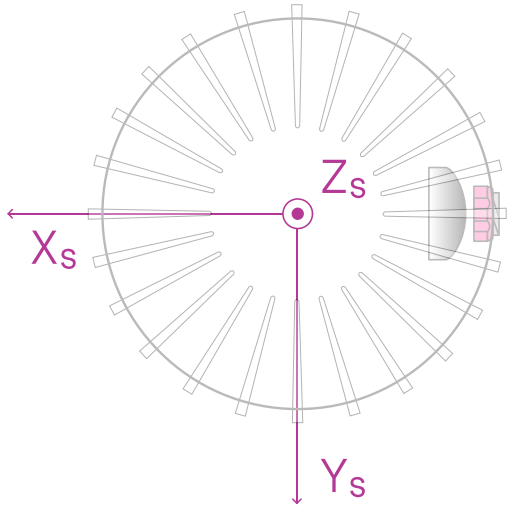


Figure 4.4: Top-down view of Sensor Coordinate Frame

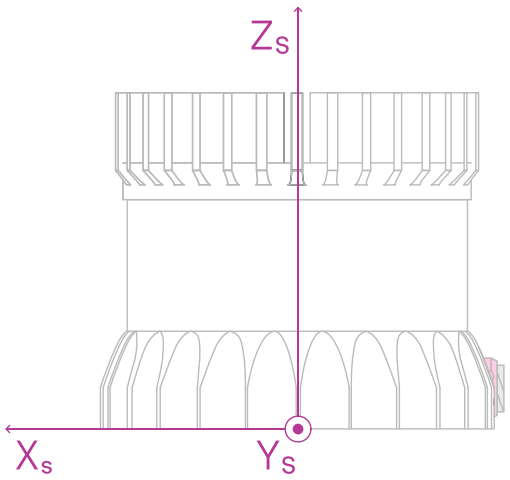


Figure 4.5: Side view of Sensor Coordinate Frame

4.1.4 Combining Lidar and Sensor Coordinate Frame

The Lidar Coordinate Frame's positive X-axis (0 encoder value) is opposite the Sensor Coordinate Frame's positive X-axis to center lidar data about the Sensor Coordinate Frame's positive X-axis. A single measurement frame starts at the Lidar Coordinate Frame's 0° position and ends at the 360° position. This is convenient when viewing a "range image" of the Ouster Sensor measurements, allowing the "range image" to be centered in the Sensor Coordinate Frame's positive X-axis, which is generally forward facing in most robotic systems.

The Ouster Sensor scans in the clockwise direction when viewed from the top, which is a negative rotational velocity about the Z-axis. Thus, as encoder ticks increase from 0 to 90,111, the actual angle about the Z-axis in the Lidar Coordinate Frame will decrease.

4.1.5 Lidar Intrinsic Beam Angles

The intrinsic beam angles for each beam may be queried with a HTTP command *GET /api/v1/sensor/metadata/beam_intrinsics* to provide an azimuth and elevation adjustment offset to each beam. The azimuth adjustment is referenced off of the current encoder angle and the elevation adjustment is referenced from the XY plane in the Sensor and Lidar Coordinate Frames.

4.1.6 Lidar Range Data To Sensor XYZ Coordinate Frame

For applications that require calibration against a precision mount or use the IMU data (Inertial Measurement Unit) in combination with the lidar data, the XYZ points should be adjusted to the Sensor Coordinate Frame. This requires a Z translation and a rotation of the X,Y,Z points about the Z-axis. The Z translation is the height of the lidar aperture stop above the sensor origin, which varies depending on the sensor you have, and the data must be rotated 180° around the Z-axis. This information can be queried via HTTP in the form of a homogeneous transformation matrix in row-major ordering.

Example JSON formatted query using the HTTP command *GET /api/v1/sensor/metadata/lidar_intrinsics*:

```
{
  "lidar_to_sensor_transform": [-1, 0, 0, 0, 0, -1, 0, 0, 0, 0, 1, 38.195, 0, 0, 0, 1]
}
```


Which corresponds to the following matrix

$$M\_lidar\_to\_sensor = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 38.195 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4.1.7 IMU Data To Sensor XYZ Coordinate Frame

The IMU is slightly offset in the Sensor Coordinate Frame for practical reasons. The IMU origin in the Sensor Coordinate Frame can be queried over HTTP command in the form of an homogeneous transformation matrix in row-major ordering.

Example 1- Expected response for HTTP command *GET /api/v1/sensor/metadata/imu_intrinsics* when using Gen1 OS1 (all revisions), Gen2 OS01 (all revisions) and Gen2 OS2 (top-level revisions A, B, C)


```
{
  "imu_to_sensor_transform": [1, 0, 0, 6.253, 0, 1, 0, -11.775, 0, 0, 1, 7.645, 0, 0, 0, 1]
}
```


Which corresponds to the following matrix

$$M\_imu\_to\_sensor = \begin{bmatrix} 1 & 0 & 0 & 6.253 \\ 0 & 1 & 0 & -11.775 \\ 0 & 0 & 1 & 7.645 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Example 2- Expected response for HTTP command *GET /api/v1/sensor/metadata/imu_intrinsics* when using Gen2 OS2 (top-level revisions D and higher)


```
{
  "imu_to_sensor_transform": [1, 0, 0, 6.253, 0, 1, 0, -11.775, 0, 0, 1, 11.645, 0, 0, 0, 1]
}
```


Which corresponds to the following matrix

$$M\_imu\_to\_sensor = \begin{bmatrix} 1 & 0 & 0 & 6.253 \\ 0 & 1 & 0 & -11.775 \\ 0 & 0 & 1 & 11.645 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

5 Lidar Data Packet Format

Note: For all users transitioning from firmware version 3.0 to 3.1, please note that `LEGACY` profile has been **deprecated** and will not be available for use in a future firmware release. Please refer to the current `default` profile on the sensor i.e.., *RNG19_RFL8_SIG16_NIR16 Return Profile*.

With firmware version v3.1 and above, users will have the option to switch between different lidar data packet formats as shown below.

- *Configurable Data Packet Format*
  - *RNG19_RFL8_SIG16_NIR16 Return Profile* (`Default`)
  - *RNG15_RFL8_NIR8 Return Profile*
  - *RNG19_RFL8_SIG16_NIR16_DUAL Return Profile*
- *FUSA_RNG15_RFL8_NIR8_DUAL Return Profile*
- *LEGACY Data Packet Format* (**Deprecated** - Not Available starting FW v3.1)

By default, the data packet format will be set to *RNG19_RFL8_SIG16_NIR16 Return Profile* for Firmware v3.0 and later.

Dual Returns

The dual return feature allows the sensor to output up to 2 lidar returns, enabling better performance in scenarios with semi-transparent obscurants, such as rain, fog, or chain-link fences. In these scenarios, the strongest and second strongest returns are required to see both the semi-transparent object, as well as whatever may lie behind it.

Return Order

The following `return_order` can be set `STRONGEST_TO_WEAKEST` (**Default**), `NEAREST_TO_FARTHEST` and `FARTHEST_TO_NEAREST`.

When a `DUAL` UDP profile is selected, the sensor returns the two strongest returns for each radial beam. The order in which these two returns appear depends on the setting of the `return order` which has the following possible values.

- `STRONGEST_TO_WEAKEST`: The strongest of the two returns is the first return and the next strongest (or the weakest of these two returns) follows. This return order prioritizes the points based on their signal strength, with the strongest signals coming first. This can be useful in applications where identifying the most prominent or reflective objects is crucial.

- `FARTHEST_TO_NEAREST`: The farthest of the two returns is the first return and the next strongest and therefore nearest of the two strongest returns follows. This return order organizes the points based on their distance from the lidar sensor, with the farthest points listed first. It is valuable when the focus is on understanding the spatial distribution of objects in the sensor's field of view.

- `NEAREST_TO_FARTHEST`: The nearest of the two strongest returns is the first return and the farthest of the two strongest returns follows. This return order prioritizes the closest point, listing it first. This order can be beneficial in applications where identifying nearby obstacles or points of interest is critical.

The choice of `return_order` depends on the application. For example, in obstacle detection scenarios, `NEAREST_TO_FARTHEST` might be preferred for identifying nearby objects, whilst in mapping applications `FARTHEST_TO_NEAREST` could be more suitable for capturing the spatial layout of the environment.

5.1 Configurable Data Packet Format

Different options for `udp_profile_lidar` maintain a uniform packet structure, which is described in detail below.

5.1.1 Lidar Data Format

Each data packet consists of `Packet Header`, `Measurement Header`, `Channel Data Blocks` and `Packet Footer`. The packet rate is dependent on the lidar mode. Words are 32 bits in length and little endian.

By default, lidar UDP data is forwarded to Port `7502`. Please refer to the *HTTP API Reference Guide* section of this manual for more information on setting this parameter. Alternately, this mode can also be configured via the Web Interface.

Packet layout

Packet Header [256 bits]

- **Packet type** [16 bit unsigned int] - Identifies lidar data vs. other packets in stream. Packet Type is 0x1 for Lidar packets.

- **Frame ID** [16 bit unsigned int] - Index of the lidar scan, increments every time the sensor completes a rotation, crossing the zero azimuth angle.

- **Init ID** [24 bit unsigned int] - Initialization ID. Updates on every reinitialization, which may be triggered by the user or an error, and every reboot. This value may also be obtained by running the HTTP command *GET /api/v1/sensor/metadata/sensor_info*.

- **Serial No** [40 bit unsigned int] - Serial number of the sensor. This value is unique to each sensor and can be found on a sticker affixed to the top of the sensor. In addition, this information is also available on the Sensor Web UI and by reading the field `prod_sn` from *GET /api/v1/sensor/metadata/sensor_info*.

- **Shot limiting status** [4 bit unsigned int] - Indicates the shot limiting status of the sensor. Different codes indicates whether the sensor is in *Normal Operation* or in *Shot Limiting*. Please refer to *Shot Limiting* section for more details.

- **Shutdown Status** [4 bit unsigned int] - Indicates whether thermal shutdown is imminent. Please refer to *Shot Limiting* section for more details.
- **Shot limiting Countdown** [8 bit unsigned int] - Countdown from 30s to indicate when shot limiting is imminent. Please refer to *Shot Limiting* section for more details.
- **Shutdown Countdown** [8 bit unsigned int] - Countdown from 30s to indicate that thermal shutdown is imminent. Please refer to *Shot Limiting* section for more details.
- **Alert Flags [8 bit unsigned int]:**
    - `bit [0-5]`: alert_cursors (Increments sequentially everytime a new alert is active. At this time users can query *GET /api/v1/sensor/alerts* to understand which alert was activated).
    - `bit [6]`: cursor_overflow (true if cursor overflows, cleared when *GET /api/v1/sensor/alerts* is read. cursor_overflow turns on whenever alert_cursors goes from 63->0, and stays on until the next time *GET /api/v1/sensor/alerts* is called).
    - `bit [7]`: alerts_active (true if ANY alerts are active).

Column Header Block [96 bits]

- **Timestamp** [64 bit unsigned int] - Timestamp of the measurement in nanoseconds.
- **Measurement ID** [16 bit unsigned int] - Sequentially incrementing measurement counting up from 0 to 511, or 0 to 1023, or 0 to 2047 depending on lidar_mode.
- **Status** [1 bit unsigned int] - Indicates validity of the measurements. Status is 0x01 for valid measurements. Status is 0x00 for dropped or disabled columns.

Channel Data Blocks [Varies based on channel data profile]

- The size and the structure of the channel data block varies based on the configurable data packet format chosen by the user. More information on each of these options are described below in the following sections.

Packet Footer [256 bits]

- **Reserved** [192 bits]
- **E2E CRC** [64 bits] - This covers the end to end **cyclic redundancy check (CRC)** on the entire data packet. For more details refer to *E2E CRC64 calculation parameters*.

Figure 5.1: Configurable Data Packet Configuration

E2E CRC64 calculation parameters

The **CRC64** is calculated on the received UDP lidar packet payload bytes, in the same received bit order, without the encoded **CRC64** value [I.E. excluding the last 64 bits of the received lidar packet], and by using the following CRC algorithm calculation parameters:

Table 5.1: E2E CRC Calculation

CRC Result Width	64 bits
Polynomial	0x42f0e1eba9ea3693
Initial Value	0xffffffffffffffff
Input data reflected	Yes
Result data reflected	Yes
XOR Value	0xffffffffffffffff

Since the value of the **CRC64** in the received lidar packet is encoded as a Little-Endian hex value; you will have to reverse the **CRC64** bytes (last 8 bytes of the lidar packet) before comparing them with the hex value of the calculated **CRC64** that is based on the received lidar packet bytes.

5.1.2 Channel Data Profiles

This section describes the different channel data profile options that are available to the users as part of the configurable data packet format. Each of these data profiles can be selected by setting the configuration parameter udp_profile_lidar to one of the following options:

- *RNG19_RFL8_SIG16_NIR16 Return Profile* (`Default`)
- *RNG15_RFL8_NIR8 Return Profile*
- *RNG19_RFL8_SIG16_NIR16_DUAL Return Profile*

More details on how to set the configuration parameters are described in the *HTTP API Reference Guide* portion of this Firmware User Manual.

Note: Calibrated reflectivity has certain hardware requirements. Please refer to the *Calibrated Reflectivity* section for more details.

Table 5.2: Configurable Data Packet Profiles

Description	*RNG19_RFL8_SIG16_NIR16 Return Profile*	*RNG15_RFL8_NIR8 Return Profile*	*RNG19_RFL8_SIG16_NIR16_DUAL Return Profile*
Profiles	`RNG19_RFL8_SIG16_NIR16`	`RNG15_RFL8_NIR8`	`RNG19_RFL8_SIG16_NIR16_DUAL`
Words per pixel	3	1	4
Range RET1	19 bits	15 bits	19 bits
Reflectivity RET1	8 bits	8 bits	8 bits
Range RET2	Not Available	Not Available	19 bits
Reflectivity RET2	Not Available	Not Available	8 bits
Signal RET1	16 bits	Not Available	16 bits
Signal RET2	Not Available	Not Available	16 bits
NIR	16 bits	8 bits	16 bits

5.1.3 RNG19_RFL8_SIG16_NIR16 Return Profile

The data packet format for all sensors by default is set to `RNG19_RFL8_SIG16_NIR16` i.e., Single Return Profile. This channel data profile can also be activated from a different setting by changing the configuration parameter udp_profile_lidar to RNG19_RFL8_SIG16_NIR16.

This channel data profile is identical to the channel data block present in previously available `LEGACY` format (Deprecated), but makes use of the configurable data packet format. Users looking to take advantage of the configurable data packet format can use this profile in place of `LEGACY`. The channel data profile for this is described below.

Channel Data Blocks [96 bits each for RNG19_RFL8_SIG16_NIR16 profile]

For RNG19_RFL8_SIG16_NIR16 profile the channel data block consists of 3 words to accommodate data for porting over the `LEGACY` profile (Deprecated) to configurable Data Packet format. Only a single return will be made available to the user.

- **Range** [19 bit unsigned int] - Range in millimeters, discretized to the nearest 1 millimeters with a maximum range of 524m. Note that range value will be set to 0 if out of range or if no detection is made.
- **Calibrated Reflectivity** [8 bit unsigned int] - Sensor Signal Photons measurements are scaled based on measured range and sensor sensitivity at that range, providing an indication of target reflectivity.
- **Signal Photons** [16 bit unsigned int] - Signal intensity photons in the signal return measurement are reported.
- **Near Infrared Photons** [16 bit unsigned int] - NIR photons related to natural environmental illumination are reported.

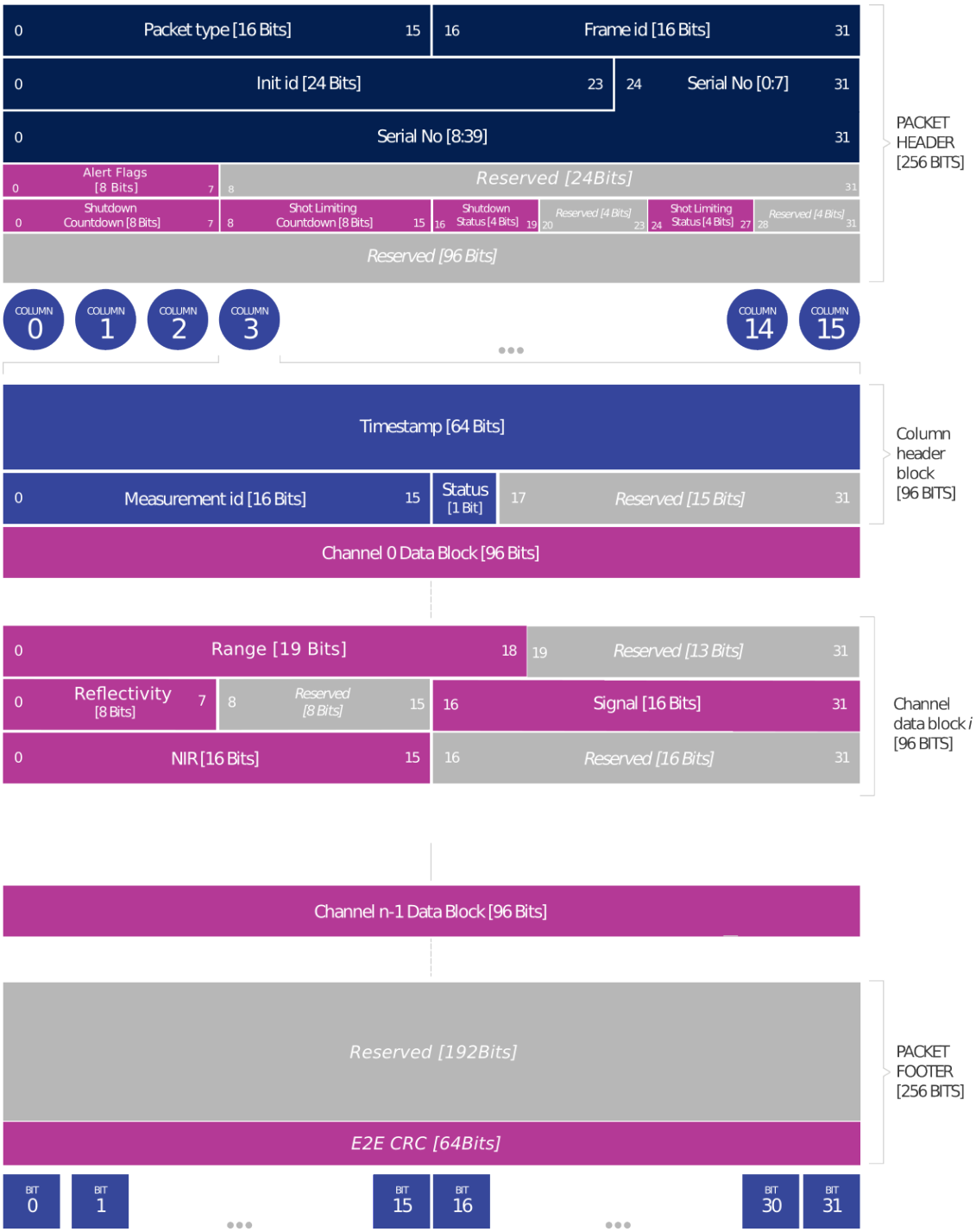


Figure 5.2: Single Return Configuration

5.1.4 RNG15_RFL8_NIR8 Return Profile

This channel data profile can be activated by setting the configuration parameter udp_profile_lidar to `RNG15_RFL8_NIR8`.

This channel data profile is especially useful to users who are looking to adopt a channel data profile to fit with limited compute capabilities. The data rate and data packet size when using this profile is smaller compared to the other channel data profile options that are available.

The channel data profile for this is described below.

Channel Data Blocks [32 bits each for RNG15_RFL8_NIR8 profile]

For the RNG15_RFL8_NIR8 profile the channel data block consists of only 1 word to accommodate data for optimizing information at a low data rate. Only a single return is made available to the user.

- **Range** [15 bit unsigned int] - Range scaled down by a factor of 8 mm, for a maximum range of (2^15*8) = 262 m in 15 bits. **Note** The range value will be set to 0 if out of range or if no detection is made.
- **Calibrated Reflectivity** [8 bit unsigned int] - Sensor Signal Photons measurements are scaled based on measured range and sensor sensitivity at that range, providing an indication of target reflectivity.
- **Near Infrared Photons** [8 bit unsigned int] - NIR photons related to natural environmental illumination are reported. Measurements are taken similar to other data profiles (Single Data Profile and Dual Return Profile) but it is scaled down by a factor of 16.

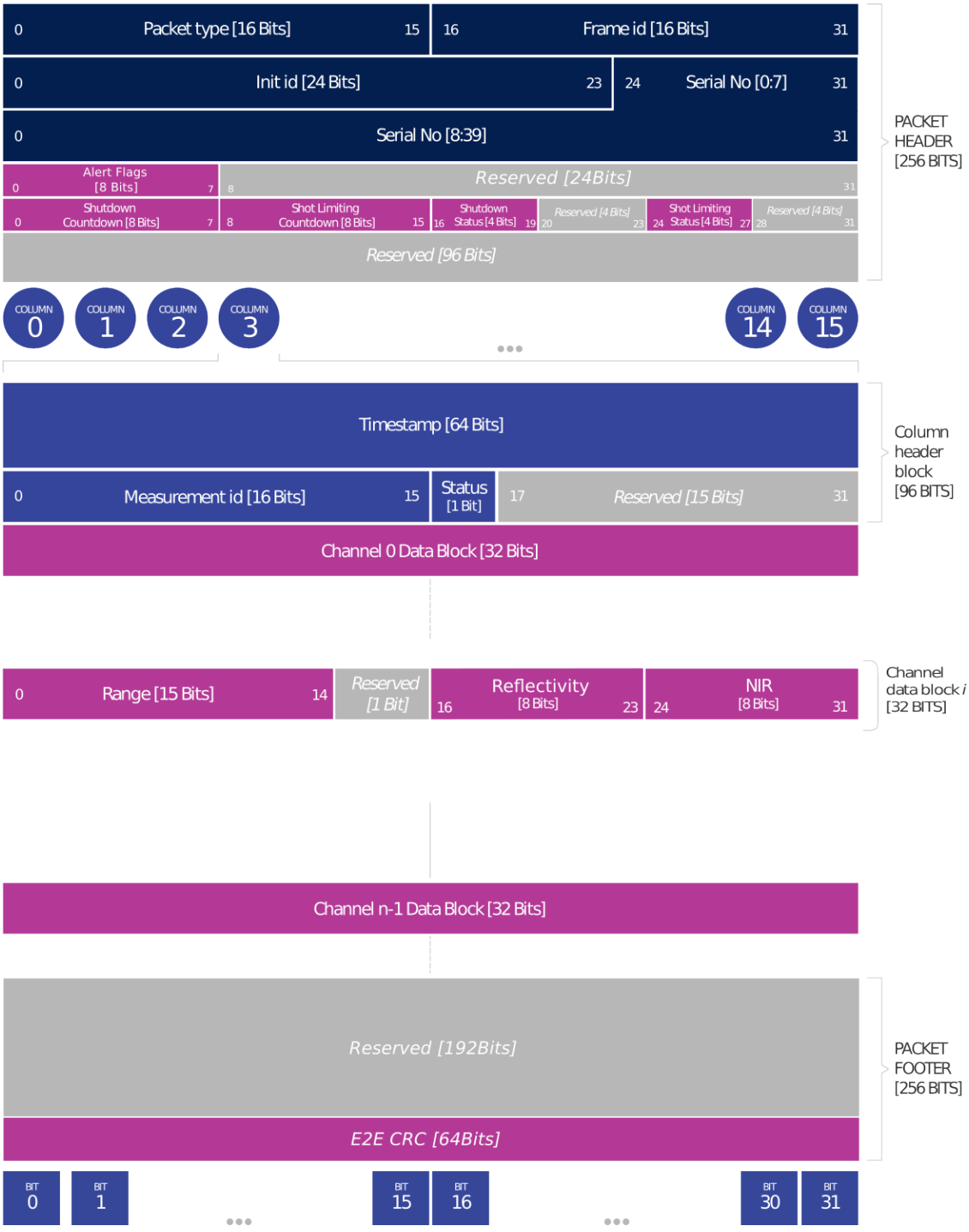


Figure 5.3: Low Data Rate Configuration

5.1.5 RNG19_RFL8_SIG16_NIR16_DUAL Return Profile

This channel data profile can be activated by setting the configuration parameter udp_profile_lidar to `RNG19_RFL8_SIG16_NIR16_DUAL`.

Channel Data Blocks [128 bits each for RNG19_RFL8_SIG16_NIR16_DUAL profile]

For RNG19_RFL8_SIG16_NIR16_DUAL profile the channel data block consists of 4 words to accommodate data for two lidar returns.

- **Range RET1/2** [19 bit unsigned int] - range in millimeters, discretized to the nearest 1 millimeters with a maximum range of 524m. Note that range value will be set to 0 if out of range or if no detection is made.
- **Calibrated Reflectivity RET1/2** [8 bit unsigned int] - Sensor Signal Photons measurements are scaled based on measured range and sensor sensitivity at that range, providing an indication of target reflectivity.
- **Signal Photons RET1/2** [16 bit unsigned int] - Signal intensity photons in the signal return measurement are reported.
- **Near Infrared Photons** [16 bit unsigned int] - NIR photons related to natural environmental illumination are reported.

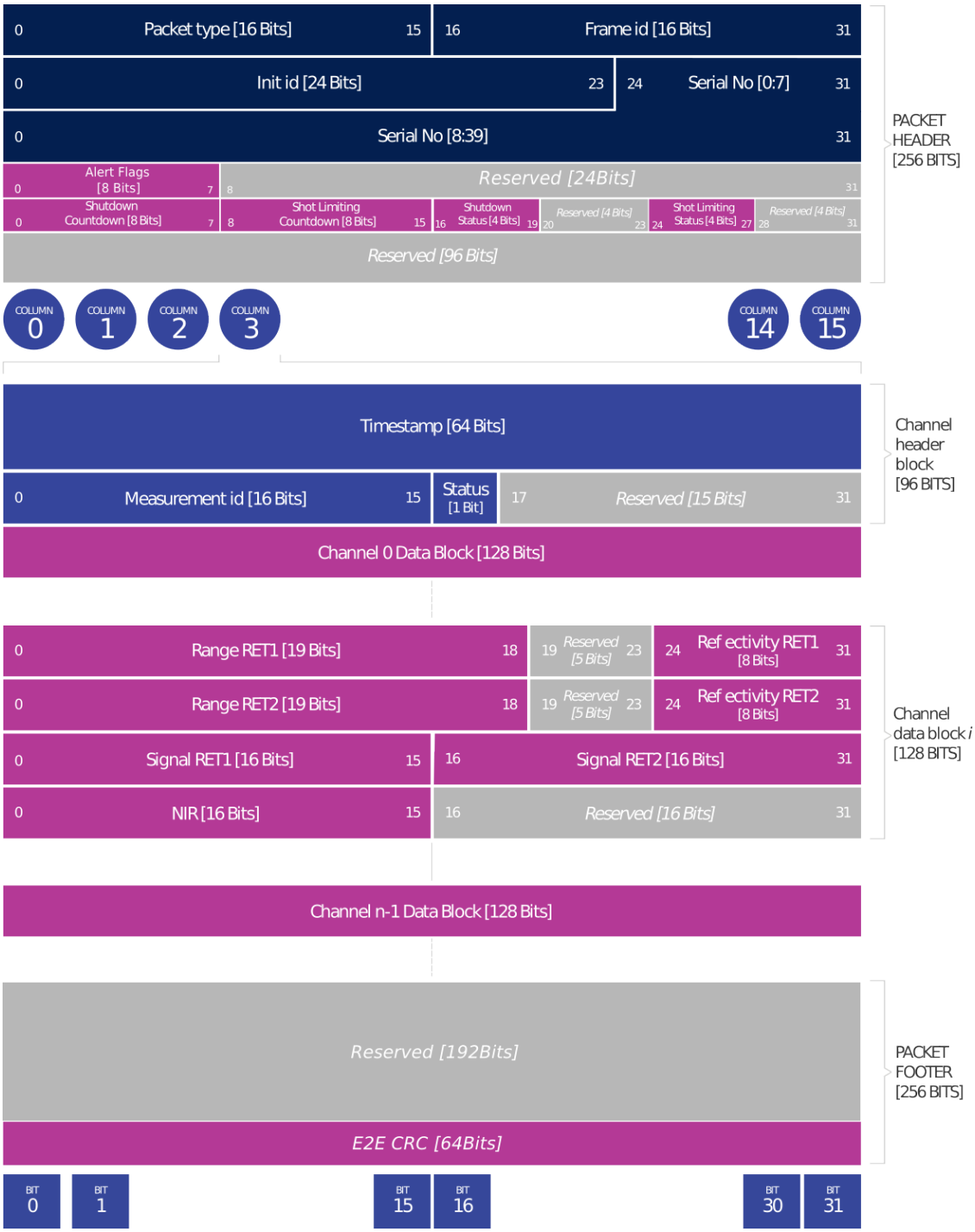


Figure 5.4: Dual Return Data Packet Configuration

5.2 FUSA_RNG15_RFL8_NIR8_DUAL Return Profile

Setting `udp_profile_lidar` to value `FUSA_RNG15_RFL8_NIR8_DUAL` activates the `Functional Safety data packet format`. This packet format will be expanded periodically with every firmware release to report flags, error checking mechanisms, and alerts necessary for a functionally safe system. This packet format has a different header and footer structure.

Note: Rev7 sensor with FW v3.1 is a minimum requirement to use this lidar packet format. **This profile is expanded periodically and it does not mean that the sensor is actually FUSA certified**.

5.2.1 Lidar Data Format

When udp_profile_lidar is set to `FUSA_RNG15_RFL8_NIR8_DUAL`, each data packet consists of `Packet Header`, `Measurement Header`, `Channel Data Blocks` and `Packet Footer`. The packet rate is dependent on the lidar mode. Words are 32 bits in length and little endian. By default, lidar UDP data is forwarded to Port 7502. Please refer to *HTTP API Reference Guide* section of this manual for more information on configuring this parameter. Alternatively this mode can also be configured via the web interface.

```
"udp_profile_lidar=FUSA_RNG15_RFL8_NIR8_DUAL"
```

This profile is meant to allow the sensor to provide an output up to 2 returns at a low data rate. Refer to *Return Order* for more information.

Packet layout

For `FUSA_RNG15_RFL8_NIR8_DUAL` profile the channel data block consists of 64 bits to accommodate data for the multiple returns. A total of up to two returns will be made available to the user.

Packet Header [256 bits]

- **Packet type** [8 bit unsigned int] - Identifies lidar data vs. other packets in stream. Packet Type is 0x1 for Lidar packets.
- **Init ID** [24 bit unsigned int] - Initialization ID. Updates on every reinitialization, which may be triggered by the user or an error, and every reboot. This value may also be obtained by running the HTTP command GET /api/v1/sensor/metadata/sensor_info.
- **Frame ID** [32 bit unsigned int] - Index of the lidar scan, increments every time the sensor completes a rotation, crossing the zero azimuth angle.
- **Serial No** [40 bit unsigned int] - Serial number of the sensor. This value is unique to each sensor and can be found on a sticker affixed to the top of the sensor. In addition, this information is also available on the Sensor Web UI and by reading the field `prod_sn` from *GET /api/v1/sensor/metadata/sensor_info*.
- **Alert Flags** [8 bit unsigned int]:
  - bit [0-5]: alert_cursors (Increments sequentially everytime a new alert is active. At this time users can query *GET /api/v1/sensor/alerts* to understand which alert was activated).

    - bit [6]: cursor_overflow (true if cursor overflows, cleared when *GET /api/v1/sensor/alerts* is read. cursor_overflow turns on whenever alert_cursors goes from 63->0, and stays on until the next time *GET /api/v1/sensor/alerts* is called).
    - bit [7]: alerts_active (true if ANY alerts are active).

- **Shutdown Countdown** [8 bit unsigned int] - Countdown from 30s to indicate that thermal shutdown is imminent. Please refer to Shot Limiting section for more details.
- **Shot limiting Countdown** [8 bit unsigned int] - Countdown from 30s to indicate when shot limiting is imminent. Please refer to Shot Limiting section for more details.
- **Shutdown Status** [4 bit unsigned int] - Indicates whether thermal shutdown is imminent. Please refer to Shot Limiting section for more details.
- **Shot limiting status** [4 bit unsigned int] - Indicates the shot limiting status of the sensor. Different codes indicate whether the sensor is in Normal Operation or in Shot Limiting. Please refer to Shot Limiting section for more details.

Column Header Block [96 bits]

- **Timestamp** [64 bit unsigned int] - Timestamp of the measurement in nanoseconds.
- **Measurement ID** [16 bit unsigned int] - Sequentially incrementing measurement counting up from 0 to 511, or 0 to 1023, or 0 to 2047 depending on lidar_mode.
- **Status** [1 bit unsigned int] - Indicates validity of the measurements. Status is 0x01 for valid measurements. Status is 0x00 for dropped or disabled columns.

Channel Data Blocks [64 bits]

- **Range RET1/2** [15 bit unsigned int] - Range scaled down by a factor of 8 mm, for a maximum range of (2^15*8) = 262 mm in 15 bits.
- **Calibrated Reflectivity RET1/2** [8 bit unsigned int] - Sensor Signal Photons measurements are scaled based on measured range and sensor sensitivity at that range, providing an indication of target reflectivity.
- **Near Infrared Photons** [8 bit unsigned int] - NIR photons related to natural environmental illumination are reported. Measurements are taken similar to other data profiles (Single Data Profile and Dual Return Profile) but it is scaled down by a factor of 16.

Packet Footer [256 bits]

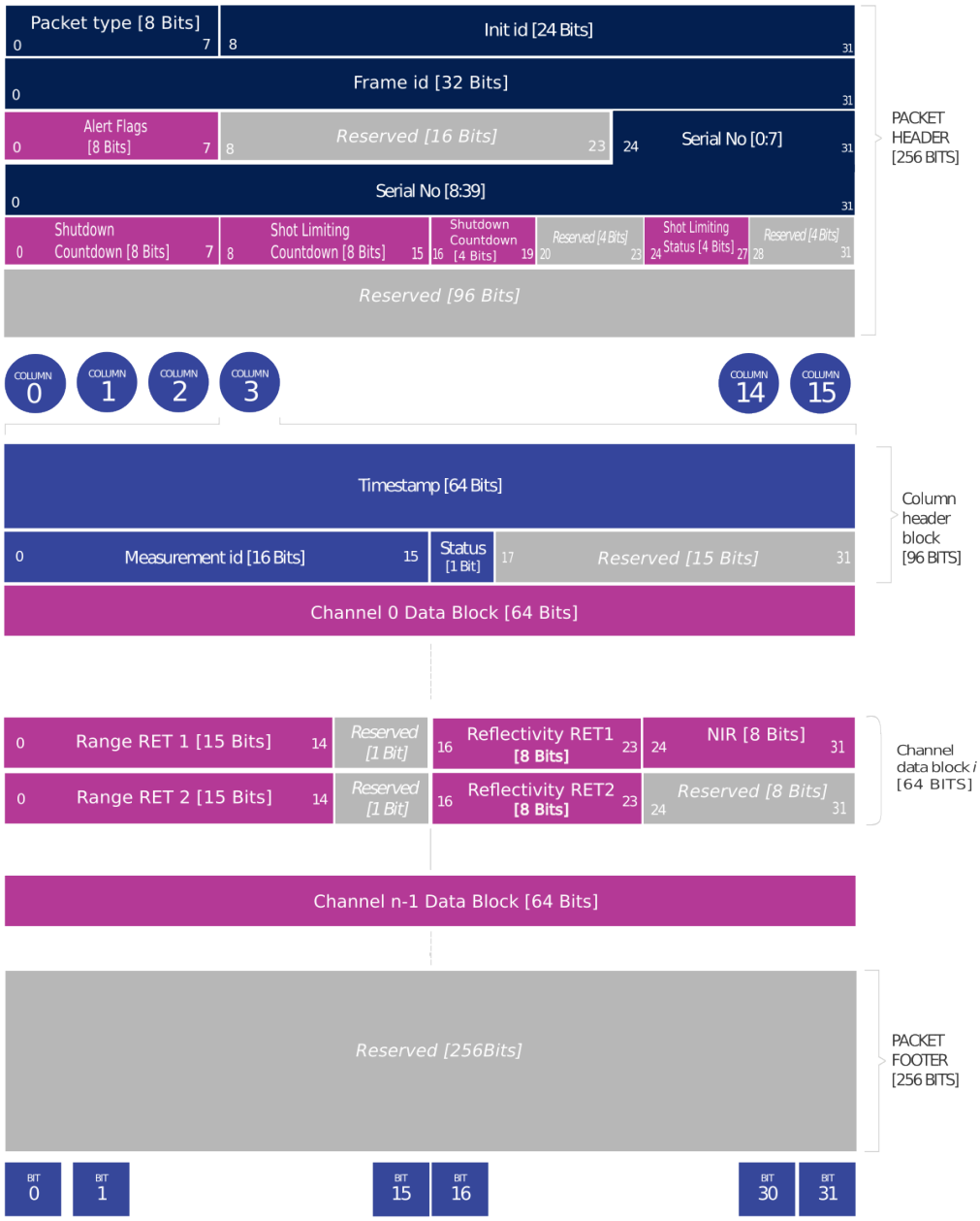


Figure 5.5: Functional Safety Data Packet Format

5.2.2 Packet Size Calculation

Packet size can be calculated by the following formula:

`packet_header_size + columns_per_packet * (measurement_header_size + pixels_per_column * channel_data_block_size) + packet_footer_size`

For example:

- 32 + 16 * (12 + n * s) + 32 bytes
  - `packet_header_size` = 32 bytes
  - `columns_per_packet` = 16
  - `measurement_header_size` = 12 bytes
  - **n** is `pixels_per_column` (correspond to the number of channels: 128 for OS1-128)
  - **s** is the size of a channel data block (16 bytes for RNG19_RFL8_SIG16_NIR16_DUAL configuration)
  - `packet_footer_size` = 32 bytes

The following tables below provide values for packet sizes, packet rates, and data rates for various products and configurations. These tables assume a default azimuth window of 360º. Providing a custom azimuth window can further lower packet rate and data rate. See the *Azimuth Window* section for details on setting a custom azimuth window.

Table 5.3: Lidar Packet Size (Bytes) Breakdown, Product vs Data Packet Format

Product	Single Return	Dual Return	Low Data Rate	FUSA Low Data Rate Dual Return
OS-x-32	6400	8448	2304	4352
OS-x-64	12544	16640	4352	8448
OS-x-128	24832	33024	8448	16640

Table 5.4: Packet Rate (Hz) Breakdown, Product vs Lidar Mode

Product	512x10	1024x10, 512x20	2048x10, 1024x20
OS-x-32	320	640	1280
OS-x-64	320	640	1280
OS-x-128	320	640	1280

Table 5.5: Data Rate (Mbps) Breakdown in 2048x10 or 1024x20 modes, Product vs Data Packet Format

Product	Single Return	Dual Return	Low Data Rate	FUSA Low Data Rate Dual Return
OS-x-32	65.57	86.55	23.63	44.56
OS-x-64	128.49	170.43	44.60	86.55
OS-x-128	254.32	338.20	86.55	170.4

5.3 LEGACY Data Packet Format

Warning: `LEGACY Data Packet Format** is **Deprecated`.

Please refer to *RNG19_RFL8_SIG16_NIR16 Return Profile* section which will be the `default` lidar packet format with firmware v3.0.0 and later. For more information on `LEGACY` packet format, please visit Downloads and refer to Firmware User Manual v3.0 or prior. For any questions on how to transition from ''LEGACY` profile to *RNG19_RFL8_SIG16_NIR16 Return Profile* profile, please contact our Field Application Team.

5.4 Calibrated Reflectivity

The calibration status is returned with the following format:

```
{
  "reflectivity":
  {
      "valid": "true: if factory calibrated for better accuracy, false: if not calibrated -- using default
                values and likely has less accuracy",
      "timestamp": "Date when the calibration has been performed"
  }
}
```

Please contact your support@ouster.io if you have questions on whether your sensor is hardware-enabled for calibrated reflectivity.

5.4.1 Reflectivity Data Mapping

Reflectivity values between 0-100 are linearly mapped for lambertian targets with values between 0% and 100% reflectivity. Values between 101-255 are mapped as $\log_2$ with linear interpolation between logarithmic points for retroreflective targets. The 255 value corresponds to a retroreflector 864 times stronger than a 100% lambertian target. The charts below show the mapping functions.

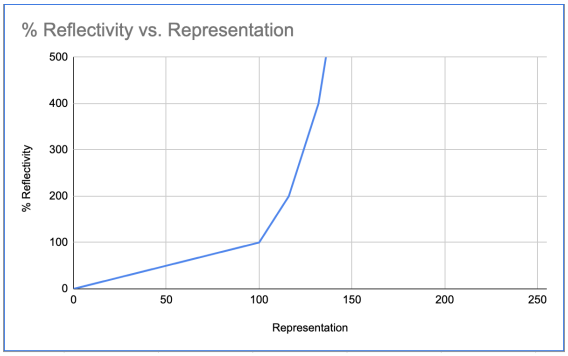


Figure 5.6: % Reflectivity vs Representation

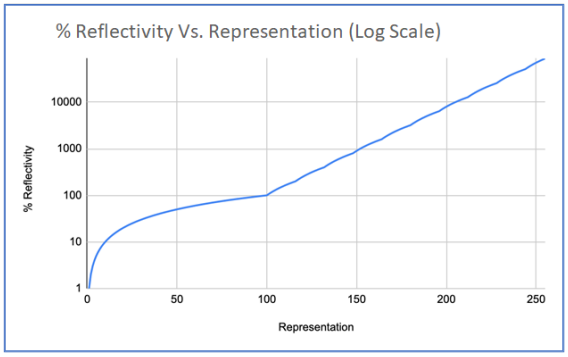


Figure 5.7: % Reflectivity vs Representation (Log Scale)

Representation	% Reflectivity		Representation	% Reflectivity		Representation	% Reflectivity		Representation	% Reflectivity
0-100	0-100		139	575		178	3000		217	16800
101	106.25		140	600		179	3100		218	17600
102	112.5		141	625		180	3200		219	18400
103	118.75		142	650		181	3400		220	19200
104	125		143	675		182	3600		221	20000
105	131.25		144	700		183	3800		222	20800
106	137.5		145	725		184	4000		223	21600
107	143.75		146	750		185	4200		224	22400
108	150		147	775		186	4400		225	23200
109	156.25		148	800		187	4600		226	24000
110	162.5		149	850		188	4800		227	24800
111	168.75		150	900		189	5000		228	25600
112	175		151	950		190	5200		229	27200
113	181.25		152	1000		191	5400		230	28800
114	187.5		153	1050		192	5600		231	30400
115	193.75		154	1100		193	5800		232	32000
116	200		155	1150		194	6000		233	33600
117	212.5		156	1200		195	6200		234	35200
118	225		157	1250		196	6400		235	36800
119	237.5		158	1300		197	6800		236	38400
120	250		159	1350		198	7200		237	40000
121	262.5		160	1400		199	7600		238	41600
122	275		161	1450		200	8000		239	43200
123	287.5		162	1500		201	8400		240	44800
124	300		163	1550		202	8800		241	46400
125	312.5		164	1600		203	9200		242	48000
126	325		165	1700		204	9600		243	49600
127	337.5		166	1800		205	10000		244	51200
128	350		167	1900		206	10400		245	54400
129	362.5		168	2000		207	10800		246	57600
130	375		169	2100		208	11200		247	60800
131	387.5		170	2200		209	11600		248	64000
132	400		171	2300		210	12000		249	67200
133	425		172	2400		211	12400		250	70400
134	450		173	2500		212	12800		251	73600
135	475		174	2600		213	13600		252	76800
136	500		175	2700		214	14400		253	80000
137	525		176	2800		215	15200		254	83200
138	550		177	2900		216	16000		255	86400

5.5 IMU Data Format

IMU UDP Packets are 48 Bytes long and by default are sent to Port 7503 at 100 Hz. Data is organized in little endian format.

Note: IMU data format is the same regardless of the lidar data profile selected by the user.

Each IMU data block contains:

- **IMU Diagnostic Time** [64 bit unsigned int] - timestamp of monotonic system time since boot in nanoseconds.
- **Accelerometer Read Time** [64 bit unsigned int] - timestamp for accelerometer time relative to *timestamp_mode* in nanoseconds.
- **Gyroscope Read Time** [64 bit unsigned int] - timestamp for gyroscope time relative to *timestamp_mode* in nanoseconds.
- **Acceleration in X-axis** [32 bit float] - acceleration in g.
- **Acceleration in Y-axis** [32 bit float] - acceleration in g.
- **Acceleration in Z-axis** [32 bit float] - acceleration in g.
- **Angular Velocity about X-axis** [32 bit float] - Angular velocity in deg per sec.
- **Angular Velocity about Y-axis** [32 bit float] - Angular velocity in deg per sec.
- **Angular Velocity about Z-axis** [32 bit float] - Angular velocity in deg per sec.

Note that the first timestamp (Words 0,1) is for diagnostics only and is rarely used under normal operation.

The second two timestamps, (Words 2,3) and (Words 4,5), are sampled on the same clock as the lidar data, so should be used for most applications.

Ouster provides timestamps for both the gyro and accelerometer in order to give access to the lowest level information. In most applications it is acceptable to use the average of the two timestamps.

Table 5.6: Data Rate - IMU Data Packet

Product	**IMU packet size** (Bytes)	**IMU packets per second**
OS1-16	48	100
OS0-32, OS1-32, OS2-32	48	100
OS0-64, OS1-64, OS2-64	48	100
OS0-128, OS1-128, OS2-128	48	100

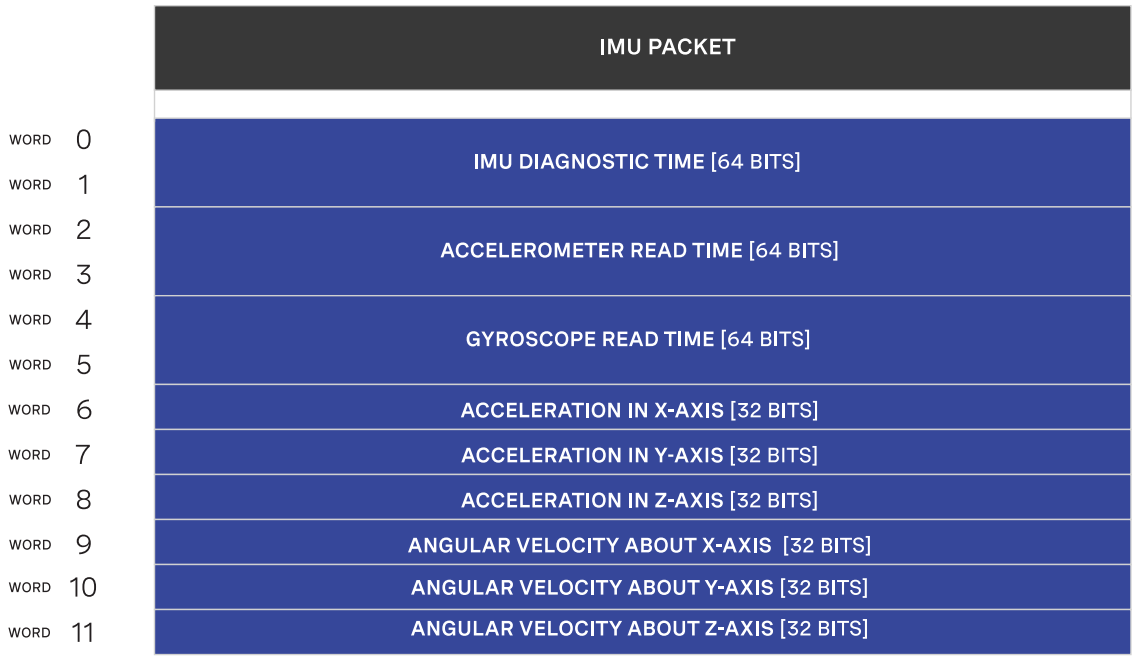


Figure 5.8: IMU Packet Format

5.5.1 Configurable IMU Scale

Users now have the capability to access the Full Scale Range (`fsr`) of the IMU integrated within Ouster sensors. This feature empowers users to adjust the scale of both Accelerometer and Gyroscope measurements captured by the IMU. Scale modifications can be toggled between a default setting termed `NORMAL` and an enhanced setting labeled `EXTENDED`. Users have the flexibility to alter the scale of the gyroscope and accelerometer either through *GET /api/v1/sensor/metadata/imu_data_format* or via the Web UI.

accel_fsr - This configuration parameter facilitates adjustment of the accelerometer scale. It offers two settings:

`NORMAL` (Default): Digital-output X-, Y-, Z-axis with a full-scale range fixed at ± 2g.

`EXTENDED`: Digital-output X-, Y-, Z-axis with an expanded full-scale range of ± 16g.

gyro_fsr - This configuration parameter enables modification of the gyroscope scale. It provides two settings:

`NORMAL` (Default): Digital-output X-, Y-, Z-axis with a full-scale range fixed at ± 250 dps (°/sec).

`EXTENDED`: Digital-output X-, Y-, Z-axis with a programmable full-scale range of ± 2000 dps (°/sec).

Note: When the scale of the IMU is altered, the measured values within the IMU packets will also be updated accordingly. However, switching to the 'EXTENDED' scale may result in a slight loss of precision due to the truncation of the least significant bits (LSB). IMU specifications can be found in the Sensor Datasheet.

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6 Feature Guides

6.1 Cold Start

There is software-enabled capability for the Ouster sensor to power-up from lower temperatures. If the sensor detects that its environmental temperature is low, it will attempt to self-heat in a warmup state before entering a normal operating state.

6.1.1 Hardware Requirements

All Rev 7 sensors have cold startup capability.

6.1.2 Cold Start Operation

There is nothing for the user to change about the sensor configuration to use this feature. The sensor will automatically begin its warmup process in the coldest parts of its operating temperature range.

Table 6.1: Cold Start

Product Line	Min Temp Specs
OS0	▪ -40°C min operating temp ▪ 8 mins to `SENSOR_RUNNING` ▪ 12 mins to lasers at temp (full range) ▪ 28W peak power
OS1	▪ -40°C min operating temp ▪ 8 mins to `SENSOR_RUNNING` ▪ 12 mins to lasers at temp (full range) ▪ 28W peak power
OS2	▪ -20°C min operating temp ▪ 15 mins to `SENSOR_RUNNING` ▪ 15 mins to lasers at temp (full range) ▪ 30W peak power

6.1.3 Indications and Alerts

In a cold start scenario, the sensor will have a short warmup phase; we've added in the additional `"WARMUP"` status to indicate when the sensor is warming up.

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 274
Content-Type: application/json
Date: Thu, 01 Jan 1970 00:02:59 GMT
Server: nginx


{
    "build_date": "2023-1-15T15:56:07Z",
    "build_rev": "v3.0,0",
    "image_rev": "ousteros-image-prod-bootes-v3.0.0+0123456789",
    "initialization_id": 2573178,
    "prod_line": "OS-1-128",
    "prod_pn": "840-103xxx-0x",
    "prod_sn": "99xxxxxxxxxx",
    "status": "WARMUP"
}
```

The following alerts are related to cold start:

Table 6.2: Cold Start Alerts

ID	Category	Level	Description
0x01000053	WARMUP_ISSUE	ERROR	Sensor warmup process has failed. Unit is shutting down. Check the sensor operating conditions are within operating bounds. Contact Ouster support with Diagnostic file.
0x0100004F	WARMUP_ISSUE	WARNING	Sensor warmup process is taking longer than expected; please ensure sensor is thermally constrained per requirements. Contact Ouster support with Diagnostic file.

6.2 Sensor Telemetry

Sensor telemetry refers to sensor system state information that changes with time, i.e. temperature, voltage, etc. Users can monitor this data live or for diagnostics and take precautionary measures if needed. This information can be obtained from running the command `GET /api/v1/sensor/telemetry` as shown in the example below.

6.2.1 GET /api/v1/sensor/telemetry

To `GET` the sensor telemetry information.

```
GET /api/v1/sensor/telemetry HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 151
Content-Type: application/json
Date: Thu, 21 Mar 2024 05:26:49 GMT
Server: nginx

{
    "input_current_ma": 198,
    "input_voltage_mv": 24033,
    "internal_temperature_deg_c": 36,
    "phase_lock_status": "DISABLED",
    "timestamp_ns": 19510164553064
}
```

Table 6.3: Example Sensor Telemetry

Fields	Notes
Timestamp	Timestamp from the FPGA measured in `ns` (Nanoseconds)
Lidar Input Voltage	Input voltage `mv` (Millivolt) that is provided to the sensor
Lidar Input Current	Input current `ma` (Milliamp) that is provided to the sensor
Internal Temperature	Internal base board temperature `°C` (Degree Celsius).
Phase Lock Status	Different codes to specify phase lock status and issues related to phase locking (`LOCKED`, `LOST`, `DISABLED`)

Note:

- **Phase lock** output will not indicate loss of lock if the PTP source is lost.

6.3 Azimuth Window

Azimuth window selection is a feature to only turn on the UDP lidar data within a region of interest. The region of interest is defined by a min bound and a max bound, both in millidegrees. As a reminder, angles in this frame increment counterclockwise when viewed from the top. Below is the Lidar Coordinate Frame from a top-down perspective:

- 0º towards the external connectors
- 90º a quarter turn counterclockwise from the connector
- 180º opposite the connector
- 270º three quarter turns counterclockwise from the connector

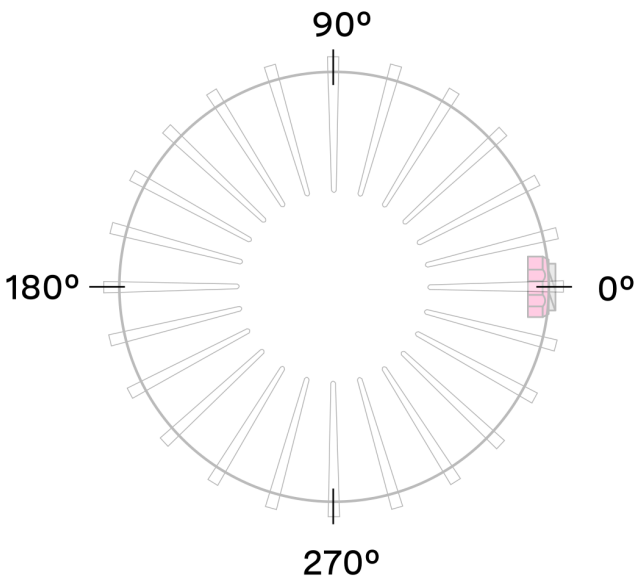

Figure 6.1: Lidar Coordinate Frame from a top-down perspective

Configuring the azimuth window lowers the average output data rate of the sensor. It also stops the lasers from firing during disabled regions and thus reduces power consumption and thermal output.

6.3.1 Expected Sensor Behavior

The sensor will round the input azimuth window bounds to the nearest *Measurement Block* IDs generating new ID-based bounds. The new bounds are used to mask *Measurement Blocks* in the lidar data packets. Lidar packets containing only masked *Measurement Blocks* are not output, and there may be partially masked *Measurement Blocks* in the two bookended lidar packets in each frame. The *Measurement Block Status* field will indicate the valid or masked/padded *Measurement Blocks* in any partially masked lidar packets. (See the *Lidar Data Packet Format* section for details on the lidar data format.)

The visualized output will contain jagged edges caused by the staggered, nonzero nature of the beam

azimuth angles. It is necessary to set more conservative (wider) bounds to push the jagged edges beyond the desired window. This can be determined through trial and error or calculated deterministically with knowledge of the queryable beam azimuth angles.

6.3.2 Azimuth Laser Masking

This feature allows thermal improvement by shutting down the Lasers on the masked azimuth window. Lasers are only shot in the azimuth window the user has configured. When the user configures a limited azimuth window (azimuth_window config param) on the sensor for their application, the sensor will automatically shut down the lasers in the unused azimuth window.

6.3.3 Azimuth Window Examples

The HTTP API Guide lists the command for setting an azimuth window. Please refer to section *azimuth_window*.

The command syntax is as follows:

```
"azimuth_window": [min_bound_millidegrees, max_bound_millidegrees]
```

- Default settings of 360º window: [0, 360000]
- Set a region of interest between 0º to 180º: [0, 180000]
- Set a region of interest between 270º to 90º with 180º field of view: [270000, 90000]
- Set a region of interest 90º to 270º with 180º field of view: [90000, 270000]
- Set a region of interest between 0º to 90º with 90º field of view: [0, 90000]
- Set a region of interest 90º to 360º with 270º field of view: [90000, 0]

6.4 Standby Operating Mode

Starting with firmware v2.0.0, the sensor can be commanded in and out of a low-power Standby Operating Mode that can be useful for power, battery, or thermal-conscious applications of the sensor.

The HTTP config param `operating_mode` has a default value of `NORMAL`. Setting it to `STANDBY` puts the sensor into Standby Operating Mode upon reinitialization.

6.4.1 Expected Sensor Behavior

Power draw in Standby mode is 5W. The motor does not spin, and light is not visible from the window. However, the sensor is on and listening to commands. The sensor status will be `STANDBY`.

6.4.2 Standby Operating Mode Examples

- Set sensor into `STANDBY` mode and keep sensor in `STANDBY` mode upon power-up at next use:

```
curl -i -X POST os-122322000614.local/api/v1/sensor/config -H 'content-type: application/json' --data-raw
'{"operating_mode": "STANDBY"}'
```

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Content-Type: application/json

{"operating_mode": "STANDBY"}
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:37:41 GMT
Server: nginx
```

- Set sensor into `NORMAL` mode and keep sensor in `NORMAL` mode upon power-up at next use:

```
curl -i -X POST os-122322000614.local/api/v1/sensor/config -H 'content-type: application/json' --data-raw
'{"operating_mode": "NORMAL"}'
```

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Content-Type: application/json

{"operating_mode": "NORMAL"}
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:37:41 GMT
Server: nginx
```

6.5 Signal Multiplier

The `signal_multiplier` config parameter allows the user to set a multiplier for the signal strength of the sensor. By default the sensor has a signal multiplier value of `1`. Choosing a signal multiplier greater than 1 requires reducing the azimuth window below 360° as explained below. Lasers are disabled outside of the maximum allowable azimuth window.

6.5.1 Use Cases

The config parameter `signal_multiplier <0.25/0.5/1/2/3>` sets the signal multiplier value. The higher the signal multiplier value, the smaller the maximum azimuth window can be.

Table 6.4: Maximum azimuth window size at each signal multiplier level

Signal Multiplier Value	Max Azimuth Window
0.25	360°
0.5	360°
1 (Default)	360°
2	180°
3	120°

Besides affecting the sensor's signal strength, the signal multiplier choice can also impact power draw and thermal behavior. Choosing a signal multiplier less than 1 reduces overall power. Similarly, choosing a smaller azimuth window means the lasers do not emit pulses in sections not included in the azimuth window, thus reducing overall power. However, while this can increase the max operating temp of the sensor, it can also degrade the performance at low temperatures. This discrepancy will be resolved in a future firmware. The table below outlines some example use cases. User can access *Sensor Telemetry* information and monitor the sensor temperature.

Table 6.5: Example Use Cases

Use Case	`signal_multiplier` **Parameter**	`azimuth_window` **Parameter**
Signal boost	3	[0,120000]
Signal boost with power draw reduction	2	[0,90000]

6.5.2 Expected Behavior

For all signal multiplier levels, the lasers are enabled only in the chosen azimuth window.

If an invalid combination of signal multiplier and azimuth window values are set, the sensor will throw an error. If a valid pair of values are set, upon reinitializing, the sensor will operate in the signal multiplier mode.

6.5.3 Examples

The following shows the HTTP API example commands and responses.

Set sensor in 3x signal multiplier mode with 120° HFoV:

First set the azimuth_window to [120000, 240000] using *azimuth_window*. Then the user can run a `POST` command to set signal multiplier to a value `3`.

```
curl -i -X POST 192.0.2.123/api/v1/sensor/config -H 'content-type: application/json' --data
'{"signal_multiplier": "3"}'
```

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json

{"signal_multiplier": "3"}
```

```
HTTP/1.1 204 No Content
Server: nginx
Date: Mon, 04 Mar 2024 19:50:36 GMT
Connection: keep-alive
```

Sensor will throw an error if invalid parameters set are of any value other than `0.25`, `0.5`, `1`, `2`, `3`.

Note: Please refer to the *Maximum azimuth window size at each signal multiplier level* before configuring a signal multiplier value.

6.6 Sensor Performance by Operating Configuration

Depending upon the sensor's lidar mode and signal multiplier setting, the sensor performance will vary from its baseline as listed on the datasheet. This section will present the estimated performance multiplier depending on the sensor and the operating configuration.

6.6.1 Estimated range multiplier

When using a signal multiplier higher than 1x and depending on the lidar mode, the sensor will get a range increase. The following tables present an estimated range multiplier depending on the operating configuration.

OS0 and OS1

For the OS0, OSDome and OS1 sensors the baseline is the 1024x10 mode

Table 6.6: Frame Rate / Horizontal Resolution 512 Mode

Signal Multiplier	0.25x	0.5x	1x	2x	3x
10 Hz	0.84	1	1.19	1.41	1.57
20 Hz	0.71	0.84	1	1.19	1.32

Table 6.7: Frame Rate / Horizontal Resolution 1024 Mode

Signal Multiplier	0.25x	0.5x	1x	2x	3x
10 Hz	0.71	0.84	1	1.19	1.32
20 Hz	0.59	0.71	0.84	1	1.11

Table 6.8: Frame Rate / Horizontal Resolution 2048 Mode

Signal Multiplier	0.25x	0.5x	1x	2x	3x
10 Hz	0.59	0.71	0.84	1	1.11
20 Hz	NA	NA	NA	NA	NA

Note: The values in the tables above are given for guidance only. The only specs guaranteed are the ones defined in the datasheet for a specific mode.

OS2

For OS2 sensors the baseline is the 2048x10 mode.

Frame Rate / Horiz. Res.	**512**			**1024**			**2048**		
Signal multiplier	**1x**	**2x**	**3x**	**1x**	**2x**	**3x**	**1x**	**2x**	**3x**
10 Hz	1.41	1.68	1.86	1.19	1.41	1.57	1.00	1.19	1.32
20 Hz	1.19	1.41	1.57	1.00	1.19	1.32	NA		

Note: The values in the tables above are given for guidance only. The only specs guaranteed are the ones defined in the datasheet for a specific mode.

Maximal representable range

Depending upon the signal multiplier, the maximal representable range of the sensor will be different. The table below shows the maximal representable range values for each sensor type and multiplier value.

Table 6.9: Maximum Representation Range

Signal Multiplier Value	**OSDome**	**OS0**	**OS1**	**OS2**
0.25x	491 m	491 m	491 m	491 m
0.5x	491 m	491 m	491 m	491 m
1x	270 m	270 m	270 m	465 m
2x	135 m	135 m	135 m	232 m
3x	90 m	90 m	90 m	155 m

Range returns beyond the maximal representable range may experience range aliasing. Therefore, these modes are only recommended in scenarios where there will not be any returns beyond the maximal representable range.

6.7 Shot Limiting

Shot limiting is a process by which the Ouster sensor will automatically enter into state to safely prolong the operational performance of the sensor in high operating temperature conditions. There are several different levels of shot limiting that are described in the Shot Limiting Status Flags table.

The sensor has three operating states in order to manage high temperatures:

- `NORMAL (Status 0x00)`
- `SHOT_LIMITING_IMMINENT (Status 0x01)`
- `SHOT_LIMITING (Status 0x02 and greater)`

In the `NORMAL` state the sensor will perform to the range and precision specifications of the datasheet. When the sensor reaches a certain temperature, the sensor enters the `SHOT_LIMITING_IMMINENT` state and issues alert `0x0100000E` which indicates shot-limiting will commence in 30 seconds. After 30 seconds have elapsed and the temperature remains elevated, the sensor issues alert `0x0100000F` and enters a `SHOT_LIMITING` state.

In shot limiting state, the sensor reduces power to the lasers in order to reduce the thermal load. While in this state, sensor range and precision may degrade by up to 30%. The sensor will progressively increase shot limiting if the temperature remains elevated. If the sensor reaches its maximum degree of shot-limiting, it will throw alert `0x0100003A`.

If the sensor cools down while it is in either `SHOT_LIMITING_IMMINENT` or `SHOT_LIMITING` state, the sensor will return to the `NORMAL` state.

An independent state machine runs for thermal shutdown. When the sensor reaches the maximum operating temperature specified in the table Maximum Thermal Performance, the sensor will enter a `SHUTDOWN_IMMINENT` state and issue an alert in category `OVERTEMP`. If the sensor temperature remains elevated after 30 seconds, the sensor will shut down and issue alert `0x0100006B`.

Note: Please refer to the Hardware User Manual to learn more about the maximum thermal performance.

Information regarding the shot limiting status is presented as part of the lidar data packet in the *Configurable Data Packet Format*. Shot limiting status will be a part of the packet header when config parameter `udp_profile_lidar` is set to one of the following values shown below.

- *RNG19_RFL8_SIG16_NIR16 Return Profile*
- *RNG15_RFL8_NIR8 Return Profile*
- *RNG19_RFL8_SIG16_NIR16_DUAL Return Profile*

The following flags are present in configurable data packet header:

Shot limiting status [4 bit unsigned int] - Indicates the shot limiting status of the sensor. Different codes indicates whether the sensor is in *Normal Operation* or in *Shot limiting*.

Shutdown Status [4 bit unsigned int] - Indicates whether thermal shutdown is imminent. This can be due to *shot limiting* being saturated, or due to any other over temperature conditions and depending upon the situation the appropriate alert is generated. When thermal shutdown is imminent, this flag will be set to 1 and the Thermal Shutdown Countdown field will be set to 30 seconds.

Shot limiting Countdown [8 bit unsigned int] - Countdown from 30 seconds to indicate when shot limiting is imminent. When the condition for entering shot limiting is met, the shot limiting status bit is set to 0x01 and the alert 0x0100000E takes effect. At this point the shot limiting counter will be set to 30 seconds and a countdown to initiate shot limiting will start.

Shutdown Countdown [8 bit unsigned int] - Countdown from 30 seconds to indicate that thermal shutdown is imminent. When a thermal shutdown is completed, the alert 0x0100006B will take effect and the sensor will automatically go to the ERROR state and stop outputting data.

The following table describes the codes in the shot limiting status flags, and what mode it corresponds to:

Table 6.10: Shot Limiting Status Flags

Shot Limiting status flags	Description
0x00	Normal Operation. When the sensor is not in shot limiting, the shot limiting status flag will be set to 0x00, and shot limiting countdown will be set to 0x00.
0x01	When the condition for entering Shot limiting is met, we set the Shot Limiting Status bit 0x01 and the alert 0x0100000E is in effect, informing that shot limiting is imminent.
0x02	In this mode, we reduce the % of nominal laser duty cycle by 0-10% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 3%.
0x03	In this mode, we reduce the % of nominal laser duty cycle by 10-20% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 6%.
0x04	In this mode, we reduce the % of nominal laser duty cycle by 20-30% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 9%.

Table 6.11: Shot Limiting Status Flags Cntd.

Shot Limiting status flags	Description
0x05	In this mode, we reduce the % of nominal laser duty cycle by 30-40% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 12%.
0x06	In this mode, we reduce the % of nominal laser duty cycle by 40-50% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 16%. For OS2 and OSDome sensors this mode is when shot limiting is saturated and alert 0x0100003A is in effect. There will be an approximate reduction in the sensor max range by 21%.
0x07	In this mode, we reduce the % of nominal laser duty cycle by 50-60% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 21%.
0x08	In this mode, we reduce the % of nominal laser duty cycle by 60-70% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 25%.
0x09	In this mode, we reduce the % of nominal laser duty cycle by 70-75% from NORMAL OPERATION. There will be an approximate reduction in the sensor max range by 27%. For OS0 and OS1 sensors this mode is when shot limiting is saturated and alert 0x0100003A is in effect. There will be an approximate reduction in the sensor max range by 27%.

6.8 Minimum Range Threshold

Minimum Range Threshold (cm) is a new feature added in FW v3.1 that reduces the minimum range of the sensor, enabling it to detect targets all the way up to the sensor window.

In the past, Ouster sensors were subject to a minimum range limitation dictated by the hardware revision. However, Ouster has made significant strides in overcoming this limitation. Now, users have the capability to eliminate the blind zone and extend the field of view (FOV) to the sensor window.

Additionally, users have the flexibility to configure the minimum range according to their specific requirements (Valid Values= `0cm`, `30cm` and `50cm`).

6.8.1 Configuring min_range

Users can use HTTP API endpoint to set this parameter, please refer to *min_range_threshold_cm*.

- `Min_range_threshold` = `0 cm` (Sensor Window): This setting allows the sensor to operate within its full range capability, from the closest detectable point up to the sensor window.
- `Min_range_threshold` = `30 cm` (Min_range of previous sensors i.e., Rev6 and prior): Users can set the minimum range to 30 cm, excluding detection within the first 30 cm from the sensor.
- `Min_range_threshold` = `50 cm` (Default for Rev7 and later): The default setting for Rev7 is a minimum range of 50 cm, providing a standard configuration for most applications.

Note: When `min_range_threshold_cm` is set to 30cm or less, Ouster recommends setting `return_order` to `FARTHEST_TO_NEAREST`, especially when the `udp_profile_lidar` is also set to `Single Return`. Also, for best performance in the region closer than 50cm, Ouster recommends keeping the sensor window clean.

6.8.2 Use Cases

- **Vehicle Applications:** When mounted on vehicles or machinery, users have the flexibility to adjust the minimum range based on the detection of nearby objects. This feature helps in minimizing false positives and significantly enhances safety, as it ensures that the system responds accurately to potential obstacles or hazards in the vicinity.
- **Customized Sensing:** In applications where specific ranges of interest are known in advance, such as robotics or drones, adjusting the minimum range allows for more precise and efficient sensing.
- **Environmental Adaptability:** Users operating in challenging environments, such as crowded spaces or highly reflective surfaces, can tailor the sensor's minimum range to improve performance and accuracy.
- **Filtering out unwanted detections:** and focusing on relevant objects within the sensor's field of view. This customization enhances data quality and reliability, particularly in complex operating environments.

6.9 Return Order

6.9.1 Overview

The Rev7 Ouster sensors are equipped with the capability to detect up to a total of 2 returns from the target. This hardware-enabled feature allows for the independent collection of information regardless of the lidar mode selected by the user, meaning the lidar can detect up to 2 returns in all modes including Single Return, Dual Return, and Low Data Rate modes.

With the introduction of Firmware 3.1, a new feature has been introduced, allowing users to sort returns by their order of detection. This feature enables users to rearrange returns based on factors such as range or signal strength, providing the ability to optimize sensor performance to meet specific application requirements.

6.9.2 Sorting Returns

Rev 7 sensors are capable of processing two returns, regardless of the `udp_data_profile` that has been selected (`Single Return`, `Dual Return`, `Low Data Packet` and `FUSA Data Packet`). Users can configure the sensor (using *return_order*) to order returns based on either signal strength or range. This flexibility allows for optimized data processing and interpretation, ensuring that the most relevant information is utilized for decision-making tasks.

This customization provides users with the ability to tailor the sensor's behavior to suit their specific application requirements and this extends to the following data formats:

- *RNG19_RFL8_SIG16_NIR16 Return Profile*,
- *RNG15_RFL8_NIR8 Return Profile*,
- *RNG19_RFL8_SIG16_NIR16_DUAL Return Profile* and
- *FUSA_RNG15_RFL8_NIR8_DUAL Return Profile*

When `return_order` is selected the sensor returns the two strongest returns for each radial beam. The order in which these two returns appear depends on the setting of the `return order` which has the following possible values.

- `STRONGEST_TO_WEAKEST`: The first return corresponds to the strongest signal strength among the two returns, while the subsequent return represents the next strongest signal (or the weaker of the two returns). This order of returns prioritizes points based on their signal strength, ensuring that the strongest signals are processed first. Such prioritization proves beneficial in applications where identifying the most prominent or reflective objects is essential.

- `FARTHEST_TO_NEAREST`: The two returns are sorted based on their measured Range value. The first return corresponds to the farthest of the two returns, followed by the next strongest, and consequently the nearest of the two strongest returns. This order of returns arranges points according to their distance from the lidar sensor, listing the farthest points first. Such sorting proves invaluable when emphasis is placed on comprehending the spatial distribution of objects within the sensor's field of view.

Note: When `min_range_threshold_cm` is set to 30cm or less, Ouster recommends setting `return_order` to `FARTHEST_TO_NEAREST`, especially when the `udp_profile_lidar` is also set to `Single Return`.

- `NEAREST_TO_FARTHEST`: The nearest of the two strongest returns is the first return and the farthest of the two strongest returns follows. This return order prioritizes the closest point, listing it first. This order can be beneficial in applications where identifying nearby obstacles or points of interest is critical.

The choice of `return order` depends on the application. For example, in obstacle detection scenarios, `NEAREST_TO_FARTHEST` might be preferred for identifying nearby objects, whilst in mapping applications `FARTHEST_TO_NEAREST` could be more suitable for capturing the spatial layout of the environment.

The following `return order` can be set `STRONGEST_TO_WEAKEST` (**Default**), `NEAREST_TO_FARTHEST` and `FARTHEST_TO_NEAREST`. Users can use HTTP API endpoint to set this parameter, please refer to *return_order*. By default, the `return_order` parameter is set to `STRONGEST_TO_WEAKEST`. However, users can adjust this parameter according to their specific preferences.

6.10 User Editable Data Field

The User Editable Data Field is a versatile feature embedded within the Ouster Sensor, providing users with a preallocated text field for storing various types of information directly on the sensor itself. This field serves multiple purposes, including storing specific sensor information, calibration data, or any other relevant data crucial for operational efficiency.

Notably, the User Editable Data Field offers the flexibility to retain or delete its respective data, depending on the action taken, such as deleting the sensor configuration.

Note: Additional Information:

- **Valid values for UED:** empty string or string containing non-binary ASCII and/or Unicode characters
- **Size limit for UED string:** 128KB with 1KB = 1024bytes (Total = 131,072 bytes)

6.10.1 Example Use Case:

A common challenge faced by systems employing multiple Ouster sensors with differing hardware and firmware versions is ensuring the compatibility of mounted sensors with the application requirements. In scenarios where numerous sensors are deployed remotely and in large quantities, visually inspecting and identifying the appropriate sensor for each location becomes impractical. This lack of clarity can lead to incorrect installations and operational disruptions.

6.10.2 Proposed Solution:

To mitigate this challenge, a solution is proposed that harnesses the User Editable Field (UEF) on Ouster sensors, coupled with client-generated signatures using private keys. This solution aims to establish a robust validation mechanism, ensuring the authenticity and compatibility of Ouster lidar sensors within the users system.

6.10.3 Implementation of the Proposed Solution:

Ouster provides each sensor with a User Editable Field (UEF), initially empty, enabling users to write signatures without impacting core sensor functionality. This feature empowers users to customize and authenticate sensor data seamlessly.

6.10.4 Customer Signing Process:

Upon receiving a sensor, the customer retrieves the unique and unalterable serial number (SN) from the sensor.

The customer then employs their private key to sign the SN securely, generating a unique signature, which is subsequently written to the User Editable Field (UEF) on the sensor.

6.10.5 Customer System Validation:

During system startup, the customer's system retrieves both the SN and the signature from the sensor.

Utilizing the customer's widely available public key, the system meticulously verifies the signature within the UEF against the SN.

A successful verification assures the integrity of the sensor, confirming that it hasn't been tampered with, and that the signature corresponds accurately to the intended sensor.

6.10.6 HTTP Endpoints for User Editable Field (UEF)

This field can be used for a number of purposes such as storing specific information about the sensor, qualifying a sensor, calibration data, or any other information.

Example HTTP API endpoints:

- *GET /api/v1/user/data*
- *PUT /api/v1/user/data*
- *DELETE /api/v1/user/data*

6.10.7 HTTP Endpoints for Optional Parameters - data policy

The policy key maps to the active policy as applied with `PUT api/v1/user/data?policy=<policy_str>`.

`<policy_str>` have the following options available:

- `clear_on_config_delete` by default
- `keep_on_config_delete`

The User Editable Data comes with the ability to `keep` or `delete` its respective data based on the action of deleting the sensor config. That can be done by setting the value of the User Editable Data `policy` to either `keep_on_config_delete` or `clear_on_config_delete` (which is default), where if the `keep_on_config_delete` policy is set then the User Editable Data data will not be deleted when the sensor config is deleted, and if the `clear_on_config_delete` policy is set then the User Editable Data data will be deleted when the sensor config is deleted. The User Editable Data data and User Editable Data policy must be set in the same `HTTP PUT` request. If the User Editable Data value is set without the policy, then the policy will automatically be reset to `clear_on_config_delete`.

The User Editable Data data value (i.e. text) is persisted across sensor config resets, config reboots, firmware upgrades, and sensor power cycles.

When querying the User Editable Data, the `include_metadata` field can be specified to control the verbosity of the returned data. If set to 'true' then the value of the User Editable Data field will be returned in addition to the value of the policy. If set to 'false' (which is default) then only the value of the User Editable Data field will be returned.

Note: `Data policy` has no effect on the User Editable Data field.

Example HTTP API endpoints:

- *PUT /api/v1/user/data?policy=clear_on_config_delete*
- *PUT /api/v1/user/data?policy=keep_on_config_delete*

6.10.8 Optional Parameters - include_metadata

Same as nominal `GET` but returns a JSON dictionary of the form `{ "value": str, "policy": str }` where the value key maps to the nominal value returned by `GET` with no arguments.

Note: `include_metadata` has no effect on the User Editable Data field.

This feature lets user to query the user editable data field to get `policy` and `value` when `include_metadata` is set to `true`/`1` and only the `value` when `include_matadata` is set to `false`/`0`

Example HTTP API endpoints:

- *GET /api/v1/user/data?include_metadata=true*
- *GET /api/v1/user/data?include_metadata=false*

7 Multi-Sensor Synchronization

7.1 Phase Lock

Phase locking allows a sensor to consistently pass through a specific angle at the top, tenth (1024X10 Hz mode), or the twentieth (1024x20 Hz mode) of a second on each rotation. The phase lock control loop runs at 1000 Hz. Phase locking is useful for synchronizing a sensor with other devices including camera, radar, and other lidar.

A sensor must first be time-synchronized from an external source and must be in either the `TIME_FROM_PTP_1588` or `TIME_FROM_SYNC_PULSE_IN` *timestamp_mode* before entering phase lock.

7.1.1 Phase Locking Reference Frame

Phase locking commands use angles defined in the Lidar Coordinate Frame in millidegrees. As a reminder, angles in this frame increment counterclockwise when viewed from the top. Below is the Lidar Coordinate Frame from a top-down perspective:

- 0º towards the external connector
- 90º a quarter turn counterclockwise from the connector
- 180º opposite the connector
- 270º three quarter turns counterclockwise from the connector

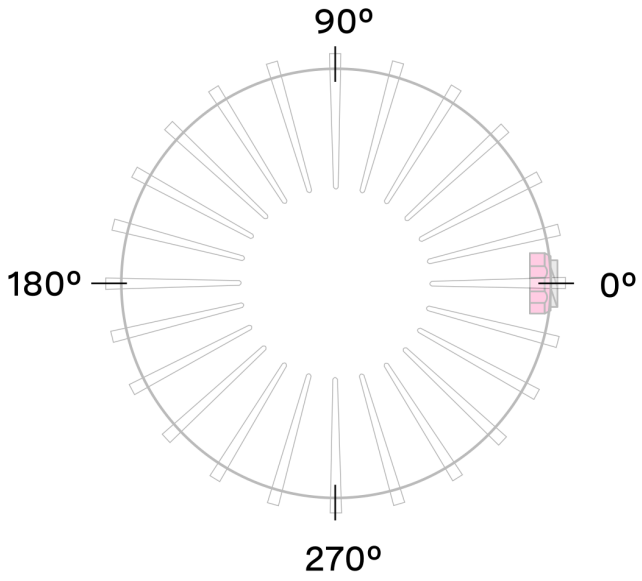

Figure 7.1: Lidar coordinate frame Top-Down view

7.1.2 Phase Locking Commands

- Command to enable or disable phase lock:

By default, `phase_lock_enable` is `false`. Please use the below HTTP API Example.

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_enable:=false"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

- Command to set the phase lock offset angle in the Lidar Coordinate Frame:

By default, `phase_lock_offset` value is `0`. `<angle_in_millidegrees>` is an integer from `0` to `360000`. Please use the below HTTP API Example to set `phase_lock_offset` from `0` to `180000`.

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_offset:=180000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

7.1.3 Multi-sensor Example

In this example below, we are trying to phase lock all three sensors on the car so that they point towards the front of the car at the same time. Note that their external connectors point in different directions.

Assuming the three sensors are properly time synchronized via an external source, the following shows the netcat console input commands and responses from configuring the sensors so that they point forward at the same time.

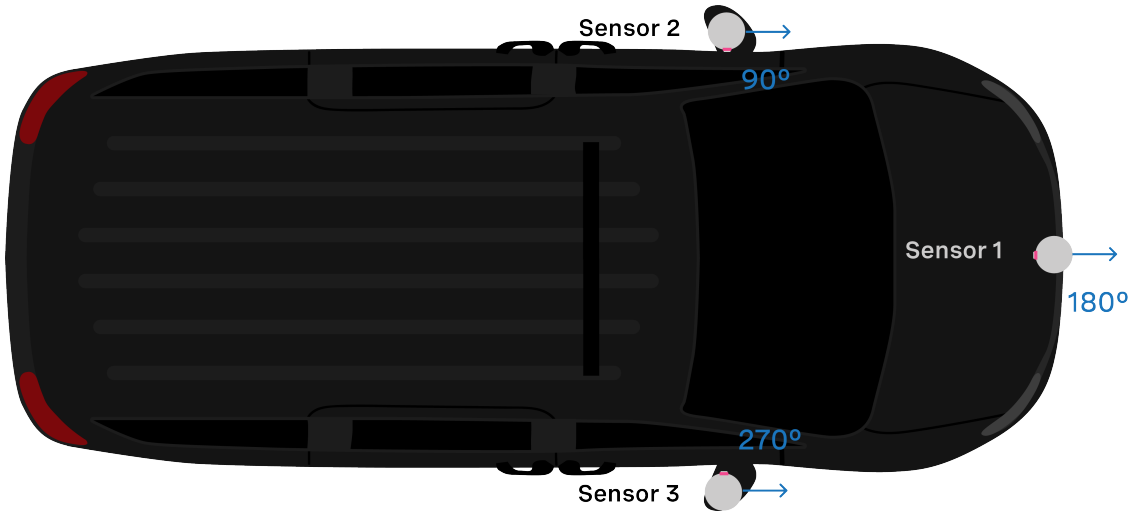

Figure 7.2: Van with 3 Sensors mounted

- Set Sensor 1 to phase lock at 180º:

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_offset:=180000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

- Set Sensor 2 to phase lock at 90º:

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_offset:=90000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

- Set Sensor 3 to phase lock at 270º:

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
```

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```
Content-Type: application/json

"phase_lock_offset:=270000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

7.1.4 Accuracy

The following chart shows the expected angular position accuracy under normal operating conditions.

Table 7.1: Phase Lock Accuracy

Product line	10Hz	20Hz
OS0 and OS1 (Gen 1 and Gen 2)	0.5°	0.5°
OS2	5°	10°

7.1.5 Phase Locking Alerts

The following alerts related to phase locking errors are listed below. For the full list of alerts and errors see the *Alerts and Errors* section in the Appendix.

Table 7.2: Phase Lock Alerts

id	category	level	description
0x01000050	MOTOR_CONTROL	WARNING	The phase lock offset error has exceeded the threshold.
0x01000051	MOTOR_CONTROL	ERROR	The phase lock control failed to achieve a lock multiple times; please contact Ouster at https://ouster.com/tech-support.
0x01000024	STARTUP	ERROR	The phase lock control failed to achieve a lock during startup.

Note: For information on how to mitigate crosstalk between different Ouster lidars in the same system refer to *Inter-sensor Interference Mitigation* section of this manual.

7.2 Inter-sensor Interference Mitigation

Inter-sensor crosstalk occurs when two sensors are operating close together and they interpret each other's laser pulses as their own. Mitigating crosstalk between two sensors is a two step process:

1) Phase lock the two sensors

2) Set azimuth window on each sensor so that they don't send data when they are pointing at each other

7.2.1 Two Sensor Example

In this example below, we are trying to mitigate inter-sensor crosstalk between Sensor 1 and Sensor 2 on the car. Both of their connectors are facing towards the back of the car. The Lidar Coordinate Frame is printed on the back of the vehicle for reference.

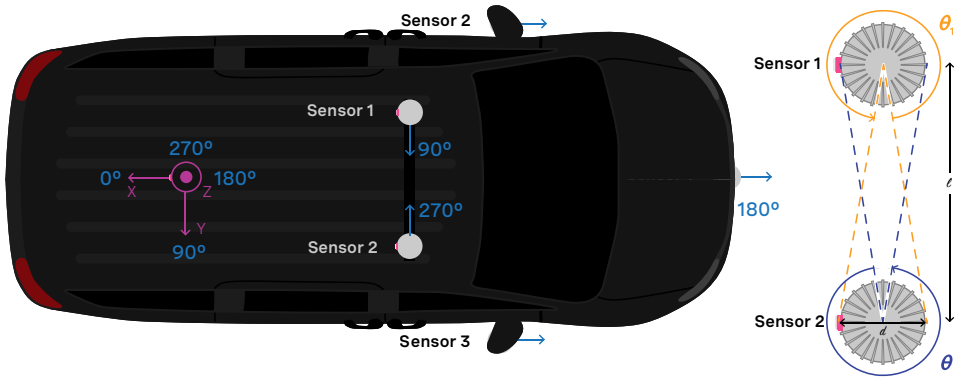

Figure 7.3: Example: Inter-sensor crosstalk mitigation between 2 sensors

First and foremost, placing a physical barrier between the two sensors is the best option to mitigate cross talk in this example and most scenarios. If this is not possible, we can use the phase locking feature to eliminate the problem. Crosstalk only occurs when one sensor shines its lasers into the window of another sensor. The goal of phase locking is to force the sensors to point at each other simultaneously so that crosstalk occurs when sensors aren't generating important data about the environment.

1. Time synchronize the two sensors via an external source. See the *Time Synchronization* section for more details on time synchronizing sensors with an external GPS or via PTP.

2. Phase lock both sensors such that they point directly at each other at the same time. In this case, we want Sensor 1 to be pointing at 90º at the same time that Sensor 2 is pointing at 270º. The example netcat console output would look like below.

Note: In the examples below, to distinguish between the command and expected response, a dash has been added before the expected response. The actual response will be without the dash.

Example: Set Sensor 1 to phase lock at 90º:

- Step 1: Set "phase_lock_enable" to `true`

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_enable:=true"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

- Step 2: Set "phase_lock_offset" to `90000`

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_offset:=90000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

Example: Set Sensor 2 to phase lock at 270º:

- Step 1: Set "phase_lock_enable" to `true`

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json

"phase_lock_enable:=true"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

- Step 2: Set "phase_lock_offset" to `270000`

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json
Content-Type: application/json
```

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```
"phase_lock_offset:=270000"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 04 Mar 2024 21:20:16 GMT
Server: nginx
```

3. Set an azimuth window for both sensors. In this case, the region of interest for Sensor 1 is θ_1 and the region of interest for Sensor 2 is θ_2

The calculation for θ_1 and θ_2 is as follows:

$$\theta_1 = \theta_2 = 360^\circ - 2 \cdot \arctan \frac{d}{l}$$

In this case, if the two sensors were placed a distance of 100 mm apart, $360^\circ - 2 \cdot \arctan \frac{81}{1000} = 360^\circ - 78^\circ = 282^\circ$ We want to set azimuth window of size 282º for the two sensors, so that they do not send data in the 78º where they would point at each other. Sensor 1's azimuth window is the 282º centered around 270º. Sensor 2's region of interest is the 282º centered around 90º.

Sensor 1's azimuth window starts at 129º and follows the CCW direction to end at 51º:

Example CURL command:

```
curl -i -X POST 192.0.2.123/api/v1/sensor/config -H 'content-type: application/json' --data '{"azimuth_window": [129000, 51000]}'
```

Example HTTP command:

```
http POST 10.34.24.132/api/v1/sensor/config "azimuth_window:=[129000, 51000]"
```

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json

"azimuth_window": [129000, 51000]
```

```
HTTP/1.1 204 No Content
Server: nginx
Date: Thu, 28 Apr 2022 18:09:49 GMT
Connection: keep-alive
```

Sensor 2's azimuth window starts at 309° and follows the CCW direction to end at 231°:

Example CURL command:

```
curl -i -X POST 192.0.2.123/api/v1/sensor/config -H 'content-type: application/json' --data '{"azimuth_window": [309000, 231000]}'
```

Example HTTP command:

```
http POST 10.34.24.132/api/v1/sensor/config "azimuth_window:=[309000, 231000]"
```

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
Accept: application/json

"azimuth_window": [309000, 231000]
```

```
HTTP/1.1 204 No Content
Server: nginx
Date: Thu, 28 Apr 2022 18:09:49 GMT
Connection: keep-alive
```

Table 7.3: Product Line and their Diameter

Product Line	At Window	At base including fins
OS0 and OS1 (Gen1 and Gen2)	81mm	88mm
OS2	111mm	121mm

8 Time Synchronization

8.1 Timing Overview Diagram

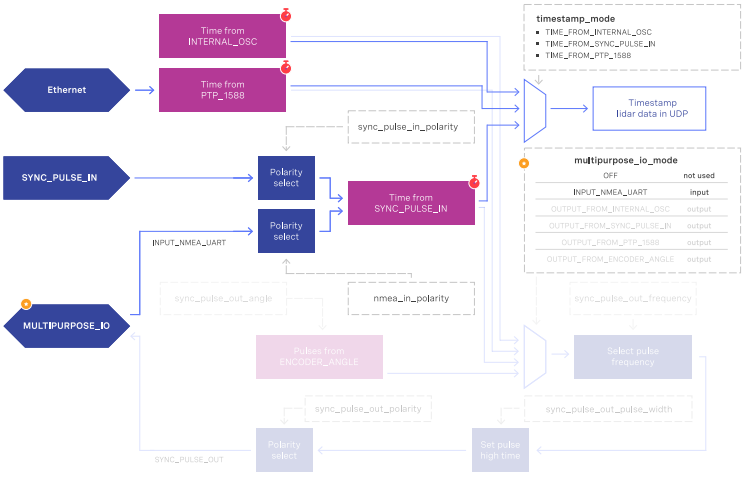

Figure 8.1: Signal path with MULTIPURPOSE_IO set as input

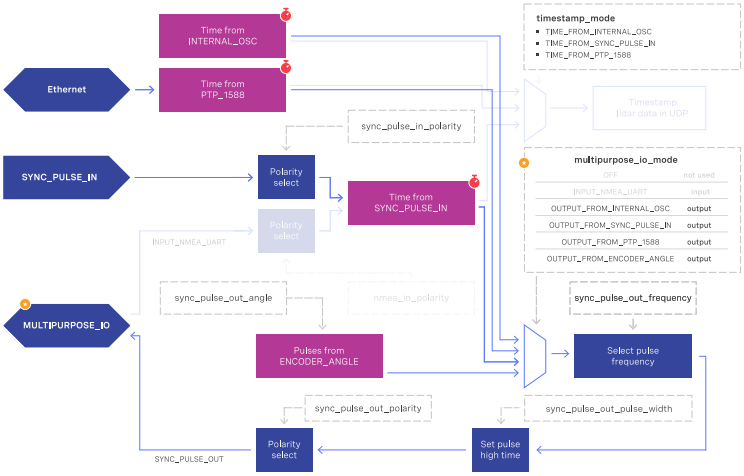

Figure 8.2: Signal path with MULTIPURPOSE_IO set as output

8.2 Sensor Time Source

- All lidar and IMU data is timestamped to a common timer with 10 nanosecond precision.
- The common timer can be programmed to run off one of three clock sources:
  - An internal clock derived from a high accuracy, low drift oscillator.
  - An opto-isolated digital input from the external connector for timing off an external hardware trigger such as a GPS. The polarity of this input signal is programmable. For instance, both a GPS PPS pulse and a 30 Hz frame sync from an industrial camera can supply a timing signal to the sensor.
  - The IEEE 1588 Precision Time Protocol. PTP provides the convenience of configuring timing over a network that supports IEEE 1588 with no additional hardware signals.

8.2.1 Setting Ouster Sensor Time Source

The source for measurement timestamps can be configured using the `timestamp_mode`. The available modes are described below:

Table8.1: Timestamp Modes

Command	Response
`TIME_FROM_INTERNAL_OSC`	Use the internal clock. Free running counter based on the sensor's internal oscillator. Counts seconds and nanoseconds since sensor turn on, reported at ns resolution (both a second and nanosecond register in every UDP packet), but minimum increment is on the order of 10 ns.
`TIME_FROM_SYNC_PULSE_IN`	A free running counter synced to the SYNC_PULSE_IN input counts seconds (# of pulses) and nanoseconds since sensor turn on. If `multipurpose_io_mode` is set to `INPUT_NMEA_UART` then the seconds register jumps to time extracted from a NMEA $GPRMC message read on the `multipurpose_io` port. Reported at ns resolution (both a second and nanosecond register in every UDP packet), but minimum increment is on the order of 10 ns.
`TIME_FROM_PTP_1588`	Synchronize with an external PTP master. A monotonically increasing counter that will begin counting seconds and nanoseconds since startup. As soon as a 1588 sync event happens, the time will be updated to seconds and nanoseconds since 1970. The counter must always count forward in time. If another 1588 sync event happens the counter will either jump forward to match the new time, or slow itself down. It is reported at ns resolution (there is both a second and nanosecond register in every UDP packet), but the minimum increment varies.

If configuring the sensor to synchronize time from an external sync pulse, the pulse polarity can be specified as described in the *Sensor Configuration*. Pulse-in frequency is assumed to be 1 Hz. For example, using `POST` commands will set the sensor to expect an active low pulse and configure the seconds timestamp to be pulse count since sensor startup:

- *timestamp_mode*
- *sync_pulse_in_polarity*

Note: Please refer to *HTTP API Reference Guide* for detailed `POST` command.

To configure the multipurpose-io port of the sensor to accept an external NMEA UART message, the `multipurpose_io_mode` parameter must be set to `INPUT_NMEA_UART` as described in *External Trigger Clock Source*. Once a valid UART message is received by the sensor, the seconds timestamp will snap to the latest timestamp received. The expected NMEA UART message is configurable. For example, the below commands will set the sensor to accept an NMEA UART message that is active high with a baud rate of 115200 bits per second, add 27 additional leap seconds, and accept messages even with a valid character not set:

- *multipurpose_io_mode*
- *nmea_in_polarity*
- *nmea_baud_rate*
- *nmea_leap_seconds*
- *nmea_ignore_valid_char*

Note: After POST api/v1/sensor/config request is received successfully, the sensor will reinitialize automatically to make the new configuration active and the config settings are persisted across power cycles.

8.2.2 External Trigger Clock Source

Additionally, the sensor can be configured to output a SYNC_PULSE_OUT signal from a variety of sources. See example commands in the *HTTP API Reference Guide* section. Pulses will always be evenly spaced.

This can be enabled through the `multipurpose_io_mode` configuration parameter.

Table 8.2: `multipurpose_io_mode` Configuration Parameters

Configuration	Response
`OFF`	Do not output a `SYNC_PULSE_OUT` signal.
`INPUT_NMEA_UART`	Reconfigures the `MULTIPURPOSE_IO` port as an input. See *Setting Ouster Sensor Time Source* for more information.
`OUTPUT_FROM_INTERNAL_OSC`	Output a `SYNC_PULSE_OUT` signal synchronized with the internal clock.
`OUTPUT_FROM_SYNC_PULSE_IN`	Output a `SYNC_PULSE_OUT` signal synchronized with a `SYNC_PULSE_IN` provided to the unit.
`OUTPUT_FROM_PTP_1588`	Output a `SYNC_PULSE_OUT` signal synchronized with an external PTP IEEE 1588 master.
`OUTPUT_FROM_ENCODER_ANGLE`	Output a `SYNC_PULSE_OUT` signal with a user defined rate in an integer number of degrees.

When the sensor's `multipurpose_io_mode` is set to `OUTPUT_FROM_INTERNAL_OSC`, `OUTPUT_FROM_SYNC_PULSE_IN`, or `OUTPUT_FROM_PTP_1588`, then `sync_pulse_out_frequency` (Hz) parameter can be used to define the output rate. It defaults to 1 Hz. It should be greater than 0 Hz and maximum `sync_pulse_out_frequency` is limited by the criterion below.

When the sensor is set to `OUTPUT_FROM_ENCODER_ANGLE`, then the `sync_pulse_out_angle` (deg) parameter can be used to define the output pulse rate. This allows the user to output a SYNC_PULSE_OUT signal when the encoder passes a specified angle, or multiple of the angle, indexed from 0 crossing, in degrees. It should be an integer between 0 and 360 degrees, inclusive. However, the minimum `sync_pulse_out_angle` is also limited by the criterion below.

In all modes, the output pulse width is defined by `sync_pulse_out_pulse_width` (ms).

Note: If `sync_pulse_out_pulse_width` x `sync_pulse_out_frequency` is close to 1 second, the output pulses will not function (will not return to 0). For example, at 10 Hz rotation and a 10 ms pulse width, the limitation on the number of pulses per rotation is 9.

Examples

Here are examples and their effect on output pulse when `lidar_mode` is `1024x10`, and assuming `sync_pulse_out_pulse_width` is 10 ms. Please refer to `POST` command examples on *HTTP API Reference Guide* for detailed command line.

Table 8.3: Table representation with valid values and expected response

Configuration (POST /api/v1/sensor/config)	Response

`multipurpose_io_mode=OUTPUT_FROM_SYNC_PULSE_IN`
`sync_pulse_out_pulse_width=10`
`sync_pulse_out_frequency=1`
	The output pulse frequency is 1 Hz. Each pulse is 10 ms wide. `sync_pulse_out_pulse_width` and `sync_pulse_out_frequency` commands are optional because they just re-command the default values.

`multipurpose_io_mode=OUTPUT_FROM_SYNC_PULSE_IN` `sync_pulse_out_frequency=50`	The output pulse frequency is 50 Hz. Each pulse is 10 ms wide.
`multipurpose_io_mode=OUTPUT_FROM_ENCODER_ANGLE` `sync_pulse_out_angle=360`	The output pulse frequency is 10 Hz, since the sensor is in 10 Hz mode (10 rotations / sec) and the angle is set to 360º, a full rotation. Each pulse is 10 ms wide.
`multipurpose_io_mode=OUTPUT_FROM_ENCODER_ANGLE` `sync_pulse_out_angle=45`	The output pulse frequency is 80 Hz, since the sensor is in 10 Hz mode (10 rotations / sec) and the angle is set to 45º. Each full rotation will have 8 pulses. Each pulse is 10 ms wide.

8.3 NMEA Message Format

The Ouster Sensor expects a standard NMEA $GPRMC UART message. Data (called a sentence) is a simple ASCII string starting with a '$' character and ending with a return character. Fields of the sentence are separated with a ',' character, and the last field (a checksum) is separated by a '*' character.

The max character length of a standard message is 80 characters; however, the Ouster Sensor can support non-standard messages up to 85 characters (see Example 2 below).

The Ouster Sensor will deliver time in the UDP packet by calculating seconds since 00:00:00 Thursday, 1 January 1970. `nmea_leap_seconds` by default is 0, meaning this calculation will not take into account any leap seconds. If `nmea_leap_seconds` is 0 then the reported time is Unix Epoch time. As of February, 2019, Coordinated Universal Time (UTC) lags behind International Atomic Time (TAI) by an offset of 37 seconds (10 seconds from the initial UTC offset when UTC was introduced in 1972 + 27 leap seconds announced in the intervening years). Therefore, setting `nmea_leap_seconds` to 37 in February of 2019 would make the timestamps match the TAI standard.

`nmea_in_polarity` by default is `ACTIVE_HIGH`. This means that a UART start bit will occur directly after a falling edge. If using RS-232, the UART signal may be inverted (where a start bit occurs directly after a rising edge). In this case, `nmea_in_polarity` should be set to `ACTIVE_LOW`.

8.3.1 Example 1 Message:

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A
```

Field	Description
$GPRMC	Recommended Minimum sentence C
123519	Fix taken at 12:35:19 UTC
A	Status A=active or V=Void
4807.038	Latitude 48 deg 07.038′
N	Latitude cardinal reference
01131.000	Longitude 11 deg 31.000′
E	Longitude cardinal reference
022.4	Speed over the ground in knots
084.4	Track angle in degrees True
230394	Date - 23rd of March 1994
003.1	Magnetic Variation
W	Magnetic cardinal reference
A	[Optional] A=autonomous, D=differential, E=Estimated, N=not valid, S=Simulator
*6A	The checksum data, always begins with *

8.3.2 Example 2 Message:

```
$GPRMC,042901.00,A,3745.871698,N,12224.825960,W,0.874,327.72,130219,13.39,E,A,*60
```

Field	Description
$GPRMC	Recommended Minimum sentence C
042901.00	Fix taken at 4:29:01 UTC
A	Status A=active or V=Void
3745.871698	Latitude 37 deg 45.871698′
N	Latitude cardinal reference
12224.825960	Longitude 12 deg 24.825960′
W	Longitude cardinal reference
0.874	Speed over the ground in knots
327.72	Track angle in degrees True
130219	Date - 13th of February 2019
13.39	Magnetic Variation
E	Magnetic cardinal reference
A	[Optional] A=autonomous, D=differential, E=Estimated, N=not valid, S=Simulator
*60	The checksum data, always begins with *

9 GPS/GNSS Synchronization Guide

For more information on how to physically connect a GPS to your Ouster sensor and synchronise the Ouster sensor timestamp to an NMEA sentence, please refer to your sensor's Hardware User Manual.

9.1 Configuring the Ouster Sensor

Now that all GPS configurations are in place and connections to the Ouster sensor have been successfully established, it's time to initiate the synchronization process on the Ouster sensor, ensuring its timestamp aligns precisely with the GPS signal.

- Set the `timestamp_mode` to `TIME_FROM_SYNC_PULSE_IN`:
  - *timestamp_mode*
- Set the `multipurpose_io_mode` to `INPUT_NMEA_UART`:
  - *multipurpose_io_mode*
- Set the polarity of the `sync_pulse_in` pin to match the GPS PPS polarity:
  - *sync_pulse_in_polarity*
- Set the polarity of the `multipurpose_io` pin to match the GPS NMEA UART polarity:
  - *nmea_in_polarity*
- Set the `nmea_baud_rate` to match the GPS NMEA baud rate:
  - *nmea_baud_rate*
- Set the `nmea_leap_seconds` to match the current leap seconds as defined by TAI Time at this website, at time of writing this the leap seconds are `37`:
  - *nmea_leap_seconds*

Note: After POST api/v1/sensor/config request is received successfully, the sensor will reinitialize automatically to make the new configuration active and the config settings are persisted across power cycles.

9.1.1 Checking for Sync

Once you have completed all the above you should be able to check for synchronization

- Check the output from the HTTP Endpoint *GET /api/v1/time*.
- Verify that the sensor is `locked` onto the PPS signal.
  - "sync_pulse_in": { "locked": 1 }
  - If not check the polarity and change it if necessary.
- Verify that the sensor is `locked` on the NMEA signal.

        - "nmea": { "locked": 1 }
        - If not check the polarity and baud rate and change them if necessary.
    - Verify that `last_read_message` looks like a valid GPRMC sentence.
        - "decoding": {"last_read_message": "GPRMC,024041.00,A,5107.0017737,N,11402.3291611, W,0.080,323.3,020420,0.0,E,A*20"}
    - Verify that `timestamp` time has updated to a reasonable GPS time.
        - "timestamp": {"time": 1585881641.96139565999999,

          "mode": "TIME_FROM_SYNC_PUSLE_IN",

          "time_options": { "sync_pulse_in": 1585881641}}

Example output from *GET /api/v1/time*:


```
{
   "timestamp":{
      "time":1585881641.96139565999999,
      "mode":"TIME_FROM_SYNC_PUSLE_IN",
      "time_options":{
         "sync_pulse_in":1585881641,
         "internal_osc":302,
         "ptp_1588":309
      }
   },
   "sync_pulse_in":{
      "locked":1,
      "diagnostics":{
         "last_period_nsec":10,
         "count_unfiltered":832,
         "count":832
      },
      "polarity":"ACTIVE_HIGH"
   },
   "multipurpose_io":{
      "mode":"INPUT_NMEA_UART",
      "sync_pulse_out":{
         "pulse_width_ms":10,
         "angle_deg":360,
         "frequency_hz":1,
         "polarity":"ACTIVE_HIGH"
      },
      "nmea":{
         "locked":1,
         "baud_rate":"BAUD_9600",
         "diagnostics":{
            "io_checks":{
               "bit_count":2938457,
               "bit_count_unfilterd":2938457,
               "start_char_count":832,
               "char_count":66526
            },
            "decoding":{
               "last_read_message":"GPRMC,024041.00,A,5107.0017737,N,11402.3291611,W,
```


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```
                                0.080,323.3,020420,0.0,E,A*20",
            "date_decoded_count":832,
            "not_valid_count":0,
            "utc_decoded_count":832
         }
      },
      "leap_seconds":37,
      "ignore_valid_char":0,
      "polarity":"ACTIVE_HIGH"
   }
  }
}
```

10 Sensor Configuration

10.1 Overview

Overview of sensor configuration parameters. For detailed description of each parameter refer to *Description*.

Table10.1: Overview

Parameter	Type	Valid Values
udp_dest	String	"" (default)
udp_port_lidar	Integer	7502 (default)
udp_port_imu	Integer	7503 (default)
sync_pulse_in_polarity	Keyword	ACTIVE_HIGH (default) ACTIVE_LOW
sync_pulse_out_polarity	Keyword	ACTIVE_LOW (default) ACTIVE_HIGH
sync_pulse_out_frequency	Integer >= 1	1 (default)
sync_pulse_out_angle	Integer [0 ... 360]	360 (default)
sync_pulse_out_pulse_width	Integer >= 0	10 (default)
nmea_in_polarity	Keyword	ACTIVE_HIGH (default) ACTIVE_LOW
nmea_ignore_valid_char	Integer	0 (default) 1
nmea_baud_rate	Keyword	BAUD_9600 (default) BAUD_115200
nmea_leap_seconds	Integer >= 0	0 (default)
azimuth_window	List	[0,360000] (default)
signal_multiplier	Number	0.25 0.5 1 (default) 2 3
udp_profile_lidar	Keyword	RNG19_RFL8_SIG16_NIR16 (default) RNG19_RFL8_SIG16_NIR16_DUAL RNG15_RFL8_NIR8 FUSA_RNG15_RFL8_NIR8_DUAL
udp_profile_imu	Keyword	LEGACY (default)

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Table 10.1 - continued from previous page

Parameter	Type	Valid Values
phase_lock_enable	Boolean	false (default) true
phase_lock_offset	Integer [0 ... 360]	0 (default)
lidar_mode	Keyword	512x10 1024x10 (default) 2048x10 512x20 1024x20
timestamp_mode	Keyword	TIME_FROM_INTERNAL_OSC (default) TIME_FROM_PTP_1588 TIME_FROM_SYNC_PULSE_IN
multipurpose_io_mode	Keyword	OFF (default) INPUT_NMEA_UART OUTPUT_FROM_INTERNAL_OSC OUTPUT_FROM_SYNC_PULSE_IN OUTPUT_FROM_PTP_1588 OUTPUT_FROM_ENCODER_ANGLE
operating_mode	Keyword	NORMAL (default) STANDBY
min_range_threshold_cm	Number	0 30 50 (default)
return_order	Keyword	STRONGEST_TO_WEAKEST (Default), NEAREST_TO_FARTHEST FARTHEST_TO_NEAREST

10.2 Description

10.2.1 udp_dest

Description:

- Type: String
- Default: "192.0.2.123"
- Destination to which the sensor sends UDP traffic.

Note: As of now, setting the udp_dest to "@auto" is only supported through HTTP POST /api/v1/sensor/config. Parameter udp_ip has been deprecated in firmware v2.4, please use the udp_dest parameter.

10.2.2 udp_port_lidar

Description:

- Type: Integer [0 ... 65535]
- Default: 7502
- The <port> on udp_dest to which lidar data will be sent (7502, default).

10.2.3 udp_port_imu

Description:

- Type: Integer [0 ... 65535]
- Default: 7503
- The <port> on udp_dest to which IMU data will be sent (7503, default).

10.2.4 sync_pulse_in_polarity

Description:

- Type: Keyword
- Default: "ACTIVE_HIGH"
- **Enum:**
    - "ACTIVE_HIGH"
    - "ACTIVE_LOW"
- The polarity of SYNC_PULSE_IN input, which controls polarity of SYNC_PULSE_IN pin when timestamp_mode is set in TIME_FROM_SYNC_PULSE_IN.

10.2.5 sync_pulse_out_polarity

Description:

- Type: Keyword
- Default: "ACTIVE_HIGH"
- The polarity of SYNC_PULSE_OUT output, if the sensor is set as the master sensor used for time synchronization.

10.2.6 sync_pulse_out_frequency

Description:

- Type: Integer >= 1
- Default: 1
- The output SYNC_PULSE_OUT pulse rate in Hz. Valid inputs are integers >0 Hz, but also limited by the criteria described in the Time Synchronization section of the Firmware User Manual.

10.2.7 sync_pulse_out_angle

Description:

- Type: Integer [0 ... 360]
- Default: 360
- The angle in terms of degrees that the sensor traverses between each SYNC_PULSE_OUT pulse. E.g. a value of 180 means a sync pulse is sent out every 180° for a total of two pulses per revolution and angular frequency of 20 Hz if the sensor is 1024x10 Hz lidar mode. Valid inputs are integers between 0 and 360 inclusive but also limited by the criteria described in the Time Synchronization section of Firmware User Manual.

10.2.8 sync_pulse_out_pulse_width

Description:

- Type: Integer >= 0
- Default: 10
- The polarity of SYNC_PULSE_OUT output, if the sensor is set as the master sensor used for time synchronization. Output SYNC_PULSE_OUT pulse width is in ms, increments in 1 ms. Valid inputs are integers greater than 0 ms, but also limited by the criteria described in the Time Synchronization section of Firmware User Manual.

10.2.9 nmea_in_polarity

Description:

- Type: Keyword
- Default: "ACTIVE_HIGH"
- **Enum:**
    - "ACTIVE_HIGH"
    - "ACTIVE_LOW"
- Set the polarity of NMEA UART input $GPRMC messages. See Time Synchronization section in sensor user manual for NMEA use case. Use `ACTIVE_HIGH` if UART is active high, idle low, and start bit is after a falling edge.

10.2.10 nmea_ignore_valid_char

Description:

- Type: Integer [0 ... 1]
- Default: 0
- Set `0` if NMEA UART input $GPRMC messages should be ignored if valid character is not set, and `1` if messages should be used for time syncing regardless of the valid character.

10.2.11 nmea_baud_rate

Description:

- Type: Keyword
- Default: "BAUD_9600"
- **Enum:**
    - "BAUD_9600"
    - "BAUD_115200"
- `BAUD_9600` (default) or `BAUD_115200` for the expected baud rate the sensor is attempting to decode for NMEA UART input $GPRMC messages.

10.2.12 nmea_leap_seconds

Description:

- Type: Integer >= 0
- Default: 0
- Set an integer number of leap seconds that will be added to the UDP timestamp when calculating seconds since 00:00:00 Thursday, 1 January 1970. For Unix Epoch time, this should be set to `0`.

10.2.13 azimuth_window

Description:

- Type: List
- Default: [0,360000]
- Set the visible region of interest of the sensor in millidegrees. Only data from within the specified azimuth window bounds is sent. The value should be provisioned as: [min_bound_millideg, max_bound_millideg]

10.2.14 signal_multiplier

Description:

- Type: Number [0.25, 0.5, 1 ... 3]
- Default: 1
- The value that the signal_multiplier is configured. By default the sensor has a signal multiplier value of 1.

  For 2x and 3x multipliers, the azimuth_window parameter sets the azimuth window that the lasers will be enabled in.

  The higher the signal multiplier value, the smaller the maximum azimuth window can be.

  Signal Multiplier Value Max Azimuth Window for 0.25, 0.5 and 1: (Default) 360º, 2: 180º, 3: 120º.

  All sensors have equivalent power draw and thermal output when operating at the max azimuth window for a particular signal multiplier value. Therefore, using an azimuth window that is smaller than the maximum allowable azimuth window with a particular signal multiplier value (excluding 1x) can reduce the power draw and thermal output of the sensor.

  However, while this can increase the max operating temp of the sensor, it can also degrade the performance at low temps. This discrepancy will be resolved in a future firmware. The table below outlines some example use cases.

10.2.15 udp_profile_lidar

Description:

- Type: Keyword
- Default: "RNG19_RFL8_SIG16_NIR16"
- **Enum:**
  - "RNG19_RFL8_SIG16_NIR16"
  - "RNG19_RFL8_SIG16_NIR16_DUAL"
  - "RNG15_RFL8_NIR8"
  - "FUSA_RNG15_RFL8_NIR8_DUAL"
- The configuration of the LIDAR data packets. Valid values are RNG19_RFL8_SIG16_NIR16 *[Default]*, RNG19_RFL8_SIG16_NIR16_DUAL, RNG15_RFL8_NIR8 and FUSA_RNG15_RFL8_NIR8_DUAL.

10.2.16 udp_profile_imu

Description:

- Type: Keyword
- Default: "LEGACY"
- Value: "LEGACY"
- The configuration of the IMU data packets. Valid value is LEGACY.

10.2.17 `phase_lock_enable`

Description: Whether phase locking is enabled. Refer to Phase Lock Section in the Firmware User Manual for more details on using phase lock.

- Type: Boolean
- Default: False
- Whether phase locking is enabled. Refer to Phase Lock Section in the Firmware User Manual for more details on using phase lock.

10.2.18 `phase_lock_offset`

Description:

- Type: Integer [0 ... 360000]
- Default: 0
- The angle in the Lidar Coordinate Frame that sensors are locked to in millidegrees if phase locking is enabled. Angle is traversed at the top of the second.

10.2.19 `lidar_mode`

Description:

- Type: Keyword
- Default: "1024x10"
- **Enum:**
    - "512x10"
    - "1024x10"
    - "2048x10"
    - "512x20"
    - "1024x20"
- The horizontal resolution and rotation rate of the sensor. The effective range of the sensor is increased by 15-20% for every halving of the number of points gathered e.g. 512x10 has 15-20% longer range than 512x20.

10.2.20 `timestamp_mode`

Description:

The method used to timestamp measurements. Valid modes are `TIME_FROM_INTERNAL_OSC`, `TIME_FROM_SYNC_PULSE_IN`, or `TIME_FROM_PTP_1588`.

10.2.21 multipurpose_io_mode

Description:

- Type: Keyword
- Default: "OFF"
- **Enum:**
    - "OFF"
    - "INPUT_NMEA_UART"
    - "OUTPUT_FROM_INTERNAL_OSC"
    - "OUTPUT_FROM_SYNC_PULSE_IN"
    - "OUTPUT_FROM_PTP_1588"
    - "OUTPUT_FROM_ENCODER_ANGLE"
- Configure the mode of the MULTIPURPOSE_IO pin. Refer to Time Synchronization section in Firmware user manual for a detailed description of each option.

10.2.22 operating_mode

Description:

- Type: Any
- Default: "NORMAL"
- Set `NORMAL` to put the sensor into a normal operating mode or `STANDBY` to put the sensor into a low power (5W) operating mode where the motor does not spin and lasers do not fire.

Note: `auto_start_flag` is deprecated parameter in Firmware 2.4 and later. `auto_start_flag 0` is equivalent to `operating_mode STANDBY` and `auto_start_flag 1` is equivalent to `operating_mode NORMAL`.

10.2.23 min_range_threshold_cm

Description:

- Type: Number
- Default:
    - `50` (default)
- Enum:
    - `30`
    - `0`
- Set `0` or `30` (centimeters) to change the sensor's minimum reported range. Points below the configured minimum range will not be reported. This parameter is present in firmware v3.1 and newer.

Note: When `min_range_threshold_cm` is set to 30 or less, Ouster recommends setting `return_order` to `FARTHEST_TO_NEAREST`.

10.2.24 `return_order`

- Type: Keyword
- Default:
  - `STRONGEST_TO_WEAKEST`
- Enum:
  - `NEAREST_TO_FARTHEST`
  - `FARTHEST_TO_NEAREST`
- This parameter configures how the lidar returns are ordered. The return order can be set by the user (`STRONGEST_TO_WEAKEST``(default), ``NEAREST_TO_FARTHEST` AND `FARTHEST_TO_NEAREST`). This parameter applies regardless of the configured `udp_profile_lidar` and can be used to configure the only reported return in single return UDP profiles. This parameter is present in firmware v3.1 and newer.

Note: When `min_range_threshold_cm` is set to 30 or less, Ouster recommends setting `return_order` to `FARTHEST_TO_NEAREST`.

10.2.25 `imu_data_format`

- Type: Keyword
- Default:
  - `NORMAL`
- Enum:
  - `NORMAL`
  - `EXTENDED`
- Two valid values for "gyro_fsr" and "accel_fsr" are `NORMAL` (**Default**), `EXTENDED`. Please refer to *GET /api/v1/sensor/metadata/imu_data_format* for more information.

11 HTTP API Reference Guide

This reference guide documents the interface for HTTP API and is accessible via `/api/v1` on the sensor hosted HTTP server.

The sensor can be queried and configured using HTTP requests. This can be done using several different tools such as HTTPie, cURL, Advanced REST Client, etc.

Here is an example using **curl** command:

```
$ curl --request GET --url http://192.0.2.123/api/v1/sensor/metadata/lidar_intrinsics

 {
   "lidar_to_sensor_transform": [-1, 0, 0, 0, 0, -1, 0, 0, 0, 0, 1, 38.195, 0, 0, 0, 1]
 }
```

Note: All sensor configuration parameters are `CASE SENSITIVE`, please refer to this user manual to make sure the implementation is correct. Additionally all the examples provided for endpoints are tested on Linux, if you are using Mac OS or Windows please adhere to correct command structure.

11.1 Sensor Metadata

11.1.1 GET /api/v1/sensor/metadata/sensor_info

To `GET` the sensor information.

```
GET /api/v1/sensor/metadata/sensor_info HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 285
Content-Type: application/json

{
    "build_date": "2023-1-15T15:56:07Z",
    "build_rev": "v3.0.0",
    "image_rev": "ousteros-image-prod-bootes-v3.0.0+0123456789",
    "initialization_id": 390072,
    "prod_line": "OS-1-128",
    "prod_pn": "860-105010-07",
    "prod_sn": "992244000006",
    "status": "RUNNING"
}
```

Description: Returns JSON-formatted response that includes sensor serial number, product number, FW image revision, and sensor status along with other parameters as shown.

11.1.2 GET /api/v1/sensor/metadata/lidar_data_format

To GET the sensor lidar data format.

```
GET /api/v1/sensor/metadata/lidar_data_format HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 724
Content-Type: application/json
Date: Thu, 28 Apr 2022 19:00:38 GMT
Server: nginx

{
 "column_window": [0, 1023],
 "columns_per_frame": 1024,
 "columns_per_packet": 16,
 "pixel_shift_by_row": [
   12, 4, -4, -12, 12, 4, -4,
  -12, 12, 4, -4, -12, 12, 4,
  -4, -12, 12, 4, -4, -12, 12,
   4, -4, -12, 12, 4, -4, -12,
   12, 4, -4, -12, 12, 4, -4,
  -12, 12, 4, -4, -12, 12, 4,
  -4, -12, 12, 4, -4, -12, 12,
   4, -4, -12, 12, 4, -4, -12,
   12, 4, -4, -12, 12, 4, -4,
  -12, 12, 4, -4, -12, 12, 4,
  -4, -12, 12, 4, -4, -12, 12,
   4, -4, -12, 12, 4, -4, -12,
   12, 4, -4, -12, 12, 4, -4,
  -12, 12, 4, -4, -12, 12, 4,
   4, -12, 12, 4, -4, -12, 12,
   4, -4, -12, 12, 4, -4, -12,
   12, 4, -4, -12, 12, 4, -4,
  -12, 12, 4, -4, -12, 12, 4,
  -4, -12],
 "pixels_per_column": 128,
 "udp_profile_imu": "LEGACY",
 "udp_profile_lidar": "RNG19_RFL8_SIG16_NIR16_DUAL"
}
```

Description: Returns JSON-formatted response that describes the structure of a lidar packet.

- columns_per_frame: Number of measurement columns per frame. This can be 512, 1024 or 2048 depending upon the set lidar mode.
- columns_per_packet: Number of measurement blocks contained in a single lidar packet. **Note:** This is not user configurable.
- pixel_shift_by_row: Offset in terms of pixel count. Can be used to destagger image. Varies by lidar mode. Length of this array is equal to the number of channels of the sensor.
- pixels_per_column: Number of channels of the sensor.
- column_window: Index of measurement blocks that are active. Default is [0, lidar_mode-1], e.g.

[0,1023]. If there is an azimuth window set, this parameter will reflect which measurement blocks of data are within the region of interest.

- `udp_profile_lidar`: Lidar data profile format. Defaults to single return profile (`RNG19_RFL8_SIG16_NIR16`).
- `udp_profile_imu`: IMU data profile format. Default is `LEGACY`.

Note: This command only works when the sensor is in **RUNNING** status.

11.1.3 GET /api/v1/sensor/metadata/imu_data_format

To `GET` the sensor IMU data format. Valid values are `NORMAL` (Default) and `EXTENDED`.

```
GET /api/v1/sensor/metadata/imu_data_format HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 45
Content-Type: application/json
Date: Mon, 04 Mar 2024 20:07:50 GMT
Server: nginx

{
    "accel_fsr": "NORMAL",
    "gyro_fsr": "NORMAL"
}
```

Description:

- `"accel_fsr"` parameter refers to the Full Scale Range of the accelerometer.
- `"gyro_fsr"` parameter relates to the Full Scale Range of the gyroscope.

Note: User can run *DELETE /api/v1/sensor/config* command to configure `imu_data_format` back to default i.e., `NORMAL`. For more information on the IMU specifications refer to Sensor Datasheet.

11.1.4 GET /api/v1/sensor/metadata/beam_intrinsics

To `GET` the sensor beam intrinsics.

```
GET /api/v1/sensor/metadata/beam_intrinsics HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 1895
```

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```
Content-Type: application/json

{
    "beam_altitude_angles": [
        20.38, 20.12, 19.79, 19.45, 19.14, 18.85, 18.55, 18.2, 17.86, 17.58, 17.27, 16.93,
        16.58, 16.29, 15.98, 15.61, 15.27, 14.97, 14.66, 14.3, 13.96, 13.65, 13.33, 12.97,
        12.62, 12.31, 11.98, 11.63, 11.27, 10.96, 10.63, 10.26, 9.91, 9.59, 9.26, 8.89,
        8.54, 8.21, 7.87, 7.52, 7.15, 6.82, 6.47, 6.11, 5.76, 5.42, 5.08, 4.73, 4.36, 4.03,
        3.66, 3.31, 2.96, 2.62, 2.27, 1.91, 1.55, 1.22, 0.85, 0.51, 0.16, -0.2, -0.55, -0.91,
        -1.26, -1.62, -1.96, -2.3, -2.66, -3.02, -3.36, -3.72, -4.07, -4.42, -4.77, -5.11,
        -5.46, -5.82, -6.16, -6.49, -6.85, -7.21, -7.55, -7.88, -8.23, -8.59, -8.93, -9.25,
        -9.6, -9.96, -10.31, -10.63, -10.96, -11.32, -11.67, -11.97, -12.31, -12.68, -13,
        -13.32, -13.64, -14, -14.33, -14.63, -14.96, -15.31, -15.64, -15.94, -16.26,
        -16.62, -16.93, -17.22, -17.54, -17.9,  -18.22, -18.49, -18.8, -19.16, -19.47,
        -19.73, -20.04, -20.39, -20.7, -20.94, -21.25, -21.6, -21.9, -22.14
    ],
    "beam_azimuth_angles": [
        4.24, 1.41, -1.42, -4.23, 4.23, 1.41, -1.41, -4.23, 4.23, 1.41, -1.41, -4.21, 4.23,
        1.42, -1.4, -4.23, 4.24, 1.41, -1.4, -4.23, 4.24, 1.42, -1.4, -4.22, 4.23, 1.41,
        -1.41, -4.22, 4.23, 1.42, -1.4, -4.22, 4.24, 1.41, -1.4, -4.23, 4.23, 1.41, -1.41,
        -4.22, 4.23, 1.41, -1.41, -4.23, 4.23, 1.4, -1.42, -4.23, 4.23, 1.41, -1.42, -4.23,
        4.23, 1.4, -1.42, -4.24, 4.22, 1.41, -1.43, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22,
        1.4, -1.42, -4.23, 4.22, 1.4, -1.4, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22, 1.41,
        -1.41, -4.22, 4.22, 1.39, -1.42, -4.23, 4.22, 1.41, -1.41, -4.22, 4.23, 1.41,
        -1.41, -4.23, 4.23, 1.41, -1.41, -4.22, 4.23, 1.41, -1.41, -4.22, 4.22, 1.41,
        -1.41, -4.22, 4.23, 1.41, -1.4, -4.23, 4.22, 1.41, -1.41, -4.23, 4.22, 1.4, -1.41,
        -4.23, 4.22, 1.4, -1.41, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22, 1.4, -1.42, -4.23
    ],
    "beam_to_lidar_transform": [ 1, 0, 0, 15.805999755859375, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1 ],
    "lidar_origin_to_beam_origin_mm": 15.8059998
}
```

Description: Returns JSON-formatted beam altitude and azimuth offsets, in degrees. Length of arrays is equal to the number of channels in the sensor. Also returns distance between lidar origin and beam origin in mm, to be used for point cloud calculations.

11.1.5 GET /api/v1/sensor/metadata/imu_intrinsics

To GET the sensor imu intrinsics

```
GET /api/v1/sensor/metadata/imu_intrinsics HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 91
Content-Type: application/json

{
  "imu_to_sensor_transform": [1, 0, 0, 6.253, 0, 1, 0, -11.775, 0, 0, 1, 7.645, 0, 0, 0, 1]
}
```

Description: Returns JSON-formatted IMU transformation matrix needed to transform to the Sensor Coordinate Frame.

11.1.6 GET /api/v1/sensor/metadata/lidar_intrinsics

To `GET` the sensor lidar intrinsics

```
GET /api/v1/sensor/metadata/lidar_intrinsics HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 86
Content-Type: application/json

{
  "lidar_to_sensor_transform": [-1, 0, 0, 0, 0, -1, 0, 0, 0, 0, 1, 38.195, 0, 0, 0, 1]
}
```

Description: Returns JSON-formatted lidar transformation matrix needed to transform to the Sensor Coordinate Frame.

11.1.7 GET /api/v1/sensor/metadata/calibration_status

To `GET` the sensor calibration status.

```
GET /api/v1/sensor/metadata/calibration_status HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 69
Content-Type: application/json

{
"reflectivity":
  {
    "timestamp": "2022-11-18T20:31:06",
    "valid": true
  }
}
```

Description: Returns JSON formatted calibration status of the sensor reflectivity. `valid`: true/false depending on calibration status. `timestamp`: if valid is true; time at which the calibration was completed.

11.1.8 GET /api/v1/sensor/config

To GET all sensor configuration parameters.

```
GET /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 829
Content-Type: application/json
Date: Mon, 04 Mar 2024 20:14:33 GMT
Server: nginx

{
    "accel_fsr": "NORMAL",
    "azimuth_window": [
        0,
        360000
    ],
    "columns_per_packet": 16,
    "gyro_fsr": "NORMAL",
    "lidar_mode": "1024x10",
    "min_range_threshold_cm": 0,
    "multipurpose_io_mode": "OFF",
    "nmea_baud_rate": "BAUD_9600",
    "nmea_ignore_valid_char": 0,
    "nmea_in_polarity": "ACTIVE_HIGH",
    "nmea_leap_seconds": 0,
    "operating_mode": "NORMAL",
    "phase_lock_enable": false,
    "phase_lock_offset": 0,
    "return_order": "STRONGEST_TO_WEAKEST",
    "signal_multiplier": 0.25,
    "sync_pulse_in_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_angle": 360,
    "sync_pulse_out_frequency": 1,
    "sync_pulse_out_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_pulse_width": 10,
    "timestamp_mode": "TIME_FROM_INTERNAL_OSC",
    "udp_dest": "192.0.2.123",
    "udp_port_imu": 7503,
    "udp_port_lidar": 7502,
    "udp_profile_imu": "LEGACY",
    "udp_profile_lidar": "RNG19_RFL8_SIG16_NIR16_DUAL"
}
```

Description: Please refer to *Description* section for a detailed description of sensor configurable parameters.

11.1.9 POST /api/v1/sensor/config - Multiple configuration parameters

Multiple configuration parameters can be set at one time using this command. All of the specified sensor configuration parameters must be set successfully for the POST request to succeed, otherwise none of the specified sensor configuration parameters will be configured, and an error will be returned.

Note: After POST api/v1/sensor/config request is received successfully, the sensor will reinitialize automatically to make the new configuration active, and the config settings are persisted across power cycles.

Example 1

```
POST /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123

{
    "accel_fsr": "NORMAL",
    "azimuth_window": [
        0,
        360000
    ],
    "columns_per_packet": 16,
    "gyro_fsr": "NORMAL",
    "lidar_mode": "1024x10",
    "min_range_threshold_cm": 0,
    "multipurpose_io_mode": "OFF",
    "nmea_baud_rate": "BAUD_9600",
    "nmea_ignore_valid_char": 0,
    "nmea_in_polarity": "ACTIVE_HIGH",
    "nmea_leap_seconds": 0,
    "operating_mode": "NORMAL",
    "phase_lock_enable": false,
    "phase_lock_offset": 0,
    "return_order": "STRONGEST_TO_WEAKEST",
    "signal_multiplier": 0.25,
    "sync_pulse_in_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_angle": 360,
    "sync_pulse_out_frequency": 1,
    "sync_pulse_out_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_pulse_width": 10,
    "timestamp_mode": "TIME_FROM_INTERNAL_OSC",
    "udp_dest": "10.34.24.163",
    "udp_port_imu": 7503,
    "udp_port_lidar": 7502,
    "udp_profile_imu": "LEGACY",
    "udp_profile_lidar": "RNG15_RFL8_NIR8"
}
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:37:41 GMT
Server: nginx
```

To verify, the user can run *GET /api/v1/sensor/config* after POST command:


```
{
    "accel_fsr": "NORMAL",
    "azimuth_window": [
        0,
        360000
    ],
    "columns_per_packet": 16,
    "gyro_fsr": "NORMAL",
    "lidar_mode": "1024x10",
    "min_range_threshold_cm": 0,
    "multipurpose_io_mode": "OFF",
    "nmea_baud_rate": "BAUD_9600",
    "nmea_ignore_valid_char": 0,
    "nmea_in_polarity": "ACTIVE_HIGH",
    "nmea_leap_seconds": 0,
    "operating_mode": "NORMAL",
    "phase_lock_enable": false,
    "phase_lock_offset": 0,
    "return_order": "STRONGEST_TO_WEAKEST",
    "signal_multiplier": 0.25,
    "sync_pulse_in_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_angle": 360,
    "sync_pulse_out_frequency": 1,
    "sync_pulse_out_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_pulse_width": 10,
    "timestamp_mode": "TIME_FROM_INTERNAL_OSC",
    "udp_dest": "10.34.24.163",
    "udp_port_imu": 7503,
    "udp_port_lidar": 7502,
    "udp_profile_imu": "LEGACY",
    "udp_profile_lidar": "RNG15_RFL8_NIR8"
}
```

11.1.10 GET /api/v1/sensor/config/operating_mode

Any configuration parameter can be queried by using a URI with the format `/api/v1/sensor/config/parameter_name`.

Example 1

```
GET /api/v1/sensor/config/operating_mode HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:37:41 GMT
Server: nginx

"NORMAL"
```

11.1.11 POST /api/v1/sensor/config/operating_mode

Any configuration parameter can be set by using a URI with the format `/api/v1/sensor/config/parameter_name`. In this example the operating mode is changed.

Note: After a POST api/v1/sensor/config request is received successfully, the sensor will reinitialize automatically to make the new configuration active, and the config settings are persisted across power cycles.

Example 1

```
POST /api/v1/sensor/config/operating_mode HTTP/1.1
Host: 192.0.2.123

"STANDBY"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:37:41 GMT
Server: nginx
```

11.1.12 DELETE /api/v1/sensor/config

Note: This API command resets all sensor configuration to the default state, including static IP address settings, and restarts the sensor.

```
DELETE /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 10 Jul 2023 17:12:47 GMT
Server: nginx
```

11.1.13 GET /api/v1/sensor/metadata

To GET the sensor metadata information.

```
GET /api/v1/sensor/metadata HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 4009
Content-Type: application/json

{
    "beam_intrinsics": {
        "beam_altitude_angles": [
            20.38, 20.12, 19.79, 19.45, 19.14, 18.85, 18.55, 18.2, 17.86, 17.58, 17.27, 16.93,
            16.58, 16.29, 15.98, 15.61, 15.27, 14.97, 14.66, 14.3, 13.96, 13.65, 13.33, 12.97,
            12.62, 12.31, 11.98, 11.63, 11.27, 10.96, 10.63, 10.26, 9.91, 9.59, 9.26, 8.89,
            8.54, 8.21, 7.87, 7.52, 7.15, 6.82, 6.47, 6.11, 5.76, 5.42, 5.08, 4.73, 4.36, 4.03,
            3.66, 3.31, 2.96, 2.62, 2.27, 1.91, 1.55, 1.22, 0.85, 0.51, 0.16, -0.2, -0.55, -0.91,
            -1.26, -1.62, -1.96, -2.3, -2.66, -3.02, -3.36, -3.72, -4.07, -4.42, -4.77, -5.11,
            -5.46, -5.82, -6.16, -6.49, -6.85, -7.21, -7.55, -7.88, -8.23, -8.59, -8.93, -9.25,
            -9.6, -9.96, -10.31, -10.63, -10.96, -11.32, -11.67, -11.97, -12.31, -12.68, -13,
            -13.32, -13.64, -14, -14.33, -14.63, -14.96, -15.31, -15.64, -15.94, -16.26,
            -16.62, -16.93, -17.22, -17.54, -17.9,  -18.22, -18.49, -18.8, -19.16, -19.47,
            -19.73, -20.04, -20.39, -20.7, -20.94, -21.25, -21.6, -21.9, -22.14
        ],
        "beam_azimuth_angles": [
            4.24, 1.41, -1.42, -4.23, 4.23, 1.41, -1.41, -4.23, 4.23, 1.41, -1.41, -4.21, 4.23,
            1.42, -1.4, -4.23, 4.24, 1.41, -1.4, -4.23, 4.24, 1.42, -1.4, -4.22, 4.23, 1.41,
            -1.41, -4.22, 4.23, 1.42, -1.4, -4.22, 4.24, 1.41, -1.4, -4.23, 4.23, 1.41, -1.41,
            -4.22, 4.23, 1.41, -1.41, -4.23, 4.23, 1.4, -1.42, -4.23, 4.23, 1.41, -1.42, -4.23,
            4.23, 1.4, -1.42, -4.24, 4.22, 1.41, -1.43, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22,
            1.4, -1.42, -4.23, 4.22, 1.4, -1.4, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22, 1.41,
            -1.41, -4.22, 4.22, 1.39, -1.42, -4.23, 4.22, 1.41, -1.41, -4.22, 4.23, 1.41,
            -1.41, -4.23, 4.23, 1.41, -1.41, -4.22, 4.23, 1.41, -1.41, -4.22, 4.22, 1.41,
            -1.41, -4.22, 4.23, 1.41, -1.4, -4.23, 4.22, 1.41, -1.41, -4.23, 4.22, 1.4, -1.41,
            -4.23, 4.22, 1.4, -1.41, -4.24, 4.22, 1.4, -1.42, -4.24, 4.22, 1.4, -1.42, -4.23
```

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```
        ],
        "beam_to_lidar_transform": [ 1, 0, 0, 15.805999755859375, 0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1 ],
        "lidar_origin_to_beam_origin_mm": 15.8059998
    }
    "calibration_status": {
        "reflectivity": {
            "timestamp": "2022-11-18T20:31:06",
            "valid": true
        }
    },
    "config_params": {
    "azimuth_window": [
        0,
        360000
    ],
    "columns_per_packet": 16,
    "lidar_mode": "1024x10",
    "multipurpose_io_mode": "OFF",
    "nmea_baud_rate": "BAUD_9600",
    "nmea_ignore_valid_char": 0,
    "nmea_in_polarity": "ACTIVE_HIGH",
    "nmea_leap_seconds": 0,
    "operating_mode": "NORMAL",
    "phase_lock_enable": false,
    "phase_lock_offset": 0,
    "signal_multiplier": 1,
    "sync_pulse_in_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_angle": 360,
    "sync_pulse_out_frequency": 1,
    "sync_pulse_out_polarity": "ACTIVE_HIGH",
    "sync_pulse_out_pulse_width": 10,
    "timestamp_mode": "TIME_FROM_INTERNAL_OSC",
    "udp_dest": "169.254.225.4",
    "udp_port_imu": 7503,
    "udp_port_lidar": 7502,
    "udp_profile_imu": "LEGACY",
    "udp_profile_lidar": "RNG19_RFL8_SIG16_NIR16_DUAL"
},
    "imu_intrinsics": {
        "imu_to_sensor_transform": [
            1, 0, 0, 6.253, 0, 1, 0, -11.775, 0, 0, 1, 7.645, 0, 0, 0, 1
        ]
    },
    "lidar_data_format": {
        "column_window": [
            0,
            1023
        ],
        "columns_per_frame": 1024,
        "columns_per_packet": 16,
        "pixel_shift_by_row": [12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
```


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```
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12, 12, 4, -4, -12, 12, 4, -4,
            -12, 12, 4, -4, -12, 12, 4, -4, -12, 12,
            4, -4, -12
        ],
        "pixels_per_column": 128,
        "udp_profile_imu": "LEGACY",
        "udp_profile_lidar": "RNG19_RFL8_SIG16_NIR16_DUAL"
    },

    "lidar_intrinsics": {
        "lidar_to_sensor_transform": [
            -1, 0, 0, 0, 0, -1, 0, 0, 0, 0, 1, 38.195, 0, 0, 0, 1
        ]
    },
    "sensor_info": {
        "build_date": "2023-1-15T15:56:07Z",
        "build_rev": "v3.0.0",
        "image_rev": "ousteros-image-prod-bootes-v3.0.0+0123456789",
        "initialization_id": 390079,
        "prod_line": "OS-1-128",
        "prod_pn": "860-105010-07",
        "prod_sn": "992244000006",
        "status": "RUNNING"
    }
}
```


11.2 User Editable Data

A user configurable data field is made available in firmware v2.5 and later.

This field can be used for a number of purposes such as storing specific information about the sensor, qualifying a sensor, calibration data, or any other information. Please refer to User Data Field section in the Firmware User Manual for more information.

Additional Information:

- **Valid values for UED:** Empty string or string containing non-binary ASCII and/or Unicode characters.
- **Size limit for UED string:** 128KB with 1KB = 1024bytes (Total = 131,072 bytes)

11.2.1 GET /api/v1/user/data

Retrieve the current value of 'user-data-field', "" is returned by default.

```
GET /api/v1/user/data HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 15
Content-Type: application/json
Date: Thu, 01 Jan 1970 01:40:23 GMT
Server: nginx

""
```

11.2.2 PUT /api/v1/user/data

Puts a "content" in the `user data field`. In the example shown below we will use **"Ouster sensor"** as the content to be put in the `user data field`.

Default `data policy` for `PUT` request on user editable data is `clear_on_config_delete`. If you would like to persist the value in the data field please see *PUT /api/v1/user/data?policy=keep_on_config_delete*.

```
PUT /api/v1/user/data HTTP/1.1
Host: 192.0.2.123

"Ouster sensor"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 01:39:16 GMT
Server: nginx
```

To verify: Run *GET /api/v1/user/data*

```
GET /api/v1/user/data HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 15
Content-Type: application/json
Date: Thu, 01 Jan 1970 01:05:14 GMT
Server: nginx

"Ouster sensor"
```

11.2.3 DELETE /api/v1/user/data

Deletes the current value ("content") in the 'user-data-field'.

```
DELETE /api/v1/user/data HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 01:05:32 GMT
Server: nginx
```

To verify: Run *GET /api/v1/user/data*

```
GET /api/v1/user/data HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 2
Content-Type: application/json
Date: Thu, 01 Jan 1970 01:05:14 GMT
Server: nginx

""
```

11.2.4 Optional Parameters - data policy

The policy key maps to the active policy as applied with `PUT api/v1/user/data?policy=<policy_str>`.

`<policy_str>` have the following options available:

- `clear_on_config_delete` by default
- `keep_on_config_delete`

Note: `Data policy` has no effect on the content of the User Editable Data field.

PUT /api/v1/user/data?policy=clear_on_config_delete

```
PUT /api/v1/user/data?policy=clear_on_config_delete HTTP/1.1
Host: 192.0.2.123

"Ouster sensor"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:43:08 GMT
Server: nginx
```

PUT /api/v1/user/data?policy=keep_on_config_delete

When `keep_on_config_delete` has been applied, the data in the user editable data field is persisted regardless of any sensor configuration resets or shutdown. If the user needs to reset this field then please run *DELETE /api/v1/user/data*.

```
PUT /api/v1/user/data?policy=keep_on_config_delete HTTP/1.1
Host: 192.0.2.123

"Ouster Sensor"
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 00:43:08 GMT
Server: nginx
```

11.2.5 Optional Parameters - include_metadata

Same as nominal `GET` but returns a JSON dictionary of the form `{ "value": str, "policy": str }` where the value key maps to the nominal value returned by `GET` with no arguments.

Note: `include_metadata` has no effect on the User Editable Data field.

This feature lets user to query the user editable data field to get `policy` and `value` when `include_metadata` is set to `true`/`1` and only the `value` when `include_matadata` is set to `false`/`0`

GET /api/v1/user/data?include_metadata=true

Returns a JSON dictionary of the form { “value”: str, “policy”: str }.

```
GET /api/v1/user/data?include_metadata=true HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 61
Content-Type: application/json
Date: Thu, 01 Jan 1970 00:20:48 GMT
Server: nginx

{
    "policy": "keep_on_config_delete",
    "value": "ouster sensor"
}
```

GET /api/v1/user/data?include_metadata=false

Returns only the value of the user data.

```
GET /api/v1/user/data?include_metadata=false HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 15
Content-Type: application/json
Date: Thu, 01 Jan 1970 00:21:41 GMT
Server: nginx

"Ouster sensor"
```

11.3 System

11.3.1 POST /api/v1/system/restart

Restarts the sensor. This command is present in firmware version v3.1 and newer.

Warning: Please contact Ouster support if you find the need to use this command.

```
POST /api/v1/system/restart HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 14 Mar 2024 20:33:01 GMT
Server: nginx
```

11.3.2 GET /api/v1/system/firmware

To GET the firmware version of the sensor.

```
GET /api/v1/system/firmware HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 82
Content-Type: application/json
Date: Thu, 01 Jan 1970 00:27:54 GMT
Server: nginx

{
    "commit_pending": false,
    "fw": "ousteros-image-prod-aries-v2.5.2+20230714195410"
}
```

>json string fw Running firmware image name and version.

11.3.3 POST /api/v1/system/firmware

To update the sensor firmware.

Example:

```
curl -vH 'content-type:  application/octet-stream' --data-binary @../../Downloads/ousteros-image-prod-aries-v2.5.x+20230607131746.staging.img http://192.0.2.123/api/v1/system/firmware
```

Response:

```
*   Trying 192.0.2.123:80...
* TCP_NODELAY set
* Connected to 192.0.2.123 (192.0.2.123) port 80 (#0)
> POST /api/v1/system/firmware HTTP/1.1
> Host: 192.0.2.123
> User-Agent: curl/7.68.0
> Accept: */*
> content-type: application/octet-stream
> Content-Length: 42755180
> Expect: 100-continue
>
* Mark bundle as not supporting multiuse
< HTTP/1.1 100 Continue
* We are completely uploaded and fine
* Mark bundle as not supporting multiuse
< HTTP/1.1 204 No Content
< Server: nginx
< Date: Wed, 14 Jun 2023 23:38:08 GMT
< Connection: keep-alive
<
* Connection #0 to host 192.0.2.123 left intact
```

11.3.4 GET /api/v1/system/network

To `GET` the system network configuration.

```
GET /api/v1/system/network HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 256
Content-Type: application/json

{
    "carrier": true,
    "duplex": "full",
    "ethaddr": "bc:0f:a7:00:84:17",
    "hostname": "192.0.2.123",
    "ipv4": {
        "link_local": "192.0.2.123/16",
        "override": null
    },
    "ipv6": {
        "link_local": "fe80::be0f:a7ff:fe00:8417/64"
    },
    "speed": 1000,
    "speed_override": null
}
```

- **>json boolean carrier:** State of Ethernet link, `true` when physical layer is connected.
- **>json string duplex:** Duplex mode of Ethernet link, `half` or `full`.
- **>json string ethaddr:** Ethernet hardware (MAC) address.
- **>json string hostname:** Hostname of the sensor, also used when requesting *DHCP* address and registering mDNS hostname.
- **>json object ipv4:** See *ipv4 object*
- **>json string ipv6.link_local:** Link-local IPv6 address.
- **>json integer speed:** Ethernet physical layer speed in Mbps, should be 1000 Mbps.

11.3.5 GET /api/v1/system/network/ipv4

To `GET` the IPv4 network configuration.

```
GET /api/v1/system/network/ipv4 HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 53
Content-Type: application/json

```

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```
{
    "link_local": "192.0.2.123/16",
    "override": null
}
```

- **>json string addr:** Current global or private IPv4 address.
- **>json string link_local:** Link-local IPv4 address.
- **>json string override:** Static IP override value, this should match `addr`. This value will be `null` when unset and operating in *DHCP* or *link-local* modes.

11.3.6 GET /api/v1/system/network/ipv4/override

To `GET` the current IPv4 static IP address override.

```
GET /api/v1/system/network/ipv4/override HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 4
Content-Type: application/json

null
```

- **>json string** Static IP override value, this should match `addr`. This value will be `null` when unset and operating in *DHCP* mode.

11.3.7 PUT /api/v1/system/network/ipv4/override

To override the default dynamic behavior and set a static IP address. Only a valid Unicast IPv4 address can be specified when using `PUT` command.

Note: The sensor will reset the network configuration after a short sub second delay (to allow for the HTTP response to be sent). After this delay the sensor will only be reachable on the newly set IPv4 address.

The sensor needs to be reachable either by *link-local* or dynamic *DHCP* configuration or by an existing static IP override from the host reconfiguring the sensor. The sensor may be reset back to using DHCP by `DELETE` ing the sensor configuration.

Warning: If an unreachable network address is set, the sensor will become unreachable. Tools such as avahi-browse, dns-sd, or mDNS browser can help with finding a sensor on a network. Static IP override should only be used in special use cases. DHCP configuration is recommended where possible.

```
PUT /api/v1/system/network/ipv4/override HTTP/1.1
Host: 192.0.2.123

"192.0.2.231"
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 17
Content-Type: application/json
Date: Thu, 30 Mar 2023 04:30:30 GMT
Server: nginx

"192.0.2.231"
```

- **<json string:** Static IP override value with subnet mask
- **>json string:** Static IP override value that system will set after a short delay.

Note: Sensor can be accessed on the sensor's self-assigned link-local IPv4 or IPv6 addresses, in case the sensor becomes unreachable on the configured network due to a misconfiguration. To discover the self-assigned link-local IPv4 or IPv6 addresses for a sensor one can use a network sniffer (such as wireshark) on the same network segment as the sensor.

11.3.8 DELETE /api/v1/system/network/ipv4/override

To delete the static IP override value and return to dynamic configuration (*DHCP*).

Note: The sensor will reset the network configuration after a short sub second delay (to allow for the HTTP response to be sent). After this delay the sensor will only be reachable on the newly set IPv4 address.

The sensor may be unreachable for several seconds while a *link-local* lease is obtained from the network or client machine.

```
DELETE /api/v1/system/network/ipv4/override HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Thu, 01 Jan 1970 19:12:15 GMT
Server: nginx
```

11.3.9 GET /api/v1/system/network/speed_override

Two options `null` (default) and `100`.

Note: Only valid for sensors with automotive ethernet (T1).

Example

```
GET /api/v1/system/network/speed_override HTTP/1.1
Content-Type: application/json
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 4
Content-Type: application/json
Date: Thu, 28 Apr 2022 17:48:51 GMT
Server: nginx

null
```

11.3.10 PUT /api/v1/system/network/speed_override

Note: Only valid for sensors with automotive ethernet (T1).

Warning: Only run this command if you have the ability to configure your networking hardware between 1000BASE-T1 and 100BASE-T1. If you do not have the configuration option available, you will no longer be able to communicate with the sensor. Please refer to an Example 100Base-T1 Connector.

Two options **1000** (`default`) and **100**. However, user can only use `PUT` command to set speed-override to **100**. In order to revert back to **1000** (`default`), please run the *DELETE /api/v1/system/network/speed_override*.

Example

```
PUT /api/v1/system/network/speed_override HTTP/1.1
Content-Type: application/json
Host: 192.0.2.123

100
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 3
Content-Type: application/json
```

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```
Date: Tue, 18 Jul 2023 19:34:27 GMT
Server: nginx

100
```

11.3.11 DELETE /api/v1/system/network/speed_override

Note: Only valid for sensors with automotive ethernet (T1).

To reset it back to `default` i.e.., `1000`

```
DELETE /api/v1/system/network/speed_override HTTP/1.1
Content-Type: application/json
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Tue, 18 Jul 2023 19:37:52 GMT
Server: nginx
```

11.4 Time

11.4.1 GET /api/v1/time

To `GET` the system time configuration for all timing components of the sensor.

```
GET /api/v1/time HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 2484
Content-Type: application/json

{
    "ptp": {
        "current_data_set": {
            "mean_path_delay": 0.0,
            "offset_from_master": 0.0,
            "steps_removed": 0
        },
        "parent_data_set": {
            "gm_clock_accuracy": 254,
            "gm_clock_class": 255,
            "gm_offset_scaled_log_variance": 65535,
            "grandmaster_identity": "bc0fa7.fffe.008417",
            "grandmaster_priority1": 128,
```

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```
            "grandmaster_priority2": 128,
            "observed_parent_clock_phase_change_rate": 2147483647,
            "observed_parent_offset_scaled_log_variance": 65535,
            "parent_port_identity": "bc0fa7.fffe.008417-0",
            "parent_stats": 0
        },
        "port_data_set": {
            "announce_receipt_timeout": 3,
            "delay_mechanism": 1,
            "log_announce_interval": 1,
            "log_min_delay_req_interval": 0,
            "log_min_pdelay_req_interval": 0,
            "log_sync_interval": 0,
            "peer_mean_path_delay": 0,
            "port_identity": "bc0fa7.fffe.008417-1",
            "port_state": "LISTENING",
            "version_number": 2
        },
        "profile": "default",
        "time_properties_data_set": {
            "current_utc_offset": 37,
            "current_utc_offset_valid": 0,
            "frequency_traceable": 0,
            "leap59": 0,
            "leap61": 0,
            "ptp_timescale": 1,
            "time_source": 160,
            "time_traceable": 0
        },
        "time_status_np": {
            "cumulative_scaled_rate_offset": 0.0,
            "gm_identity": "bc0fa7.fffe.008417",
            "gm_present": false,
            "gm_time_base_indicator": 0,
            "ingress_time": 0,
            "last_gm_phase_change": "0x0000'0000000000000000.0000",
            "master_offset": 0,
            "scaled_last_gm_phase_change": 0
        }
    },
    "sensor": {
        "multipurpose_io": {
            "mode": "OFF",
            "nmea": {
                "baud_rate": "BAUD_9600",
                "diagnostics": {
                    "decoding": {
                        "date_decoded_count": 0,
                        "last_read_message": "",
                        "not_valid_count": 0,
                        "utc_decoded_count": 0
                    },
                    "io_checks": {
                        "bit_count": 1,
```


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```
                    "bit_count_unfiltered": 0,
                    "char_count": 0,
                    "start_char_count": 0
                }
            },
            "ignore_valid_char": 0,
            "leap_seconds": 0,
            "locked": 0,
            "polarity": "ACTIVE_HIGH"
        },
        "sync_pulse_out": {
            "angle_deg": 360,
            "frequency_hz": 1,
            "polarity": "ACTIVE_HIGH",
            "pulse_width_ms": 10
        }
    },
    "sync_pulse_in": {
        "diagnostics": {
            "count": 1,
            "count_unfiltered": 0,
            "last_period_nsec": 0
        },
        "locked": 0,
        "polarity": "ACTIVE_HIGH"
    },
    "timestamp": {
        "mode": "TIME_FROM_INTERNAL_OSC",
        "time": 297.397987312,
        "time_options": {
            "internal_osc": 297,
            "ptp_1588": 1651197874,
            "sync_pulse_in": 1
        }
    }
},
"system": {
    "monotonic": 30131.822811617,
    "realtime": 1651197874.3271277,
    "tracking": {
        "frequency": -9.558,
        "last_offset": 0.0,
        "leap_status": "not synchronised",
        "ref_time_utc": 0.0,
        "reference_id": "00000000",
        "remote_host": "",
        "residual_frequency": 0.0,
        "rms_offset": 0.0,
        "root_delay": 1.0,
        "root_dispersion": 1.0,
        "skew": 0.0,
        "stratum": 0,
        "system_time_offset": 1e-09,
        "update_interval": 0.0
```


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```
        }
    }
}
```

- **>json string:** See sub objects for details.

11.4.2 GET /api/v1/time/sensor

To GET the sensor time information.

```
GET /api/v1/time/sensor HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 775
Content-Type: application/json

{
    "multipurpose_io": {
        "mode": "OFF",
        "nmea": {
            "baud_rate": "BAUD_9600",
            "diagnostics": {
                "decoding": {
                    "date_decoded_count": 0,
                    "last_read_message": "",
                    "not_valid_count": 0,
                    "utc_decoded_count": 0
                },
                "io_checks": {
                    "bit_count": 1,
                    "bit_count_unfiltered": 0,
                    "char_count": 0,
                    "start_char_count": 0
                }
            },
            "ignore_valid_char": 0,
            "leap_seconds": 0,
            "locked": 0,
            "polarity": "ACTIVE_HIGH"
        },
        "sync_pulse_out": {
            "angle_deg": 360,
            "frequency_hz": 1,
            "polarity": "ACTIVE_HIGH",
            "pulse_width_ms": 10
        }
    },
    "sync_pulse_in": {
        "diagnostics": {
            "count": 1,
```

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```
            "count_unfiltered": 0,
            "last_period_nsec": 0
        },
        "locked": 0,
        "polarity": "ACTIVE_HIGH"
    },
    "timestamp": {
        "mode": "TIME_FROM_INTERNAL_OSC",
        "time": 376.510445056,
        "time_options": {
            "internal_osc": 376,
            "ptp_1588": 1651197953,
            "sync_pulse_in": 1
        }
    }
}
```


- **Description:** Returns JSON-formatted sensor timing configuration and status of udp `timestamp`, `sync_pulse_in`, and `multipurpose_io`. For more information on these parameters refer to the *GET /api/v1/time* HTTP API command.

11.4.3 GET /api/v1/time/system

To `GET` the operating system time status. These values relate to the sensor operating system clocks, and not clocks related to hardware timestamp data from the lidar sensor.

```
GET /api/v1/time/system HTTP/1.1
Host: 192.0.2.123
```


```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 389
Content-Type: application/json

{
    "monotonic": 30348.898799855,
    "realtime": 1651198091.4031146,
    "tracking": {
        "frequency": -9.558,
        "last_offset": 0.0,
        "leap_status": "not synchronised",
        "ref_time_utc": 0.0,
        "reference_id": "00000000",
        "remote_host": "",
        "residual_frequency": 0.0,
        "rms_offset": 0.0,
        "root_delay": 1.0,
        "root_dispersion": 1.0,
        "skew": 0.0,
        "stratum": 0,
        "system_time_offset": 3e-09,
        "update_interval": 0.0
```


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```
    }
}
```

- **>json float monotonic:** Monotonic time of operating system. This timestamp never counts backwards and is the time since boot in seconds.
- **>json float realtime:** Time in seconds since the Unix epoch, should match wall time if synchronized with an external time source.
- **>json object tracking:** Operating system time synchronization tracking status. See chronyc tracking documentation for more information.
- **System `tracking` fields of interest:**
- **rms_offset:** Long-term average of the offset value.
- **system_time_offset:** Time delta (in seconds) between the estimate of the operating system time and the current true time.
- **last_offset:** Estimated local offset on the last clock update.
- **ref_time_utc:** UTC Time at which the last measurement from the reference source was processed.
- **remote_host:** This is either `ptp` if the system is synchronizing to a *PTP* time source or the address of a remote NTP server the system has selected if the sensor is connected to the Internet.

11.4.4 GET /api/v1/time/ptp

To `GET` the status of the *PTP* time synchronization daemon.

Note: See the IEEE 1588-2008 standard for more details on the standard management messages.

```
GET /api/v1/time/ptp HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 1287
Content-Type: application/json

{
    "current_data_set": {
        "mean_path_delay": 0.0,
        "offset_from_master": 0.0,
        "steps_removed": 0
    },
    "parent_data_set": {
        "gm_clock_accuracy": 254,
        "gm_clock_class": 255,
        "gm_offset_scaled_log_variance": 65535,
        "grandmaster_identity": "bc0fa7.fffe.008417",
```

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```
        "grandmaster_priority1": 128,
        "grandmaster_priority2": 128,
        "observed_parent_clock_phase_change_rate": 2147483647,
        "observed_parent_offset_scaled_log_variance": 65535,
        "parent_port_identity": "bc0fa7.fffe.008417-0",
        "parent_stats": 0
    },
    "port_data_set": {
        "announce_receipt_timeout": 3,
        "delay_mechanism": 1,
        "log_announce_interval": 1,
        "log_min_delay_req_interval": 0,
        "log_min_pdelay_req_interval": 0,
        "log_sync_interval": 0,
        "peer_mean_path_delay": 0,
        "port_identity": "bc0fa7.fffe.008417-1",
        "port_state": "LISTENING",
        "version_number": 2
    },
    "profile": "default",
    "time_properties_data_set": {
        "current_utc_offset": 37,
        "current_utc_offset_valid": 0,
        "frequency_traceable": 0,
        "leap59": 0,
        "leap61": 0,
        "ptp_timescale": 1,
        "time_source": 160,
        "time_traceable": 0
    },
    "time_status_np": {
        "cumulative_scaled_rate_offset": 0.0,
        "gm_identity": "bc0fa7.fffe.008417",
        "gm_present": false,
        "gm_time_base_indicator": 0,
        "ingress_time": 0,
        "last_gm_phase_change": "0x0000'0000000000000000.0000",
        "master_offset": 0,
        "scaled_last_gm_phase_change": 0
    }
}
```


- **>json object current_data_set:** Result of the PMC `GET CURRENT_DATA_SET` command.
- **>json object parent_data_set:** Result of the PMC `GET PARENT_DATA_SET` command.
- **>json object port_data_set:** Result of the PMC `GET PORT_DATA_SET` command.
- **>json object time_properties_data_set:** Result of the PMC `GET TIME_PROPERTIES_DATA_SET` command.
- **>json object time_status_np:** Result of the PMC `GET TIME_STATUS_NP` command. This is a linuxptp non-portable command.

Fields of interest:

- **current_data_set.offset_from_master:** Offset from master time source in nanoseconds as calculated during the last update from master.
- **parent_data_set.grandmaster_identity:** This should match the local grandmaster clock. If this displays the sensor's clock identity (derived from Ethernet hardware address) then this indicates the sensor is not properly synchronized to a grandmaster.
- **parent_data_set:** Various information about the selected master clock.
- **port_data_set.port_state:** This value will be `SLAVE` when a remote master clock is selected. See `parent_data_set` for selected master clock.
- **port_data_set:** Local sensor *PTP* configuration values. Grandmaster clock needs to match these for proper time synchronization.
- **time_properties_data_set:** *PTP* properties as given by master clock.
- **time_status_np.gm_identity:** Selected grandmaster clock identity.
- **time_status_np.gm_present:** True when grandmaster has been detected. This may stay true even if grandmaster goes off-line. Use `port_data_set.port_state` to determine up-to-date synchronization status. When this is false then the local clock is selected.
- **time_status_np.ingress_time:** Indicates when the last *PTP* message was received. Units are in nanoseconds.
- **time_status_np:** Linux *PTP* specific diagnostic values. The Red Hat manual provides some more information on these fields

11.4.5 GET /api/v1/time/ptp/profile

To `GET` the active PTP profile of the Ouster sensor.

```
GET /api/v1/time/ptp/profile HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 9
Content-Type: application/json

"default"
```

- **>json string:** Active PTP profile.

11.4.6 PUT /api/v1/time/ptp/profile

To change the PTP profile of the Ouster sensor.

```
PUT /api/v1/time/ptp/profile HTTP/1.1
Content-Type: application/json
Host: 192.0.2.123

"gptp"
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 6
Content-Type: application/json
Date: Thu, 28 Apr 2022 18:11:36 GMT
Server: nginx

"gptp"
```

<json string: PTP profile to be activated, valid options are `""`, `"default"`, `"gptp"`, `"automotive-slave"` and `"default-l2-relaxed"`.

Note: `""` and `"default"` are the same.

11.5 Alerts, Diagnostics and Telemetry

In order to correlate the alerts with sensor telemetry data, the realtime attribute that is returned in the HTTP API `/api/v1/time/system` call should be the time reference to use in such tools when timestamping telemetry data, since that will always be the time that is used by the sensor to timestamp the alerts, irrespective of the actual timing source, such as: `TIME_FROM_INTERNAL_OSC`, `TIME_FROM_SYNC_PULSE_IN`, or `TIME_FROM_PTP_1588`. This should be sufficient for tools and applications that do not require the time to have an absolute nature, i.e. where only relative time is needed.

11.5.1 GET /api/v1/sensor/alerts

To `GET` the sensor alerts.

```
GET /api/v1/sensor/alerts HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 1983
Content-Type: application/json

{
    "active": [
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 1,
            "id": "0x01000015",
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided lidar data port;
                    check that udp_dest and udp_port_lidar configured on the sensor matches
                    client IP and port. This Alert may occur on sensor startup if the
                    client is not listening at that time.",
            "msg_verbose": "Failed to send lidar UDP data to destination host 169.254.225.4:7502",
```

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```
            "realtime": "1651197616274601728"
        },
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 0,
            "id": "0x01000018",
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided IMU data port;
                    check that udp_dest and udp_port_imu configured on the sensor matches
                    client IP and port. This Alert may occur on sensor startup if the
                    client is not listening at that time.",
            "msg_verbose": "Failed to send imu UDP data to destination host 169.254.225.4:7503",
            "realtime": "1651197615284695040"
        }
    ],
    "log": [
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 0,
            "id": "0x01000018",
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided IMU data port;
                    check that udp_dest and udp_port_imu configured on the sensor matches
                    client IP and port. This Alert may occur on sensor startup if the
                    client is not listening at that time.",
            "msg_verbose": "Failed to send imu UDP data to destination host 169.254.225.4:7503",
            "realtime": "1651197615284695040"
        },
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 1,
            "id": "0x01000015",
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided lidar data port;
                    check that udp_dest and udp_port_lidar configured on the sensor matches
                    client IP and port. This Alert may occur on sensor startup if the
                    client is not listening at that time.",
            "msg_verbose": "Failed to send lidar UDP data to destination host 169.254.225.4:7502",
            "realtime": "1651197616274601728"
        }
    ],
    "next_cursor": 2
}
```


Description: Returns JSON-formatted sensor diagnostic information.

Two lists will be returned, an **active** list and a **log** list. The **active** list contains a list of currently active events. The number of events in the active event list is unlimited.

The **log** list will contain all alert trigger and clear events. An alert-clear event has the same attributes and values as its corresponding trigger event, apart from the realtime and **cursor** attributes which will

have increased, since an alert-clear event will always be received after an alert-trigger event. The **log** list has a length limit of 32 events in the form of a FIFO (First in First Out) queue. When the **log** list length limit is reached and a new event is added the oldest event is deleted.

In addition to the **active** and **log** lists, `GET /api/v1/sensor/alerts` also returns a **next_cursor** field. Every alert event has a **cursor** attribute, which increments for every alert event logged. This can be used to track the alert activity that has been viewed and reduce message bandwidth. To do this, users are recommended to save the **next_cursor** field when calling `GET /api/v1/sensor/alerts` and then use that value as the `cursor` argument on the next `GET /api/v1/sensor/alerts` call to fetch only new **log** entries.

A valid value for **mode** is either `summary` or `default`.

Additional Information:

The **cursor** will wrap at 2^32 entries. It is important to understand the behavior during the wrap case, since this may lead to some unexpected consequences:

- If cursor < (next_cursor - 32) % 2^32 then some entries may be filtered. For instance if **cursor** =0 and **next_cursor** =0 no entries will be reported immediately after **cursor** wrap, even though the log contains 32 entries, where submitting **cursor** =4294967264 (next_cursor - 32) % 2^32 will return all logged values.
- If cursor > next_cursor all 32 entries will be reported.

The recommended approach to using the interface is to always base queries on the previous value of **next_cursor**.

Alerts Example

Valid uses of GET /api/v1/sensor/alerts:

- Example: Calling alerts with **cursor** =1
  - *GET /api/v1/sensor/alerts?cursor=1*
- Example: Calling alerts with **mode** =summary
  - *GET /api/v1/sensor/alerts?mode=summary*
- Example: Calling alerts with **cursor** =2 and **mode** =summary
  - *GET /api/v1/sensor/alerts?cursor=2&mode=summary*

Note: When utilizing HTTP Endpoints, the sequence in which the cursor and mode arguments are provided for the `GET /api/v1/sensor/alerts` command is inconsequential.

The alerts reported have the following format:

```
{
   "category": "Category of the alert: e.g. OVERTEMP, UDP_TRANSMISSION",
   "level": "Level of alert: e.g. NOTICE, WARNING, ERROR",
   "realtime": "The timestamp of the alert in nanoseconds",
   "active": "Whether the alert is active or not: <true/false>",
   "msg": "A description of the alert",
   "cursor": "The sequential number of the alert, starting from 0 counting up",
   "id": "The hexadecimal identification code of the alert: e.g. 0x01000017",
   "msg_verbose": "Any additional verbose description that the alert may present"
}
```

11.5.2 GET /api/v1/sensor/alerts?cursor=1

To `GET` the sensor alerts with cursor=1.

```
GET /api/v1/sensor/alerts?cursor=1 HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 43
Content-Type: application/json
Date: Thu, 21 Mar 2024 00:01:55 GMT
Server: nginx

{
    "active": [],
    "log": [],
    "next_cursor": 0
}
```

11.5.3 GET /api/v1/sensor/alerts?mode=summary

To `GET` the sensor alerts with mode=summary.

```
GET /api/v1/sensor/alerts?mode=summary HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 351
Content-Type: application/json
Date: Thu, 21 Mar 2024 00:11:50 GMT
Server: nginx
```

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```
{
    "active": [
        {
            "cursor": 1,
            "id": "0x01000015",
            "realtime": "1710979334555586816"
        },
        {
            "cursor": 0,
            "id": "0x01000018",
            "realtime": "1710979333553802752"
        }
    ],
    "log": [
        {
            "active": true,
            "cursor": 0,
            "id": "0x01000018",
            "realtime": "1710979333553802752"
        },
        {
            "active": true,
            "cursor": 1,
            "id": "0x01000015",
            "realtime": "1710979334555586816"
        }
    ],
    "next_cursor": 2
}
```


11.5.4 GET /api/v1/sensor/alerts?cursor=2&mode=summary

To GET the sensor alerts with cursor=2 and mode=summary.

```
GET /api/v1/sensor/alerts?cursor=2&mode=summary HTTP/1.1
Host: 192.0.2.123
```


```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 1011
Content-Type: application/json
Date: Thu, 21 Mar 2024 00:21:34 GMT
Server: nginx

{
    "active": [
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 1,
            "id": "0x01000015",
```


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```
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided lidar data port;
            check that udp_dest and udp_port_lidar configured on the sensor matches client IP and port.
            This Alert may occur on sensor startup if the client is not listening at that time.",
            "msg_verbose": "Failed to send lidar UDP data to destination host 10.32.224.28:7502",
            "realtime": "1710979334555586816"
        },
        {
            "active": true,
            "category": "UDP_TRANSMISSION",
            "cursor": 0,
            "id": "0x01000018",
            "level": "WARNING",
            "msg": "Client machine announced it is not reachable on the provided IMU data port;
            check that udp_dest and udp_port_imu configured on the sensor matches client IP and port.
            This Alert may occur on sensor startup if the client is not listening at that time.",
            "msg_verbose": "Failed to send imu UDP data to destination host 10.32.224.28:7503",
            "realtime": "1710979333553802752"
        }
    ],
    "log": [],
    "next_cursor": 2
}
```


11.5.5 GET /api/v1/diagnostics/dump

To GET the diagnostics files of the sensor. This file should be sent to Ouster support if requested, and is not readable by the user.

```
GET /api/v1/diagnostics/dump HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Type: application/octet-stream
Transfer-Encoding: chunked
content-disposition: attachment; filename="192.0.2.123_diagnostics-dump_b7d348c2
                                          -c763-11ec-accf-bc0fa7008417.bin"


+----------------------------------------+
| NOTE: binary data not shown in terminal |
+----------------------------------------+
```

11.5.6 GET /api/v1/sensor/telemetry

To `GET` the sensor telemetry information.

```
GET /api/v1/sensor/telemetry HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Length: 150
Content-Type: application/json

{
    "input_current_ma": 644,
    "input_voltage_mv": 23624,
    "internal_temperature_deg_c": 48,
    "phase_lock_status": "DISABLED",
    "timestamp_ns": 2093396806056
}
```

Description: Returns a JSON-formatted response that provides sensor system state information. This includes the **Timestamp** in `ns` (Nanoseconds) at which the information was collected, **Lidar Input Voltage** in `mv` (Millivolt), **Lidar Input Current** in `ma` (Milliamp), **Internal Temperature** of the sensor in `°C` (Degree Celsius) and **Phase Lock status**, which can be `LOCKED`, `LOST`, or `DISABLED`..

Internal temperature can only be measured with Rev 06 and above sensors. **Phase lock** output will not indicate loss of lock if the time synchronization is lost.

12 TCP API Guide (Deprecated)

Warning: TCP API has now been deprecated in FW 3.1. Refer to HTTP API Guide Section instead.

Please contact Ouster Support if you need any support or have any questions regarding this transition.

13 API Changelog

13.1 Firmware v3.1.0

- Date: May 2024

Added

- Add config parameter for `min_range_threshold_cm` (Refer to *min_range_threshold_cm* for more information).
- Add config parameter for `return_order` (Refer to *return_order* for more information).
- Add config parameter for `Delete Config` (Refer to *DELETE /api/v1/sensor/config* for more information).
- Add config parameter for *POST /api/v1/system/restart* to restart sensor or reinitialize a sensor.
- Add config parameter for *User Editable Data* section, which can be used for a number of purposes such as storing specific information about the sensor, qualifying a sensor, calibration data, or any other information.
- Add config parameter for *GET /api/v1/sensor/metadata/imu_data_format*. User can get `imu_data_format` and `POST` config to change `gyro_fsr` and `accel_fsr` from `NORMAL` to `EXTENDED`.

Removed

- TCP API has now been **DEPRECATED** in FW 3.1. Please refer to *HTTP API Reference Guide* section instead.
- LEGACY Data packet profile has been **DEPRECATED**, please refer to Lidar Data Packet Format section of the Firmware User Manual for more information.

Fixed

- Fixed bug in *GET /api/v1/sensor/alerts* API.

13.2 Firmware v3.0.1

- Date: February 2023

Added

- New HTTP Command to configure speed override (Refer to *System*)

13.3 Firmware v3.0.0

- Date: January 2023

Fixed

- Bug in keep-alive behavior for HTTP 1.1.

14 Troubleshooting

14.1 Sensor Homepage and HTTP Server

The sensor HTTP server page http://os-991900123456.local/ has information about the sensor system information, sensor status, firmware, diagnostics, configuration and API documentation. To learn more about Web UI and its use to troubleshoot the sensor, please see the *Sensor Web Interface* portion of this user manual.

14.2 Networking

Many initial problems with the sensor are associated with it not properly being assigned an IP address by a network switch or DHCP server on a client computer. Check your networking settings, the steps in *What's in the box*, and that all wires are firmly connected if you suspect this problem. Note that if the sensor is not connected via gigabit Ethernet, it will stop sending data and will output an error code if it fails to achieve a 1000 Mb/s+ full duplex link. Please see the *Networking Guide* for detailed guidance on network setup.

14.3 Using Latest Firmware

Upgrading to the latest firmware can often resolve issues found in earlier firmware. The latest firmware is always found at Ouster Downloads. Our Support team is best suited to be able to help you if you are running the latest firmware. Please refer to the *Updating Firmware* section to learn more on how to update firmware.

Note: Please contact our Field Application Team and we can answer your questions and provide guidance for achieving proper operations.

14.4 Alerts and Errors

The sensor provides alerts and error messages that can be used to help diagnose the sensor. These Alerts are accessible through the diagnostics tab on the sensor homepage. Alternately, users can query the sensor via the HTTP endpoint *GET /api/v1/sensor/alerts*.

An alert gets triggered when its trigger condition is met and is cleared when the respective trigger condition no longer exists.

GET /api/v1/sensor/alerts returns two lists, an **active** list and a **log** list. The **active** list will contain alert-trigger events for alerts that are currently active. An alert-trigger event will by definition always have its active attribute set to true. There is no limit on the number of alert-trigger events that are displayed in the **active** event list. All currently active alert-trigger events will be displayed in the **active** event list.

The **log** list will contain all current and past alert-trigger and alert-clear events. An alert-clear event will by definition have the exact same attributes and attribute values as its corresponding trigger event, with the exception of the realtime and cursor attributes which should have higher values, since an alert-clear event will always be received after an alert-trigger event. The **log** list has a length limit of 32 events with the oldest events automatically removed from the log list once a new event needs to be added to the **log** list and the **log** list length limit is reached, essentially acting as a FIFO (First In First Out) queue.

In addition to the **active** and **log** lists, *GET /api/v1/sensor/alerts* also returns a **next_cursor** field. Every alert event has a cursor attribute, which increments for every alert event logged. This can be used to track the alert activity that has been viewed and reduce message bandwidth. To do this, users are recommended to save the **next_cursor** field when calling *GET /api/v1/sensor/alerts* and then use that value as the `START_CURSOR` argument on the next *GET /api/v1/sensor/alerts* call to fetch only new **log** entries.

A valid value for **mode** is either `summary` or `default`.

Additional Information:

The **cursor** will wrap at 2^32 entries. It is important to understand the behavior during the wrap case, since this may lead to some unexpected consequences:

- If cursor < (next_cursor - 32) % 2^32 then some entries may be filtered. For instance if **cursor** =0 and **next_cursor** =0 no entries will be reported immediately after **cursor** wrap, even though the log contains 32 entries, where submitting **cursor** =4294967264 (next_cursor - 32) % 2^32 will return all logged values.
- If cursor > next_cursor all 32 entries will be reported.

14.4.1 Alerts Example

Valid uses of GET /api/v1/sensor/alerts:

- Example: Calling alerts with **cursor** =1
  - *GET /api/v1/sensor/alerts?cursor=1*
- Example: Calling alerts with **mode** =summary
  - *GET /api/v1/sensor/alerts?mode=summary*
- Example: Calling alerts with **cursor** =2 and **mode** =summary
  - *GET /api/v1/sensor/alerts?cursor=2&mode=summary*

Note: When utilizing HTTP Endpoints, the sequence in which the cursor and mode arguments are provided for the `GET /api/v1/sensor/alerts` command is inconsequential.

The recommended approach to using the interface is to always base queries on the previous value of **next_cursor**.

If the watchdog is triggered, an alert code will be appended to the end of the response. The sensor has a limited-size buffer that will record the first few alerts detected by the sensor.

The full list of possible alerts and error messages can be found in *Alerts and Errors*.

The alerts reported have the following format:

```
{
   "category": "Category of the alert: e.g. OVERTEMP, UDP_TRANSMISSION",
   "level": "Level of alert: e.g. NOTICE, WARNING, ERROR",
   "realtime": "The timestamp of the alert in nanoseconds",
   "active": "Whether the alert was active or not at the time of this log: <true/false>",
   "msg": "A description of the alert",
   "cursor": "The sequential number of the alert, starting from 0 counting up",
   "id": "The hexadecimal identification code of the alert: e.g. 0x01000017",
   "msg_verbose": "Any additional verbose description that the alert may present"
}
```

Example showing active and logged forced temperature sensor failures occurring at timestamps 1569712873477772800, 1569712879991844096, 1569712884968876544 (nanoseconds).

The first logged error then resolves itself at 1569713260229536000.

The example has been JSON formatted:


```
{
   "active": [
      {
         "category": "OVERTEMP",
         "level": "ERROR",
         "realtime": "1569712879991844096",
         "active": true,
         "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
         "cursor": 1,
         "id": "0x01000001",
         "msg_verbose": ""
      },
      {
         "category": "OVERTEMP",
         "level": "ERROR",
         "realtime": "1569712884968876544",
         "active": true,
         "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
         "cursor": 2,
         "id": "0x01000002",
         "msg_verbose": ""
      }
   ],
   "next_cursor": 4,
   "log": [
      {
         "category": "OVERTEMP",
         "level": "ERROR",
         "realtime": "1569712873477772800",
         "active": true,
         "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
         "cursor": 0,
         "id": "0x01000000",
         "msg_verbose": ""
      },
      {
         "category": "OVERTEMP",
         "level": "ERROR",
         "realtime": "1569712879991844096",
         "active": true,
         "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
         "cursor": 1,
         "id": "0x01000001",
         "msg_verbose": ""
      },
      {
         "category": "OVERTEMP",
         "level": "ERROR",
         "realtime": "1569712884968876544",
         "active": true,
         "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
         "cursor":2 ,
         "id": "0x01000002",
```


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```
            "msg_verbose": ""
        },
        {
            "category": "OVERTEMP",
            "level": "ERROR",
            "realtime": "1569713260229536000",
            "active": false,
            "msg": "Unit internal temperature out of bounds; please ensure proper heat sinking.",
            "cursor": 3,
            "id": "0x01000000",
            "msg_verbose": ""
        }
    ]
}
```


Note: Please contact our Field Application Team and we can answer your questions and provide guidance for achieving proper operations.

14.4.2 Table of All Alerts and Errors

Possible alerts and errors that the sensor can provide are listed below. Where appropriate, the message from the sensor aims to help the user diagnose and fix the issue themselves.

Note: Please note that if the recommended action does not clear the ALERT and the issue persists, Users are encouraged to update to the latest FW version. If that does not mitigate the issue, please collect the diagnostics file from the sensor Web UI and contact Ouster support.

Table14.1: Alerts and Errors

ID	Category	Level	Alert Message	Sensor Action
0x01000000	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000001	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000002	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000003	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000004	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000005	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000006	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000007	UNDERTEMP	Error	Unit internal temperature too low; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000008	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x01000009	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x0100000A	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x0100000B	OVERTEMP	Error	Unit internal temperature too high; Unit is shutting down. Please refer to Thermal integration guide for heat sinking requirements.	SHUTDOWN
0x0100000C	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning. If the issue persists, update to the latest FW. Contact Ouster Support if the above steps do not resolve the alert with Diagnostic file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100000D	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning. If the issue persists, update to the latest FW. Contact Ouster Support if the above steps do not resolve the alert with Diagnostic file.	No Action
0x0100000E	SHOT_LIMITING	Notice	Temperature is high enough where shot limiting may be engaged; Please refer to Thermal integration guide for heat sinking requirements.	No Action
0x0100000F	SHOT_LIMITING	Warning	Shot limiting mode is active. Laser power is partially attenuated; Please refer to Thermal integration guide for heat sinking requirements.	No Action
0x01000010	INTERNAL_FW	Error	Unit has experienced an internal error; If the issue persists, update to the latest FW. Contact Ouster Support with Diagnostic file, if the above steps do not resolve the alert.	No Action
0x01000011	ETHERNET_LINK_BAD	Warning	Sensor has detected an issue with the connected ethernet link. Please check the network setup including the network switch and harnessing can support 1 Gbps Ethernet. If you experience no issues with this Alert active, this alert can be ignored.	No Action
0x01000012	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. No action is required from the user to clear the Alert. If the issue persists on FW update, contact Ouster Support with diagnostic file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000013	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. No action is required from the user to clear the Alert. If the issue persists on FW update, contact Ouster Support with diagnostic file.	No Action
0x01000014	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. No action is required from the user to clear the Alert. If the issue persists on FW update, contact Ouster Support with diagnostic file.	No Action
0x01000015	UDP_TRANSMISSION	Warning	Client machine announced it is not reachable on the provided lidar data port; check that udp_dest and udp_port_lidar configured on the sensor matches client IP and port.This Alert may occur on sensor startup, if the client is not listening at that time. If the issue persists, contact Ouster Support.	No Action
0x01000016	UDP_TRANSMISSION	Warning	Could not send lidar data UDP packet to host; check that network is up and the destination is reachable.	No Action
0x01000017	UDP_TRANSMISSION	Warning	Received an unknown error when trying to send lidar data UDP packet; closing socket.	No Action
0x01000018	UDP_TRANSMISSION	Warning	Client machine announced it is not reachable on the provided IMU data port; check that udp_dest and udp_port_imu configured on the sensor matches client IP and port.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000019	UDP_TRANSMISSION	Warning	Could not send IMU UDP packet to host; check that network is up and the destination is reachable.	No Action
0x0100001A	UDP_TRANSMISSION	Warning	Received an unknown error when trying to send IMU UDP packet; closing socket.	No Action
0x0100001B	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x0100001C	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x0100001D	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x0100001E	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x0100001F	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000020	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000021	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000022	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000023	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000024	STARTUP	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000025	INTERNAL_COMM	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000026	INTERNAL_COMM	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN
0x01000027	INTERNAL_COMM	Error	Unit has experienced a startup error; Unit is shutting down. Update the Firmware to the latest version, if the issue persists please contact Ouster Support.	SHUTDOWN

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000028	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x01000029	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x0100002A	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x0100002B	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x0100002C	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x0100002D	STARTUP	Warning	Unit has experienced an internal warning during startup and is restarting.	RESTART
0x0100002E	INPUT_VOLTAGE	Warning	Input voltage is close to being too low. Consult the hardware user manual for voltage requirements. Raise voltage immediately.	No Action
0x0100002F	INPUT_VOLTAGE	Error	Input voltage is too low. Unit may shut down if the voltage drops farther. Consult the hardware user manual for voltage requirements.	SHUTDOWN
0x01000030	INPUT_VOLTAGE	Warning	Input voltage is close to being too high. Consult the hardware user manual for voltage requirements. Lower voltage immediately.	No Action
0x01000031	INPUT_VOLTAGE	Error	Input voltage is too high. Unit may shut down if the voltage increases farther. Consult the hardware user manual for voltage requirements.	SHUTDOWN
0x01000032	UDP_CONNECT	Warning	Couldn't open lidar UDP socket; please contact Ouster Support.	No Action

continues on next page

Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000033	UDP_CONNECT	Warning	Couldn't resolve hostname using DNS for lidar data; check network, DNS server, and udp_dest. If using static IP override, try setting udp_dest to an IP address or via auto-setting.	No Action
0x01000034	UDP_CONNECT	Warning	Invalid UDP port number; check network and udp_port_lidar.	No Action
0x01000035	UDP_CONNECT	Warning	Couldn't reach destination client for lidar data; verify cabling, network address configuration, and subnet mask if using static IP override	No Action
0x01000036	UDP_CONNECT	Warning	Couldn't open imu UDP socket; please contact Ouster Support.	No Action
0x01000037	UDP_CONNECT	Warning	Couldn't resolve hostname using DNS for IMU data; check network, DNS server, and udp_dest. If using static IP override, try setting udp_dest to an IP address or via auto-setting.	No Action
0x01000038	UDP_CONNECT	Warning	Invalid UDP port number; check network and udp_port_imu.	No Action
0x01000039	UDP_CONNECT	Warning	Couldn't reach destination client for IMU data; verify cabling, network address configuration, and subnet mask if using static IP override	No Action
0x0100003A	SHOT_LIMITING	Warning	Shot limiting mode at maximum. Sensor shutdown imminent.	No Action

continues on next page

Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100003B	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is in Error Stopped (Shutdown) state. Please contact Ouster Support.	SHUTDOWN
0x0100003C	INTERNAL_FAULT	Error	Internal fault detected; Unit will restart to attempt recovery. If the issue persists, update Firmware to the latest version. Contact Ouster Support if the above steps don't resolve the Alert.	RESTART
0x0100003D	INTERNAL_FAULT	Error	Internal fault detected; unit will restart to attempt recovery. If the issue persists, update Firmware to the latest version. Contact Ouster Support if the above steps don't resolve the Alert.	RESTART
0x0100003E	INTERNAL_FAULT	Error	Internal fault detected; unit will restart to attempt recovery. If the issue persists, update Firmware to the latest version. Contact Ouster Support if the above steps don't resolve the Alert.	RESTART
0x0100003F	INTERNAL_COMM	Error	Unit has experienced an internal COMM error; Unit is in Error Stopped(Shutdown) state. Please contact Ouster Support.	SHUTDOWN
0x01000040	INTERNAL_FAULT	Error	Unit has experienced an internal COMM error; Unit is in Error Stopped(Shutdown) state. Please contact Ouster Support.	SHUTDOWN
0x01000041	INTERNAL_COMM	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped.	No Action
0x01000042	INTERNAL_COMM	Error	Unit has experienced an internal COMM error; please contact Ouster Support.	No Action

continues on next page

Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000043	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000044	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000045	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000046	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000047	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000048	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x01000049	INTERNAL_FW	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x0100004A	STARTUP	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x0100004B	STARTUP	Error	Unit has experienced a startup error; please contact Ouster Support.	SHUTDOWN
0x0100004C	INTERNAL_FAULT	Error	Internal fault detected; unit going to error stop state.	SHUTDOWN
0x0100004D	INTERNAL_FAULT	Error	Internal fault detected; unit going to error stop state.	SHUTDOWN
0x0100004E	WARMUP_ISSUE	Warning	Sensor warmup process is taking longer than expected; please ensure sensor is thermally constrained per requirements.	RESTART

continues on next page

Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100004F	WARMUP_ISSUE	Warning	Sensor warmup process is taking longer than expected; please ensure sensor is thermally constrained per requirements.	RESTART
0x01000050	MOTOR_CONTROL	Warning	The phase lock offset error has exceeded the threshold. Check that the time source is accurate and the reduce the movement of the sensor including mechanical movement, shock, or vibration.	No Action
0x01000051	MOTOR_CONTROL	Error	The phase lock control failed to achieve a lock multiple times; Check that the time source is accurate.	No Action
0x01000052	CONFIG	Error	Configuration value is invalid or out of bounds. Unit is shutting down. Try resetting the sensor configuration.	SHUTDOWN
0x01000053	WARMUP_ISSUE	Error	Sensor warmup process has failed. Unit is shutting down. Check the sensor operating conditions are within operating bounds.	SHUTDOWN
0x01000054	INTERNAL_FAULT	Notice	Unexpected hardware configuration detected. Please contact Ouster Support.	No Action
0x01000055	UDP_TRANSMISSION	Warning	Unit has experienced a packet drop rate above normal threshold. Please check that the network has at least 1000 Mbps connection. Common causes of this notice may be 100 or 10 Mbps network connections.	No Action
0x01000056	INTERNAL_FAULT	Error	Internal fault detected; unit will restart to attempt recovery.	RESTART
0x01000057	OVERTEMP	Warning	Sensor temperature is too high. Sensor could have degraded range performance.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000058	OVERTEMP	Error	Sensor temperature is too high; unit going to error stop state (Shutdown).	SHUTDOWN
0x01000059	INTERNAL_FAULT	Warning	Internal fault detected; unit will restart to attempt recovery.	RESTART
0x0100005A	INTERNAL_FAULT	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. Check sensor operating conditions.	No Action
0x0100005B	INTERNAL_FAULT	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. Check sensor operating conditions.	No Action
0x0100005C	INTERNAL_FAULT	Warning	Unit has experienced an internal COMM warning: some measurements may have been skipped. Check sensor operating conditions.	No Action
0x0100005D	INTERNAL_FAULT	Warning	Internal fault detected; unit will restart to attempt recovery. If the issue persists, please try updating to the latest firmware. If the procedure above does not resolve the alert, please contact Ouster Support.	RESTART
0x0100005E	INTERNAL_FAULT	Warning	Unit has experienced an overcurrent event; unit will restart to attempt recovery.	RESTART
0x0100005F	IO_CONNECTION	Warning	Unit has stopped receiving SYNC_PULSE_IN signals and is configured to expect them. Check electrical inputs to sensor.	No Action

continues on next page

Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000060	IO_CONNECTION	Warning	Unit has stopped receiving NMEA messages at the MULTIPURPOSE_IO port and is configured to expect them. Check electrical inputs to sensor.	No Action
0x01000061	INTERNAL_COMM	Error	Unit has experienced an internal COMM error Unit will restart to attempt recovery.	RESTART
0x01000062	INTERNAL_FAULT	Error	Unit has experienced a internal error; Unit is in Error stopped state. Please contact Ouster Support.	No Action
0x01000063	MOTOR_CONTROL	Warning	Unit is spinning outside of tolerant range; Check sensor operating conditions.	No Action
0x01000064	MOTOR_CONTROL	Error	Unit failed to maintain target spin rate; please contact Ouster Support.	No Action
0x01000065	MOTOR_CONTROL	Error	Unit has experienced a internal error; Unit is in Error stopped state. Please contact Ouster Support.	No Action
0x01000066	MOTOR_CONTROL	Error	Unit has experienced a startup error; Unit is in Error stopped state. Please contact Ouster Support.	SHUTDOWN
0x01000067	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is in Error stopped state. Please contact Ouster Support.	SHUTDOWN
0x01000068	INTERNAL_FW	Error	Unit has experienced a startup error; Unit is in Error stopped state. Please contact Ouster Support.	SHUTDOWN

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100006C	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100006D	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100006E	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100006F	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000070	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000071	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000072	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000073	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000074	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000075	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000076	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000077	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000078	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000079	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100007A	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100007B	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100007C	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100007D	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100007E	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100007F	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000080	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000081	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000082	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000083	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000084	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000085	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000086	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000087	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000088	CONFIG	Notice	Please note all commands in the TCP API are in planned obsolescence and are subject to deprecation shortly. Please consider using the HTTP API instead. Please refer to Firmware User Manual for more information or contact Ouster Support	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000089	CONFIG	Notice	Please note that the LEGACY profile option of config parameter udp_profile_lidar is in planned obsolescence. Please consider using a different option for the config parameter. LEGACY profile is subject to deprecation shortly. Please refer to Firmware User Manual for more information or contact Ouster Support	No Action
0x0100008A	INTERNAL_FAULT	Warning	Unit has experienced an overcurrent event that could degrade data and/or sensor performance; unit will restart to attempt recovery. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	RESTART
0x0100008B	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100008C	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100008D	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100008E	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100008F	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000090	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000091	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000092	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000093	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000094	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000095	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000096	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x01000097	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000098	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x01000099	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100009A	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100009B	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x0100009C	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100009D	CONFIG	Notice	Setting the signal multiplier value on a Rev7 OS2 sensor to 2x or 3x is not supported and the sensor has fallen back to 1x behavior. This does not apply to any other sensor models or prior generations of OS2. Please refer to Firmware User Manual for more information or contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100009E	INTERNAL_FAULT	Error	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x0100009F	INTERNAL_FAULT	Error	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x010000A0	INTERNAL_COMM	Error	Unit has experienced an internal COMM warning. If the issue persists, update to the latest FW. Contact Ouster Support if the above steps do not resolve the alert with Diagnostic file.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x010000A1	UNDERTEMP	Warning	Unit temperature is too low, this could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x010000A2	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x010000A3	INTERNAL_FAULT	Warning	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	No Action
0x010000A4	INTERNAL_FAULT	Error	Unit has experienced an internal fault that could degrade data and/or sensor performance. Please stop running sensor if this alert persists and contact Ouster Support with a copy of the diagnostics file.	Go to ERROR RESTART
0x010000A5	CONFIG	NOTICE	When 'Minimum Range (cm)' is less than 50cm, Ouster recommends setting 'Return Order' to FARTHEST_TO_NEAREST. Please refer to Ouster Firmware User Manual for more information.	No Action
0x010000A6	UDP_TRANSMISSION	Warning	Could not send lidar UDP data packet for more than 500 ms. This may occur if the network was unreachable.	No Action

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Table 14.1 - continued from previous page

ID	Category	Level	Alert Message	Sensor Action
0x010000A7	UDP_TRANSMISSION	Warning	Could not send IMU UDP data packet for more than 500 ms. This may occur if the network was unreachable.	No Action

15 Networking Guide

This guide will help you understand how to quickly get connected to your sensor to start doing great things with it. When trying to connect to the sensor for the first time there are some basics that need to be achieved for successful communication between the host machine and the sensor.

We need to ensure that the sensor receives an IP address from the host machine so that we can talk to it. This can be achieved with a few different methods such as DHCP, link-local, static IP. We also need to ensure that the sensor and the host machine are talking on the same subnet.

Once the sensor receives an IP address and is on the correct subnet we can talk to it using its host-name, `os-991234567890.local`, where `991234567890` is the sensor serial number. The sensor serial number can be found on a sticker affixed to the top of the sensor.

Based on the platform being used the user can refer to the following:

- *Windows*
- *macOS*
- *Linux*

Note: DNS Service Discovery text announced by the sensor may provide an incorrect part number that corresponds to an internal code. The correct part number can be found via the *Sensor Web Interface* or *HTTP API Reference Guide*.

15.1 Networking Terminology

If some of this terminology is new to you don't fret, we have defined some of it for you. Here is some basic terminology that will help you digest the steps and be more familiar with networking in general.

IPv4 Address This is the address that can be used to communicate with devices on a network. The format of an IPv4 address is a set of four octets, `xxx.xxx.xxx.xxx` with `xxx` being in the range `0-255`. For example, your host machine Ethernet port may have an address of `192.0.2.1` and your sensor may have an address of `192.0.2.130`.

DHCP (Dynamic Host Configuration Protocol) Server This is a server that may run on your host machine, switch, or router which will serve an IPv4 address to a device that is connected to it. It will ensure that each device connected will have a unique IPv4 address on the network.

Link-local IPv4 Address These are the addresses that are self-assigned between the host machine and a device connected to it in the absence of a DHCP server. They are only valid within the network segment that the host is connected to. The addresses lie within the block `169.254.0.0/16 (169.254.0.0 - 169.254.255.255)`.

Subnet Mask This defines which bits of the IPv4 address are the network prefix and which are the host identifiers. See the table below for an example.

	Binary Form	Decimal-dot notation
IP address	`11000000.00000000.00000010.10000010`	`192.0.2.130`
Subnet mask	`11111111.11111111.11111111.00000000`	`255.255.255.0`
Network prefix	`11000000.00000000.00000010.00000000`	`192.0.2.0`
Host identifier	`00000000.00000000.00000000.10000010`	`0.0.0.130`

Note: Subnet mask can be abbreviated with the number of bits that apply to the network prefix. E.g. /24 for 255.255.255.0 or /16 for 255.255.0.0.

Static IPv4 Address This is when you specify the addresses for the host machine and/or connected device rather than letting the host machine self-assign or using a DHCP server. For example, you may want to specify the host machine IPv4 address to be `192.0.2.100/24` and the sensor to be `192.0.2.200`.

Hostname This is the more human readable name that comes with your sensor. The sensor's hostname is `os-991234567890.local`, where `991234567890` is the sensor serial number.

Note: The `.local` portion of the hostname denotes the local domain used in combination with multicast DNS (mDNS). It is employed when using the sensor in a local network environment with supporting operating system services. This means when the sensor is directly connected to the host machine or if the host machine and sensor are on the same network connected through a router or switch. If you are trying to connect to the sensor on another domain with a supporting DHCP and DNS server configuration you should replace the .local with the domain the sensor is on. For example, if the sensor is connected to a network with domain `ouster-domain.com` the sensor will be reachable on `os-991234567890.ouster-domain.com`.

15.2 Windows

The following steps have been tested on Windows 10. The sensor's hostname is `os-991234567890.local`, where `991234567890` is the sensor serial number. The sensor serial number can be found on a sticker affixed to the top of the sensor.

15.2.1 Connecting the Sensor

1. Connect the sensor to an available Ethernet port on your host machine or router.
2. The sensor will automatically obtain an IP address either through link-local or DHCP (if preconfigured) depending on your network configuration.

Note: It can take up to 60 seconds to obtain an IP address from the initial power-up of the sensor.

15.2.2 The Sensor Homepage

1. Type `os-991234567890.local/` in the address bar of your browser to view the sensor homepage

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Note: If you are unable to load the sensor homepage, follow the steps in *Determining the IPv4 Address of the Sensor* to verify your sensor is on the network and has a valid IPv4 address.

15.2.3 Determining the IPv4 Address of the Sensor

- Open a command prompt on the host machine by pressing **Win+X** and then **A**. Use the ping command to determine the IPv4 address of the sensor

Command

```
ping -4 [sensor_hostname]
```

Example

```
C:\\WINDOWS\\system32>ping -4 |os-sn|
```

Note: If this command hangs you may need to go back and configure your interface to link-local in the section *Connecting the Sensor*

Response

```
Pinging |os-sn| [|sensor-ip|] with 32 bytes of data:
Reply from |sensor-ip|: bytes=32 time<1ms TTL=64
Reply from |sensor-ip|: bytes=32 time<1ms TTL=64
Reply from |sensor-ip|: bytes=32 time<1ms TTL=64
Reply from |sensor-ip|: bytes=32 time<1ms TTL=64

Ping statistics for |sensor-ip|:
  Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 0ms, Average = 0ms
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

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3. You can also browse for the sensor IPv4 address using dns-sd and the sensor hostname. Learn more about this in *Finding a Sensor with mDNS Service Discovery*

Command

```
dns-sd -G v4 [sensor_hostname]
```

Example

```
C:\\WINDOW\\system32>dns-sd -G v4 |os-sn|
```

Response

```
Timestamp     A/R  Flags   if   Hostname                Address         TTL
14:22:46.897  Add  2       6    |os-sn|  |sensor-ip|   120
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

15.2.4 Determining the IPv4 Address of the Interface

1. Open a command prompt by pressing **Win+X** and then **A**
2. View the IPv4 address of your interfaces

Command

```
netsh interface ip show config
```

Example

```
C:\\WINDOWS\\system32>netsh interface ip show config
```

Response

```
Configuration for interface "Local Area Connection"
    DHCP enabled:                         Yes
    IP Address:                           |interface-ip|
    Subnet Prefix:                        169.254.0.0/16 (mask 255.255.0.0)
    InterfaceMetric:                      25
    DNS servers configured through DHCP:  None
    Register with which suffix:           Primary only
    WINS servers configured through DHCP: None

Configuration for interface "Loopback Pseudo-Interface 1"
    DHCP enabled:                         No
    IP Address:                           127.0.0.1
    Subnet Prefix:                        127.0.0.0/8 (mask 255.0.0.0)
    InterfaceMetric:                      75
    Statically Configured DNS Servers:    None
    Register with which suffix:           Primary only
    Statically Configured WINS Servers:   None
```

- In this example, your sensor is plugged into interface “Local Area Connection”
- Your host IPv4 address will be on the line that starts with IP Address: In this case it is `169.254.0.1`

Note: If your interface IPv4 address is of the form `169.254.x.x`, it is connected via link-local to the

sensor. This means that Windows self-assigned an IP address in the absence of a DHCP server.

15.2.5 Setting the Host Interface to DHCP

Use this to set your interface to automatically obtain an IP address via DHCP. This is useful for architectures that need to be more plug and play. This is the method Ouster recommends to configure your sensor.

Set your interface to DHCP.

Command

```
netsh interface ip set address ["Network Interface Name"] dhcp
```

Example

with interface name `"Local Area Connection"`

```
C:\\WINDOWS\\system32>netsh interface ip set address "Local Area Connection" dhcp
```

Response

```
blank
```

15.2.6 Setting the Host Interface to Static IP

Use this to set your interface to be assigned a static IPv4 address. This is useful for controlling the IP address that the sensor will be sending data to.

Set your interface to static.

Command

```
netsh interface ip set address name="Network Interface Name" static [IP address] [Subnet Mask]
[Gateway]
```

Example

with interface name “Local Area Connection” and IPv4 address 192.0.2.1/24.

```
C:\\WINDOWS\\system32>netsh interface ip set address name="Local Area Connection"
 static 192.0.2.1/24
```

Note: The `/24` is shorthand for Subnet Mask = `255.255.255.0`

Response

```
blank
```

15.2.7 Finding a Sensor with mDNS Service Discovery

Warning: Until FW v3.0.1 Ouster sensors used Multicast Domain Name Service (mDNS) with a service type named `_roger._tcp`. This is now subject to deprecation. Please use `_ouster-lidar._tcp` starting FW v3.1 and later.

The sensor announces its presence on the network using Multicast Domain Name Service (mDNS) with a service type named `_ouster-lidar._tcp`. You can use service discovery tools such as Bonjour browser (Windows) to find all sensors connected to the network.

Note: Click Bonjour to install Bonjour Browser.

Example using Bonjour Browser:

Step 1: User can download the Bonjour Browser

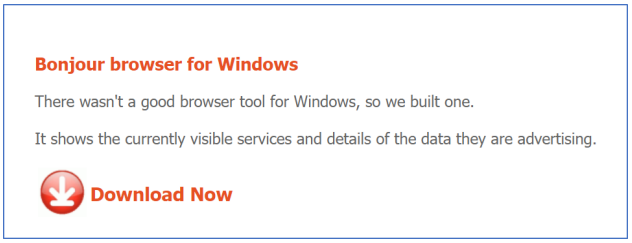

Figure 15.1: Downloading Application

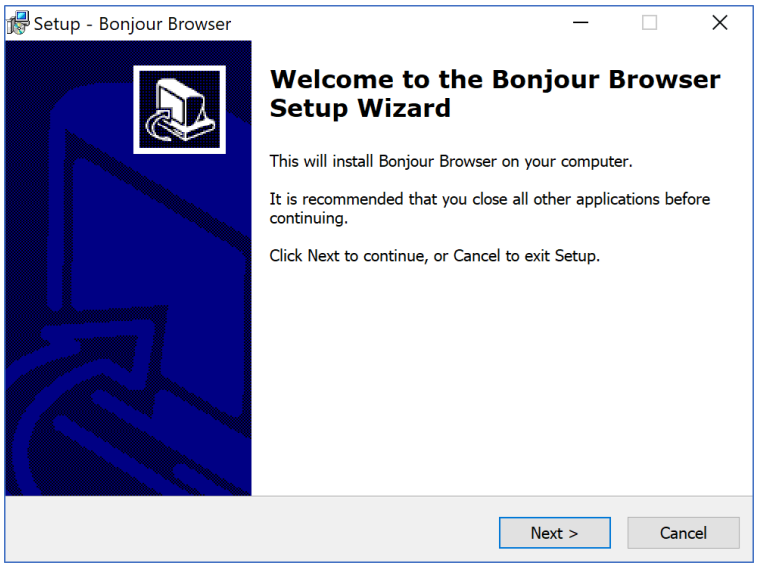

Figure 15.2: Software Setup and Installation

Step 2: Sensor announces its presence on the network using Multicast Domain Name Service (mDNS) with a service type named `_ouster-lidar._tcp`. Click on this to get all the information required.

15.3 macOS

The following steps have been tested on macOS 10.15.4. In this example the sensor's hostname is `os-991234567890.local`, where `991234567890` is the sensor serial number. The sensor serial number can be found on a sticker affixed to the top of the sensor.

15.3.1 Connecting the Sensor

1. Connect the sensor to an available Ethernet port on your host machine or router.
2. The sensor will automatically obtain an IP address either through link-local or DHCP (if preconfigured) depending on your network configuration.

Note: It can take up to 60 seconds to obtain an IP address from the initial power-up of the sensor.

15.3.2 The Sensor Homepage

1. Type `os-991234567890.local` in the address bar of your browser to view the sensor homepage

Note: If you are unable to load the sensor homepage, follow the steps in *Determining the IPv4 Address of the Sensor* to verify your sensor is on the network and has a valid IPv4 address.

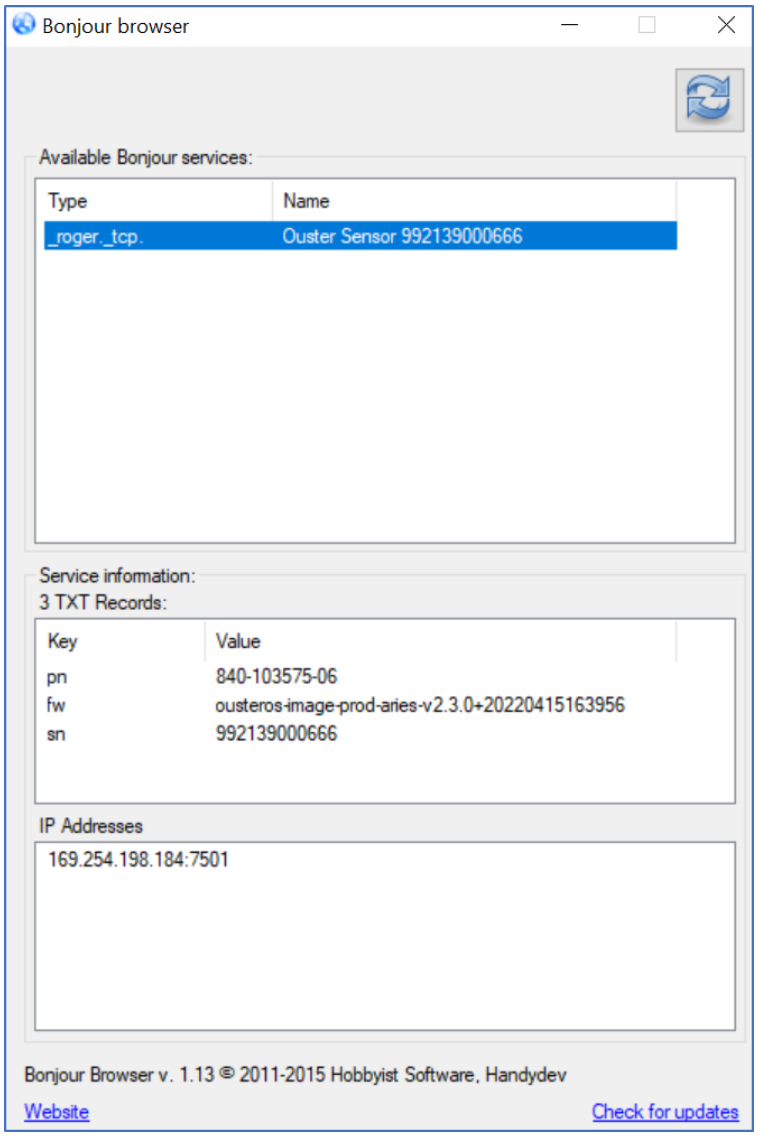

Figure 15.3: `_ouster-lidar._tcp`

15.3.3 Determining the IPv4 Address of the Sensor

1. Open a Terminal window on the host machine by pressing **CMD+SPACE** and typing **Terminal** in the search bar, then press enter.
2. Use the ping command to determine the IPv4 address of the sensor

Command

```
ping -c3 [sensor_hostname]
```

Example

```
Mac-Computer:~ username$ ping -c3 |os-sn|
```

Note: If this command hangs you may need to go back and configure your interface to link-local in the section *Connecting the Sensor*

Response

```
PING |os-sn| (|sensor-ip|): 56 data bytes
64 bytes from |sensor-ip|: icmp_seq=0 ttl=64 time=0.644 ms
64 bytes from |sensor-ip|: icmp_seq=1 ttl=64 time=0.617 ms
64 bytes from |sensor-ip|: icmp_seq=2 ttl=64 time=0.299 ms

--- |os-sn| ping statistics ---
3 packets transmitted, 3 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.299/0.520/0.644/0.157 ms
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

---

3. You can also browse for the sensor IPv4 address using dns-sd and the sensor hostname. Learn more about this in *Finding a Sensor with mDNS Service Discovery*

Command

```
dns-sd -G v4 [sensor_hostname]
```

Example

```
Mac-Computer:~ username$ dns-sd -G v4 |os-sn|
```

Response

```
DATE: ---Tue 28 Apr 2020---
11:40:43.228  ...STARTING...
Timestamp     A/R  Flags  if  Hostname               Address           TTL
11:40:43.414  Add  2      18  |os-sn|.  |sensor-ip|     120
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

15.3.4 Determining the IPv4 Address of the Interface

This will help you find the IPv4 address of the interface that you have plugged the sensor into. It is helpful to know which interface you have plugged into, e.g. `en1` in the example below.

1. Open a Terminal window on the host machine by pressing **CMD+SPACE** and typing **Terminal** in the search bar, then press enter.
2. View the IPv4 address of your interfaces

Command

```
ifconfig
```

Example

```
Mac-Computer:~ username$ ifconfig
```

Response

```
   lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
      options=1203<RXCSUM,TXCSUM,TXSTATUS,SW_TIMESTAMP>
      inet 127.0.0.1 netmask 0xff000000
      inet6 ::1 prefixlen 128
      inet6 fe80::1%lo0 prefixlen 64 scopeid 0x1
      nd6 options=201<PERFORMNUD,DAD>
   en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
      options=400<CHANNEL_IO>
      ether 38:f9:d3:d6:33:8a
      inet6 fe80::1c30:1246:93a2:9f68%en0 prefixlen 64 secured scopeid 0x7
      inet 192.0.2.7 netmask 0xffffff00 broadcast 192.0.2.255
      nd6 options=201<PERFORMNUD,DAD>
      media: autoselect
      status: active
   en1: flags=8963<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
      options=400<CHANNEL_IO>
      ether 48:65:ee:1d:22:35
      inet6 fe80::c27:1917:47ed:bcfe%en1 prefixlen 64 secured scopeid 0x12
      inet |interface-ip| netmask 0xffff0000 broadcast 169.254.255.255
      nd6 options=201<PERFORMNUD,DAD>
      media: autoselect (1000baseT <full-duplex>)
      status: active


* In this example, your sensor is plugged into interface ``en1``
* Your host IPv4 address will be on the line that starts with ``inet``: In this case it is |interface-ip|
```

Note: If your interface IPv4 address is of the form `169.254.x.x`, it is connected via link-local to the sensor. This means that the macOS self-assigned an IP address in the absence of a DHCP server.

15.3.5 Setting the Host Interface to DHCP

Use this to set your interface to automatically obtain an IP address via DHCP. This is useful for architectures that need to be more plug and play.

Set your interface to DHCP

Command

```
sudo ipconfig set [interface_name] DHCP
```

Example

with interface name `en1`

```
Mac-Computer:~ username$ sudo ipconfig set en1 DHCP
```

Response

```
blank

Note: However you can verify the change has been made with the ``ifconfig`` command.
      The ``inet`` line will be blank if nothing is plugged in or shows the DHCP or
      link-local self-assigned IPv4 address. E.g. |interface-ip|


en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500

options=6407<RXCSUM,TXCSUM,VLAN_MTU,CHANNEL_IO,PARTIAL_CSUM,ZEROINVERT_CSUM>
   ether 48:65:ee:1d:22:35
   inet6 fe80::1c24:5e0a:2ea8:12e9%en1 prefixlen 64 secured scopeid 0x7
   inet |interface-ip| netmask 0xffff0000 broadcast 169.254.255.255
   nd6 options=201<PERFORMNUD,DAD>
   media: autoselect (1000baseT <full-duplex>)
   status: active
```

15.3.6 Setting the Host Interface to Static IP

Use this to set your interface to be assigned a static IPv4 address. This is useful for controlling the IP address that the sensor will be sending data to.

Set your interface to static

Command

```
sudo ipconfig set [interface_name] MANUAL [ip_address] [subnet_mask]
```

Example

with interface name `en1` and IPv4 address `192.0.2.1` and subnet mask `255.255.255.0`.

```
Mac-Computer:~ username$ sudo ipconfig set en1 MANUAL 192.0.2.1 255.255.255.0
```

Note: The `/24` is shorthand for Subnet Mask = `255.255.255.0`

Response

```
blank

Note: However you can verify the change has been made with the ``ifconfig`` command.
      The ``inet`` line will show the static IPv4 address. e.g. ``192.0.2.1``.
```

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```
en1: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500

options=6407<RXCSUM,TXCSUM,VLAN_MTU,CHANNEL_IO,PARTIAL_CSUM,ZEROINVERT_CSUM>
 ether 48:65:ee:1d:22:35
 inet6 fe80::1c24:5e0a:2ea8:12e9%en1 prefixlen 64 secured scopeid 0x7
 inet 192.0.2.1 netmask 0xffffff00 broadcast 192.0.2.255
 nd6 options=201<PERFORMNUD,DAD>
 media: autoselect (1000baseT <full-duplex>)
 status: active
```

15.3.7 Finding a Sensor with mDNS Service Discovery

Warning: Until FW v3.0.1 Ouster sensors used Multicast Domain Name Service (mDNS) with a service type named `_roger._tcp`. This is now subject to deprecation, please use `_ouster-lidar._tcp` starting FW v3.1 and later.

With mDNS Service Discovery:

The sensor announces its presence on the network using Multicast Domain Name Service (mDNS) with a service type named `_ouster-lidar._tcp`. You can use service discovery tools such as dns-sd (Windows/macOS) to find all sensors connected to the network.

1. Find all sensors and their associated service text on a network.

Command

```
dns-sd -Z [service type]
```

Example

```
Mac-Computer:~ username$ dns-sd -Z _ouster-lidar._tcp
```

Response

```
Browsing for _ouster-lidar._tcp
DATE: ---Thu 30 Apr 2020---
17:27:52.242  ...STARTING...

; To direct clients to browse a different domain, substitute that domain in
 place of '@'
lb._dns-sd._udp                                 PTR     @

; In the list of services below, the SRV records will typically reference dot-local
 Multicast DNS names.
; When transferring this zone file data to your unicast DNS server, you'll need to
 replace those dot-local
; names with the correct fully-qualified (unicast) domain name of the target host
 offering the service.
```

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```
_ouster-lidar._tcp                                  PTR
Ouster Sensor |sn|._ouster-lidar._tcp
Ouster Sensor |sn|._ouster-lidar._tcp    SRV     0 0 7501 |os-sn|. ;
Replace with unicast FQDN of target host
Ouster Sensor |sn|._ouster-lidar._tcp    TXT     "pn=840-102145-B" "sn= |sn|"
"fw=ousteros-image-prod-aries-v2.0.0-20200417193957" "sn= |sn|"
```

2. Browse for the sensor IPv4 address using dns-sd and the sensor hostname.

Command

```
dns-sd -G v4 [sensor_hostname]
```

Example

```
Mac-Computer:~ username$ dns-sd -G v4 |os-sn|
```

Response

```
DATE: ---Thu 30 Apr 2020---
17:37:33.155  ...STARTING...
Timestamp     A/R  Flags  if  Hostname                Address           TTL
17:37:33.379  Add  2      7   |os-sn|.  |sensor-ip|     120
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`

With Discovery App:

Step 1: User can download the Discovery DNS-SD

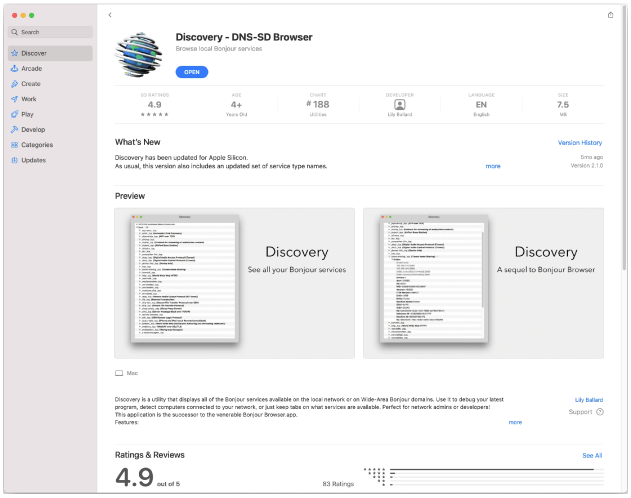

Figure 15.4: Downloading Application

Step 2: Using finder, the user can search for *Discovery*

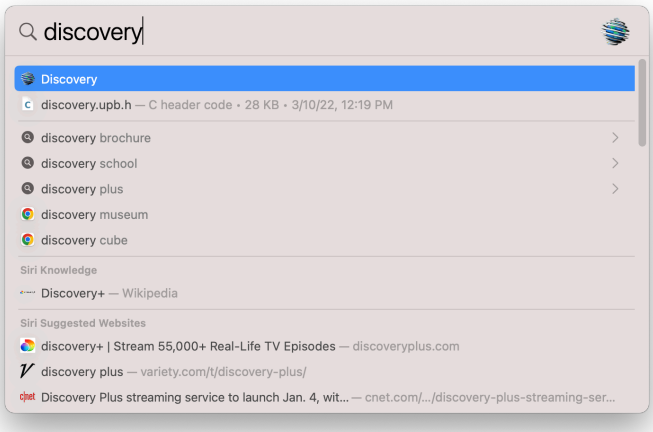

Figure 15.5: Finding the Application

Step 3: Sensor announces its presence on the network using Multicast Domain Name Service (mDNS) with a service type named `_ouster-lidar._tcp`. Click on this to get all the information required.

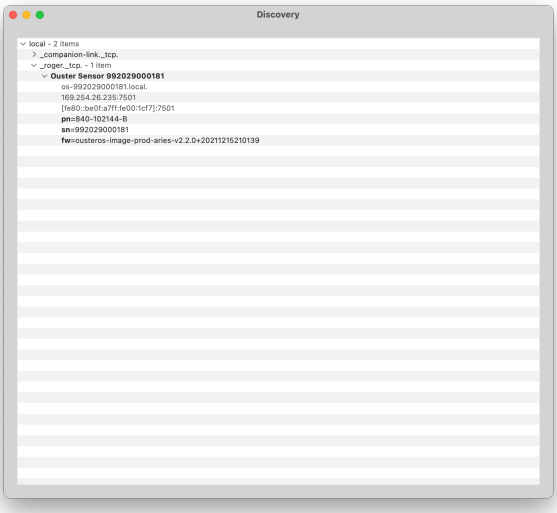

Figure 15.6: `_ouster-lidar._tcp`

15.4 Linux

The following steps have been tested on Ubuntu 18.04 & 20.04.4 LTS. In this example the sensor's hostname is `os-991234567890.local`, where `991234567890` is the sensor serial number. The sensor serial number can be found on a sticker affixed to the top of the sensor.

15.4.1 Connecting the Sensor

1. Connect the sensor to an available Ethernet port on your host machine or router.
2. The sensor will automatically obtain an IP address either through link-local or DHCP (if preconfigured) depending on your network configuration.
3. If directly connecting to the host machine you may need to set your Ethernet interface to `Link-Local Only` mode. This can be done via the command line or GUI. See instructions in *Setting the Interface to Link-Local Only*

Note: It can take up to 60 seconds to obtain an IP address from the initial power-up of the sensor.

15.4.2 Setting the Interface to Link-Local Only

Via Command Line

Command

```
nmcli con modify [interface_name] ipv4.method link-local ipv4.addresses ""
```

Note: To identify the name of your connection, please use the command: `nmcli connection show`.

Example

with interface name `eth0` and IPv4 address `""`.

```
username@ubuntu:~$ nmcli con modify eth0 ipv4.method link-local ipv4.addresses ""
```

Response

```
blank

Note: However you can verify the change has been made with the ``ip addr`` command.
      The ``inet`` line for the interface ``eth0`` will show the link-local IPv4 address automatically
      negotiated once the sensor is reconnected to the interface. e.g. |interface-ip|.


1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group
       default qlen 1000
   link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
   inet 127.0.0.1/8 scope host lo
```

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```
      valid_lft forever preferred_lft forever
   inet6 ::1/128 scope host
      valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
       default qlen 1000
   link/ether 00:0c:29:2b:cc:48 brd ff:ff:ff:ff:ff:ff
   inet |interface-ip|/16 brd 169.254.255.255 scope link noprefixroute eth0
      valid_lft forever preferred_lft forever
   inet6 fe80::be9f:d2a4:4451:3dfe/64 scope link noprefixroute
      valid_lft forever preferred_lft forever
3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
   default qlen 1000
   link/ether 00:50:56:28:7a:8a brd ff:ff:ff:ff:ff:ff
   inet 172.16.79.232/24 brd 172.16.79.255 scope global wlan0
      valid_lft forever preferred_lft forever
   inet6 fe80::250:56ff:fe28:7a8a/64 scope link
      valid_lft forever preferred_lft forever
```

Via GUI: The image below illustrates how to set the interface to `Link-Local Only` mode using the graphical user interface.

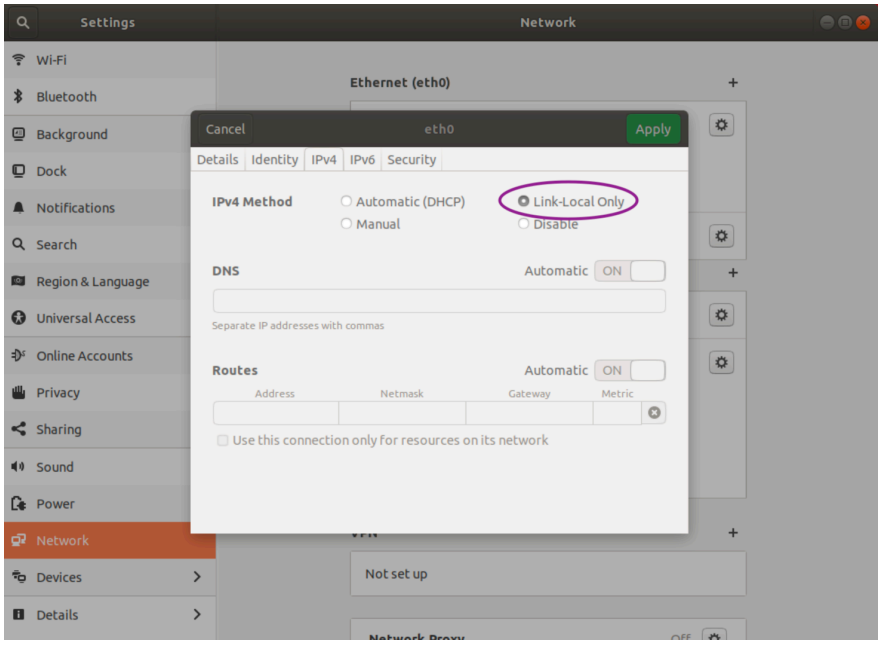

Figure 15.7: Set interface to Link-Local Only via the GUI

Note: It can take up to 60 seconds to obtain an IP address from the initial power-up of the sensor.

15.4.3 The Sensor Homepage

1. Type `os-991234567890.local/` in the address bar of your browser to view the sensor homepage

---

Note: If you are unable to load the sensor homepage, follow the steps in *Determining the IPv4 Address of the Sensor* to verify your sensor is on the network and has a valid IPv4 address.

15.4.4 Determining the IPv4 Address of the Sensor

1. Open a Terminal window on the host machine by pressing **Ctrl+Alt+T**.
2. Use the `ping` command to determine the IPv4 address of the sensor

Command

```
ping -4 -c3 [sensor_hostname]
```

Example

```
username@ubuntu:~$ ping -4 -c3 |os-sn|
```

Note: If this command hangs you may need to go back and configure your interface to link-local in the section *Setting the Interface to Link-Local Only*

Response

```
PING |os-sn| (|sensor-ip|) 56(84) bytes of data.
64 bytes from |os-sn| (|sensor-ip|): icmp_seq=1 ttl=64 time=1.56 ms
64 bytes from |os-sn| (|sensor-ip|): icmp_seq=2 ttl=64 time=0.893 ms
64 bytes from |os-sn| (|sensor-ip|): icmp_seq=3 ttl=64
time=0.568 ms

--- |os-sn| ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2025ms
rtt min/avg/max/mdev = 0.568/1.008/1.565/0.416 ms
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

---

3. You can also browse for the sensor IPv4 address using `avahi-browse` and the sensor service type, which is `_ouster-lidar._tcp`. Learn more about this in *Finding a Sensor with mDNS Service Discovery*

Command

```
avahi-browse -lrt [service type]
```

Example

```
username@ubuntu:~$ avahi-browse -lrt _ouster-lidar._tcp
```

Response

```
+   eth0 IPv6 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
+   eth0 IPv4 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
=   eth0 IPv6 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
   hostname = [|os-sn|]
   address = [fe80::be0f:a7ff:fe00:1852]
   port = [7501]
   txt = ["fw=ousteros-image-prod-aries-v2.0.0-20200417193957" "sn=99201000067
8" "pn=840-102145-B"]
=   eth0 IPv4 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
   hostname = [|os-sn|]
   address = [|sensor-ip|]
   port = [7501]
   txt = ["fw=ousteros-image-prod-aries-v2.0.0-20200417193957" "sn= |sn|"
          "pn=840-102145-B"]
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`. If your sensor IPv4 address is of the form `169.254.x.x` it is connected via link-local.

15.4.5 Determining the IPv4 Address of the Interface

This will help you find the IPv4 address of the interface that you have plugged the sensor into. It is helpful to know which interface you have plugged into, e.g. `eth0` in the example below.

1. Open a Terminal window on the host machine by pressing **Ctrl+Alt+T**.
2. View the IPv4 address of your interfaces

Command

```
ip addr
```

Example

```
username@ubuntu:~$ ip addr
```

Response

```
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group
       default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
```

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```
       default qlen 1000
    link/ether 00:0c:29:2b:cc:48 brd ff:ff:ff:ff:ff:ff
    inet |interface-ip|/16 brd 169.254.255.255 scope link noprefixroute eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::be9f:d2a4:4451:3dfe/64 scope link noprefixroute
       valid_lft forever preferred_lft forever
3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
       default qlen 1000
    link/ether 00:50:56:28:7a:8a brd ff:ff:ff:ff:ff:ff
    inet 192.0.2.232/24 brd 192.0.2.255 scope global wlan0
       valid_lft forever preferred_lft forever
    inet6 fe80::250:56ff:fe28:7a8a/64 scope link
       valid_lft forever preferred_lft forever
4: gpd0: <POINTOPOINT,MULTICAST,NOARP> mtu 1500 qdisc noop state DOWN group
       default qlen 500
    link/none
```

- In this example, your sensor is plugged into interface `eth0`.
- Your host IPv4 address will be on the line that starts with `inet`: In this case it is `169.254.0.1`.

Note: If your interface IPv4 address is of the form `169.254.x.x`, it is connected via link-local to the sensor. This means that the Linux self-assigned an IP address in the absence of a DHCP server.

15.4.6 Setting the Host Interface to DHCP

Use this to set your interface to automatically obtain an IP address via DHCP. This is useful for architectures that need to be more plug and play.

Note: It is recommended that you unplug the cable from the interface prior to making changes to the interface.

Via Command Line

Command

```
nmcli con modify [interface_name] ipv4.method auto ipv4.addresses ""
```

Example

with interface name `eth0`

```
username@ubuntu:~$ nmcli con modify eth0 ipv4.method auto ipv4.addresses ""
```

Response

```
 blank
```

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```
 Note: However you can verify the change has been made with the ``ip addr`` command.
       There will be no ``inet`` line for the interface ``eth0`` until you plug in a cable
       to a device that has a DHCP server to provide an IPv4 address the interface

1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group
   default qlen 1000
   link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
   inet 127.0.0.1/8 scope host lo
   valid_lft forever preferred_lft forever
   inet6 ::1/128 scope host
   valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
   default qlen 1000
   link/ether 00:0c:29:2b:cc:48 brd ff:ff:ff:ff:ff:ff
   inet6 fe80::be9f:d2a4:4451:3dfe/64 scope link noprefixroute
   valid_lft forever preferred_lft forever
3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
   default qlen 1000
   link/ether 00:50:56:28:7a:8a brd ff:ff:ff:ff:ff:ff
   inet 172.16.79.232/24 brd 172.16.79.255 scope global wlan0
   valid_lft forever preferred_lft forever
   inet6 fe80::250:56ff:fe28:7a8a/64 scope link
   valid_lft forever preferred_lft forever
```

Via GUI The image below illustrates how to set the interface to `Automatic (DHCP)` mode using the graphical user interface.

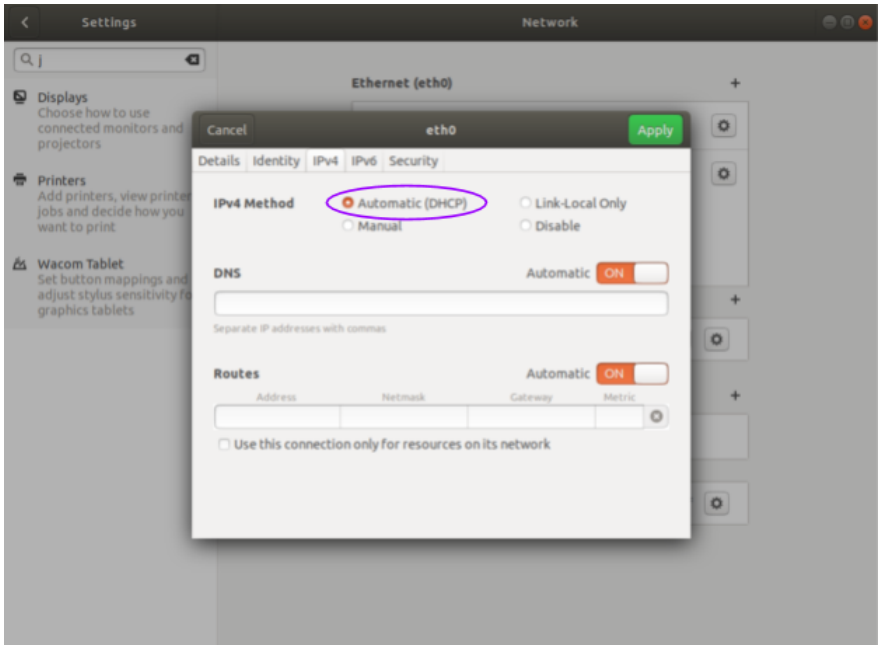


Figure 15.8: Set interface to Automatic (DHCP) via the GUI

15.4.7 Setting the Host Interface to Static IP

Use this to set your interface to be assigned a static IPv4 address. This is useful for controlling the IP address that the sensor will be sending data to.

Note: It is recommended that you unplug the cable from the interface prior to making changes to the interface.

Via Command Line

Command

```
nmcli con modify [interface_name] ipv4.method manual ipv4.addresses [ip_address]
```

Example

with interface name `eth0` and IPv4 address `192.0.2.1/24`.

```
username@ubuntu:~$ nmcli con modify eth0 ipv4.method manual ipv4.addresses 192.0.2.1/24
```

Note: The `/24` is shorthand for Subnet Mask = `255.255.255.0`

Response

```
blank

Note: However you can verify the change has been made with the ``ip addr`` command.
      The ``inet`` line for the interface ``eth0`` will show the static IPv4 address. e.g. ``192.0.2.1``

   1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group
          default qlen 1000
       link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
       inet 127.0.0.1/8 scope host lo
          valid_lft forever preferred_lft forever
       inet6 ::1/128 scope host
          valid_lft forever preferred_lft forever
   2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
          default qlen 1000
       link/ether 00:0c:29:2b:cc:48 brd ff:ff:ff:ff:ff:ff
       inet 192.0.2.1/24 brd 192.0.2.255 scope global noprefixroute eth0
          valid_lft forever preferred_lft forever
       inet6 fe80::be9f:d2a4:4451:3dfe/64 scope link noprefixroute
          valid_lft forever preferred_lft forever
   3: wlan0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group
          default qlen 1000
       link/ether 00:50:56:28:7a:8a brd ff:ff:ff:ff:ff:ff
       inet 172.16.79.232/24 brd 172.16.79.255 scope global wlan0
          valid_lft forever preferred_lft forever
       inet6 fe80::250:56ff:fe28:7a8a/64 scope link
          valid_lft forever preferred_lft forever
```

Via GUI The image below illustrates how to set the interface to `Manual (static)` mode using the graphical user interface.

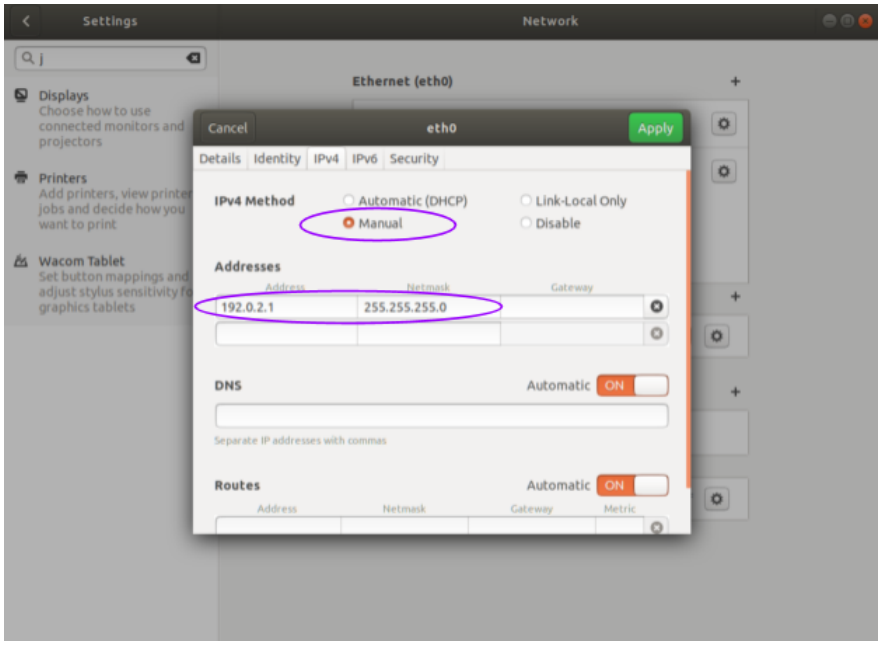


Figure 15.9: Set interface to Manual (static) via the GUI

15.4.8 Finding a Sensor with mDNS Service Discovery

Warning: Until FW v3.0.1 Ouster sensors used Multicast Domain Name Service (mDNS) with a service type named `_roger._tcp`. This is now subject to deprecation, please use `_ouster-lidar._tcp` starting FW v3.1 and later.

The sensor announces its presence on the network using Multicast Domain Name Service (mDNS) with a service type named `_ouster-lidar._tcp`. You can use service discovery tools such as `avahi-browse` (Linux) to find all sensors connected to the network.

1. Find all sensors and their associated service text which includes the sensor IPv4 address using `avahi-browse` and the sensor service type `_ouster-lidar._tcp`.

Command

```
avahi-browse -lrt [service type]
```

Example

```
username@ubuntu:~$ avahi-browse -lrt _ouster-lidar._tcp
```

Response

```
+   eth0 IPv6 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
+   eth0 IPv4 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
=   eth0 IPv6 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
   hostname = [|os-sn|]
   address = [fe80::be0f:a7ff:fe00:1852]
   port = [7501]
   txt = ["fw=ousteros-image-prod-aries-v2.0.0-20200417193957" "sn=99201000067
8" "pn=840-102145-B"]
=   eth0 IPv4 Ouster Sensor |sn|                    _ouster-lidar._tcp          local
   hostname = [|os-sn|]
   address = []
   port = [7501]
   txt = ["fw=ousteros-image-prod-aries-v2.0.0-20200417193957" "sn= |sn|"
          "pn=840-102145-B"]
```

Note: In this example, your sensor IPv4 address is determined to be `169.254.0.123`.

16 Appendix

16.1 PTP Profiles Guide

16.1.1 Overview

This guide provides instructions on setting the Precision Time Protocol (PTP) profile of the Ouster sensor. The profile of the Ouster sensor and your master clock must match for time synchronization to be possible.

PTP Profiles

There are several PTP profiles that are commonly used. The supported profiles on the Ouster sensor are listed below:

- `"default"` - The IEEE 1588 Default PTP profile addresses many common applications. Most PTP capable devices support the Default profile.
- `"gptp"` - Generalized PTP (gPTP) is the common name for the IEEE standard 802.1AS-2011 which improves the interoperability of PTP by simplifying the supported options. The gPTP profile is useful when using the Ouster sensor with gPTP compatible hardware such as an Audio Visual Bridge (AVB), e.g. the MOTU AVB.
- `"automotive-slave"` - The Automotive Slave PTP profile is an extension to gPTP for automotive specific use cases. In particular it disables the BMCA and handles time steps to expedite convergence.
- `"default-l2-relaxed"` - This profile is based on the `"default"` profile, but with the network transport set to L2 and a relaxed 1 second time step threshold.

16.1.2 PTP HTTP API

The PTP profile of the sensor is changed using an HTTP PUT request. This can be done using several different tools such as HTTPie, curl, Advanced REST Client, etc.

- The request URL is *GET /api/v1/time/ptp/profile* and *PUT /api/v1/time/ptp/profile*.
- Valid values are (“”, are included):
  - `"default"`[1]
  - `"gptp"`[2]
  - `"automotive-slave"`[3]
  - `"default-l2-relaxed"`[4]

[1] `"default"` is a layer 3 (UDP) mechanism.
[2] `"gptp"` is a layer 2 (Ethernet) mechanisms.
[3] `"automotive-slave"` is a layer 2 (Ethernet) mechanism.
[4] `"default-l2-relaxed"` is a layer 2 (Ethernet) mechanism.

Note: Changing the PTP profile does not require reinitialization or writing the configuration text file to be persistent. It is persistent as soon a valid PUT request is executed and a valid response is received.

16.1.3 Enabling the PTP profiles

Below are some examples using popular command-line tools.

Example using cURL

In this example we are setting the PTP profile of the Ouster sensor to `"gptp"` using the cURL command line tool.

- Command

```
curl -X PUT -H "Content-Type: application/json" -d '"gptp"' http://<sensor_hostname>/api/v1/time/ptp/profile/
```

- Response

```
"gptp"%
```

Example using HTTPie

In this example we are setting the PTP profile of the Ouster sensor to `"default"` using the HTTPie command line tool.

- Command

```
http PUT http://<sensor_hostname>/api/v1/time/ptp/profile <<< '"default"'
```

- Response

```
"default"%
```

Sync Verification

Please see the *Verifying Operation* section for details on how to verify the sensor is synchronized.

16.2 PTP Quickstart Guide

16.2.1 Overview

There are many configurations for a PTP network, this quick start guide aims to cover the basics by using Ubuntu 18.04 as an example. It provides configuration settings for a commercial PTP grandmaster clock and also provides directions on setting up a Linux computer (Ubuntu 18.04) to function as a PTP grandmaster.

The linuxptp project provides a suite of PTP tools that can be used to serve as a PTP master clock for a local network of sensors.

Assumptions

- Command line Linux knowledge (e.g., package management, command line familiarity, etc.).
- Ethernet interfaces that support hardware timestamping.
- Ubuntu 18.04 is assumed for this tutorial, but any modern distribution should suffice.
- Knowledge of systemd service configuration and management.
- Familiarity with Linux permissions.

Physical Network Setup

Ensure the Ouster sensor is connected to the PTP master clock with at most one network switch. Ideally the sensor should be connected directly to the PTP grandmaster. Alternatively, a simple layer-2 gigabit Ethernet switch will suffice. Multiple switches are not recommended and will add unnecessary jitter.

Third Party Grandmaster Clock

A dedicated grandmaster clock should be used for the highest absolute accuracy often with a GPS receiver.

It must be configured with the following parameters which match the *linuxptp* client defaults:

- Transport: `UDP IPv4`
- Delay Mechanism: `E2E`
- Sync Mode: `Two-Step`
- Announce Interval: `1` - sent every 2 seconds
- Sync Interval: `0` - sent every 1 second
- Delay Request Interval: `0` - sent every 1 second

For more settings, review the `port_data_set` field returned from the sensor's `HTTP /time/ptp` interface.

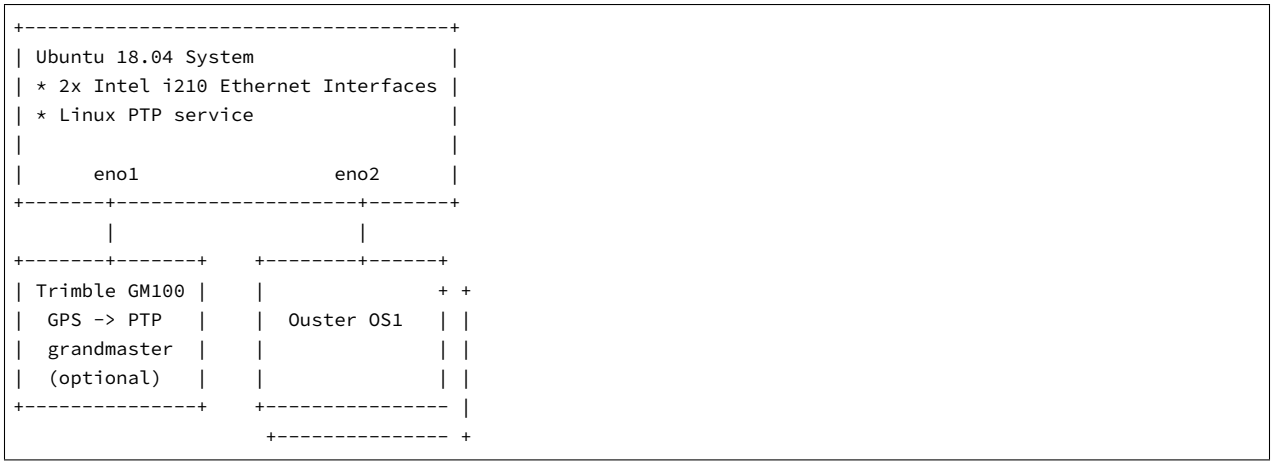
Linux PTP Grandmaster Clock

An alternative to an external grandmaster PTP clock is to run a local Linux PTP master clock if accuracy allows. This is often implemented on a vehicle computer that interfaces directly with the lidar sensors.

This section outlines how to configure a master clock.

Example Network Setup

This section assumes the following network setup as it has elements of a local master clock and the option for an upstream PTP time source.



The focus is on configuring the Linux PTP service to serve a common clock to all the downstream Ouster sensors using the Linux system time from the Ubuntu host machine.

Optionally, a grandmaster clock can be added to discipline the system time of the Linux host.

Installing Necessary Packages

Several packages are needed for PTP functionality and verification:

- `linuxptp` - Linux PTP package with the following components:
  - `ptp4l` daemon to manage hardware and participate as a PTP node
  - `phc2sys` to synchronize the Ethernet controller's hardware clock to the Linux system clock or shared memory region
  - `pmc` to query the PTP nodes on the network.
- `chrony` - A NTP and PTP time synchronization daemon. It can be configured to listen to both NTP time sources via the Internet and a PTP master clock such as one provided by a GPS with PTP support. This will validate the time configuration makes sense given multiple time sources.
- `ethtool` - A tool to query the hardware and driver capabilities of a given Ethernet interface.

```
$ sudo apt update
...
Reading package lists... Done
Building dependency tree
Reading state information... Done

$ sudo apt install linuxptp chrony ethtool
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following NEW packages will be installed:
  chrony ethtool linuxptp
0 upgraded, 3 newly installed, 0 to remove and 29 not upgraded.
Need to get 430 kB of archives.
After this operation, 1,319 kB of additional disk space will be used.
Get:1 http://us.archive.ubuntu.com/ubuntu bionic/main amd64 ethtool amd64 1:4.15-0ubuntu1 [114 kB]
Get:2 http://us.archive.ubuntu.com/ubuntu bionic/universe amd64 linuxptp amd64 1.8-1 [112 kB]
Get:3 http://us.archive.ubuntu.com/ubuntu bionic-updates/main amd64 chrony amd64 3.2-4ubuntu4.2 [203 kB]
Fetched 430 kB in 1s (495 kB/s)
Selecting previously unselected package ethtool.
(Reading database ... 117835 files and directories currently installed.)
Preparing to unpack .../ethtool_1%3a4.15-0ubuntu1_amd64.deb ...
Unpacking ethtool (1:4.15-0ubuntu1) ...
Selecting previously unselected package linuxptp.
Preparing to unpack .../linuxptp_1.8-1_amd64.deb ...
Unpacking linuxptp (1.8-1) ...
Selecting previously unselected package chrony.
Preparing to unpack .../chrony_3.2-4ubuntu4.2_amd64.deb ...
Unpacking chrony (3.2-4ubuntu4.2) ...
Setting up linuxptp (1.8-1) ...
Processing triggers for ureadahead (0.100.0-20) ...
ureadahead will be reprofiled on next reboot
Setting up chrony (3.2-4ubuntu4.2) ...
Processing triggers for systemd (237-3ubuntu10.13) ...
Processing triggers for man-db (2.8.3-2ubuntu0.1) ...
Setting up ethtool (1:4.15-0ubuntu1) ...
```

Ethernet Hardware Timestamp Verification

Identify the Ethernet interface to be used on the client (Linux) machine, e.g., eno1. Run the ethtool utility and query this network interface for supported capabilities.

Output of `ethtool -T` for a functioning Intel i210 Ethernet interface:

```
$ sudo ethtool -T eno1
Time stamping parameters for eno1:
Capabilities:
        hardware-transmit     (SOF_TIMESTAMPING_TX_HARDWARE)
        software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
        hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
        software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
        software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
```

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```
        hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 0
Hardware Transmit Timestamp Modes:
        off                   (HWTSTAMP_TX_OFF)
        on                    (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
        none                  (HWTSTAMP_FILTER_NONE)
        all                   (HWTSTAMP_FILTER_ALL)
```

16.2.2 Configurations

Configuring `ptp4l` for Multiple Ports

On a Linux system with multiple Ethernet ports (i.e. Intel i210) `/etc/linuxptp/ptp4l.conf` needs to be configured to support all of them.

```
boundary_clock_jbod 1
[eno1]
[eno2]
```

Note: Add the above required modification at the end of the existing file. Deleting or editing the default settings section of the ptp4l.conf file will result in an error.

The default systemd service file for Ubuntu 18.04 attempts to use the eth0 address on the command line. Override systemd service file so that the configuration file is used instead of hard coded in the service file.

Create a systemd drop-in directory to override the system service file:

```
$ sudo mkdir -p /etc/systemd/system/ptp4l.service.d
```

Create a file at `/etc/systemd/system/ptp4l.service.d/override.conf` with the following contents:

```
[Service]
ExecStart=
ExecStart=/usr/sbin/ptp4l -f /etc/linuxptp/ptp4l.conf
```

Restart the `ptp4l` service so the change takes effect:

```
$ sudo systemctl daemon-reload
$ sudo systemctl restart ptp4l
$ sudo systemctl status ptp4l
* ptp4l.service - Precision Time Protocol (PTP) service
   Loaded: loaded (/lib/systemd/system/ptp4l.service; enabled; vendor preset: enabled)
  Drop-In: /etc/systemd/system/ptp4l.service.d
           └─override.conf
   Active: active (running) since Wed 2019-03-13 14:38:57 PDT; 3s ago
     Docs: man:ptp4l
```

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```
 Main PID: 25783 (ptp4l)
    Tasks: 1 (limit: 4915)
   CGroup: /system.slice/ptp4l.service
           └─25783 /usr/sbin/ptp4l -f /etc/linuxptp/ptp4l.conf

Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] port 1: INITIALIZING to LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] driver changed our HWTSTAMP options
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] tx_type   1 not 1
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] rx_filter 1 not 12
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] port 2: INITIALIZING to LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 0: INITIALIZING to LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 1: link up
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 2: link down
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 2: LISTENING to FAULTY on
FAULT_DETECTED (FT_UNSPECIFIED)
Mar 13 14:38:58 leadlizard ptp4l[25783]: [590189.360] port 1: new foreign master 001747.fffe.700038-1
```

The above `systemctl status ptp4l` console output shows systemd correctly reading the override file created earlier before starting several seconds after the restart command.

The log output shows that a grandmaster clock has been discovered on port 1 (`eno1`) and port 2 (`eno2`) is currently disconnected and in the faulty state as expected. In the test network a Trimble Thunderbolt PTP GM100 Grandmaster Clock is attached on `eno1`.

Logs can be monitored (i.e. followed) like so:

```
$ journalctl -f -u ptp4l
-- Logs begin at Fri 2018-11-30 06:40:50 PST. --
Mar 13 14:51:37 leadlizard ptp4l[25783]: [590948.224] master offset   -17 s2 freq  -25963 path delay 14183
Mar 13 14:51:38 leadlizard ptp4l[25783]: [590949.224] master offset   -13 s2 freq  -25964 path delay 14183
Mar 13 14:51:39 leadlizard ptp4l[25783]: [590950.225] master offset    35 s2 freq  -25920 path delay 14192
Mar 13 14:51:40 leadlizard ptp4l[25783]: [590951.225] master offset   -59 s2 freq  -26003 path delay 14201
Mar 13 14:51:41 leadlizard ptp4l[25783]: [590952.225] master offset   -24 s2 freq  -25986 path delay 14201
Mar 13 14:51:42 leadlizard ptp4l[25783]: [590953.225] master offset   -39 s2 freq  -26008 path delay 14201
Mar 13 14:51:43 leadlizard ptp4l[25783]: [590954.225] master offset    53 s2 freq  -25928 path delay 14201
Mar 13 14:51:44 leadlizard ptp4l[25783]: [590955.226] master offset   -85 s2 freq  -26050 path delay 14207
Mar 13 14:51:45 leadlizard ptp4l[25783]: [590956.226] master offset   127 s2 freq  -25863 path delay 14207
Mar 13 14:51:46 leadlizard ptp4l[25783]: [590957.226] master offset     9 s2 freq  -25943 path delay 14208
Mar 13 14:51:47 leadlizard ptp4l[25783]: [590958.226] master offset   -23 s2 freq  -25973 path delay 14208
Mar 13 14:51:48 leadlizard ptp4l[25783]: [590959.226] master offset   -61 s2 freq  -26018 path delay 14190
Mar 13 14:51:49 leadlizard ptp4l[25783]: [590960.226] master offset    69 s2 freq  -25906 path delay 14190
Mar 13 14:51:50 leadlizard ptp4l[25783]: [590961.226] master offset   -73 s2 freq  -26027 path delay 14202
Mar 13 14:51:51 leadlizard ptp4l[25783]: [590962.226] master offset    19 s2 freq  -25957 path delay 14202
Mar 13 14:51:52 leadlizard ptp4l[25783]: [590963.226] master offset   147 s2 freq  -25823 path delay 14202
...
```

Configuring ptp4l as a Local Master Clock

The IEEE-1588 Best Master Clock Algorithm (*BMCA*) will select a grandmaster clock based on a number of masters. In most networks there should be only a single master. In the example network the Ubuntu machine will be configured with a non-default *clockClass* so its operation qualifies it to win the BMCA.

Replace the default value with a lower clock class (higher priority) and restart linuxptp. Edit `/etc/linuxptp/ptp4l.conf` and comment out the default `clockClass` value and insert a line setting it 128.

```
#clockClass     248
clockClass      128
```

Restart ptp4l so the configuration change takes effect.

```
$ sudo systemctl restart ptp4l
```

This will configure `ptp4l` to advertise a master clock on eno2 as a clock that will win the BMCA for an Ouster OS1 sensor.

However, the `ptp4l` service is only advertising the Ethernet controller's PTP hardware clock, not the Linux system time as is often expected.

Configuring phc2sys to Synchronize the System Time to the PTP Clock

To synchronize the Linux system time to the PTP hardware clock the `phc2sys` utility needs to be run. The following configuration will tell `phc2sys` to take the Linux `CLOCK_REALTIME` and write that time to the PTP hardware clock in the Ethernet controller for `eno2`. These interfaces are then connected to PTP slaves such as Ouster OS1 sensors.

Create a systemd drop-in directory to override the system service file:

```
$ sudo mkdir -p /etc/systemd/system/phc2sys.service.d
```

Create a file at `/etc/systemd/system/phc2sys.service.d/override.conf` with the following contents:

```
[Service]
ExecStart=
ExecStart=/usr/sbin/phc2sys -w -s CLOCK_REALTIME -c eno2
```

Note: If multiple interfaces need to be synchronized from `CLOCK_REALTIME` then multiple instances of the `phc2sys` service need to be run as it only accepts a single slave (i.e. `-c`) argument.

Restart the `phc2sys` service so the change takes effect:

```
$ sudo systemctl daemon-reload
$ sudo systemctl restart phc2sys
$ sudo systemctl status phc2sys
```

Configuring Chrony to Set System Clock Using PTP

An upstream PTP grandmaster clock (e.g., a GPS disciplined PTP clock) can be used to set the system time if precise absolute time is needed for sensor data.

Chrony is a Linux time service that can read from NTP and PTP and set the Linux system time using the most accurate source available. With a properly functioning PTP grandmaster the PTP time source will be selected and the error from the public time servers can be reviewed.

The following phc2shm service will synchronize the time from `eno1` (where the external grandmaster is attached) to the system clock.

Create a file named `/etc/systemd/system/phc2shm.service` with the following contents:

```
# /etc/systemd/system/phc2shm.service
[Unit]
Description=Synchronize PTP hardware clock (PHC) to NTP SHM
Documentation=man:phc2sys
After=ntpdate.service
Requires=ptp4l.service
After=ptp4l.service

[Service]
Type=simple
ExecStart=/usr/sbin/phc2sys -s eno1 -E ntpshm -w

[Install]
WantedBy=multi-user.target
```

Then start the newly created service and check that it started.

```
$ sudo systemctl start phc2shm
$ sudo systemctl status phc2shm
```

Add the PTP time source to the chrony configuration which will read the shared memory region managed by the `phc2shm` service created above.

Append the following to the `/etc/chrony/chrony.conf` file:

```
refclock SHM 0 poll 1 refid ptp
```

Restart chrony so the updated configuration file takes effect:

```
$ sudo systemctl restart chrony
```

After waiting a minute for the clock to synchronize, review the chrony client timing accuracy:

```
$ chronyc tracking
Reference ID    : 70747000 (ptp)
Stratum         : 1
Ref time (UTC)  : Thu Mar 14 02:22:58 2019
System time     : 0.000000298 seconds slow of NTP time
```

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```
Last offset     : -0.000000579 seconds
RMS offset      : 0.001319735 seconds
Frequency       : 0.502 ppm slow
Residual freq   : -0.028 ppm
Skew            : 0.577 ppm
Root delay      : 0.000000001 seconds
Root dispersion : 0.000003448 seconds
Update interval : 2.0 seconds
Leap status     : Normal

$ chronyc sources -v
210 Number of sources = 9

  .-- Source mode  '~' = server, '=' = peer, '#' = local clock.
 / .- Source state '*' = current synced, '+' = combined , '-' = not combined,
| /   '?' = unreachable, 'x' = time may be in error, '~' = time too variable.
||                                               .- xxxx [ yyyy ] +/- zzzz
||      Reachability register (octal) -.         |  xxxx = adjusted offset,
||      Log2(Polling interval) --.      |        |  yyyy = measured offset,
||                                \     |        |  zzzz = estimated error.
||                                 |    |         \
MS Name/IP address         Stratum Poll Reach LastRx Last sample
===============================================================================
#* ptp                           0   1   377     1    +27ns[  +34ns] +/-  932ns
~~ chilipepper.canonical.com     2   6   377    61   -482us[ -482us] +/-   99ms
~~ pugot.canonical.com           2   6   377    62   -498us[ -498us] +/-  112ms
~~ golem.canonical.com           2   6   337    59   -467us[ -468us] +/-   95ms
~~ alphyn.canonical.com          2   6   377    58   +957us[ +957us] +/-   95ms
~~ legacy13.chi1.ntfo.org        3   6   377    62    -10ms[  -10ms] +/-  178ms
~~ tesla.selinc.com              2   6   377   128   +429us[ +514us] +/-   42ms
~~ io.crash-override.org         2   6   377    59   +441us[ +441us] +/-   58ms
~~ hadb2.smatwebdesign.com       3   6   377    58  +1364us[+1364us] +/-   99ms
```

Note that the `Reference ID` matches the `ptp` reference ID from the chrony.conf file and that the sources output shows the `ptp` reference ID as selected (signified by the `*` state in the second column). Additionally, the NTP time sources show a small relative error to the high accuracy PTP time source.

In this case the PTP grandmaster is properly functioning.

If this error is large, chrony will select the NTP time sources and mark the PTP time source as invalid. This typically signifies that something is mis-configured with the PTP grandmaster upstream of this device or the linuxptp configuration.

16.2.3 Verifying Operation

Changing the profile prompts the sensor to restart the synchronization process, generally preferred over rebooting the entire product. Typically, only the relaxed profiles adjust the clock more than once.

Table 16.1: Verifying PTP Operation for Rev7 with FW v3.1 and later

PTP Parameters	Default	gPTP	Automotive Slave	Default-L2 Relaxed
parent_data_set. grandmaster_identity	00005e.fffe. 005301	00005e.fffe. 005301	NA	00005e.fffe. 005301
port_data_set.port_state	SLAVE	SLAVE	SLAVE	SLAVE
time_status_np.gm_present	true	true	false	true
time_status_np. master_offset	< 1µs	< 1µs	< 1µs	< 1µs

PTP Example JSON Response for "Profile": `"default"`

To Query Sensor PTP State: Refer to *GET /api/v1/time/ptp/profile* and *PUT /api/v1/time/ptp/profile*.


```
{
  "profile": "default",
  "parent_data_set":
  {
    "grandmaster_identity": "001747.fffe.700038",
    "parent_port_identity": "ac1f6b.fffe.1db84e-2",
    "parent_stats": 0,
    "gm_clock_class": 6,
    "observed_parent_clock_phase_change_rate": 2147483647,
    "gm_clock_accuracy": 33,
    "gm_offset_scaled_log_variance": 65535,
    "grandmaster_priority1": 128,
    "grandmaster_priority2": 128,
    "observed_parent_offset_scaled_log_variance": 65535
  },
  "current_data_set":
  {
    "steps_removed": 1,
    "offset_from_master": 61355,
    "mean_path_delay": 117977.0
  },
  "port_data_set":
  {
    "port_state": "SLAVE",
    "peer_mean_path_delay": 0,
    "log_min_delay_req_interval": 0,
    "port_identity": "bc0fa7.fffe.c48254-1",
    "log_sync_interval": 0,
    "log_announce_interval": 1,
    "delay_mechanism": 1,
    "log_min_pdelay_req_interval": 0,
```


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```
    "announce_receipt_timeout": 3,
    "version_number": 2
  },
  "time_status_np":
  {
    "gm_time_base_indicator": 0,
    "gm_identity": "001747.fffe.700038",
    "cumulative_scaled_rate_offset": 0,
    "scaled_last_gm_phase_change": 0,
    "ingress_time": 0,
    "master_offset": 61355,
    "last_gm_phase_change": "0x0000'0000000000000000.0000",
    "gm_present": true
  },
  "time_properties_data_set":
  {
    "frequency_traceable": 0,
    "leap61": 0,
    "time_traceable": 0,
    "current_utc_offset": 37,
    "leap59": 0,
    "current_utc_offset_valid": 0,
    "time_source": 160,
    "ptp_timescale": 1
  }
}
```


LinuxPTP PMC Tool

The sensor will respond to PTP management messages. The linuxptp `pmc` (see `man pmc`) utility can be used to query all PTP devices on the local network.

On the Linux host for the `pmc` utility to communicate with then run the following command:

```
$ sudo pmc 'get PARENT_DATA_SET' 'get CURRENT_DATA_SET' 'get PORT_DATA_SET' 'get TIME_STATUS_NP' -i eno2
sending: GET PARENT_DATA_SET
sending: GET CURRENT_DATA_SET
sending: GET PORT_DATA_SET
sending: GET TIME_STATUS_NP
        bc0fa7.fffe.c48254-1 seq 0 RESPONSE MANAGEMENT PARENT_DATA_SET
                parentPortIdentity                    ac1f6b.fffe.1db84e-2
                parentStats                           0
                observedParentOffsetScaledLogVariance 0xffff
                observedParentClockPhaseChangeRate    0x7fffffff
                grandmasterPriority1                  128
                gm.ClockClass                         6
                gm.ClockAccuracy                      0x21
                gm.OffsetScaledLogVariance            0x4e5d
                grandmasterPriority2                  128
                grandmasterIdentity                   001747.fffe.700038
        bc0fa7.fffe.c48254-1 seq 1 RESPONSE MANAGEMENT CURRENT_DATA_SET
```

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```
                stepsRemoved     2
                offsetFromMaster 61355.0
                meanPathDelay    117977.0
        bc0fa7.fffe.c48254-1 seq 2 RESPONSE MANAGEMENT PORT_DATA_SET
                portIdentity            bc0fa7.fffe.c48254-1
                portState               SLAVE
                logMinDelayReqInterval  0
                peerMeanPathDelay       0
                logAnnounceInterval     1
                announceReceiptTimeout  3
                logSyncInterval         0
                delayMechanism          1
                logMinPdelayReqInterval 0
                versionNumber           2
        bc0fa7.fffe.c48254-1 seq 3 RESPONSE MANAGEMENT TIME_STATUS_NP
                master_offset              61355
                ingress_time               0
                cumulativeScaledRateOffset +0.000000000
                scaledLastGmPhaseChange    0
                gmTimeBaseIndicator        0
                lastGmPhaseChange          0x0000'0000000000000000.0000
                gmPresent                  true
                gmIdentity                 001747.fffe.700038
```

Tested Grandmaster Clocks

Trimble Thunderbolt PTP GM100 Grandmaster Clock

- Firmware version: `20161111-0.1.4.0, November 11 2016 15:58:25`
- PTP configuration:

```
 > get ptp eth0
             Enabled : Yes
           Clock ID : 001747.fffe.700038-1
            Profile : 1588
      Domain number : 0
  Transport protocol : IPV4
            IP Mode : Multicast
    Delay Mechanism : E2E
          Sync Mode : Two-Step
        Clock Class : 6
         Priority 1 : 128
         Priority 2 : 128
      Multicast TTL : 0
      Sync interval : 0
   Del Req interval : 0
       Ann. interval : 1
Ann. receipt timeout : 3
```

- Ubuntu 18.04 + Linux PTP as a master clock
    - Intel i210 Ethernet interface
    - PCI hardware identifiers: `8086:1533 (rev 03)`
- Ubuntu 18.04 kernel package: `linux-image-4.18.0-16-generic`
- Ubuntu 18.04 linuxptp package: `linuxptp-1.8-1`

16.3 Analyzing Linux Networking Issues

Note: Users are recommended to follow this section only in the case of intermittent packet drops or packet reordering. Please make sure to double check `udp_dest` settings at the beginning of this section, as the information provided is not useful if users are getting zero data.

In case the users are getting zero data and are unable to resolve the issue please contact our Field Application Team.

This section captures tools and procedures to troubleshoot networking issues for a system consisting of a PC/Workstation L2 Switch and one or more Ouster Sensors. Though examples use the Linux Operating System as a model, the material is equally relevant to debugging issues in the Windows environment. Where possible Windows command-line and UI analogs will be discussed in passing.

Debugging the Workstation Data Path

The workstation maintains a set of statistics associated with each layer in the network stack that can be used to diagnose packet loss. The correct way to approach a network stack problem is to start with the lowest layer in the stack first, examine the statistics for errors, and work your way up to the highest layer. The reason that we start with the lowest layer is that issues in the lowest layer can cause issues in other parts of the data-path.

16.3.1 Link Layer Statistics and Configuration

ethtool

In Linux, ethtool is used to query the NIC for statistics as well as view and change the NIC configuration. Linux also offers more generic mechanisms to do this by writing/reading keys in the kernel file-system. Ethtool is often the tool that is widely use to debug system, and is generally the most complete system for configuration and debug. Ethtool is a double edged-sword, because ethtool is vendor-centric the output of its commands and range of configuration options will be slightly different depending on which NIC is used.

Line Interface Statistics

The most useful starting point when debugging the link-layer is to examine the line-interface statistics, these are queried with ethtool -S <ethX> where ethX is the identifier of the NIC as listed by ifconfig, if the device has multiple NICs and you are uncertain which NIC is receiving the traffic, run some traffic and monitor the stats reported by ifconfig.

Note: The output of ethtool -S <ethX> is 100% NIC vendor specific and will be quite different depending on NIC vendor used in your system.

Example: Output of ethtool -S:

```
NIC statistics:
    rx_packets: 0
    tx_packets: 0
    rx_bytes: 0
```

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```
    tx_bytes: 0
    rx_broadcast: 0
    tx_broadcast: 0
    rx_multicast: 0
    tx_multicast: 0
    rx_errors: 0
    tx_errors: 0
    tx_dropped: 0
    multicast: 0
    collisions: 0
    rx_length_errors: 0
    rx_over_errors: 0
    rx_crc_errors: 0
    rx_frame_errors: 0
    rx_no_buffer_count: 0
    rx_missed_errors: 0
    tx_aborted_errors: 0
    tx_carrier_errors: 0
    tx_fifo_errors: 0
    tx_heartbeat_errors: 0
    tx_window_errors: 0
    tx_abort_late_coll: 0
    tx_deferred_ok: 0
    tx_single_coll_ok: 0
    tx_multi_coll_ok: 0
    tx_timeout_count: 52
    tx_restart_queue: 0
    rx_long_length_errors: 0
    rx_short_length_errors: 0
    rx_align_errors: 0
    tx_tcp_seg_good: 0
    tx_tcp_seg_failed: 0
    rx_flow_control_xon: 0
    rx_flow_control_xoff: 0
    tx_flow_control_xon: 0
    tx_flow_control_xoff: 0
    rx_csum_offload_good: 0
    rx_csum_offload_errors: 0
    rx_header_split: 0
    alloc_rx_buff_failed: 0
    tx_smbus: 0
    rx_smbus: 0
    dropped_smbus: 0
    rx_dma_failed: 0
    tx_dma_failed: 0
    rx_hwtstamp_cleared: 0
    uncorr_ecc_errors: 0
    corr_ecc_errors: 0
    tx_hwtstamp_timeouts: 0
    tx_hwtstamp_skipped: 0
```

MAC Errors

Users are mainly interested in the path where the sensor is transmitting to the workstation, focusing on the "rx" (receive) statistics. Generally, anything that is labeled as rx.*error on this NIC constitutes a stats that might be helpful in diagnosing the problem.

Based on the NIC, these "error" statistics are primarily associated with problems identified by the MAC. Such problems are generally indicative of an L1 problem (though they could also indicate a problem with the link-partner's MAC), such as a loose connector, faulty transceiver, or an out-of-spec cable.

Internal System Errors

User might come across stats like rx_dma_failed and rx_no_buffer_count that do not have an "error" postfix but constitute very real errors. These are indicative of failures in the hand-off between the NIC driver.

Solving MAC Errors

If users encounter MAC errors this most likely points to a cabling issue, so the first step would be to replace the cable. If the errors persist, the next step would be to try to test against a different node. One can use the "iPerf" or "iPerf3" utility (discussed below) to validate that the workstation against another workstation computer. A final step would be to swap out the sensor.

Solving Internal System Errors

These errors are often the most difficult to understand. It can be quite surprising that the MAC is receiving everything and traffic is still being dropped. The root cause is generally that the processor cannot handle the peak rate. Though the average load may be only a few hundred megabits, the real situation is that all traffic received by the NIC arrives at line rate - for a 10G NIC this means that many frames may be received back-to-back at the line rate of the NIC.

Just how many frames arrive depends on the behavior of the sensors. Ouster sensor attempts to transmit the data as it is captured. Assuming a 40K (on the wire) LiDAR frame and 10 sensors, the worst case load will be 40K x 10 = 400K at 10G (since the peak transmit rate of each sensor is 1G x 10 = 10G.) 400K is a lot of 10G data to process all at once, and without hardware buffering things will certainly fail.

The NIC maintains a hardware ring-buffer or on advanced hardware, potentially multiple ring-buffers. The entries in the ring-buffer are pointers into kernel packet-buffer structures. This mechanism enables the NIC to efficiently deliver packets to the kernel at line rate. For our specific use-case the default size of this ring-buffer may be too small.

To update this value user can use ethtool:

- ethtool -g <ethX> will display the current setting and device limits
- ethtool -G <ethX> rx <value> is used to update the setting

Example: Using a laptop/system, ring-buffer has enough buffer for 256 entries by default:

```
ethtool -g enp0s31f6
Ring parameters for enp0s31f6:
Pre-set maximums:
RX: 4096
```

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```
RX Mini: 0
RX Jumbo: 0
TX: 4096
Current hardware settings:
RX: 256
RX Mini: 0
RX Jumbo: 0
TX: 256
```

To find out how much buffer is sufficient we can apply the burst-tolerance equation:

```
fill_rate = NIC_line_speed - max_measured_throughput
fill_time = rx_buffer_size * 1518 * 8 / fill_rate
MBS = fill_time * NIC_line_speed
```

Note: It is not always easy to obtain max_measured_throughput, and in a busy workstation it can be subject to variable delay.

As a rule-of-thumb we need to at least accommodate one max-burst (one LiDAR packet) from the sensor. Assuming a 40KB LiDAR packet that's 40KB/1518=27 frames. So 256 should be more than adequate.

However, even with the default buffer of 256, user can observe packet loss due to DMA errors. This is because the work-station is not a real-time system and the delay can be quite variable. Linux uses a technique called interrupt coalescence that determines how often it will service the driver, when it gets very busy.

Interrupt coalescence is controlled by the kernel filesystem key:

```
/proc/sys/net/core/netdev_budget_usecs and by default its 8000us!
```

If the problem is not resolved by increasing the buffer size, its possible to reduce net-dev_budget_usecs in order to favor moving data over other activities that the system could be doing. Its also possible to increase the maximum number of frames the OS is willing to process when the line interface does get serviced which is controlled by:

```
/proc/sys/net/core/netdev_budget
```

Note: On some systems the user need to make the rx-ring-buffer quite large or disable interrupt coalescence all together.

In addition to the "soft" interrupt coalescence that is found under /proc/sys/net/core the NIC itself will delay the hardware interrupt. User can find the settings with ethtool in the usual way. Here is an example that shows the ACQ107's default settings:

```
ethtool -c enp4s0
Coalesce parameters for enp4s0:
Adaptive RX: off
```

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```
TX: off
stats-block-usecs: 0
sample-interval: 0
pkt-rate-low: 0
pkt-rate-high: 0
rx-usecs: 112
rx-frames: 0
rx-usecs-irq: 0
rx-frames-irq: 0
tx-usecs: 510
tx-frames: 0
tx-usecs-irq: 0
tx-frames-irq: 0
rx-usecs-low: 0
rx-frames-low: 0
tx-usecs-low: 0
tx-frames-low: 0
rx-usecs-high: 0
rx-frames-high: 0
tx-usecs-high: 0
tx-frames-high: 0
```

Another useful parameter is the /proc/sys/net/core/netdev_max_backlog. The backlog queue, is a FIFO on the other side of the NIC ring-buffer. Increasing the backlog buffer is one more way to add capacity earlier in the data-path. Its difficult to determine when to increase netdev_max_backlog vs increasing the rx ring-buffer. Certainly the ring-buffer is the only place where we can add capacity that can absorb traffic bursts at line rate.

Troubleshooting Advanced NICs

Advanced hardware interfaces have multiple ring-buffers that are typically mapped to different CPU cores (a technique known as RSS.) Each NIC has its own proprietary scheme for mapping input traffic flows to ring-buffers, and sometimes a NIC will incorrectly split a traffic flow into multiple FIFOs. If you see this behavior it means that the NIC itself will cause frames to be reordered in a way that will horribly disrupt the IP stack above it. The ACQ107 is one such NIC. The problem can be identified by looking at ethtool -S <ethX>. The NIC will list stats for each FIFO, and by sending a single large traffic flow we can see that device errantly split the flow into all of the different FIFOs. Below you can see that this NIC has stats labeled Queue[0] ... Queue[7].

Example:

```
ethtool -S enp4s0
NIC statistics:
InPackets: 350287807
InUCast: 350048688
InMCast: 231724
InBCast: 7395
InErrors: 0
OutPackets: 363162007
OutUCast: 363160208
OutMCast: 1306
OutBCast: 493
```

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```
InUCastOctets: 525223100117
OutUCastOctets: 545214487081
InMCastOctets: 16440320
OutMCastOctets: 206101
InBCastOctets: 1316312
OutBCastOctets: 58497
InOctets: 525240856749
OutOctets: 545214751679
InPacketsDma: 23207849
OutPacketsDma: 22064728
InOctetsDma: 34568308793
OutOctetsDma: 33164524696
InDroppedDma: 2002075
Queue[0] InPackets: 23087183
Queue[0] InJumboPackets: 0
Queue[0] InLroPackets: 0
Queue[0] InErrors: 0
Queue[0] AllocFails: 0
Queue[0] SkbAllocFails: 0
Queue[0] Polls: 7373190
Queue[0] OutPackets: 649028
Queue[0] Restarts: 0
Queue[1] InPackets: 80
Queue[1] InJumboPackets: 0
Queue[1] InLroPackets: 0
Queue[1] InErrors: 0
Queue[1] AllocFails: 0
Queue[1] SkbAllocFails: 0
Queue[1] Polls: 14672
Queue[1] OutPackets: 1651541
Queue[1] Restarts: 0
Queue[2] InPackets: 103
Queue[2] InJumboPackets: 0
Queue[2] InLroPackets: 0
Queue[2] InErrors: 0
Queue[2] AllocFails: 0
Queue[2] SkbAllocFails: 0
Queue[2] Polls: 215484
Queue[2] OutPackets: 3815296
Queue[2] Restarts: 0
Queue[3] InPackets: 269
Queue[3] InJumboPackets: 0
Queue[3] InLroPackets: 0
Queue[3] InErrors: 0
Queue[3] AllocFails: 0
Queue[3] SkbAllocFails: 0
Queue[3] Polls: 14469
Queue[3] OutPackets: 1580307
Queue[3] Restarts: 0
Queue[4] InPackets: 119681
Queue[4] InJumboPackets: 0
Queue[4] InLroPackets: 0
Queue[4] InErrors: 0
Queue[4] AllocFails: 0
```

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```
Queue[4] SkbAllocFails: 0
Queue[4] Polls: 157920
Queue[4] OutPackets: 3670607
Queue[4] Restarts: 0
Queue[5] InPackets: 83
Queue[5] InJumboPackets: 0
Queue[5] InLroPackets: 0
Queue[5] InErrors: 0
Queue[5] AllocFails: 0
Queue[5] SkbAllocFails: 0
Queue[5] Polls: 9006
Queue[5] OutPackets: 931971
Queue[5] Restarts: 0
Queue[6] InPackets: 407
Queue[6] InJumboPackets: 0
Queue[6] InLroPackets: 0
Queue[6] InErrors: 0
Queue[6] AllocFails: 0
Queue[6] SkbAllocFails: 0
Queue[6] Polls: 15387
Queue[6] OutPackets: 1636793
Queue[6] Restarts: 0
Queue[7] InPackets: 43
Queue[7] InJumboPackets: 0
Queue[7] InLroPackets: 0
Queue[7] InErrors: 0
Queue[7] AllocFails: 0
Queue[7] SkbAllocFails: 0
Queue[7] Polls: 11584
Queue[7] OutPackets: 343508
Queue[7] Restarts: 0
PTP Queue[16] InPackets: 0
PTP Queue[16] InJumboPackets: 0
PTP Queue[16] InLroPackets: 0
PTP Queue[16] InErrors: 0
PTP Queue[16] AllocFails: 0
PTP Queue[16] SkbAllocFails: 0
PTP Queue[16] Polls: 0
PTP Queue[16] OutPackets: 0
PTP Queue[16] Restarts: 0
PTP Queue[31] InPackets: 0
PTP Queue[31] InJumboPackets: 0
PTP Queue[31] InLroPackets: 0
PTP Queue[31] InErrors: 0
PTP Queue[31] AllocFails: 0
PTP Queue[31] SkbAllocFails: 0
PTP Queue[31] Polls: 0
MACSec InCtlPackets: 0
MACSec InTaggedMissPackets: 0
MACSec InUntaggedMissPackets: 23252064
MACSec InNotagPackets: 23252064
MACSec InUntaggedPackets: 0
MACSec InBadTagPackets: 0
MACSec InNoSciPackets: 0
```

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```
MACSec InUnknownSciPackets: 0
MACSec InCtrlPortPassPackets: 0
MACSec InUnctrlPortPassPackets: 23252064
MACSec InCtrlPortFailPackets: 0
MACSec InUnctrlPortFailPackets: 0
MACSec InTooLongPackets: 0
MACSec InIgpocCtlPackets: 0
MACSec InEccErrorPackets: 0
MACSec InUnctrlHitDropRedir: 0
MACSec OutCtlPackets: 1
MACSec OutUnknownSaPackets: 22064727
MACSec OutUntaggedPackets: 0
MACSec OutTooLong: 0
MACSec OutEccErrorPackets: 0
MACSec OutUnctrlHitDropRedir: 0
```

The vendor provided a workaround in their README.

Note: RSS for UDP

Currently, NIC does not support RSS for fragmented IP packets, which leads to an incorrect handling of RSS for fragmented UDP traffic. To disable RSS for UDP one can use the following RX Flow L3/L4 rule: ethtool -N eth0 flow-type udp4 action 0 loc 32

When Stats Fail

Sometimes a NIC will drop frames without any error stats incrementing. When this happens, the issue can be detected by inserting a managed L2 switch in between the sensor and the workstation. The managed switch will report receive and transmit stats, which can be correlated against the rx stats of the NIC to determine that the NIC has dropped frames without incrementing any stat.

16.3.2 IP Statistics

After the link layer the next layer up is IP. IP errors can be identified with the netstat tool:

```
netstat -s
```

This tool will output a lot of information, but in this document we will focus on only the IP section.

In this report you can see that there are a few different error categories, and you have to review carefully through all of the text to find them:

Let's look at each class of error and consider its implications:

- Packets received with invalid address means that they were sent to our MAC, but with an incorrect source IP.
- Packets dropped because of missing route indicates that the packet was sent to the correct IP address but no client program was listening on the destination port.
- Fragments dropped after timeout means that we received some data but subsequent data didn't

arrive in time to be processed.

- Fragments reassemblies failed means that some data was missing due to an Ethernet frame being aborted by the stack or being lost in transit and the IP layer was not able to reassemble a complete datagram.

Debugging a Layer 3 Issue

The best way to debug issues in the IP layer is to find them in the link layer, because generally speaking layer-3 issues are caused by layer-2 bugs, but this is not always the case.

For instance, packets received with invalid address are probably indicative of stale ARP table entries or some other external network bug or temporal state that will most likely clear up on its own. This sort of problem is probably not worth debugging unless its persistent. Packets dropped because of missing route is more indicative of an issue at the application layer (the client or server simply wasn't listening when the packets arrived).

If a problem is detectable by L3 and not by L2, then it's most likely a problem in the NIC itself, and if the NIC isn't providing a FIFO or DMA stat that explains it. One possibility is packet reordering by the NIC. This can be detected by modifying

`/proc/sys/net/ipv4/ipfrag_max_dist`

This kernel attribute determines the systems tolerance to receiving out-of-order IPv4 frames. Nominally L2 networks do not reorder packets, so you should be able to configure a value of 1 and not observe a change in behavior. However, if setting a low threshold exacerbates the issue, or setting a high value makes the problem less severe then the NIC is most likely to blame.

16.3.3 Useful network debugging tools

iPerf

`iPerf` is a useful tool when debugging the performance of a network. It can be used to quickly validate whether or not a system can handle a given throughput. It can be configured to output a stream of data in a variety of formats to mimic the expected load on the system during use. For more information refer to iPerf documentation.

How to use iPerf to debug sensor network issues

`iPerf` can be used to rule out sensor failures, and quickly reproduce errors that occur when the network is under a high-traffic load. `iPerf` must be used from two machines:

- Server (receiving data)
- Client (sending data)

Both the server and client will measure the number of packets sent/received, and report a percentage of packets lost.

Example usage of `iPerf` to test sender can send 300Mbps of UDP packets of 20KB to receiver:

Receiver arguments

- `--server` : Required to indicate that this is the machine that will be RECEIVING data.

- `--port 5300` : Specify the port at which to listen for incoming data. Useful if testing with multiple sources simultaneously.

Sender arguments

- `--client` 192.168.88.248 : The IP address to send data to. Must be the IP address or hostname of the receiver.
- `--port 5300` : The port to send data to. This must match the -port argument provided by the receiver.
- `--udp` : Indicates that UDP traffic will be sent. If not supplied, TCP data will be sent.
- `--bitrate 300M` : The rate in (in bits per second) to send data to the receiver. This can be used to simulate different amounts of network load.This supports a suffix such as K , M , or G to indicate Kbps, Mbps, or Gbps instead of bps.
- `--length` 20K

17 Errata and Notices

Note: This section provides more information on new feature releases and certain bug fixes which might help users understand correct working/operation of the sensor.

17.1 Sensor restarts after long-term continuous operation

Change Type:

Firmware Bug (Affects FW v3.0, FW v2.5.2 and prior)

Approximate implementation date of bug fix in Firmware:

FW 2.5.3 and FW 3.1 will be available in Q1 2024.

Description of change:

All Ouster lidars running firmware versions prior to v2.5.3 and v3.1 will restart approximately every 36 - 118 days when left continuously operating in the `RUNNING` state; after three of such restarts sensors will enter `ERROR` state requiring a power cycle of the sensor. The issue is fixed in firmware versions v2.5.3 and v3.1. This issue can be mitigated by proactively fully power cycling the sensor at least once every 36 days.

Benefit of change:

All customers are strongly recommended to upgrade to the latest firmware version that fixes this issue. If this is not possible, refer to *Proposed workaround* section for a way to mitigate the issue.

Affected Products:

- For sensors running firmware versions 1.x or 2.x, all firmware versions prior to 2.5.3.
- For sensors running firmware versions 3.x, all firmware versions prior to 3.1.

Across all HW versions (Gen1, RevC, RevD, Rev5, Rev6, Rev7), all sensor variants OS0, OS1, OS2, OS-Dome.

Detailed description:

Sensors operating in the `RUNNING` state continuously (without restart/Power-cycle) will continue to operate until approximately the specified number of days in the table below have elapsed. This timeframe is contingent on the configured lidar mode. After this number of days elapses, if the sensor remains in the `RUNNING` state, it will restart automatically and raise alerts `0x100003d` and `0x100003e`, and go back to the `RUNNING` state. After this time period elapses 3 times, the sensor will transition to the `ERROR` state and log the alert `0x1000040`.

Table 17.1: Table

Sensor state	Lidar mode	Approximate time until automatic restart	Maximum restarts until ERROR state
INITIALIZING	N/A	N/A	N/A
ERROR	N/A	N/A	N/A
STANDBY	N/A	N/A	N/A
RUNNING	2048x10, 1024x20	~36 days	3
RUNNING	1024x10, 512x20	~67 days	3
RUNNING	512x10	~118 days	3

Note: All customers are strongly recommended to upgrade to the latest firmware version that fixes this issue. If this is not possible, please refer to the *Proposed workaround* section below for a way to mitigate the issue.

17.1.1 Proposed workaround

Some customers may not be able to update the firmware version to the latest firmware version. In such cases the following workarounds can be used:

Mitigation 1:

The error condition can be preempted by the user proactively power cycling the sensor at a convenient time before the error occurs.

Mitigation 2:

Send any compatible Ouster firmware update to the sensor using the `dry_run=1` argument. This will not actually perform any update and the sensor will restart afterwards.

Example Command (Linux):

```
curl -vH 'Content-Type: application/octet-stream' --data-binary @ousteros-image-prod-bootes-v3.0.1+20230209044733.img 'http://192.0.2.123/api/v1/system/firmware?dry_run=1'
```

```
POST /api/v1/system/firmware?dry_run=1 HTTP/1.1
Host: 192.0.2.123


User-Agent: curl/7.68.0
Accept: */*
```

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```
Content-Type: application/octet-stream
Content-Length: 42134428
Expect: 100-continue


Mark bundle as not supporting multiuse
HTTP/1.1 100 Continue
We are completely uploaded and fine
Mark bundle as not supporting multiuse
HTTP/1.1 204 No Content
Server: nginx
Date: Thu, 28 Apr 2022 17:49:58 GMT
Connection: keep-alive

Connection #0 to host 192.0.2.123 left intact
```

Mitigation 3:

Update the sensor firmware with the same firmware version running on the sensor. The sensor will automatically restart after the update completes.

Example Command (Linux):

```
curl -vH 'Content-Type: application/octet-stream' --data-binary @ousteros-image-prod-bootes-v3.0.1+20230209044733.img 'http://192.0.2.123/api/v1/system/firmware'
```

```
POST /api/v1/system/firmware HTTP/1.1
Host: 192.0.2.123


User-Agent: curl/7.68.0
Accept: */*
Content-Type: application/octet-stream
Content-Length: 42134428
Expect: 100-continue


Mark bundle as not supporting multiuse
HTTP/1.1 100 Continue
We are completely uploaded and fine
Mark bundle as not supporting multiuse
HTTP/1.1 204 No Content
Server: nginx
Date: Thu, 28 Apr 2022 17:49:58 GMT
Connection: keep-alive

Connection #0 to host 192.0.2.123 left intact
```

Sensor Firmware can also be updated by using the Sensor WebUI. Please refer to the *Sensor Web Interface* for more information on how to update the firmware using the Sensor WebUI.

Mitigation 4:

Alternatively, performing `DELETE` of the sensor configuration will also cause the sensor to reboot and reset the internal counter. After `DELETE` of the sensor configuration is performed, the sensor can be reconfigured. Issuing a `reinit` command or reconfiguring the sensor will not reset this counter or prevent this error condition from occurring.

```
DELETE /api/v1/sensor/config
```

Example HTTP command:

```
http DELETE 192.0.2.123/api/v1/sensor/config
```

Example curl command:

```
curl -i -X DELETE http://192.0.2.123/api/v1/sensor/config -H 'Content-Type: application/json'
```

```
DELETE /api/v1/sensor/config HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 204 No Content
Connection: keep-alive
Date: Mon, 10 Jul 2023 17:12:47 GMT
Server: nginx
```

Note: In addition to the sensor configuration being reset to the factory default settings, fields such as Static IP override, PTP profiles and the User Editable Data filed will be reset. Each of these mitigations resets the internal counters and will need to be performed periodically before the error occurs to be effective.

Recovery:

If the sensor reaches the `ERROR` state because it operated for long enough and a workaround was not performed, the counter can be reset by reconfiguring the sensor or issuing a `reinit` API command.

In case of any questions or concerns, Please contact Ouster Support.

18 Firmware Changelog

Firmware versions (3.0 & later) are only compatible on OS0/OS1/OSDome Hardware versions Rev7 and later. Please refer to FW 2.x or prior if you have hardware version Rev7 OS2, Rev 06 OS0/OS1/OS2 and prior generation sensors.

18.1 Firmware v3.1.0

Date May 2024

Description

"Added"

- Add Low Data Rate Dual Return profile i.e., *FUSA_RNG15_RFL8_NIR8_DUAL Return Profile*.
- Add config parameter for `min_range_threshold_cm` (Refer to *min_range_threshold_cm* for more information).
- Add config parameter for `return_order` (Refer to *return_order* for more information).
- Add config parameter for `Delete Config` (Refer to *DELETE /api/v1/sensor/config* for more information).
- Add PTP L2 E2E support, via a new PTP profile "default-l2-relaxed".
- Add new alerts, please refer to *Table of All Alerts and Errors* section for more information.
- Add config parameter for *User Editable Data* section in the API user guide, this field can be used for a number of purposes such as storing specific information about the sensor, qualifying a sensor, calibration data, or any other information.
- Add config parameter for *POST /api/v1/system/restart* to restart sensor or reinitialize a sensor.
- Add End-to-End Cyclic Redundancy Check (CRC) in configurable data packet format.
- Add config parameter for *GET /api/v1/sensor/metadata/imu_data_format*. User can get `imu_data_format` and `POST` config to change `gyro_fsr` and `accel_fsr` from `NORMAL` to `EXTENDED`.
- Add `Alert Flags` in Lidar data packet. All of the `udp_lidar_profile` have been updated to include alert flags at the packet level.

"Improved"

- Improved robustness for cold start.
- Reduced the occurrence of false alerts for `VCSEL_CURRENT_LOW`.
- Improved motor stability when decelerating to lower RPM during lidar mode switches.
- Minor PTP software update and reduced fault recovery time.
- Improved existing alerts to notify users when the network is not reachable. This enhancement enables users to promptly address connectivity issues, improving the overall reliability of the system.

- Improved startup time/reinit time by ~10-15 seconds.
- Improved sensor's webUI (*Sensor Web Interface*) to display client and UDP destination address.
- Allow IMU port to be set to `0` to disable IMU packet transmission.
- Improved recovery after Ethernet link loss that previously caused UDP stream to stall.

"Fixed"

- Apply PPS setting in `STANDBY` in order for `api/v1/time/sensor` to reflect provisioned configuration in `STANDBY`.
- Fixed handling of `NMEA` messages with fractional seconds. Previously, If NMEA sentence contains a fraction of a second time, the sensor would round the fraction up resulting into a future timestamp. This has been fixed.
- Fixed PPS/NMEA lock and time synchronisation. Previously, Sensor does not lock when gps is connected and Sync pulse in is selected. The sensor does not lock to an external PPS signal from GPS. This has now been fixed.
- Correct `IMU` polling rate to `100hz`.
- Fixed *GET /api/v1/sensor/alerts* input cursor correctly limits alert log.
- Fixed timestamp loop in PPS mode when PPS signal is lost. Timestamp will free-run instead of looping.
- Fixed sensor error that occurred when using continuously for 1-4 months depending on mode. Please refer to *Errata and Notices* for more information.
- Support for local `udp_dest` address via sensor Web_UI.
- Fixed a bug where the lidar starts to send data when powering ON before establishing connection with the client machine.
- Fixed a bug where the sensor would be stuck in `UNKNOWN` state during multiple API requests while streaming point clouds.
- Fixed Alert section i.e., categories changed from `WARNING` to `ERROR`. No functional changes to alert behavior.
- Fixed a bug in point cloud behaviour that caused highly reflective objects below min_range to make other objects disappear.
- Fixed a bug that prevents sensor from going into `ERROR` stopped state or restarting while doing cold start. This improves the reliability and overall robustness of the cold start path.

"Changed"

- Replaced mDNS name from `_roger._tcp` to `_ouster-lidar._tcp`. `_roger._tcp` is in planned deprecation.
- Replaced alert category for `CONFIG_INVALID` to `` `CONFIG ``. Please refer to alerts and error section in the firmware user manual.

"Removed"

- TCP API has now been **DEPRECATED** in FW 3.1. Please refer to *HTTP API Reference Guide* section instead.

- LEGACY Data packet profile has been **DEPRECATED**, please refer to *Lidar Data Packet Format* for more information.

18.2 Firmware v3.0.1

Date February 2023

Description

"Updated"

- `beam_to_lidar_transform` for Rev7 OS0 and OS1 sensors.
- `lidar_to_sensor_transform` for Rev7 OSDOME sensors.

"Added"

- New HTTP Command to configure speed override (Refer to *System*)

18.3 Firmware v3.0.0

Date January 2023

Description

"Fixed"

- Bug Fix in High Input Voltage Alert behavior.
- Bug in keep-alive behavior for HTTP 1.1.
- Bug fix in get_lidar_data_format.

"Improvements"

- Improved point cloud behavior due to enhanced retro-reflector range accuracy improvement.

"Changed"

- Default value of udp_profile_lidar will be set to single return profile. For more information refer to *RNG19_RFL8_SIG16_NIR16 Return Profile*.

"Added"

- 1024x20 and 2048x10 lidar modes with dual returns.
- Shot limiting status flags and thermal shutdown.
- Azimuth laser masking.
- Two new Signal multiplier modes - 0.25 and 0.5 Mode.
- New alerts, refer to *Table of All Alerts and Errors*.