HESAI

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# AT360

## Hybrid Solid-State Lidar
## User Manual

**Classification: C0 (Public)**

**Doc version: A04-en-250810**

# Table of Contents

# About this manual

Please make sure to read through this user manual before your first use and follow the instructions herein when you operate the product. Failure to comply with the instructions may result in product damage, property loss, personal injuries, and/or a breach of warranty.

## Access to this manual

To obtain the latest version, please do one of the following:

- Contact your sales representative of Hesai.
- Contact Hesai technical support at service@hesaitech.com.

## Technical support

If your question is not addressed in this user manual, please contact us at:

- service@hesaitech.com
- https://www.hesaitech.com/technical-support/
- https://github.com/HesaiTechnology

## Legends and format

**Warnings**: Instructions that must be followed to ensure safe and proper use of the product.

**Notes**: Additional information that may be helpful.

Names of data fields are in monospace font.

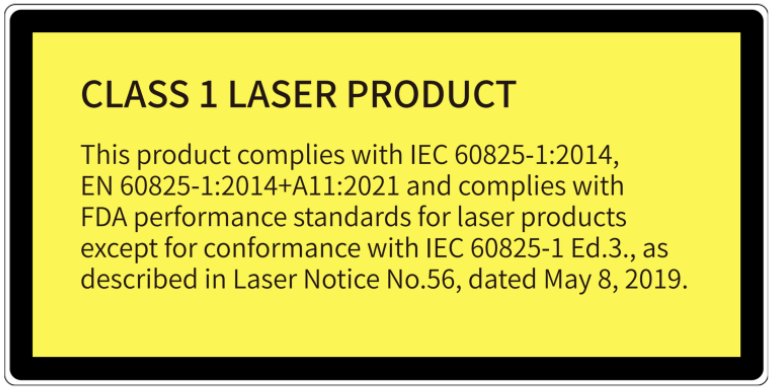
For example: `Distance` represents the Distance field.

# Safety notice

- Please make sure to read through this safety notice and follow all the instructions and warnings. Failure to comply with the instructions and warnings may result in product damage, property loss, and/or personal injuries.
- Please check the certification information on the product's nameplate. If an agreement has been made not to present certification information on the nameplate, please follow the agreed-to arrangements.
- If you incorporate this lidar product into your product(s), you are required to provide this user manual (or access to this user manual) to the intended users of your product(s).
- This lidar product is intended as a component of an end product. The end-product supplier is responsible for assessing the risk of use in accordance with applicable standards and informing the intended user of safety-related information.
- Should there be other agreements with specific users, the other agreements shall apply.
- Before using a product, please confirm with Hesai the development maturity of the product in a timely manner. For products still in development, Hesai makes no warranty of non-infringement nor assumes any responsibility for quality assurance.

## Special warnings

**Laser safety**



**Hot surface**

**Hot parts!**
Burned fingers when handling the parts.
Wait one-half hour after switching off before handling the parts.

### Abnormalities

In any of the circumstances listed below, stop using the product immediately:

- If you suspect malfunctions of or damage to the product, with symptoms such as significant noise or visible vibration.
- If you or people in the nearby environment feel discomfort.
- If any device or equipment in the nearby environment malfunctions.

Meanwhile, contact Hesai or an authorized Hesai service provider for more information on product disposal.

### Prohibition of disassembly

Unless expressly agreed to in writing by Hesai, do NOT disassemble the product.

## Operating environment

### Radio frequency (RF) interference

- Before using the product, make sure to read all the signs and notices on the product enclosure (including the nameplate). If specific users require not presenting certification information on the nameplate, please follow the agreed-to arrangements.
- Although the product is designed, tested, and manufactured to comply with the regulations on RF radiation (such as FCC, CE-EMC, or KCC), the radiation from the product may still influence electronic devices.

### Vibration

- If significant mechanical shocks and vibration exist in the product's operating environment, please contact Hesai's technical support to obtain the shock and vibration limits of your product model. Exposure to over-the-limit shocks or vibration may damage the product.
- Make sure to package the product in shock-proof materials to avoid damage during transport.

### Explosive atmosphere and other air conditions

- Do NOT use the product in any area where a potentially explosive atmosphere is present, such as where the air contains high concentrations of flammable chemicals, vapors, or particulates (including particles, dust, and metal powder).
- Do NOT expose the product to environments that have high concentrations of industrial chemicals, including liquefied gases that are easily vaporized (such as helium). Such exposure can damage or impair product functionality.

### Chemical environment

Do NOT expose the product to corrosive or strong polar chemical environments (such as liquids or gases), including but not limited to strong acids, strong bases, esters, and ethers. This is to avoid damage to the product (including but not limited to water resistance failure).

### Ingress protection (IP)

Please check the product's user manual for its IP rating (refer to Section 1.4 Specifications). Make sure to avoid any ingress beyond that rating.

### Operating temperature

Please check the product's user manual for its operating temperature (refer to Section 1.4 Specifications). Make sure not to exceed the operating temperature range.

### Recommended storage conditions

Please store the product in a dry and well-ventilated place. The recommended ambient temperature is 23 ± 5°C, and the humidity is between 30% and 70% RH.

### Light interference

Certain precision optical instruments may interfere with the laser light emitted from the product. Please check all the instructions for these instruments and take preventive measures if necessary. For example, protective leather covers are provided for certain product models; when these lidars are temporarily not used for measurement, the leather covers can be applied to block laser light emission.

## Personnel

### Recommended operator qualifications

The product should be operated by professionals with engineering backgrounds or experience in operating optical, electrical, and mechanical instruments. Please follow the instructions in this manual when operating the product and contact Hesai technical support if needed.

### Medical device interference

- Some components in the product can emit electromagnetic fields. If the product operators or people in the nearby environment wear medical devices (such as cochlear implants, implanted pacemakers, and defibrillators), make sure to consult the physicians and medical device manufacturers for medical advice, such as determining whether keeping the product a safe distance away from the medical devices is needed.
- If you suspect that the product is interfering with your medical device, stop using the product immediately.

## Installation and operation

### Power supply

- Before powering on the product, make sure the electrical interfaces are dry and clean. Do NOT power on the product in humid conditions.
- Do NOT use out-of-spec or damaged cables or adapters.
- You are recommended to use only the cables and power adapters provided by Hesai. If you are to design, configure, or select the power supply system (including cables) for the product, make sure to comply with the electrical specifications in the product's user manual (refer to Section 1.4 Specifications and the Power Supply Requirements section if available); for technical support, please contact Hesai.
- Please check Section 2.2 Electrical interface and strictly follow the instructions on plugging/unplugging the connector. If abnormalities already exist (such as bent pins, broken cables, and loose screws), stop using the product and contact Hesai technical support.

### Eye safety

The product is a Class 1 laser product. It satisfies the requirements of:

- IEC 60825-1:2014
- EN 60825-1:2014+A11:2021
- 21 CFR 1040.10 and 1040.11 except for deviations (IEC 60825-1 Ed.3) pursuant to Laser Notice No.56, dated May 8, 2019.

**CAUTION**: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

**CAUTION**

- For maximum self-protection, it is strongly warned that users do NOT look into the transmitting laser through a magnifying product (microscope, eye loupe, magnifying glass, etc.).
- This product does not have a power switch. It starts operating once connected to power. During operation, the entire optical window can be regarded as the product's laser emitting window; looking at the optical window can be regarded as looking into transmitting laser.

### Product enclosure

- Do NOT squeeze or pierce the product. If the product enclosure is broken, stop using it immediately and contact Hesai technical support.
- Certain product models contain high-speed rotating parts. To avoid potential injuries, do NOT operate the product if the enclosure is loose.
- If the product enclosure consists of fins or grooves, please wear gloves when handling the product. Applying too much pressure with your bare hands may cause cuts, bruises or other injuries.

### Drops and burns

The product contains metal, glass, and plastic, as well as sensitive electronic components. If the product is dropped or burnt, stop using it immediately and contact Hesai technical support.

### Optical window

The location of the optical window is illustrated in Section 1 Introduction.

- Do NOT apply protective film, wax or any other substance on the optical window.
- To keep the product's optical window from fingerprints and other stains, do NOT touch the optical window with bare hands. If the optical window is already stained, please refer to the cleaning method in Section 4 Maintenance.
- To prevent scratches, do NOT touch the product's optical window with hard or sharp objects. If scratches already exist, stop using the product and contact Hesai technical support. Severe scratches may affect the quality of the product's point cloud data.

### Mounting

- Before operating the product, make sure it is properly and securely mounted. The mounting should prevent the product from leaving its mounting position under external forces (such as collisions, high winds, and stone impacts).
- Before installing any exterior part, please ensure that each exterior part and its movable area do not overlap the Field of View (FOV) of the lidar.

The FOV of lidar is the spatial angular range bounded by the horizontal and vertical FOV ranges (see Section 1.4 Specifications); the distance to the origin of the lidar's coordinate system is not limited. For inquiries about the FOV, please contact Hesai technical support.

### Hot surface

During operation or the time period after the operation, the product's enclosure can be hot.

- To prevent discomfort or even burns, do NOT touch the product's enclosure with your skin.
- To prevent fires, make sure to keep flammable materials away from the product's enclosure.

Certain product models support active heating of the optical window to reduce the impact of ice and frost.

- While active heating is ON, the optical window can be hot. To prevent discomfort or even burns, avoid direct skin contact with the optical window.
- When the optical window is free of ice and frost, you may turn off active heating.

### Peripherals

The product may be used along with accessories and devices, such as suction cup mounts, extension cables, power supplies, network devices, GNSS/PTP devices, CAN transceivers, and cleaning equipment.

When selecting a peripheral, please refer to all relevant specifications in the product's user manual or contact Hesai technical support. Using out-of-spec or unsuitable devices may result in product damage or even personal injuries.

### Firmware and software upgrading

Make sure to use only the upgrade files provided by Hesai. Make sure to observe all the instructions provided for that upgrade file.

### Customized firmware and software

- Before using a customized version of firmware and software, please fully understand the differences in functions and performance between the customized version and the standard version.
- Make sure to strictly follow all the instructions and safety precautions provided for that customized version. If the product does not function as anticipated, stop using the product immediately and contact Hesai technical support.

**Point cloud data processing**

- Certain product models support one or more point cloud data processing functions, including but not limited to: Noise Filtering, Interstitial Points Filtering, Retro Multi-Reflection Filtering, and Non-Linear Reflectivity Mapping.
- These functions are configurable and are intended only to assist the user in extracting information from the point cloud data. Users are in full control of whether to use any of these functions. Moreover, users are responsible for analyzing the product's intended application scenarios and evaluating the risk of enabling one or more of these functions in combination.
- To learn about the supported functions of a product model, please contact Hesai technical support.

# Repair

- Unless expressly agreed to in writing by Hesai, do NOT disassemble, repair, modify, or retrofit the product by yourself or entrust any third party to do so. Such a breach:
  - can result in product damage (including but not limited to water resistance failure), property loss, and/or injuries;
  - shall constitute a breach of warranty.
- For more product repair issues, please contact Hesai or an authorized Hesai service provider.

# 1. Introduction

## 1.1. Operating principle

Distance measurement: Time of Flight (ToF)

1. A laser diode emits a beam of ultrashort laser pulses onto the target object.
2. The laser pulses are reflected after hitting the target object. The returning beam is detected by an optical sensor.
3. Distance to the object can be accurately measured by calculating the time between laser emission and receipt.

| | |
|---|---|
| $d = \frac{ct}{2}$ | d: Distance<br>c: Speed of light<br>t: Travel time of the laser beam |

# 1.2. Basic structure

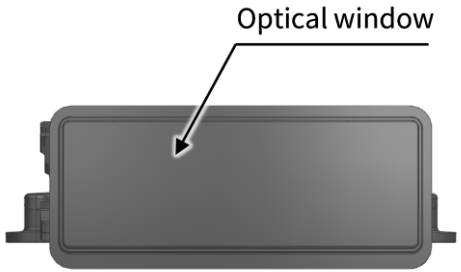



Figure 1. Front view

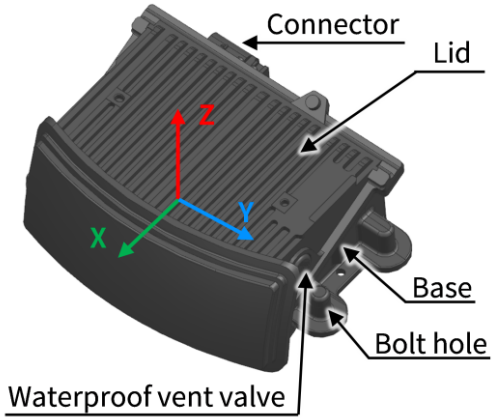



Figure 2. Coordinate system (isometric view)

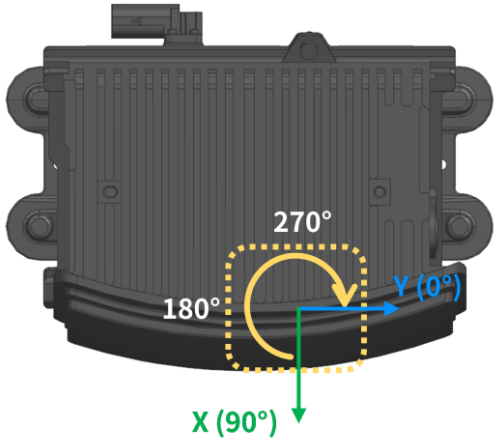



Figure 3. Mirror rotation direction (top view)

The lidar's coordinate system is illustrated in Figure 2.

- Z-axis is the axis of rotation.
- The origin's exact position is shown in Figure 5. All measurements are relative to the origin.

A rotating mirror is used for horizontal scanning, shown as the dotted box in Figure 3.

The lidar's azimuthal position (i.e., azimuth of the current firing channel) is defined in Figure 3.

- The mirror rotates clockwise in the top view.
- Y-axis corresponds to 0°.

# 1.3. Channel distribution

As shown in Figure 4 and detailed in Appendix A Channel distribution data, the laser channels are almost evenly distributed. The designed vertical resolution is 0.05° in the central FOV and slightly larger in the margins.

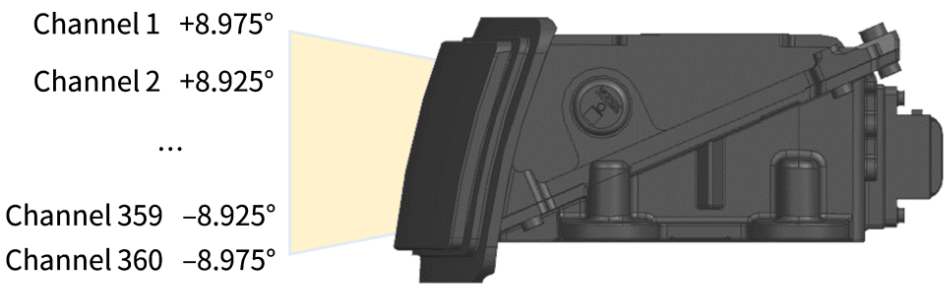



Figure 4. Channel vertical distribution

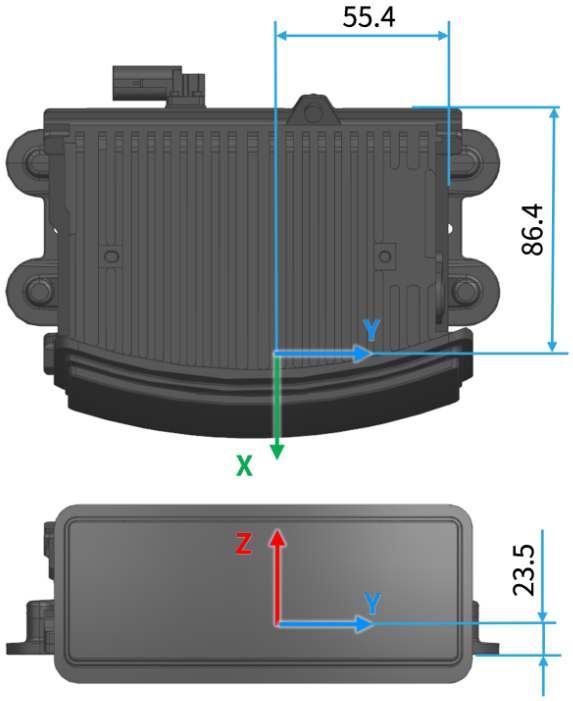



Figure 5. Origin of coordinates (unit: mm)

Each channel has an intrinsic angle offset, both horizontally and vertically. The offset angles are recorded in this lidar unit's angle correction file (see Section A.2 Angle correction file).

# 1.4. Specifications

### SENSOR

| | |
|---|---|
| Scanning method | 1-D rotating mirror (hybrid solid-state) |
| Number of channels | 360 (300 enabled) |
| Ranging capability | 250 m (at 10% reflectivity) |
| Ranging accuracy | ±5 cm (typical) |
| Ranging precision | 3 cm (typical, 1σ) |
| FOV (H × V) ① | 120° × 18° (-9° to +9°) |
| ROI (H × V) ① | 35° × 12° (-6° to +6°) |
| Resolution (H × V) | **ROI:** 0.06° × 0.05°<br>**Non-ROI:** 0.12° × 0.10° |
| Frame rate | 10 Hz |
| Return mode | **Dual Return:** First and Strongest |

### MECHANICAL/ELECTRICAL/OPERATIONAL

| | |
|---|---|
| Wavelength | 905 nm |
| Laser class | Class 1 Eye Safe |
| Ingress protection | IP6K7 & IP6K9K |
| Dimensions | 158 × 119 × 52 (WDH, mm) |
| Rated voltage range ② | DC 9 to 16 V |
| Power consumption ③ | 16 W |
| Operating temperature | -40°C to 85°C |

| | |
|---|---|
| Storage temperature | -40°C to 105°C |
| Weight | 1080 g |

**DATA I/O**

| | |
|---|---|
| Data transmission | Automotive Ethernet, 1000BASE-T1, slave mode |
| Measurements | Distance, azimuth angle, and reflectivity |
| Valid point rate ④ | 5 700 000 points/sec |
| Point cloud data rate ⑤ | 233/672 Mbps (avg/peak) |
| Clock source | PTP (802.1AS AUTOSAR) |
| PTP clock accuracy | ⩽1 µs |
| PTP clock drift ⑥ | ⩽5 µs/s |

Specifications are subject to change. Please refer to the latest version of this manual.

### Notes to specifications

| | |
|---|---|
| ① **FOV and ROI** | Horizontally symmetric with respect to the 90° azimuthal position (i.e. the X-axis, as shown in Figure 3) |
| ② **Rated voltage range** | Nominal voltage: 12 V |
| ③ **Power consumption** | • Typical value, not including accessories such as the connection box.<br>• The external power supply should be able to provide at least 40 W. |
| ④ **Valid point rate** | Defined as the point cloud data points (number of returns) generated per second. |
| ⑤ **Point cloud data rate** | Considering the duty cycle for point cloud data transmission and the FOV's ROI design, the peak data rate is higher than the average data rate. |
| ⑥ **PTP clock drift** | Defined as the drift at a constant temperature after the lidar (slave clock) loses connection to the PTP master. |

# 2. Setup

Before operating the lidar, strip away the transparent protective film on the optical window.

The information in this section may be different for customized models. The mechanical drawings and data exclusively provided for customized models shall prevail.

## 2.1. Mechanical installation

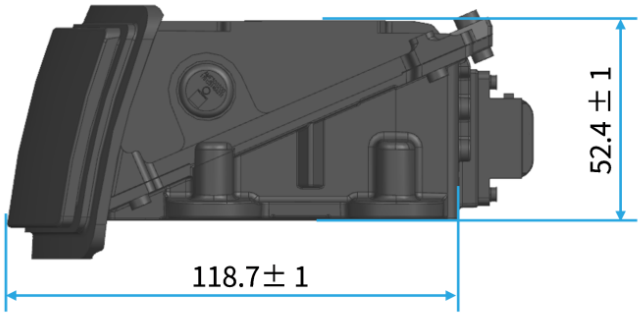



Figure 6. Right side view (unit: mm)

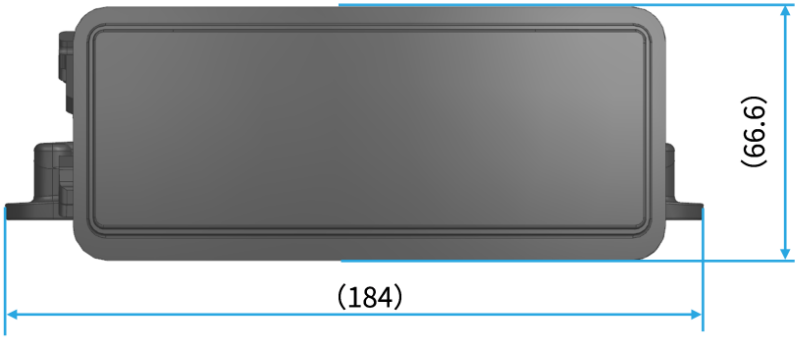



Figure 7. Front view (unit: mm)

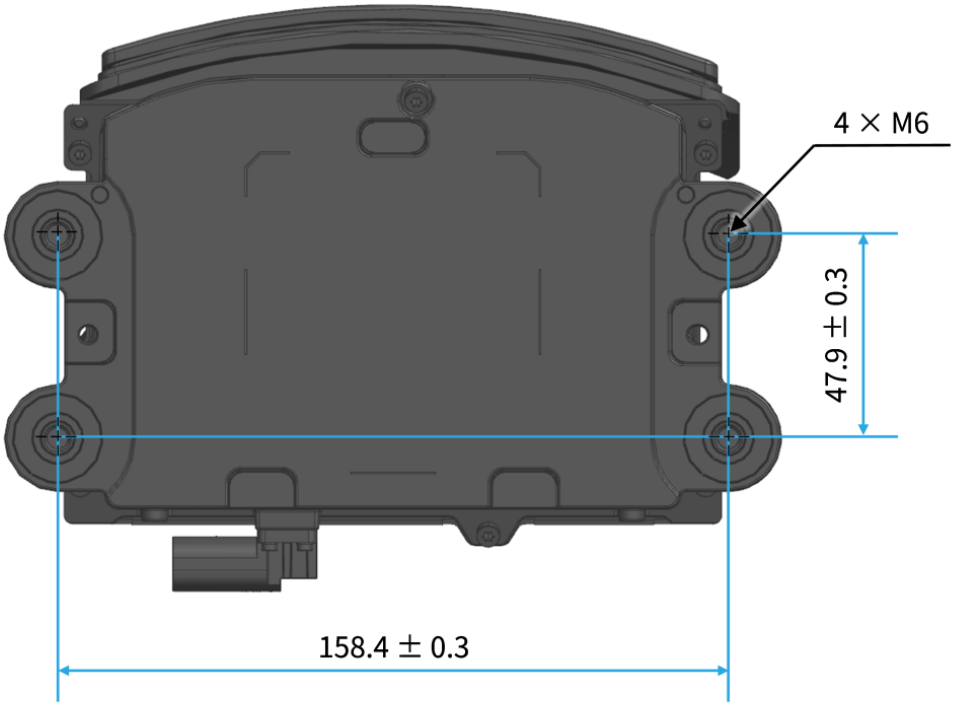



Figure 8. Bottom view (unit: mm)

# 2.2. Electrical interface

## 2.2.1. Connector use

TE connector part number: 2413280-1 (male socket, on the lidar)

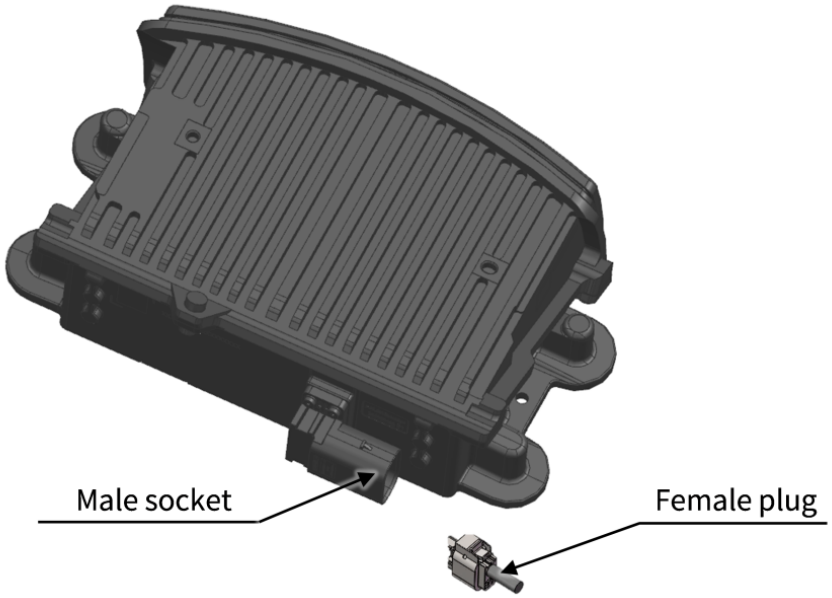



Figure 9. Connectors

- Before connection, check the pins on the socket and the holes on the plug. In case of bent pins or damaged holes, stop using the connector and contact technical support.
- To prevent breakdowns, turn off the power source before connection and disconnection.
- Do NOT attempt to force open a connection by pulling on the cables or by twisting the connectors in any way. Doing so can loosen the connectors' shells, or even damage the contacts.
- If the connector's shell is accidentally pulled off, stop using the connector and contact Hesai technical support.
- Do NOT attempt to assemble the connector's shell and cable collet; do NOT connect a connector without its shell. Doing so may damage the lidar's circuits.
- For further troubleshooting, please contact Hesai technical support or obtain work instructions from the connector manufacturer.
- The connector is designed to withstand at least 20 mating cycles; exceeding this number may increase the risk of connector damage.

| | |
|---|---|
| Connection | 1. Turn off the power source.<br>2. Make sure the plug's red CPA is on the same side as the socket's locking nose.<br>3. Push the plug straight into the socket until you feel and hear a click.<br>4. Push the red CPA towards the socket until you feel and hear a click. |
| Disconnection | 1. Turn off the power source.<br>2. Pull the red CPA away from the socket until you feel and hear a click.<br>3. Depress the black locking latch; then pull the plug from the socket. |

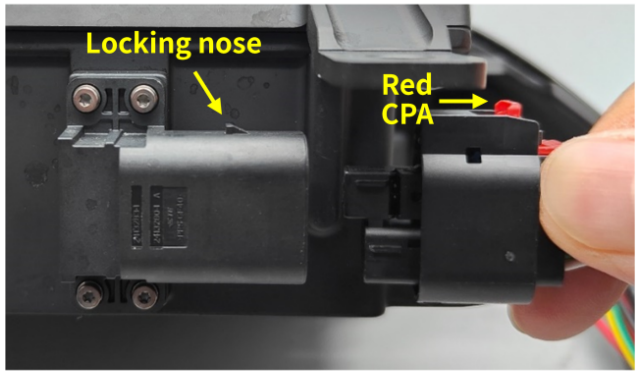



Figure 10. Connection

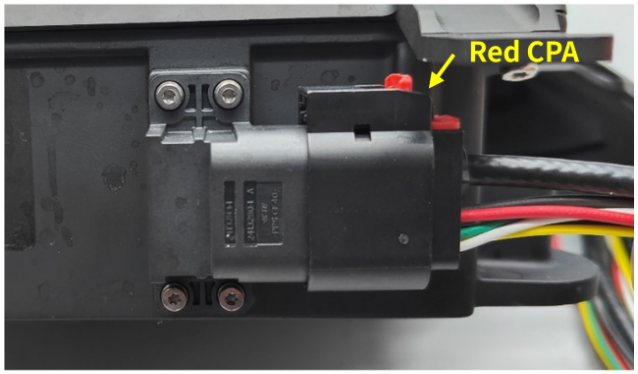



Figure 11. Disconnection

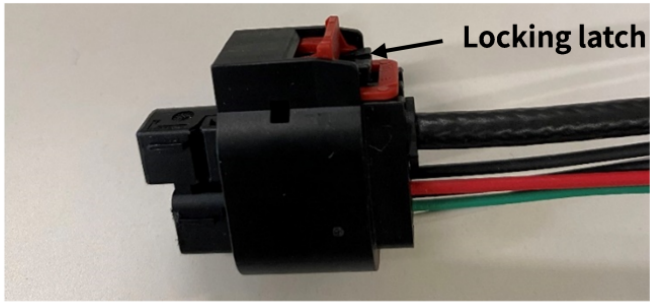



Figure 12. Locking latch

### 2.2.2. Cable (Ethernet)

Outer diameter (OD) = 4.10 ± 0.20 mm
Minimum bend radius:

- Single: 5 × OD
- Multiple: 15 × OD

# 2.3. Connection box (optional)

Users may connect the lidar with or without a connection box.

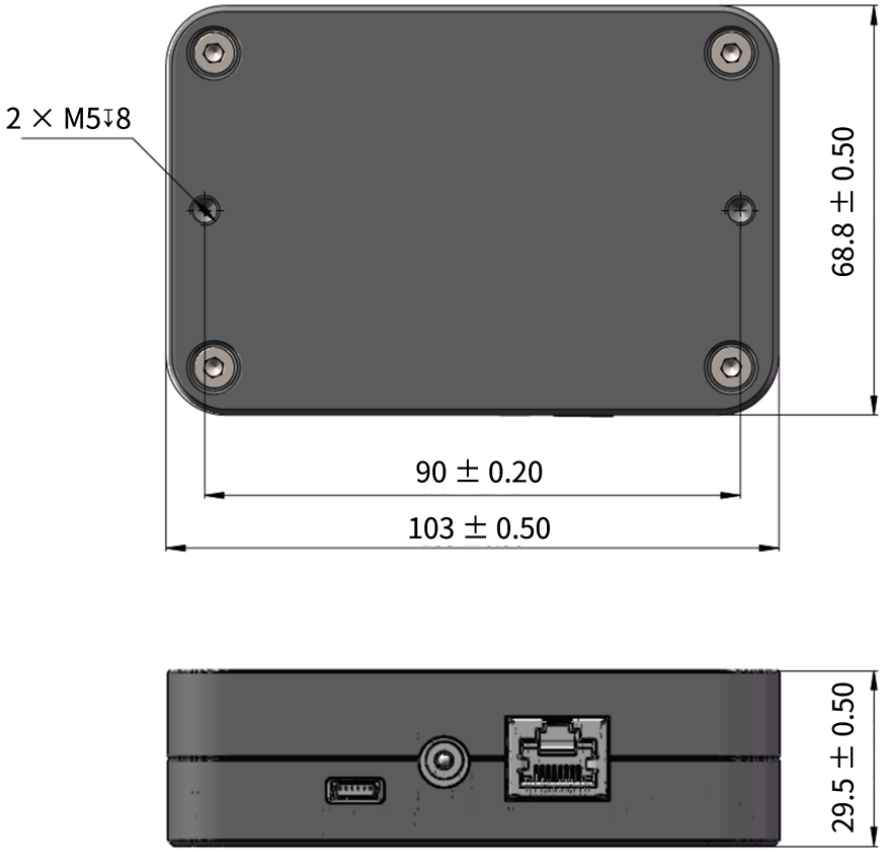



Figure 13. Connection box (unit: mm)

An additional cable assembly is used for connecting the lidar (on the left) and the connection box (on the right), as shown below.

One cable's head cannot connect to another cable's tail, so each lidar can only use one cable.

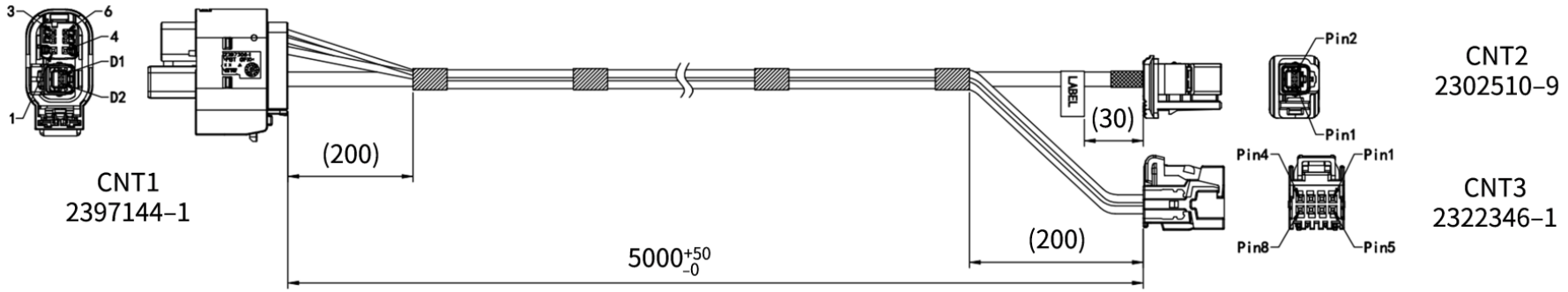



Figure 14. Cable assembly between lidar and connection box (unit: mm)

The wire colors and cross-section areas are listed below.

| Pin No. on CNT1 | Pin No. on CNT3 | Signal | Wire color | Wire cross section |
|---|---|---|---|---|
| 1 | 4 | VCC | Red | 0.75 $mm^2$ |
| 2 | 5 | Reserved | Green | 0.35 $mm^2$ |
| 3 | 2 | Reserved | White | 0.35 $mm^2$ |
| 4 | 8 | GND | Black | 0.75 $mm^2$ |
| 5 | 7 | Reserved | Black | 0.35 $mm^2$ |
| 6 | 6 | Reserved | Yellow | 0.35 $mm^2$ |
| Pin No. on CNT1 | Pin No. on CNT2 | Signal | Wire color | Wire cross section |
| D2 | 1 | MDI-P | White | - |
| D1 | 2 | MDI-N | Green | - |

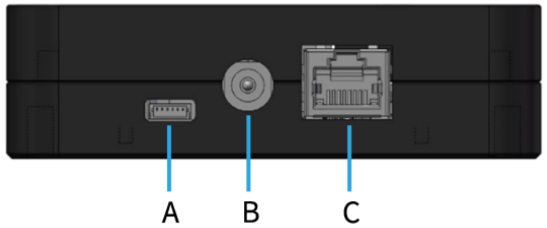



Figure 15. Connection box (front)

| Port number | Port name | Description |
|---|---|---|
| A | Reserved port | Do NOT connect this port to external signals. |
| B | Power port | Use a DC-005 power socket (outer diameter: 5.5 mm; inner diameter: 2.1 mm). |
| C | Standard Ethernet port | RJ45, 1000 Mbps Ethernet |

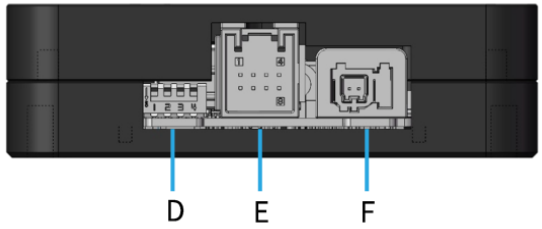



Figure 16. Connection box (back)

| Port number | Port name | Description |
|---|---|---|
| D | Reserved port | Do NOT toggle or connect the DIP switches. |
| E | Power output port | See CNT3 in Figure 14; part number: 2311621-1 |
| F | Automotive Ethernet port | See CNT2 in Figure 14; part number: 2304372-1 |

### 2.3.1. Connection

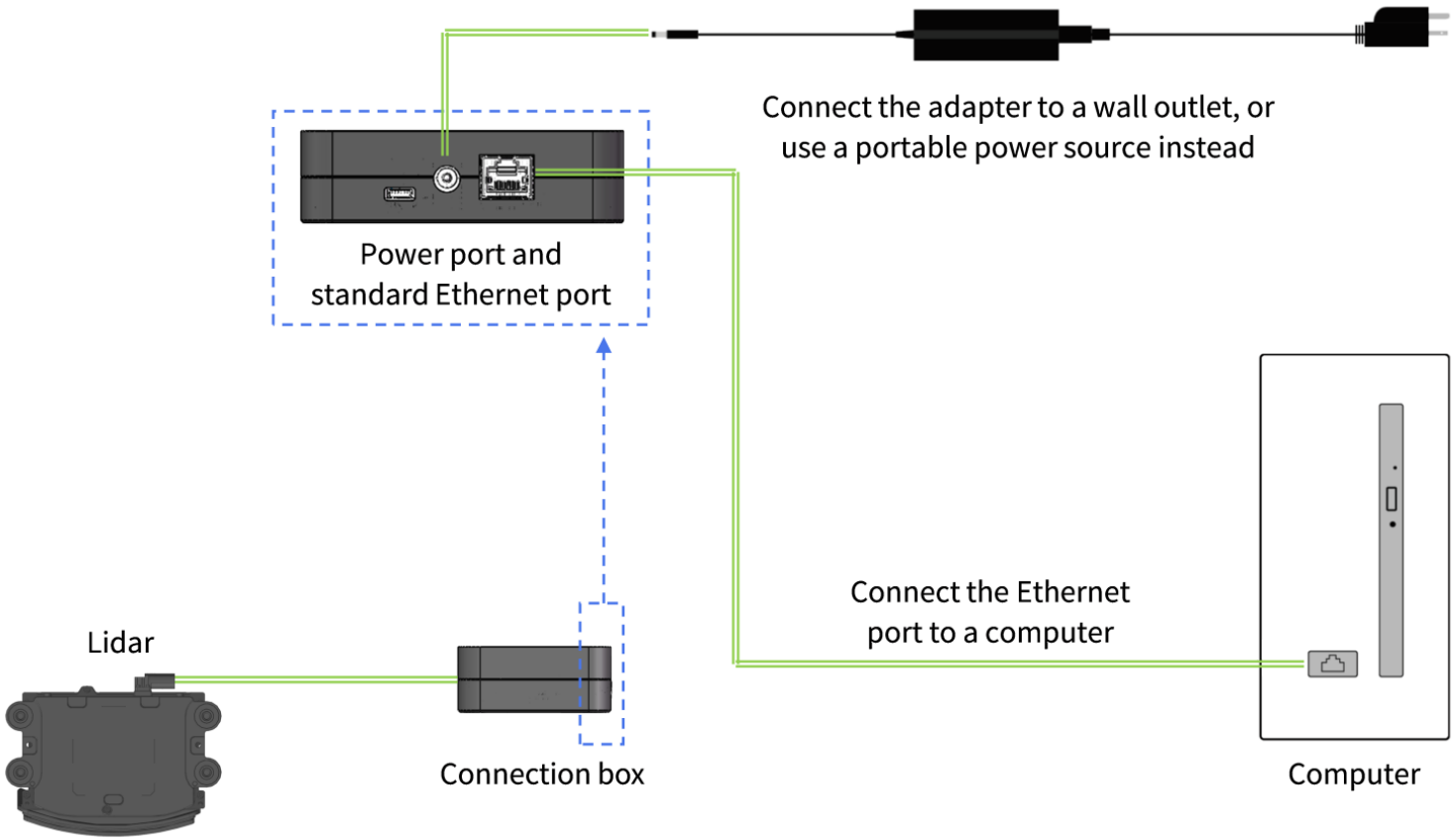



Figure 17. Connection with PTP (software simulation)

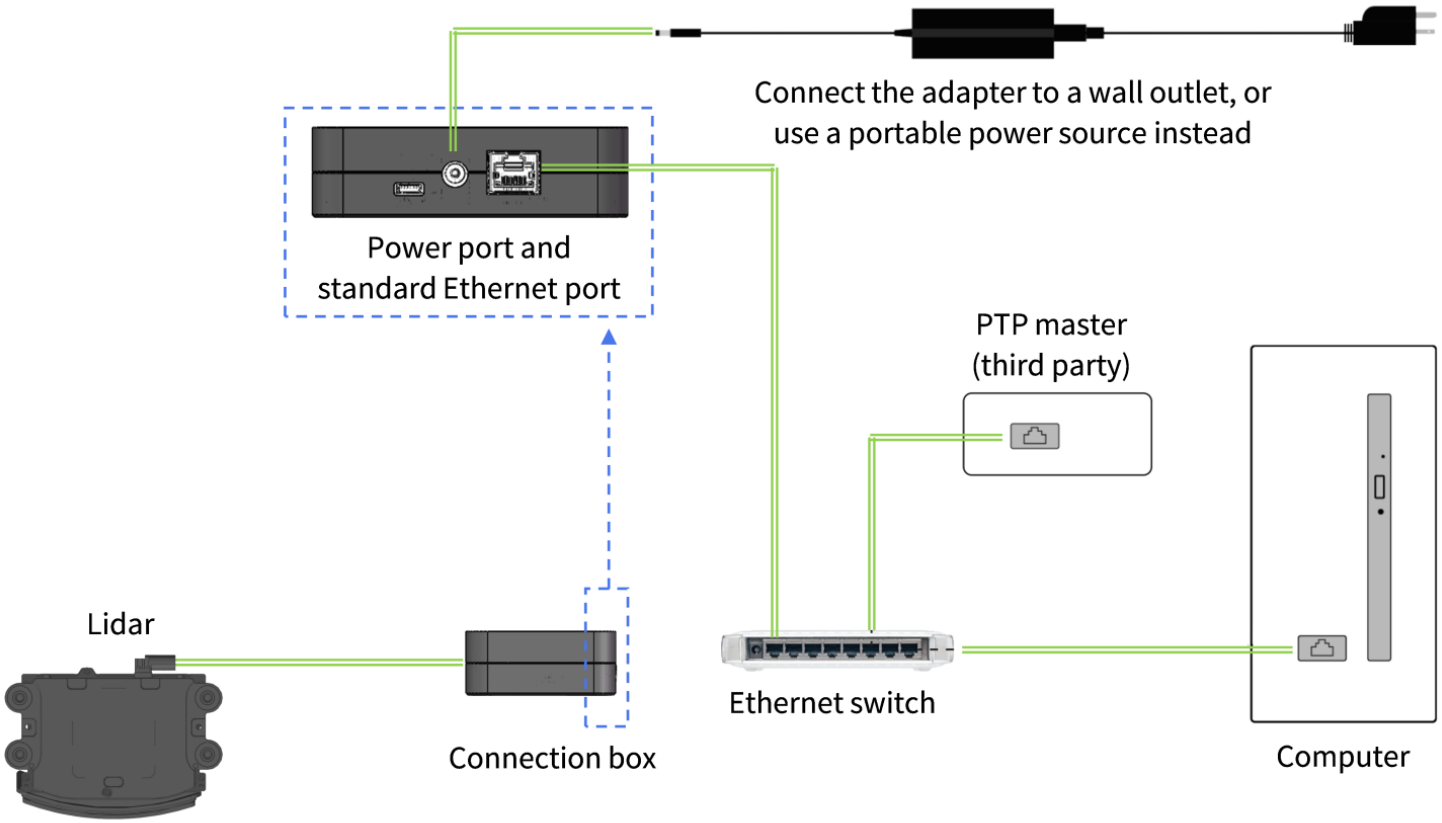



Figure 18. Connection with PTP (hardware device)

# 2.4. Network settings on the host computer

The lidar has no power switch. It starts transmitting data when both of these conditions are met:

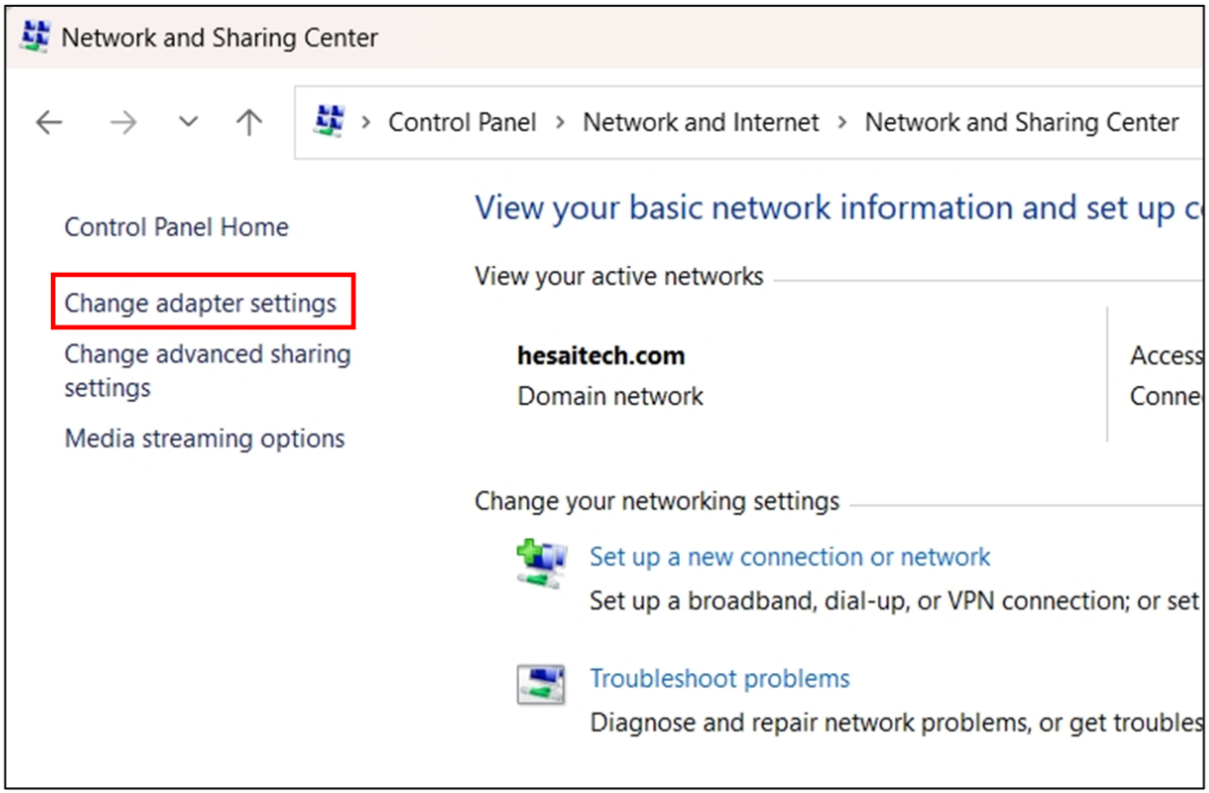
- The lidar is connected to power.
- The lidar is connected to a host computer via Ethernet.

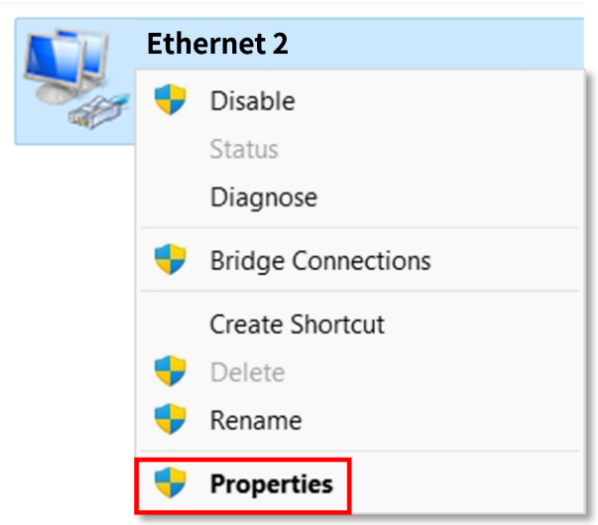
To analyze point cloud data, configure the network parameters of the host computer:

| Network parameters | Value | Description |
|---|---|---|
| IP address | 192.168.1.**X** | **X** can be selected from 2 to 200 and from 202 to 254. |
| Subnet mask | 255.255.255.0 | - |
| VLAN ID | Range: 1 to 4094 | Required only when VLAN tagging is used.<br>Make sure the host computer and the lidar use the same VLAN ID. |

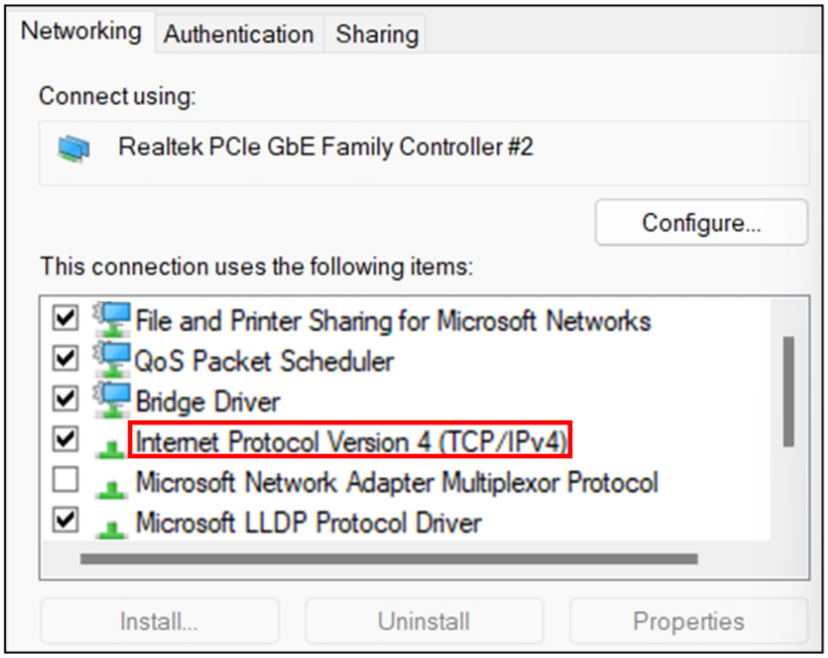
## 2.4.1. In Windows

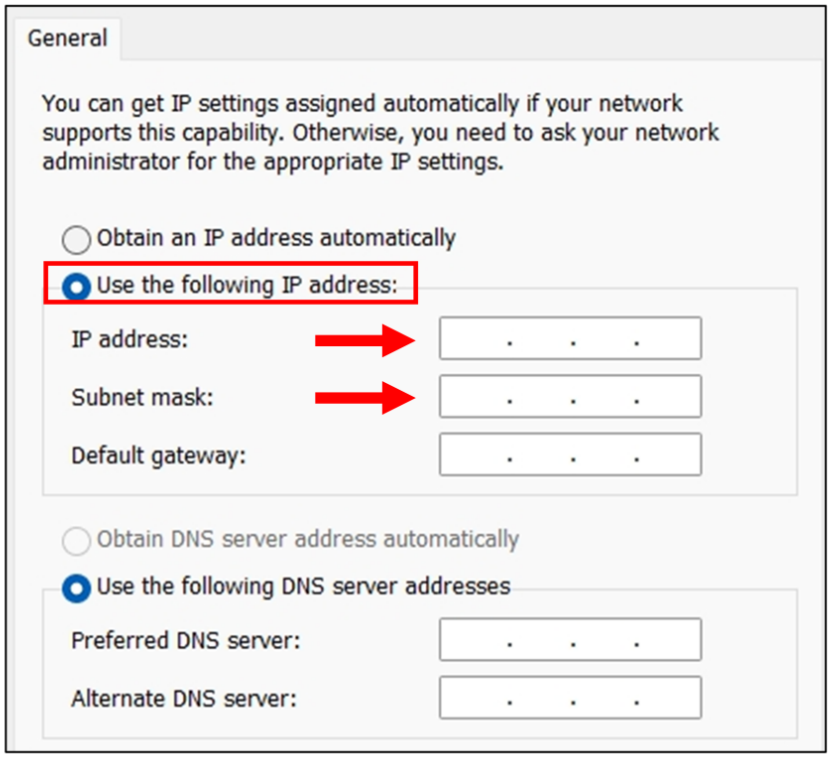
1. **[ Control Panel ]** > **[ Network and Internet ]** > **[ Network and Sharing Center ]** > **[ Change adapter settings ]**.
2. Right-click **[ Ethernet ]** or **[ Ethernet X ]** which shows Ethernet connection (with no red cross at the bottom left of the icon) > Select **[ Properties ]**.



3. Double-click [ **Internet Protocol Version 4 (TCP/IPv4)** ].
4. Select [ **Use the following IP addresses** ] > Input the host computers's IP address and subnet mask.

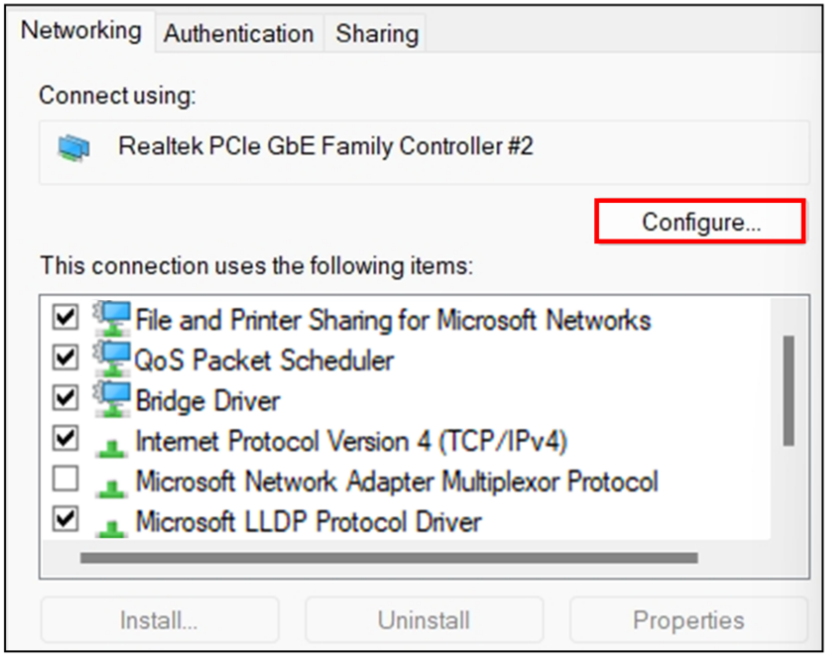


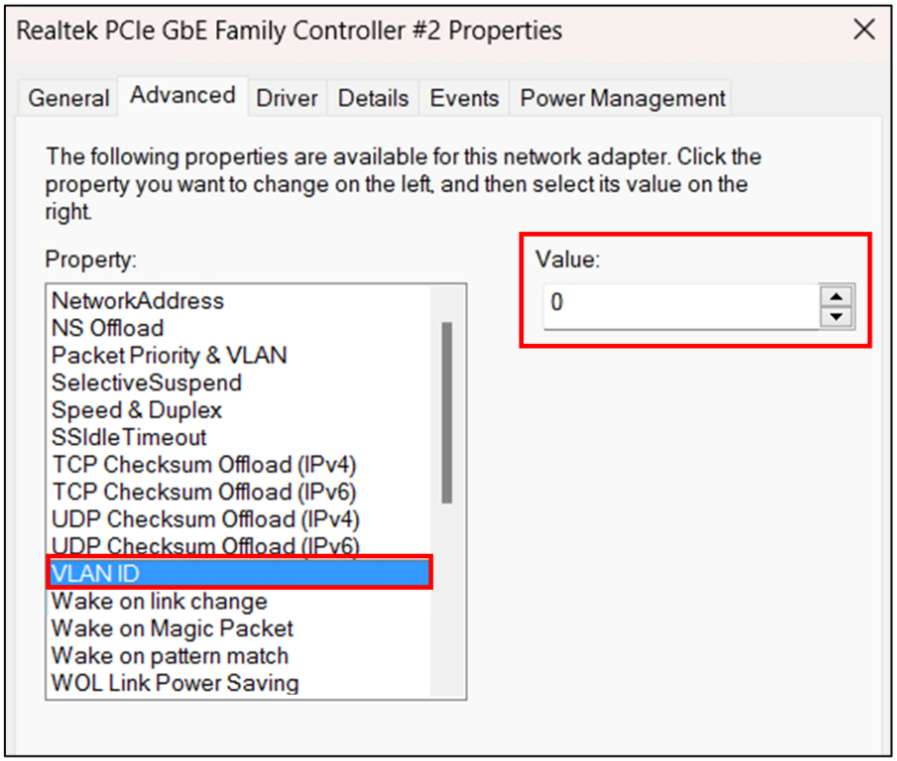




Ping command can be used to check the connection:

1. Press Win + R to open the Run dialog box.
2. Enter "cmd" and click [ **OK** ] to open the Command Prompt.
3. Enter "ping 192.168.1.201" and check the output.

5. To enable VLAN tagging:
   Click [ **Configure** ] > Under the [ **Advanced** ] tag, select [ **VLAN ID** ] from the [ **Property** ] list > Input a VLAN ID in the [ **Value** ] box > Click [ **OK** ].




If the [ **Property** ] list has no [ **VLAN ID** ], it is recommended to update the network adapter driver.

## 2.4.2. In Ubuntu

1. Find the host computer's network interface name.

   **Method 1**

   a. Open **Settings — Network**.
   b. Look for the interface whose status is "Connected".
   The name in parentheses after "Ethernet" is the network interface name.


   **Method 2**

   a. Open a terminal and run this command:

```
ifconfig
```

   b. Look for the interface with non-zero RX packets and bytes.
   (In the example below, **enp5s0** shows non-zero Rx packets and bytes, indicating active data transmission.)

```
❯ ifconfig
docker0: flags=4099<UP,BROADCAST,MULTICAST>  mtu 1500
        inet [redacted]  netmask [redacted]  broadcast [redacted]
        ether [redacted]  txqueuelen 0  (Ethernet)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

enp2s0f0: flags=4099<UP,BROADCAST,MULTICAST>  mtu 1500
        ether [redacted]  txqueuelen 1000  (Ethernet)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

enp5s0: flags=4099<UP,BROADCAST,MULTICAST>  mtu 1500
        ether [redacted]  txqueuelen 1000  (Ethernet)
        RX packets 267706980  bytes 300970909734 (300.9 GB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 3184  bytes 590575 (590.5 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

### When not using VLAN

2. Run this command in the terminal:

```
sudo ifconfig ${interface_name} ${ip_addr}
```

   - Replace `${interface_name}` with the host computer's network interface name.
   - Replace `${ip_addr}` with the host computer's IP address.

### When using VLAN

2. Run this command in the terminal:

```
sudo ip link add link ${interface_name} name ${interface_name}.${vlan_id} type vlan id ${vlan_id}
sudo ip link set up ${interface_name}.${vlan_id}
sudo ip addr add ${ip_addr}/24 dev ${interface_name}.${vlan_id}
ip addr show ${interface_name}.${vlan_id}
```

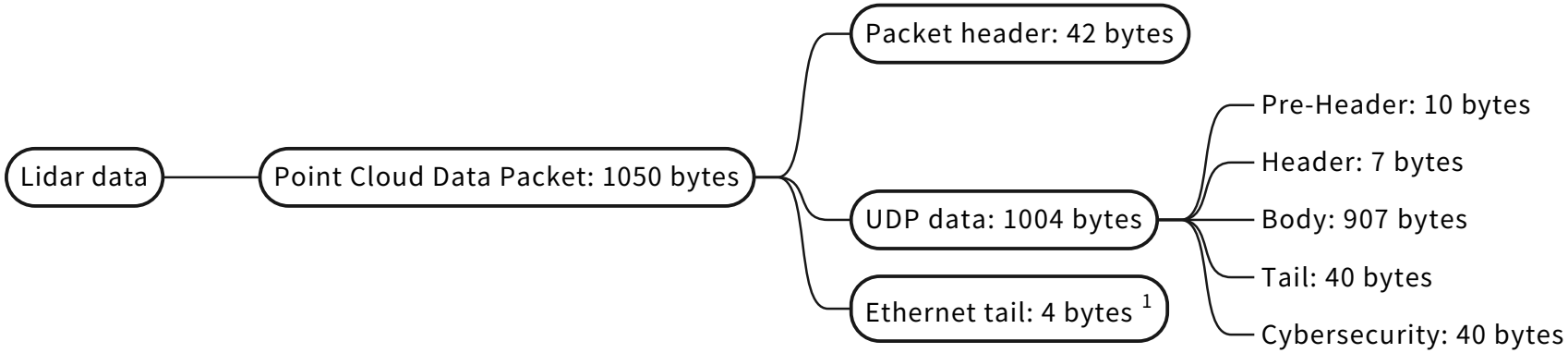
- Replace `${interface_name}` with the host computer's network interface name.
- Replace `${vlan_id}` with the host computer's VLAN ID.
- Replace `${ip_addr}` with the host computer's IP address.

# 2.5. Tools

| Tool | Purpose | Where to find it |
| --- | --- | --- |
| PandarView 2 | Point cloud visualization software:<br>To record and display point cloud data. | Contact Hesai technical support to obtain it. |
| Pandar TCP Commands (PTC) API | To set parameters, check device info and status, or upgrade firmware and software.<br>Network parameters:<br>• Default Source IPv4 address: 192.168.1.201<br>• Default PTC port: 9347 | Contact Hesai technical support to receive the API Reference Manuals. |

# 3. Data structure

The lidar outputs Point Cloud Data Packets.
Unless otherwise specified, all the multi-byte fields are unsigned values in little-endian format.




1. Network monitoring software (such as WireShark) usually does not display the **Ethernet tail** (4 bytes).

Figure 19. Data structure

# 3.1. Point Cloud Data Packet

Before receiving Point Cloud Data Packets, please perform Network settings on the host computer.

## 3.1.1. Ethernet Header

**Point Cloud Data Packet: Ethernet Header**

| Field | Byte(s) | Description |
|---|---|---|
| Ethernet II MAC | 12 | Destination MAC: xx:xx:xx:xx:xx:xx (FF:FF:FF:FF:FF:FF for broadcast)<br>Source MAC: xx:xx:xx:xx:xx:xx |
| Ethernet Data Packet Type | 2 | 0x08, 0x00 |
| Internet Protocol | 20 | Protocol parameters |
| UDP Port Number | 4 | Source port (default: 10000)<br>Destination port (default: 2368) |
| UDP Length | 2 | Eight bytes more than point cloud UDP data (see Figure 19. Data structure). |
| UDP Checksum | 2 | Checksum of the Ethernet Header |

## 3.1.2. UDP data

### Pre-Header

| Field | Byte(s) | Description |
|---|---|---|
| Start of Packet | 1 | 0xEE |
| Start of Packet | 1 | 0xFF |
| Protocol Version Major | 1 | Main class of the point cloud UDP packet structure<br>Current value: 0x04 |
| Protocol Version Minor | 1 | Subclass of the point cloud UDP packet structure<br>Current value: 0x0A |
| Protocol Version Patch | 1 | Patch of the point cloud UDP packet structure<br>Current value: 0x00 |
| SW Version Major | 1 | Main class of the SW Version<br>Current value: 0x00 |
| SW Version Minor | 1 | Subclass of the SW Version<br>Current value: 0x00 |
| SW Version Patch | 1 | Patch of the SW Version<br>Current value: 0x00 |
| Reserved | 2 | - |

**Header**

<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Channel Num</td><td>2</td><td>Number of channels<br>Fixed: 0x012C (300)</td></tr>
<tr><td>Block Num</td><td>1</td><td>Number of block(s) per packet<br>Fixed: 0x01 (1)</td></tr>
<tr><td>First Block Return</td><td>1</td><td>Indicating the return in the block of this packet.<br><br>0x01 — Dual Return mode: The first block stores the No. 1 return of this return mode.<br>0x02 — Dual Return mode: The first block stores the No. 2 return of this return mode.<br><br>For example, if the <code>First Block Return</code> field is 0x02 and the <code>Return Mode</code> field is 0x3C (Dual Return – First and Strongest), then the first block in this packet stores the strongest return of a firing.</td></tr>
<tr><td>Dis Unit</td><td>1</td><td>Unit of the <code>Distance</code> field in Section 3.1.2.3 Body.<br>Fixed: 0x05 (5 mm)</td></tr>
<tr><td>Return Num</td><td>1</td><td>Maximum number of returns from each channel<br>Fixed: 0x02 (2)</td></tr>
<tr><td>Flags</td><td>1</td><td>Each bit indicates whether this data packet contains certain information.<br>1 — YES<br>0 — NO<br><table><tr><th>Bit</th><th>Value</th></tr><tr><td>[7:4] Reserved</td><td>-</td></tr><tr><td>[3] Digital Signature</td><td>1</td></tr><tr><td>[2:1] Reserved</td><td>-</td></tr><tr><td>[0] UDP Sequence</td><td>1</td></tr></table></td></tr>
</table>

**Body**

| Field | Byte(s) | Description |
|---|---|---|
| Azimuth | 2 | Low-resolution part of the encoder angle<br>Unit: 0.01°<br>• Encoder angle is measured by the optical encoder and is used as the current reference azimuth of this block.<br>• To convert from encoder angle to point cloud horizontal angle, refer to Section A.3 Angle correction calculation. |
| Fine Azimuth | 1 | High-resolution part of the encoder angle<br>Unit: 0.01°/256<br>Encoder angle of the Block = `Azimuth` × 0.01° + `Fine Azimuth` × 0.01°/256 |
| Block | 900 | Measurements made by each channel, starting from Enabled Channel 1 (see Each block in the Body). |
| CRC | 4 | CRC-32 checksum of the Body |

**Each block in the Body**

<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Enabled Channel 1</td><td>3</td><td>Measurements of enabled channel 1
<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Distance</td><td>2</td><td>Object distance = Distance × Dis Unit<br>Dis Unit is specified in Section 3.1.2.2 Header.</td></tr>
<tr><td rowspan="3">Confidence and Reflectivity</td><td rowspan="3">1</td><td>[7] Confidence level<br><br>0 — Normal<br>1 — Low confidence</td></tr>
<tr><td>[6] Reserved</td></tr>
<tr><td>[5:0] Reflectivity<br><br>Range: 0 to 62 (0b111110)<br><br>The mapping between this field and target reflectivity is detailed in Appendix B Nonlinear reflectivity mapping.</td></tr>
</table></td></tr>
<tr><td>Enabled Channel 2</td><td>3</td><td>Measurements of enabled channel 2</td></tr>
<tr><td>…</td><td>…</td><td>…</td></tr>
<tr><td>Enabled Channel 300</td><td>3</td><td>Measurements of enabled channel 300</td></tr>
</table>

### Tail

| Field | Byte(s) | Description |
|---|---|---|
| Reserved | 6 | - |
| High Temperature Shutdown Flag | 1 | This field is not yet supported. |
| ROI Start Channel | 1 | Channel number of the ROI's topmost channel<br>Current value: 60 (indicating Channel 61)<br>Dynamic ROI is not yet supported. |
| Reserved | 3 | - |
| Frame Rolling Counter | 1 | Cycle counter of frames<br>Range: 0 to 254<br>Increments by 1 at the end of each frame. Reset to 0 at every start-up. |
| Reserved | 6 | - |
| Motor Speed | 2 | Spin rate of the motor<br>Unsigned integer<br>Unit: 0.1 RPM<br>Motor speed in RPM = `Motor Speed` × 0.1 - 3276.8<br>• By default, each of the 3 mirror surfaces corresponds to a point cloud frame. Thus, for every motor rotation, 3 frames are generated.<br>• Spin rate of the motor (RPM) = frame rate (Hz) × 60 / 3 |
| Timestamp Nanosec | 4 | The nanosecond part of the timestamp of this data packet<br>Unit: ns<br>Range: 0 to 999 999 999 ns (1 s) |
| Return Mode | 1 | 0x3C — First and Strongest |

| Field | Byte(s) | Description |
| --- | --- | --- |
| Factory Information | 1 | Fixed: 0x42 |
| Timestamp Sec | 4 | Whole second part of the Coordinated Universal Time (UTC) of this data packet<br>Format: number of seconds since the Unix epoch (1970–01–01 00:00:00 UTC) |
| Reserved | 2 | - |
| UDP Sequence | 4 | Sequence number of this UDP packet<br>Range: 0 to 0xFF FF FF FF |
| CRC | 4 | CRC-32 checksum of the Tail |

**Cybersecurity**

| Field | Byte(s) | Description |
| --- | --- | --- |
| Signature | 32 | Point cloud signature<br>Calculated using point cloud UDP data (from Pre-Header to Tail)<br>Algorithm: CMAC (128 bits) or HMAC-SHA256 (256 bits)<br>This field is not yet supported. |
| SQC | 4 | Sequence counter<br>Current value: 0 |
| CRC | 4 | Current value: 0 |

### 3.1.3. Ethernet tail

| Field | Byte(s) | Description |
| --- | --- | --- |
| FCS | 4 | Frame check sequence |

### 3.1.4. Point cloud data analysis method

A software development kit (SDK) is available for analyzing point cloud data. Please contact Hesai technical support.

# 4. Maintenance

The lidar's optical window is made of plastic (polycarbonate, PC), similar to the material used for car lamps.

- Do NOT wipe the optical window when it is dry, nor use abrasive cleaners. Doing so can damage the optical coating.
- Do NOT use organic cleaners, which can damage the optical window and even cause cracking.
  - Organic cleaners include but are not limited to tar removers, self-cleaning agents, adhesive removers, coating removers, foam cleaners, iron powder removers for car paint, glass cleaners, thinning agents, de-icers, paint surface treatment agents, alcohol, and vinegar.
  - If organic cleaners may be present when cleaning the equipment or performing related operations, please protect the optical window to prevent any contact with organic cleaners.
- Do NOT apply excessive force to the lidar, as this can damage the optical window.
  - If a pressure washer is used to clean the optical window, make sure the distance between the nozzle and the optical window remains at least 60 cm.
  - Using automatic cleaning devices that are not specifically designed for lidars may pose risks. Please contact Hesai technical support for assessment.
  - Do NOT use sharp objects (such as knives or metal tweezers) or hard brushes (such as stiff nylon brushes or wire brushes) to scratch the optical window cover surface. Such actions may damage the optical window surface, and in severe cases, may cause malfunction.
- After prolonged exposure to strong sunlight and high temperatures, the optical window should NOT be cleaned immediately.
- If snow or ice accumulates on the optical window, do NOT use a pressure washer or ice scraper.
  - A small broom is recommended to remove snow.
  - A solvent-free (i.e., free of organic solvents) ice removal spray is recommended to remove ice; alternatively, wait for the ice to melt by itself.
- Do NOT wax the optical window.

Please regularly check on the optical window, considering your use frequency, storage environment, and climate conditions.

- If foreign objects (such as dust, fingerprints, or oil stains) are found on the optical window, make sure to clean them.
- If corrosive foreign objects (such as insect remains, bird droppings, tree resin, road dust, industrial dust, asphalt, soot particles, and road salt) are found on the optical window, make sure to clean them immediately.

### Cleaning procedure

1. Make sure the lidar is powered OFF.
2. Choose an appropriate cleaning agent:
   - For light stains, use room temperature water.
   - For heavier stains, use a mild soap solution (no more than two tablespoons of soap per quart or liter of water).
   - For stubborn stains, use a solvent-free (i.e., free of organic solvents), pH-neutral detergent at room temperature, such as car shampoo.
3. Take a clean soft sponge or anti-static microfiber cloth, dampen it with the chosen cleaning agent, and gently wipe the dirty area on the optical window back and forth.
4. For stubborn stains, cover the dirty area with the dampened sponge or cloth to soften the stains before wiping.
5. Immediately after removing the stains, rinse the optical window with clean water. Then, use a clean soft sponge or microfiber cloth to gently wipe away any remaining liquid (which may contain residual cleaning agents or contaminants).

# Appendix A: Channel distribution data

## A.1. Angular position and performance

### Notes to the table

**Channel number** Counts from 1, top to bottom.

**Angular position** The design values of each channel's horizontal (azimuth) angle offset and vertical (elevation) angle.

- The accurate values are recorded in this lidar unit's angle correction file.
- To analyze point cloud data, refer to Section 3.1.4 Point cloud data analysis method.

**Enable** 300 out of the 360 channels are enabled.

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 1 | 2.547° | 8.975° | Yes |
| 2 | 2.547° | 8.925° | No |
| 3 | 2.547° | 8.875° | Yes |
| 4 | 2.547° | 8.825° | No |
| 5 | 2.547° | 8.775° | Yes |
| 6 | 2.547° | 8.725° | No |
| 7 | 2.547° | 8.675° | Yes |
| 8 | 2.547° | 8.625° | No |
| 9 | 2.547° | 8.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 10 | 2.547° | 8.525° | No |
| 11 | 2.547° | 8.475° | Yes |
| 12 | 2.547° | 8.425° | No |
| 13 | 2.547° | 8.375° | Yes |
| 14 | 2.547° | 8.325° | No |
| 15 | 2.547° | 8.275° | Yes |
| 16 | 2.547° | 8.225° | No |
| 17 | 2.547° | 8.175° | Yes |
| 18 | 2.547° | 8.125° | No |
| 19 | 2.547° | 8.075° | Yes |
| 20 | 2.547° | 8.025° | No |
| 21 | 2.547° | 7.975° | Yes |
| 22 | 2.547° | 7.925° | No |
| 23 | 2.547° | 7.875° | Yes |
| 24 | 2.906° | 7.825° | No |
| 25 | 2.906° | 7.775° | Yes |
| 26 | 2.906° | 7.725° | No |
| 27 | 2.906° | 7.675° | Yes |
| 28 | 2.906° | 7.625° | No |
| 29 | 2.906° | 7.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 30 | 2.906° | 7.525° | No |
| 31 | 2.906° | 7.475° | Yes |
| 32 | 2.906° | 7.425° | No |
| 33 | 2.906° | 7.375° | Yes |
| 34 | 2.906° | 7.325° | No |
| 35 | 2.906° | 7.275° | Yes |
| 36 | 2.906° | 7.225° | No |
| 37 | 2.906° | 7.175° | Yes |
| 38 | 2.906° | 7.125° | No |
| 39 | 2.906° | 7.075° | Yes |
| 40 | 2.906° | 7.025° | No |
| 41 | 2.906° | 6.975° | Yes |
| 42 | 2.906° | 6.925° | No |
| 43 | 2.906° | 6.875° | Yes |
| 44 | 2.906° | 6.825° | No |
| 45 | 2.906° | 6.775° | Yes |
| 46 | 2.547° | 6.725° | No |
| 47 | 2.547° | 6.675° | Yes |
| 48 | 2.547° | 6.625° | No |
| 49 | 2.547° | 6.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 50 | 2.547° | 6.525° | No |
| 51 | 2.547° | 6.475° | Yes |
| 52 | 2.547° | 6.425° | No |
| 53 | 2.547° | 6.375° | Yes |
| 54 | 2.547° | 6.325° | No |
| 55 | 2.547° | 6.275° | Yes |
| 56 | 2.547° | 6.225° | No |
| 57 | 2.547° | 6.175° | Yes |
| 58 | 2.547° | 6.125° | No |
| 59 | 2.547° | 6.075° | Yes |
| 60 | 2.547° | 6.025° | No |
| 61 | 2.547° | 5.975° | Yes |
| 62 | 2.547° | 5.925° | Yes |
| 63 | 2.547° | 5.875° | Yes |
| 64 | 2.547° | 5.825° | Yes |
| 65 | 2.547° | 5.775° | Yes |
| 66 | 2.547° | 5.725° | Yes |
| 67 | 2.547° | 5.675° | Yes |
| 68 | 2.547° | 5.625° | Yes |
| 69 | 2.906° | 5.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 70 | 2.906° | 5.525° | Yes |
| 71 | 2.906° | 5.475° | Yes |
| 72 | 2.906° | 5.425° | Yes |
| 73 | 2.906° | 5.375° | Yes |
| 74 | 2.906° | 5.325° | Yes |
| 75 | 2.906° | 5.275° | Yes |
| 76 | 2.906° | 5.225° | Yes |
| 77 | 2.906° | 5.175° | Yes |
| 78 | 2.906° | 5.125° | Yes |
| 79 | 2.906° | 5.075° | Yes |
| 80 | 2.906° | 5.025° | Yes |
| 81 | 2.906° | 4.975° | Yes |
| 82 | 2.906° | 4.925° | Yes |
| 83 | 2.906° | 4.875° | Yes |
| 84 | 2.906° | 4.825° | Yes |
| 85 | 2.906° | 4.775° | Yes |
| 86 | 2.906° | 4.725° | Yes |
| 87 | 2.906° | 4.675° | Yes |
| 88 | 2.906° | 4.625° | Yes |
| 89 | 2.906° | 4.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 90 | 2.906° | 4.525° | Yes |
| 91 | 2.547° | 4.475° | Yes |
| 92 | 2.547° | 4.425° | Yes |
| 93 | 2.547° | 4.375° | Yes |
| 94 | 2.547° | 4.325° | Yes |
| 95 | 2.547° | 4.275° | Yes |
| 96 | 2.547° | 4.225° | Yes |
| 97 | 2.547° | 4.175° | Yes |
| 98 | 2.547° | 4.125° | Yes |
| 99 | 2.547° | 4.075° | Yes |
| 100 | 2.547° | 4.025° | Yes |
| 101 | 2.547° | 3.975° | Yes |
| 102 | 2.547° | 3.925° | Yes |
| 103 | 2.547° | 3.875° | Yes |
| 104 | 2.547° | 3.825° | Yes |
| 105 | 2.547° | 3.775° | Yes |
| 106 | 2.547° | 3.725° | Yes |
| 107 | 2.547° | 3.675° | Yes |
| 108 | 2.547° | 3.625° | Yes |
| 109 | 2.547° | 3.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 110 | 2.547° | 3.525° | Yes |
| 111 | 2.547° | 3.475° | Yes |
| 112 | 2.547° | 3.425° | Yes |
| 113 | 2.547° | 3.375° | Yes |
| 114 | 2.906° | 3.325° | Yes |
| 115 | 2.906° | 3.275° | Yes |
| 116 | 2.906° | 3.225° | Yes |
| 117 | 2.906° | 3.175° | Yes |
| 118 | 2.906° | 3.125° | Yes |
| 119 | 2.906° | 3.075° | Yes |
| 120 | 2.906° | 3.025° | Yes |
| 121 | 2.906° | 2.975° | Yes |
| 122 | 2.906° | 2.925° | Yes |
| 123 | 2.906° | 2.875° | Yes |
| 124 | 2.906° | 2.825° | Yes |
| 125 | 2.906° | 2.775° | Yes |
| 126 | 2.906° | 2.725° | Yes |
| 127 | 2.906° | 2.675° | Yes |
| 128 | 2.906° | 2.625° | Yes |
| 129 | 2.906° | 2.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 130 | 2.906° | 2.525° | Yes |
| 131 | 2.906° | 2.475° | Yes |
| 132 | 2.906° | 2.425° | Yes |
| 133 | 2.906° | 2.375° | Yes |
| 134 | 2.906° | 2.325° | Yes |
| 135 | 2.906° | 2.275° | Yes |
| 136 | 2.547° | 2.225° | Yes |
| 137 | 2.547° | 2.175° | Yes |
| 138 | 2.547° | 2.125° | Yes |
| 139 | 2.547° | 2.075° | Yes |
| 140 | 2.547° | 2.025° | Yes |
| 141 | 2.547° | 1.975° | Yes |
| 142 | 2.547° | 1.925° | Yes |
| 143 | 2.547° | 1.875° | Yes |
| 144 | 2.547° | 1.825° | Yes |
| 145 | 2.547° | 1.775° | Yes |
| 146 | 2.547° | 1.725° | Yes |
| 147 | 2.547° | 1.675° | Yes |
| 148 | 2.547° | 1.625° | Yes |
| 149 | 2.547° | 1.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 150 | 2.547° | 1.525° | Yes |
| 151 | 2.547° | 1.475° | Yes |
| 152 | 2.547° | 1.425° | Yes |
| 153 | 2.547° | 1.375° | Yes |
| 154 | 2.547° | 1.325° | Yes |
| 155 | 2.547° | 1.275° | Yes |
| 156 | 2.547° | 1.225° | Yes |
| 157 | 2.547° | 1.175° | Yes |
| 158 | 2.547° | 1.125° | Yes |
| 159 | 2.906° | 1.075° | Yes |
| 160 | 2.906° | 1.025° | Yes |
| 161 | 2.906° | 0.975° | Yes |
| 162 | 2.906° | 0.925° | Yes |
| 163 | 2.906° | 0.875° | Yes |
| 164 | 2.906° | 0.825° | Yes |
| 165 | 2.906° | 0.775° | Yes |
| 166 | 2.906° | 0.725° | Yes |
| 167 | 2.906° | 0.675° | Yes |
| 168 | 2.906° | 0.625° | Yes |
| 169 | 2.906° | 0.575° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 170 | 2.906° | 0.525° | Yes |
| 171 | 2.906° | 0.475° | Yes |
| 172 | 2.906° | 0.425° | Yes |
| 173 | 2.906° | 0.375° | Yes |
| 174 | 2.906° | 0.325° | Yes |
| 175 | 2.906° | 0.275° | Yes |
| 176 | 2.906° | 0.225° | Yes |
| 177 | 2.906° | 0.175° | Yes |
| 178 | 2.906° | 0.125° | Yes |
| 179 | 2.906° | 0.075° | Yes |
| 180 | 2.906° | 0.025° | Yes |
| 181 | -2.906° | -0.025° | Yes |
| 182 | -2.906° | -0.075° | Yes |
| 183 | -2.906° | -0.125° | Yes |
| 184 | -2.906° | -0.175° | Yes |
| 185 | -2.906° | -0.225° | Yes |
| 186 | -2.906° | -0.275° | Yes |
| 187 | -2.906° | -0.325° | Yes |
| 188 | -2.906° | -0.375° | Yes |
| 189 | -2.906° | -0.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 190 | -2.906° | -0.475° | Yes |
| 191 | -2.906° | -0.525° | Yes |
| 192 | -2.906° | -0.575° | Yes |
| 193 | -2.906° | -0.625° | Yes |
| 194 | -2.906° | -0.675° | Yes |
| 195 | -2.906° | -0.725° | Yes |
| 196 | -2.906° | -0.775° | Yes |
| 197 | -2.906° | -0.825° | Yes |
| 198 | -2.906° | -0.875° | Yes |
| 199 | -2.906° | -0.925° | Yes |
| 200 | -2.906° | -0.975° | Yes |
| 201 | -2.906° | -1.025° | Yes |
| 202 | -2.906° | -1.075° | Yes |
| 203 | -2.906° | -1.125° | Yes |
| 204 | -2.547° | -1.175° | Yes |
| 205 | -2.547° | -1.225° | Yes |
| 206 | -2.547° | -1.275° | Yes |
| 207 | -2.547° | -1.325° | Yes |
| 208 | -2.547° | -1.375° | Yes |
| 209 | -2.547° | -1.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 210 | -2.547° | -1.475° | Yes |
| 211 | -2.547° | -1.525° | Yes |
| 212 | -2.547° | -1.575° | Yes |
| 213 | -2.547° | -1.625° | Yes |
| 214 | -2.547° | -1.675° | Yes |
| 215 | -2.547° | -1.725° | Yes |
| 216 | -2.547° | -1.775° | Yes |
| 217 | -2.547° | -1.825° | Yes |
| 218 | -2.547° | -1.875° | Yes |
| 219 | -2.547° | -1.925° | Yes |
| 220 | -2.547° | -1.975° | Yes |
| 221 | -2.547° | -2.025° | Yes |
| 222 | -2.547° | -2.075° | Yes |
| 223 | -2.547° | -2.125° | Yes |
| 224 | -2.547° | -2.175° | Yes |
| 225 | -2.547° | -2.225° | Yes |
| 226 | -2.906° | -2.275° | Yes |
| 227 | -2.906° | -2.325° | Yes |
| 228 | -2.906° | -2.375° | Yes |
| 229 | -2.906° | -2.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 230 | -2.906° | -2.475° | Yes |
| 231 | -2.906° | -2.525° | Yes |
| 232 | -2.906° | -2.575° | Yes |
| 233 | -2.906° | -2.625° | Yes |
| 234 | -2.906° | -2.675° | Yes |
| 235 | -2.906° | -2.725° | Yes |
| 236 | -2.906° | -2.775° | Yes |
| 237 | -2.906° | -2.825° | Yes |
| 238 | -2.906° | -2.875° | Yes |
| 239 | -2.906° | -2.925° | Yes |
| 240 | -2.906° | -2.975° | Yes |
| 241 | -2.906° | -3.025° | Yes |
| 242 | -2.906° | -3.075° | Yes |
| 243 | -2.906° | -3.125° | Yes |
| 244 | -2.906° | -3.175° | Yes |
| 245 | -2.906° | -3.225° | Yes |
| 246 | -2.906° | -3.275° | Yes |
| 247 | -2.906° | -3.325° | Yes |
| 248 | -2.906° | -3.375° | Yes |
| 249 | -2.547° | -3.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 250 | -2.547° | -3.475° | Yes |
| 251 | -2.547° | -3.525° | Yes |
| 252 | -2.547° | -3.575° | Yes |
| 253 | -2.547° | -3.625° | Yes |
| 254 | -2.547° | -3.675° | Yes |
| 255 | -2.547° | -3.725° | Yes |
| 256 | -2.547° | -3.775° | Yes |
| 257 | -2.547° | -3.825° | Yes |
| 258 | -2.547° | -3.875° | Yes |
| 259 | -2.547° | -3.925° | Yes |
| 260 | -2.547° | -3.975° | Yes |
| 261 | -2.547° | -4.025° | Yes |
| 262 | -2.547° | -4.075° | Yes |
| 263 | -2.547° | -4.125° | Yes |
| 264 | -2.547° | -4.175° | Yes |
| 265 | -2.547° | -4.225° | Yes |
| 266 | -2.547° | -4.275° | Yes |
| 267 | -2.547° | -4.325° | Yes |
| 268 | -2.547° | -4.375° | Yes |
| 269 | -2.547° | -4.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 270 | -2.547° | -4.475° | Yes |
| 271 | -2.906° | -4.525° | Yes |
| 272 | -2.906° | -4.575° | Yes |
| 273 | -2.906° | -4.625° | Yes |
| 274 | -2.906° | -4.675° | Yes |
| 275 | -2.906° | -4.725° | Yes |
| 276 | -2.906° | -4.775° | Yes |
| 277 | -2.906° | -4.825° | Yes |
| 278 | -2.906° | -4.875° | Yes |
| 279 | -2.906° | -4.925° | Yes |
| 280 | -2.906° | -4.975° | Yes |
| 281 | -2.906° | -5.025° | Yes |
| 282 | -2.906° | -5.075° | Yes |
| 283 | -2.906° | -5.125° | Yes |
| 284 | -2.906° | -5.175° | Yes |
| 285 | -2.906° | -5.225° | Yes |
| 286 | -2.906° | -5.275° | Yes |
| 287 | -2.906° | -5.325° | Yes |
| 288 | -2.906° | -5.375° | Yes |
| 289 | -2.906° | -5.425° | Yes |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 290 | -2.906° | -5.475° | Yes |
| 291 | -2.906° | -5.525° | Yes |
| 292 | -2.906° | -5.575° | Yes |
| 293 | -2.906° | -5.625° | Yes |
| 294 | -2.547° | -5.675° | Yes |
| 295 | -2.547° | -5.725° | Yes |
| 296 | -2.547° | -5.775° | Yes |
| 297 | -2.547° | -5.825° | Yes |
| 298 | -2.547° | -5.875° | Yes |
| 299 | -2.547° | -5.925° | Yes |
| 300 | -2.547° | -5.975° | Yes |
| 301 | -2.547° | -6.025° | No |
| 302 | -2.547° | -6.075° | Yes |
| 303 | -2.547° | -6.125° | No |
| 304 | -2.547° | -6.175° | Yes |
| 305 | -2.547° | -6.225° | No |
| 306 | -2.547° | -6.275° | Yes |
| 307 | -2.547° | -6.325° | No |
| 308 | -2.547° | -6.375° | Yes |
| 309 | -2.547° | -6.425° | No |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 310 | -2.547° | -6.475° | Yes |
| 311 | -2.547° | -6.525° | No |
| 312 | -2.547° | -6.575° | Yes |
| 313 | -2.547° | -6.625° | No |
| 314 | -2.547° | -6.675° | Yes |
| 315 | -2.547° | -6.725° | No |
| 316 | -2.906° | -6.775° | Yes |
| 317 | -2.906° | -6.825° | No |
| 318 | -2.906° | -6.875° | Yes |
| 319 | -2.906° | -6.925° | No |
| 320 | -2.906° | -6.975° | Yes |
| 321 | -2.906° | -7.025° | No |
| 322 | -2.906° | -7.075° | Yes |
| 323 | -2.906° | -7.125° | No |
| 324 | -2.906° | -7.175° | Yes |
| 325 | -2.906° | -7.225° | No |
| 326 | -2.906° | -7.275° | Yes |
| 327 | -2.906° | -7.325° | No |
| 328 | -2.906° | -7.375° | Yes |
| 329 | -2.906° | -7.425° | No |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 330 | -2.906° | -7.475° | Yes |
| 331 | -2.906° | -7.525° | No |
| 332 | -2.906° | -7.575° | Yes |
| 333 | -2.906° | -7.625° | No |
| 334 | -2.906° | -7.675° | Yes |
| 335 | -2.906° | -7.725° | No |
| 336 | -2.906° | -7.775° | Yes |
| 337 | -2.906° | -7.825° | No |
| 338 | -2.906° | -7.875° | Yes |
| 339 | -2.547° | -7.925° | No |
| 340 | -2.547° | -7.975° | Yes |
| 341 | -2.547° | -8.025° | No |
| 342 | -2.547° | -8.075° | Yes |
| 343 | -2.547° | -8.125° | No |
| 344 | -2.547° | -8.175° | Yes |
| 345 | -2.547° | -8.225° | No |
| 346 | -2.547° | -8.275° | Yes |
| 347 | -2.547° | -8.325° | No |
| 348 | -2.547° | -8.375° | Yes |
| 349 | -2.547° | -8.425° | No |

| Channel number | Angular position | | Enabled? |
|---|---|---|---|
| | Horizontal angle offset (azimuth) | Vertical angle (elevation) | |
| 350 | -2.547° | -8.475° | Yes |
| 351 | -2.547° | -8.525° | No |
| 352 | -2.547° | -8.575° | Yes |
| 353 | -2.547° | -8.625° | No |
| 354 | -2.547° | -8.675° | Yes |
| 355 | -2.547° | -8.725° | No |
| 356 | -2.547° | -8.775° | Yes |
| 357 | -2.547° | -8.825° | No |
| 358 | -2.547° | -8.875° | Yes |
| 359 | -2.547° | -8.925° | No |
| 360 | -2.547° | -8.975° | Yes |

# A.2. Angle correction file

**Purpose**

- For analyzing point cloud data
- For accurately displaying point cloud in PandarView 2

**How to obtain it (using one of these ways)**

- Send PTC command 0x05; see the TCP API Reference Manual.
- Export the file using PandarView 2; see the PandarView 2 User Manual.
- Ask Hesai technical support or your sales representative.

**Data format**

See table below.

- To view the .dat file, use a hex viewer to open it.
- Byte size of the file: $32 + 8 \times M + (8 + 1) \times N + 180 \times 2 \times V = 9056$
- Unless otherwise specified, all the multi-byte fields are in little-endian format.

| Field | Byte(s) | Type | Description |
|---|---|---|---|
| Beginning of File | 1 | uint | 0xEE |
| Beginning of File | 1 | uint | 0xFF |
| Protocol Version Major | 1 | uint | Main class of the angle correction data structure<br>Current value: 0x01 |
| Protocol Version Minor | 1 | uint | Subclass of the angle correction data structure<br>Current value: 0x09 |
| File Length | 2 | uint | Current value: 0x23 60 (9056 bytes) |
| Channel Number | 2 | uint | Number of channels N<br>Fixed: 0x01 68 (360) |

| Field | Byte(s) | Type | Description |
|---|---|---|---|
| Laser Number | 1 | uint | Fixed: 0x10 (16) |
| Mirror Number | 1 | uint | Mirror number M<br>Fixed: 0x03 (3 mirror surfaces) |
| Frame Number | 1 | uint | Frame number F for every 360° rotation<br>Default: 0x03 (3 frames; each mirror surface corresponds to one frame)<br>This field is only used for PandarView 2 display configuration, not for point cloud data analysis. |
| Frame Config Byte | 8 | uint 8 array | The first F bytes represent the configuration of F frames, with one byte per frame; the other bytes are not used.<br>Each byte is a bitmap: The first M bits correspond to M mirror surfaces; the other bits are not used.<br>If a bit is set to 1, the measurements from the corresponding mirror surface are output to the byte's corresponding frame; otherwise, the measurements from that mirror surface are not output.<br>See Examples of the Frame Config Byte.<br>This field is only used for PandarView 2 display configuration, not for point cloud data analysis. |
| Angle_Division | 2 | uint | Used in the units of the fields below.<br>Always 0x64 00 (25600) |
| Mirror_Start_Angle[0:M-1] | 12 (4 × M) | uint32 array | The encoder angle of each mirror surface's starting side<br>Unit: (1/`Angle_Division`)° |

| Field | Byte(s) | Type | Description |
|---|---|---|---|
| Mirror_End_Angle[0:M-1] | 12 (4 × M) | uint32 array | The encoder angle of each mirror surface's ending side<br>Unit: (1/`Angle_Division`)°<br>The range of each mirror surface (`Mirror_End_Angle` – `Mirror_Start_Angle`) ≈ 80° |
| Channel_Laser_Map[0:N-1] | 360 (1 × N) | uint8 array | Mapping of each channel to one of the 16 lasers, one byte per channel.<br>E.g., if Channel_Laser_Map[199] = 8, then Channel 200 corresponds to Laser 8.<br>Channel number starts from 1. |
| Azimuth_Offset[0:N-1] | 1440 (4 × N) | int32 array | Each channel's horizontal angle offset, irrelevant to mirror rotation<br>Unit: (1/`Angle_Division`)° |
| Elevation[0:N-1] | 1440 (4 × N) | int32 array | Each channel's vertical angle offset, irrelevant to mirror rotation<br>Unit: (1/`Angle_Division`)° |
| Reserved | 1 | - | - |
| Angle_Adjust_Division | 2 | uint | Used in the units of the fields below.<br>Always 0x64 00 (25600) |

| Field | Byte(s) | Type | Description |
|---|---|---|---|
| Azimuth_Adjust[0:2880-1] | 2880 (V × 180) | int8 array | Each channel's horizontal angle adjustments for every 2° encoder angle, relevant to mirror rotation<br><br>Format: 2D array[16][180]<br>• The 16 rows correspond to Lasers 0 to 15.<br>• The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯, and 358°.<br><br>Unit: (1/`Angle_Adjust_Division`)°<br><br>E.g., if Channel_Laser_Map[199] = 8, then the horizontal angle adjustment of Channel 200 at the 180° encoder angle position is Azimuth_Adjust[8][90].<br><br>Channel number starts from 1. |
| Elevation_Adjust[0:2880-1] | 2880 (V × 180) | int8 array | Each channel's vertical angle adjustments for every 2° encoder angle, relevant to mirror rotation<br><br>Format: 2D array[16][180]<br>• The 16 rows correspond to Lasers 0 to 15.<br>• The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯, and 358°.<br><br>Unit: (1/`Angle_Adjust_Division`)° |
| CRC | 8 | uint | CRC64 checksum of this angle correction file |

**Examples of the Frame Config Byte**

| Frame number F | First F bytes of `Frame Config Byte` | Description |
|---|---|---|
| F = 3 | 0000 0001, 0000 0010, 0000 0100 | • The measurements from Mirror Surfaces 0/1/2 are output to Frames 0/1/2, respectively.<br>• The frames are not stitched. |
| F = 1 | 0000 0111 | • The measurements from Mirror Surfaces 0/1/2 are output to one frame.<br>• Every three frames are stitched as one.<br>• The frame rate is 1/3 of that in the previous case, while the data points per frame are three times that of the previous case. |
| F = 1 | 0000 0000 | • The measurements from Mirror Surfaces 0/1/2 are output to one frame according to their encoder angles in Point Cloud Data Packets.<br>• No angle correction is performed. |

# A.3. Angle correction calculation

## A.3.1. Horizontal angle of the current firing channel

$$h_{angle} = (\frac{\alpha}{100} + \frac{\alpha_{fine}}{25600} - \frac{Mirror\_Start\_Angle\,(frame\_id)}{25600}) \times 2 - \frac{\alpha_{offset}(channel\_id)}{Angle\_Division} + \frac{\alpha_{adjust}(channel\_id,\ azimuth\_id)}{Adjust\_Angle\_Division}$$

| | |
|---|---|
| Encoder angle of each mirror surface's starting side (Mirror_Start_Angle) | See angle correction file. |
| Each channel's horizontal angle offset ($\alpha_{offset}$) | See angle correction file. |
| Each channel's horizontal angle adjustments for every 2° encoder angle ($\alpha_{adjust}$) | See angle correction file. |
| Unit: (resolution) | See angle correction file. |
| Encoder angle of the current data block (low-resolution part α and high-resolution part $\alpha_{fine}$) | See **`Azimuth`** and **`Fine Azimuth`** in Section 3.1.2.3 Body. |

## A.3.2. Vertical angle of the current firing channel

$$v_{angle} = \frac{\varepsilon(channel\_id)}{Anglel\_Division} + \frac{\varepsilon_{adjust}(channel\_id,\ azimuth\_id)}{Anglel\_Adjust\_Division}$$

| | |
|---|---|
| Each channel's vertical angle (ε) | See angle correction file. |
| Each channel's vertical angle adjustments for every 2° encoder angle ($\varepsilon_{adjust}$) | See angle correction file. |

If the encoder angle (α) is not divisible by 2°, the horizontal angle adjustments ($\alpha_{adjust}$) and vertical angle adjustments ($\varepsilon_{adjust}$) should be linearly interpolated. For example:

- If the $\alpha_{adjust}$ for 50° and 52° encoder angles are a and b, respectively, then at the 51° encoder angle position, $\alpha_{adjust}$ = (a + b)/2.
- If the $\varepsilon_{adjust}$ for 50° and 52° encoder angles are c and d, respectively, then at the 50.5° encoder angle position, $\varepsilon_{adjust}$ = (3c + d)/4.

# Appendix B: Nonlinear reflectivity mapping

Alternatively, users may choose the Nonlinear Mapping mode using PTC commands.

This mapping increases the contrast in the low-reflectivity region.

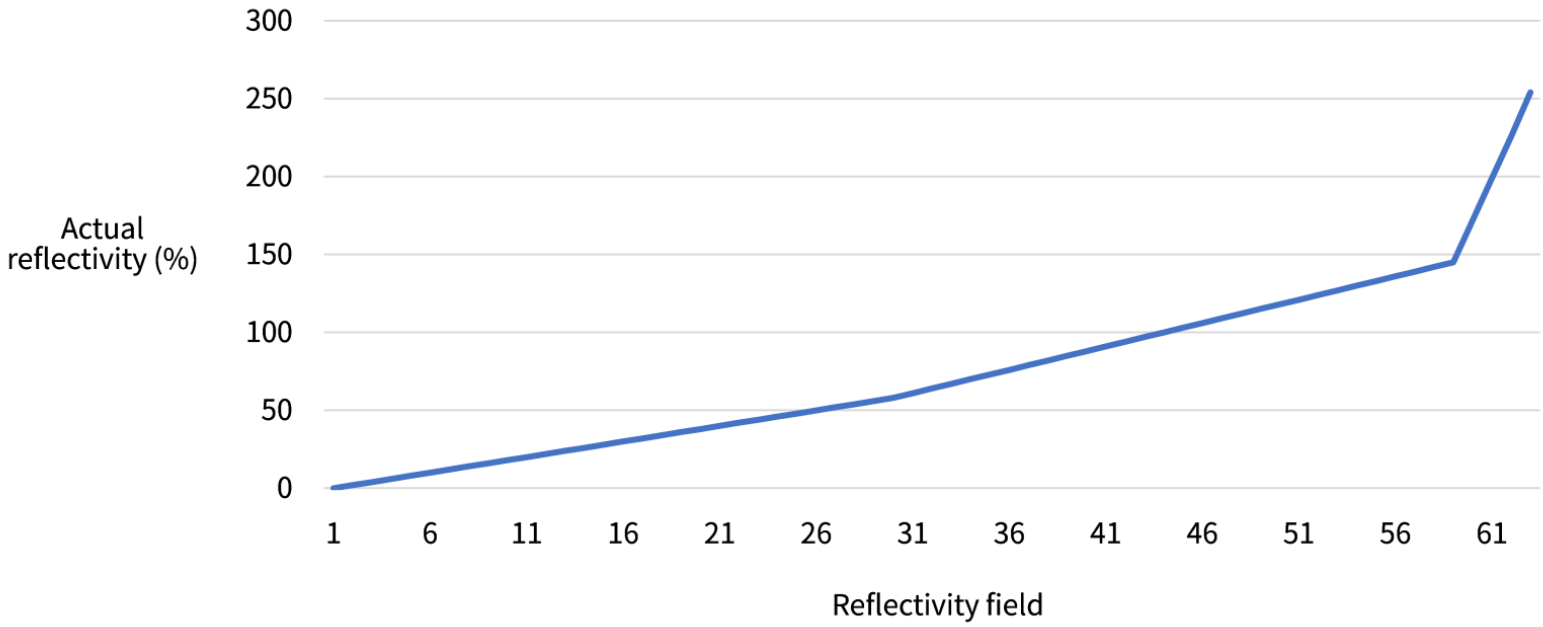



Figure 20. Nonlinear mapping

**Nonlinear mapping**

| Reflectivity field | Actual reflectivity (%) | Reflectivity field | Actual reflectivity (%) |
|---|---|---|---|
| 0 | 0 | 32 | 67 |
| 1 | 2 | 33 | 70 |

| Reflectivity field | Actual reflectivity (%) | Reflectivity field | Actual reflectivity (%) |
|---|---|---|---|
| 2 | 4 | 34 | 73 |
| 3 | 6 | 35 | 76 |
| 4 | 8 | 36 | 79 |
| 5 | 10 | 37 | 82 |
| 6 | 12 | 38 | 85 |
| 7 | 14 | 39 | 88 |
| 8 | 16 | 40 | 91 |
| 9 | 18 | 41 | 94 |
| 10 | 20 | 42 | 97 |
| 11 | 22 | 43 | 100 |
| 12 | 24 | 44 | 103 |
| 13 | 26 | 45 | 106 |
| 14 | 28 | 46 | 109 |
| 15 | 30 | 47 | 112 |
| 16 | 32 | 48 | 115 |
| 17 | 34 | 49 | 118 |
| 18 | 36 | 50 | 121 |
| 19 | 38 | 51 | 124 |
| 20 | 40 | 52 | 127 |
| 21 | 42 | 53 | 130 |
| 22 | 44 | 54 | 133 |

| Reflectivity field | Actual reflectivity (%) | Reflectivity field | Actual reflectivity (%) |
|---|---|---|---|
| 23 | 46 | 55 | 136 |
| 24 | 48 | 56 | 139 |
| 25 | 50 | 57 | 142 |
| 26 | 52 | 58 | 145 |
| 27 | 54 | 59 | 172 |
| 28 | 56 | 60 | 199 |
| 29 | 58 | 61 | 226 |
| 30 | 61 | 62 | 254 |
| 31 | 64 | 63 | N/A |

# Appendix C: Legal notice



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