

# Pandar128E3X

## 128-Channel Mechanical Lidar User Manual

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## ■ 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:

- Visit the Download page of Hesai's official website: <https://www.hesaitech.com/downloads/>
- Contact your sales representative of Hesai.
- Contact Hesai technical support: [service@hesaitech.com](mailto:service@hesaitech.com)

### Technical support

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

- [service@hesaitech.com](mailto: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.

Monospace font: field names

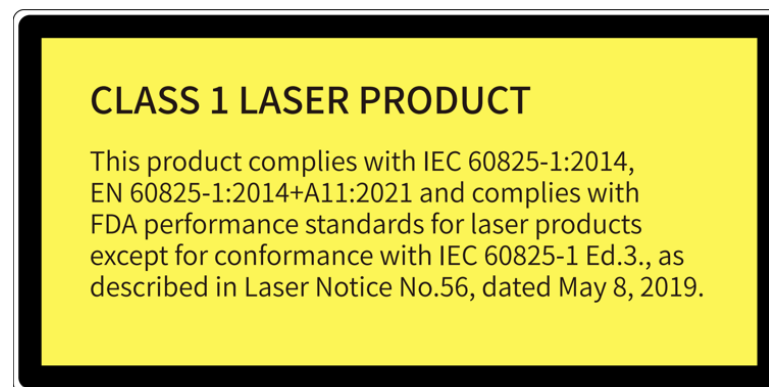
For example: **Distance** represents the Distance field.

## ■ 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 and read through the corresponding certification warnings. If specific users require not presenting 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. It is the responsibility of the end-product supplier to assess the risk of use in accordance with applicable standards and inform 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 potentially explosive atmospheres are present, such as environments with high concentrations of flammable chemicals, vapors, or particulates (including particles, dust, and metal powder) in the air.
- Do NOT expose the product to environments having 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  $23 \pm 5^{\circ}\text{C}$ , and the humidity is between 30% and 70%.



### **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 cover lens can be regarded as the product's laser emitting window; looking at the cover lens can be regarded as looking into transmitting laser.

## Product enclosure

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


## Cover lens

 The location of the cover lens is illustrated in [Section 1 Introduction](#).

- Do NOT apply protective film, wax or any other substance on the cover lens.
- To keep the product's cover lens from fingerprints and other stains, do NOT touch the cover lens with bare hands. If the cover lens is already stained, please refer to the cleaning method in [Section 6 Maintenance](#).
- To prevent scratches, do NOT touch the product's cover lens 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 cover lens to reduce the impact of ice and frost.

- While active heating is ON, please avoid direct skin contact with the cover lens.
- Users can 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, GPS/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

c: Speed of light

t: Travel time of the laser beam

## 1.2. Basic structure

The basic structure is shown in [Figure 1. Partial cross-sectional diagram](#). Multiple pairs of laser emitters and receivers are attached to a motor that rotates 360° horizontally.

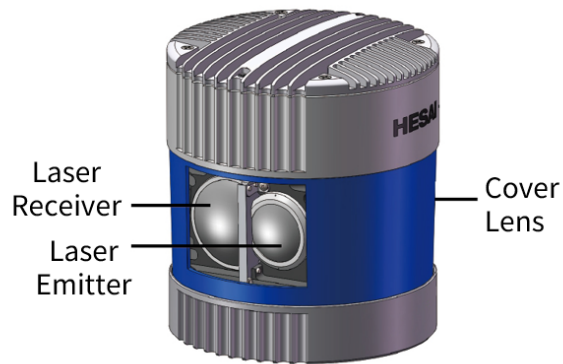


Figure 1. Partial cross-sectional diagram

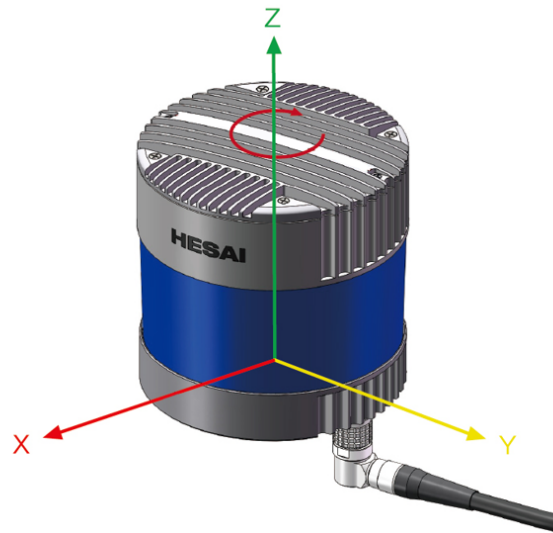


Figure 2. Coordinate system (isometric view)

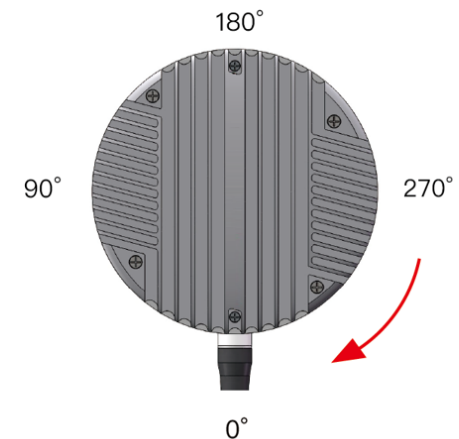


Figure 3. Lidar azimuthal position (top view)

The lidar's coordinate system is illustrated in [Figure 2. Coordinate system \(isometric view\)](#).

- Z-axis is the axis of rotation.
- The origin's exact position is shown as a red dot in [Figure 5. Laser firing position \(unit: mm\)](#). All measurements are relative to the origin.

Lidar azimuthal position is defined in [Figure 3. Lidar azimuthal position \(top view\)](#).

- By default, the lidar rotates clockwise in the top view. To select counterclockwise rotation, use either `web_control` or `PTC` commands.
- Y-axis corresponds to 0°.
- Each laser channel has an intrinsic azimuth offset. Channel 42 is selected to define the lidar's azimuthal position.

For example, when Channel 42 passes the 90° position:

- the lidar is at the 90° position.
- the azimuth of the corresponding data block in the Point Cloud Data Packet is 90°.



## 1.3. Channel distribution

All channels are unevenly distributed, as illustrated in [Figure 4. Channel vertical distribution](#).

- Vertical resolution: See [Section 1.4 Specifications](#).
- The design values of each channel's angular position: See [Appendix A Channel distribution data](#).
- Channel number counts from 1, top to bottom.

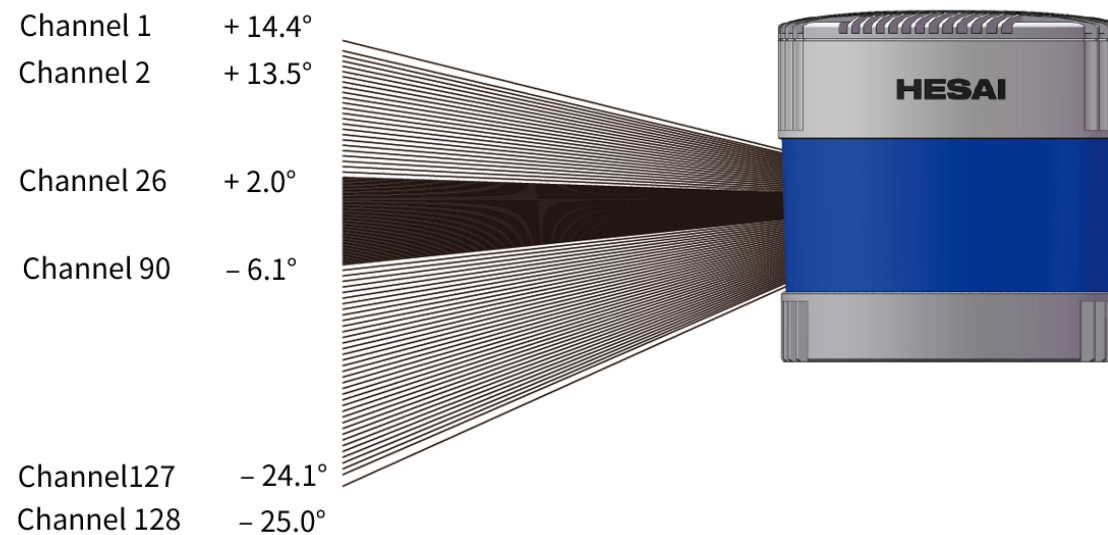


Figure 4. Channel vertical distribution

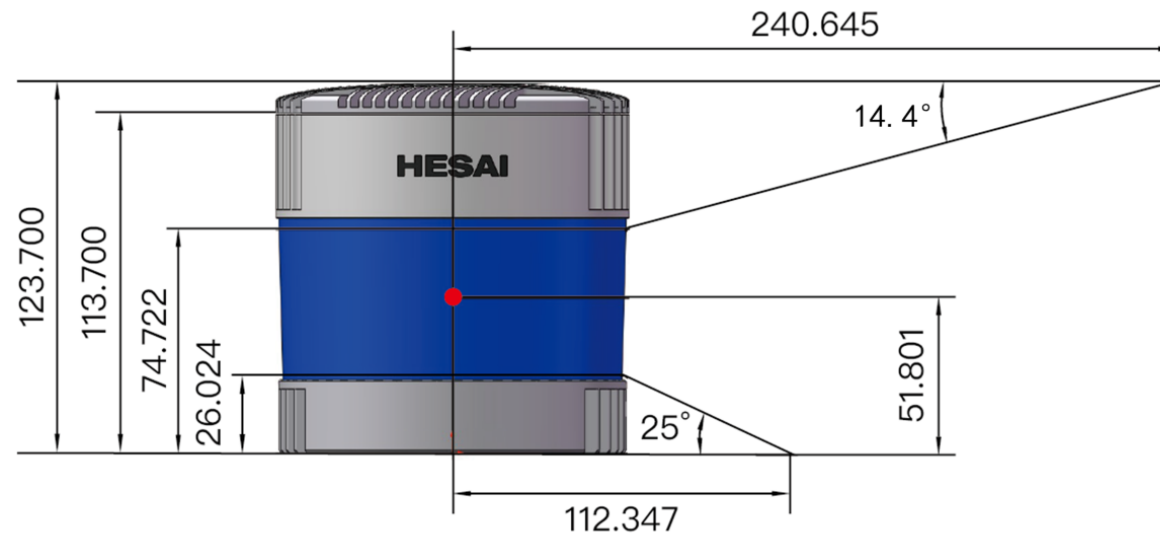


Figure 5. Laser firing position (unit: mm)

Each channel has an intrinsic angle offset, both horizontally and vertically. These angles are recorded in the angle correction file of this lidar, which is provided when shipping.

#### Angle correction file

In case you need to obtain this file again, please do one of the following:

- Send PTC command 0x05, as described in the TCP API Reference Manual (see [Section 5 Communication protocol](#)).
- Export the file using PandarView 2 according to PandarView 2 user manual.
- Contact sales representatives or technical support.

## 1.4. Specifications

### SENSOR

Scanning method	Mechanical rotation
Number of channels	128
Ranging capability ①③	0.3 to 200 m (at 10% reflectivity)
Ranging accuracy ②	±8 cm (0.3 to 0.5 m, each channel) ±5 cm (0.5 to 1 m, each channel) ±2 cm (1 to 200 m, average)
Horizontal FOV	360°
Horizontal resolution ③	Configurable on-the-fly 0.1°/0.2° (10 Hz) 0.2°/0.4° (20 Hz)
Vertical FOV	40° (-25° to +15°)
Vertical resolution	0.125° (Channel 26 to 90) 0.5° (Channels 2 to 26, 90 to 127) 1° (Channels 1 to 2, 127 to 128)
Frame rate	10 Hz, 20 Hz
Return mode	<b>Single Return:</b> Last/Strongest/First <b>Dual Return:</b> Last and Strongest, Last and First, First and Strongest

### MECHANICAL/ELECTRICAL/OPERATIONAL

Wavelength	905 nm
Laser class	Class 1 Eye Safe

Ingress protection	IP6K7 & IP6K9K
Dimensions	Height: 123.7 mm Top/bottom: $\Phi$ 118.0/116.0 mm
Rated voltage range	DC 9 to 48 V
Power consumption <sup>④</sup>	27 W (high-resolution mode) 23 W (standard mode)
Operating temperature	-40°C to 85°C
Storage temperature	-40°C to 85°C
Weight	1.63 kg

**DATA I/O**

Data transmission	Standard 1000BASE-T or automotive 1000BASE-T1 Slave Mode by default
Measurements	Distance, azimuth angle, and reflectivity
Valid data points	<b>Single Return:</b> 3 456 000 pts/sec (max) <b>Dual Return:</b> 6 912 000 pts/sec (max)
Point cloud data rate	<b>Single Return:</b> 135.22 Mbps (max) <b>Dual Return:</b> 270.44 Mbps (max)
Clock source	GPS/PTP (1588v2, 802.1AS, 802.1AS Automotive)
PTP clock accuracy	$\leq 1 \mu\text{s}$
PTP clock drift <sup>⑤</sup>	$\leq 1 \mu\text{s/s}$



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

## Notes to specifications

- |  |  |
|--|--|
| ① Ranging capability                         | <ul style="list-style-type: none"><li>• Measured under 100 klux ambient illuminance.</li><li>• The ranging capability of each channel is listed in <a href="#">Appendix A Channel distribution data</a>.</li></ul>   |
| ② Ranging accuracy                           | May vary with range, temperature, and target reflectivity.   |
| ③ Ranging capability & horizontal resolution | The data of each channel is in <a href="#">Appendix A Channel distribution data</a> .  |
| ④ Power consumption                          | <ul style="list-style-type: none"><li>• Measured under 10 Hz frame rate.</li><li>• Not including accessories such as the connection box.</li><li>• High-resolution and standard modes: See <a href="#">Section 4.4 High resolution</a>.</li><li>• The external power supply should be able to provide at least 27 W.</li></ul> |
| ⑤ 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 protective cover on the cover lens.

### 2.1. Mechanical installation

#### 2.1.1. Exterior dimensions

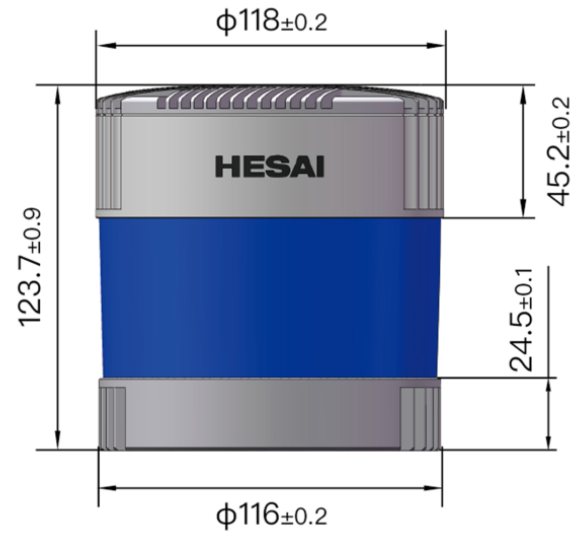


Figure 6. Front view (unit: mm)

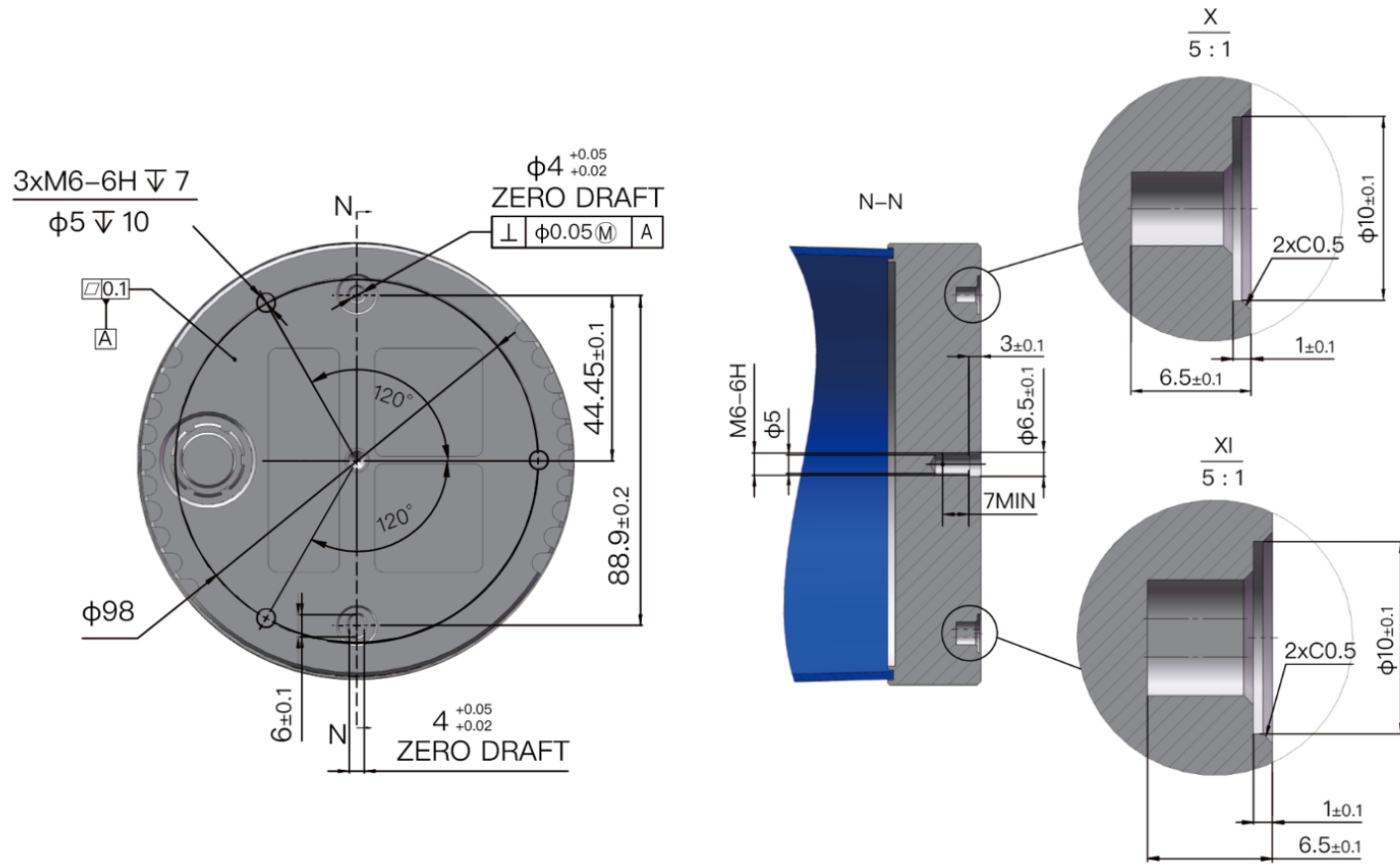


Figure 7. Bottom view (unit: mm)

### 2.1.2. Quick installation

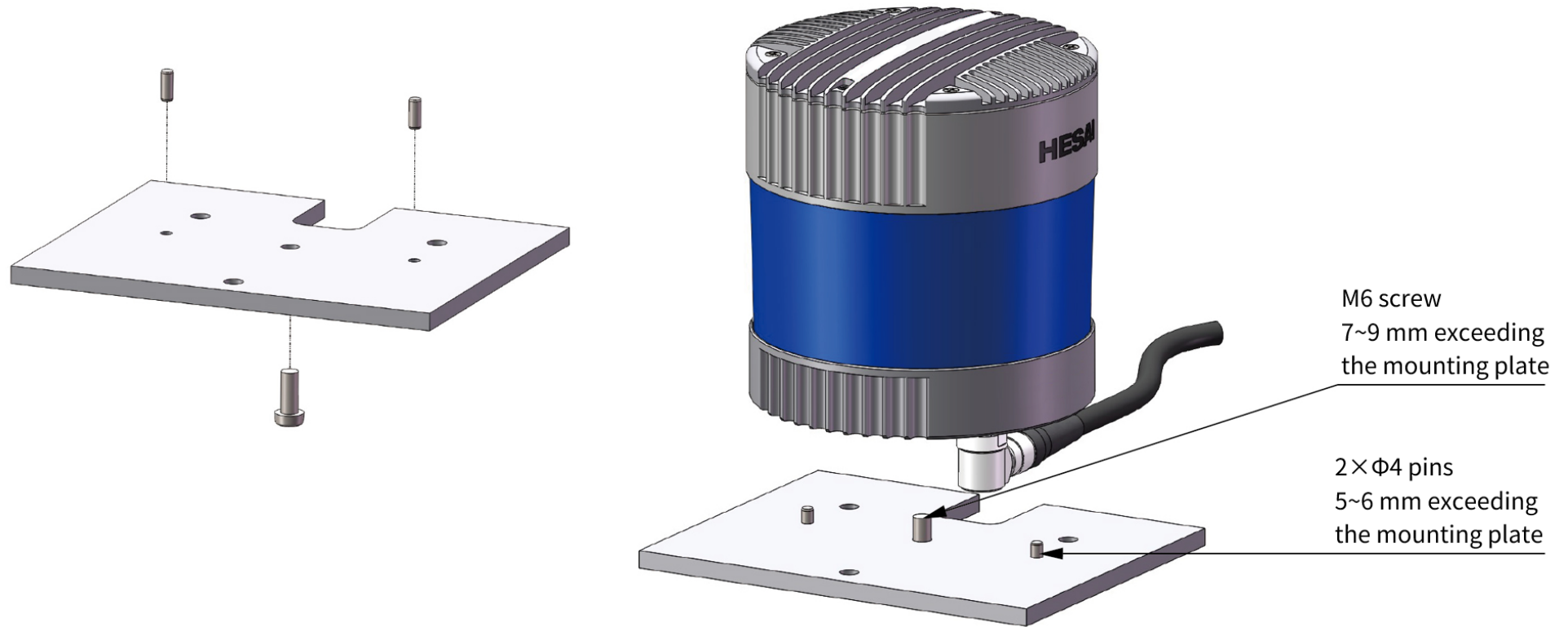


Figure 8. Quick installation



### 2.1.3. Stable installation

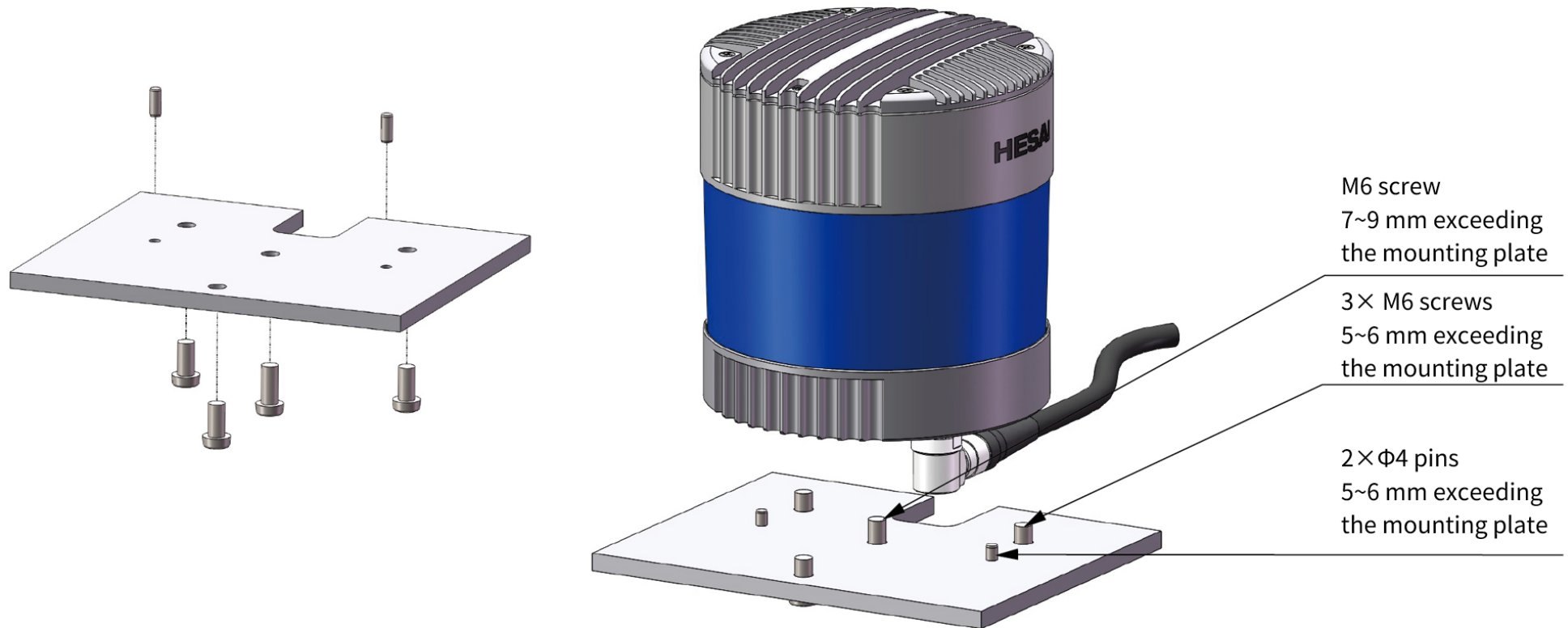


Figure 9. Stable installation

## 2.1.4. Notes on screw installation

### Screw type

SEMS screws (with pre-attached flat washers and lock washers) are recommended. Property class should be at least 4.8.

### Threadlocker

Before fastening a screw, apply 1 or 2 dots of threadlocker in the thread fit area. LOCTITE® 263 Threadlocker is recommended. To ensure curing it in place, wait for at least 12 hours before operating the lidar.

### Screw torque

The base material of the threaded holes is aluminum alloy instead of steel. Refer to the following table for the appropriate screw torque.

Thread size	Recommended screw torque
M2	0.2 to 0.3 Nm
M3	0.5 to 0.6 Nm
M4	1 to 1.5 Nm
M5	2 to 2.5 Nm
M6	3.5 to 4 Nm

### Thread service life

25 times

Each screwing counts as one time, so as each unscrewing.

## 2.2. Electrical interface

Lemo part number: EEG.2T.316.CLN (female socket, on the lidar)

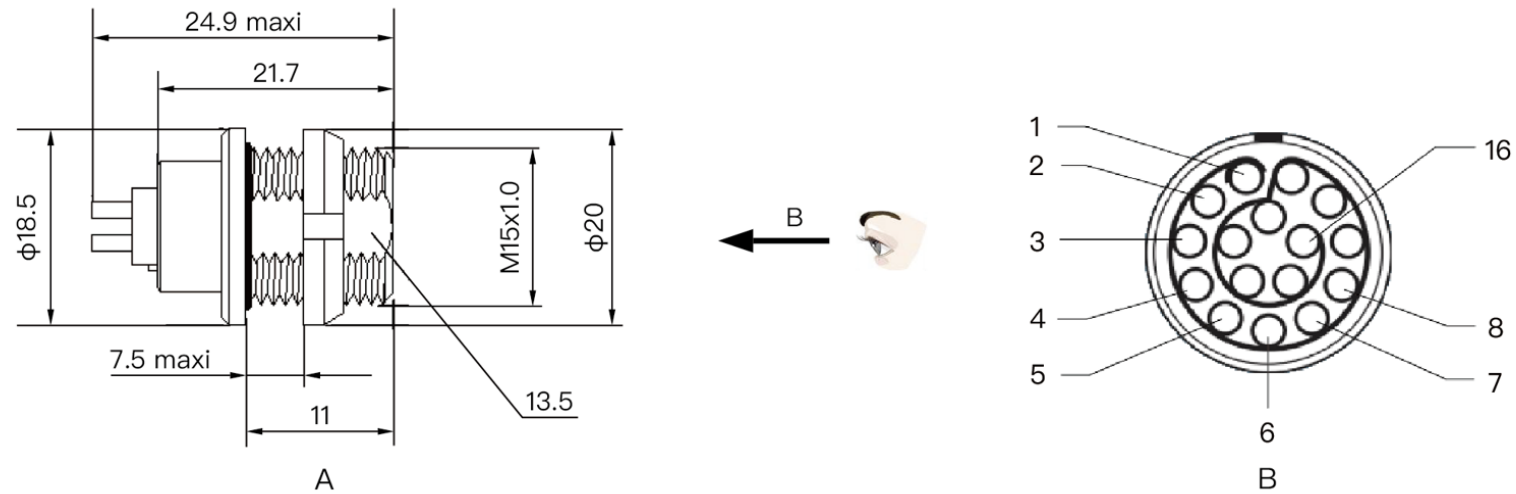


Figure 10. Lemo connector (female socket)


## 2.2.1. Pin description

### Standard 1000BASE-T

No.	Signal	Voltage	Wire color
1	Ground (Return)	0 V	Black
2	Ground (Return)	0 V	White
3	Ethernet BI_DC-	-1 to 1 V	Blue
4	Ethernet BI_DC+	-1 to 1 V	Blue/White
5	Ethernet BI_DB-	-1 to 1 V	Green
6	Ethernet BI_DB+	-1 to 1 V	Green/White
7	Ethernet BI_DA-	-1 to 1 V	Orange
8	Ethernet BI_DA+	-1 to 1 V	Orange/White
9	GPS Serial Data	-13 to 13 V	Yellow
10	Power	9 to 48 V	Red
11	Power	9 to 48 V	Green
12	GPS PPS	3.3/5 V	Purple
13	Ethernet BI_DD-	-1 to 1 V	Brown
14	Ethernet BI_DD+	-1 to 1 V	Brown/White
15	Index	0 to 3.3 V	Gray
16	Encoder	0 to 3.3 V	Gray/White

### Automotive 1000BASE-T1

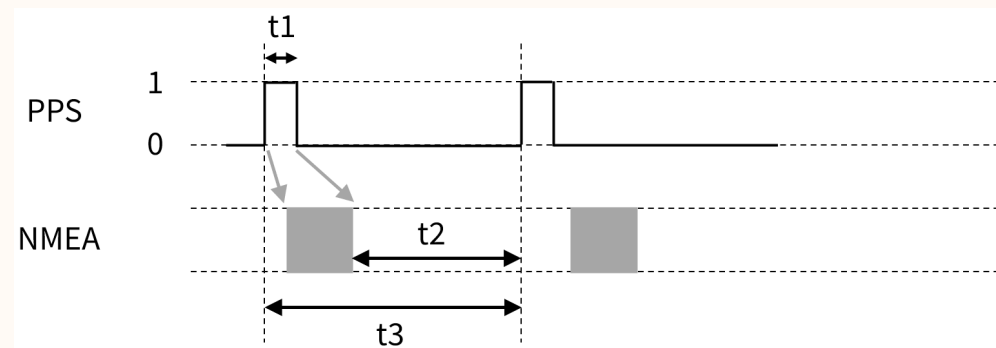
No.	Signal	Voltage	Wire color
1	Ground (Return)	0 V	Black
2	Ground (Return)	0 V	White
3	Ethernet_Data-	-1 to 1 V	Blue
4	Ethernet_Data+	-1 to 1 V	Blue/White
5 to 8	—	—	—
9	GPS Serial Data	-13 to 13 V	Yellow
10	Power	9 to 48 V	Red
11	Power	9 to 48 V	Green
12	GPS PPS	3.3/5 V	Purple
13 to 14	—	—	—
15	Index	0 to 3.3 V	Gray
16	Encoder	0 to 3.3 V	Gray/White

 Wire colors: applicable to extension cables and connection box cables.



- Before connecting or disconnecting an external GPS signal (either using the cable's GPS wire or via the connection box's GPS port), make sure the lidar is powered off.
- If the lidar has to stay powered on, make sure to ground yourself in advance. Do NOT touch the GPS wire or GPS port with bare hands.

## Timing requirements of GPS PPS and GPS Serial Data (NMEA)



GPS PPS: signal cycle	$t_3 = 1 \text{ s} \pm 50 \mu\text{s}$ (rising edge to rising edge)
GPS PPS: pulse width	$t_1 \geq 1 \text{ ms}$ (10 to 100 ms recommended)
Timing relationship	NMEA signal starts after the PPS rising edge of the current second, and ends after the PPS falling edge of the current second, as shown by the gray arrows in the figure above. NMEA signal ends before the PPS rising edge of the next second; $t_2 \geq 100 \text{ ms}$ .

### 2.2.2. Connector use

Connection	<ol style="list-style-type: none"> <li>1. Turn off the power source.</li> <li>2. Align the red dots on the connector shells.</li> <li>3. Push the plug straight into the socket.</li> </ol>
Disconnection	<ol style="list-style-type: none"> <li>1. Turn off the power source.</li> <li>2. Pull the release sleeve on the male connector to its outermost position and hold it.</li> <li>3. Pull the plug from the socket.</li> </ol>

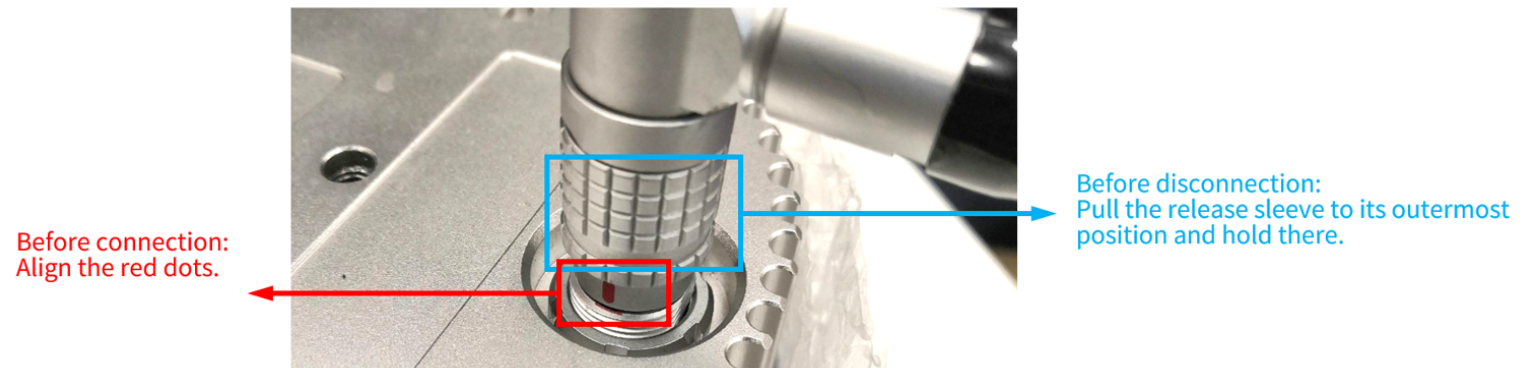


Figure 11. Connection/disconnection



- 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's technical support or obtain work instructions from the connector manufacturer.

- The connector is designed to withstand at least 1000 mating cycles; exceeding this number may increase the risk of connector damage.

### 2.2.3. Bending of cables

Outer diameter (OD) =  $7.70 \pm 0.30$  mm

Minimum bend radius =  $5 \times OD$



## 2.3. Connection box (optional)

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

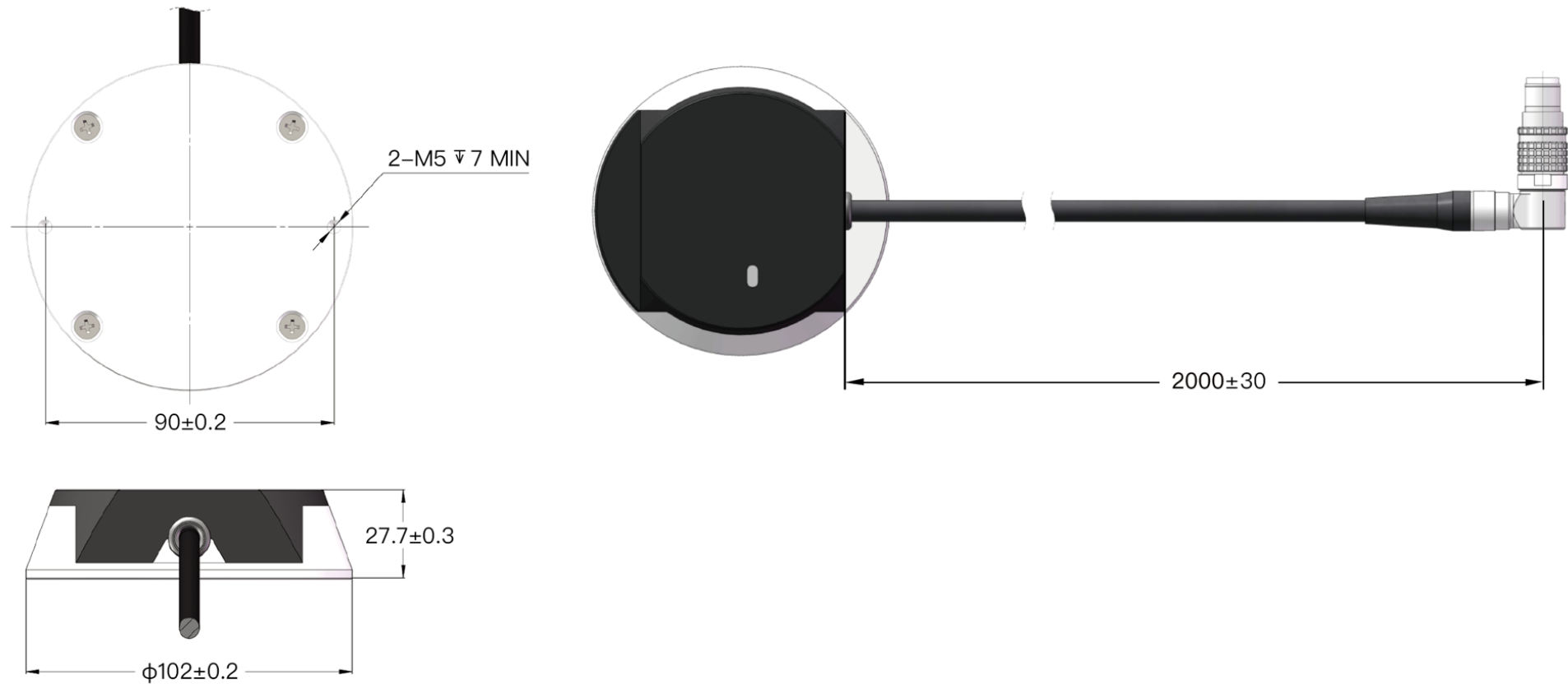


Figure 12. Connection box



- Unit: mm
- Lemo part number: FSG.2T.316.CLAC80Z (male plug, on the connection box)

### 2.3.1. Ports

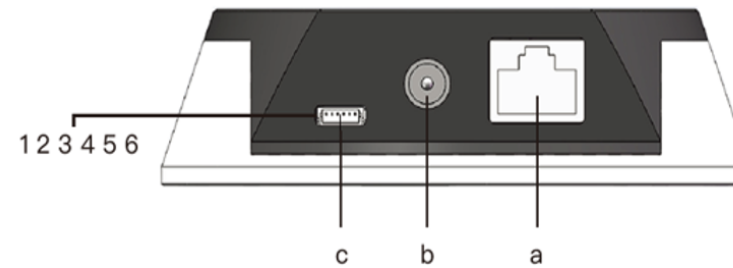


Figure 13. Connection box (front)

Port No.	Port name	Description								
a	Standard Ethernet port	RJ45, Standard 1000BASE-T Ethernet								
b	Power port	Use a DC-005 power adapter.								
c	GPS port	Accepts GPS signals (for time synchronization). <table border="1" data-bbox="741 820 2074 1099"> <tbody> <tr> <td>Connector</td> <td>JST: SM06B-SRSS-TB</td> </tr> <tr> <td>Recommended connector for the external GPS module</td> <td>JST: SHR-06V-S-B</td> </tr> <tr> <td>Voltage standard</td> <td>RS232</td> </tr> <tr> <td>Baud rate</td> <td>9600 bps</td> </tr> </tbody> </table>	Connector	JST: SM06B-SRSS-TB	Recommended connector for the external GPS module	JST: SHR-06V-S-B	Voltage standard	RS232	Baud rate	9600 bps
Connector	JST: SM06B-SRSS-TB									
Recommended connector for the external GPS module	JST: SHR-06V-S-B									
Voltage standard	RS232									
Baud rate	9600 bps									

GPS port pins (left to right):

Pin No.	Direction	Description	Requirements
1	Input	PPS signal for synchronization	TTL level 3.3/5 V  Recommended pulse width: $\geq 1$ ms Signal cycle: 1 s (rising edge to rising edge)

### 2.3. Connection box (optional)

Pin No.	Direction	Description	Requirements
2	Output	Power for the external GPS module	5 V
3	Output	Ground for the external GPS module	-
4	Input	Receiving serial data from the external GPS module	RS232 level
5	Output	Ground for the external GPS module	-
6	-	Reserved	-

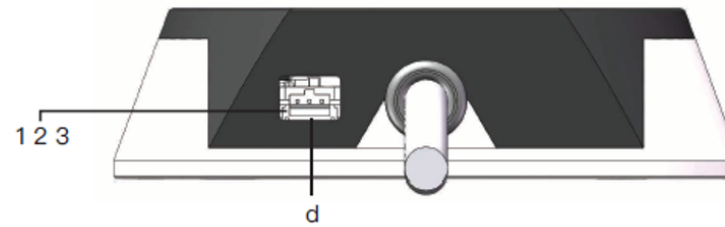


Figure 14. Connection box (back)

Port No.	Port name	Description										
d	Trigger port	Outputs external trigger signals for multi-sensor synchronization.										
		<table border="1"> <tr> <td>Connector (male plug)</td> <td>Molex, LLC: 5023520300</td> </tr> <tr> <td>Recommended wire connector (female socket)</td> <td>Molex, LLC: 5023510300</td> </tr> <tr> <td>Voltage</td> <td>0 to 3.3 V</td> </tr> <tr> <td>Signal type</td> <td>Pulse</td> </tr> <tr> <td>Max. output current</td> <td>3 mA</td> </tr> </table>	Connector (male plug)	Molex, LLC: 5023520300	Recommended wire connector (female socket)	Molex, LLC: 5023510300	Voltage	0 to 3.3 V	Signal type	Pulse	Max. output current	3 mA
Connector (male plug)	Molex, LLC: 5023520300											
Recommended wire connector (female socket)	Molex, LLC: 5023510300											
Voltage	0 to 3.3 V											
Signal type	Pulse											
Max. output current	3 mA											

Trigger port pins (left to right):

Pin No.	Direction	Signal	Description
1	Input	GND	Ground signal.
2	Output	Trigger-Encoder	Outputs one pulse when the lidar rotates 0.05° Pulse width: 8.31 $\mu$ s @ 600 RPM, 4.17 $\mu$ s @ 1200 RPM
3	Output	Trigger-Index	Outputs one pulse when Channel 42 passes the lidar's 180° position (see <a href="#">Figure 3. Lidar azimuthal position (top view)</a> ). Pulse width: 2.87 $\mu$ s @ 600 RPM, 1.44 $\mu$ s @ 1200 RPM

### 2.3.2. Connection

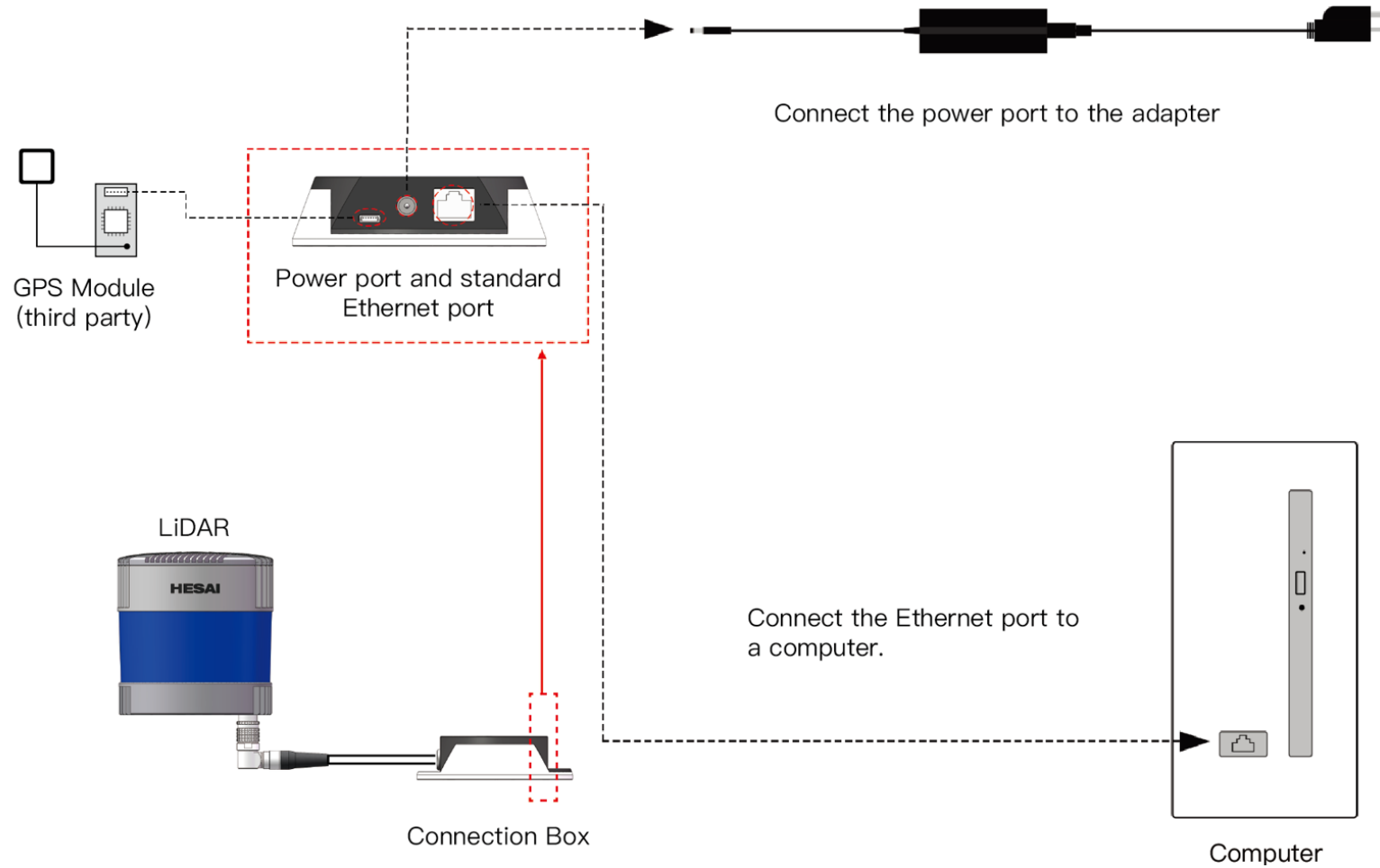


Figure 15. Connection when using GPS

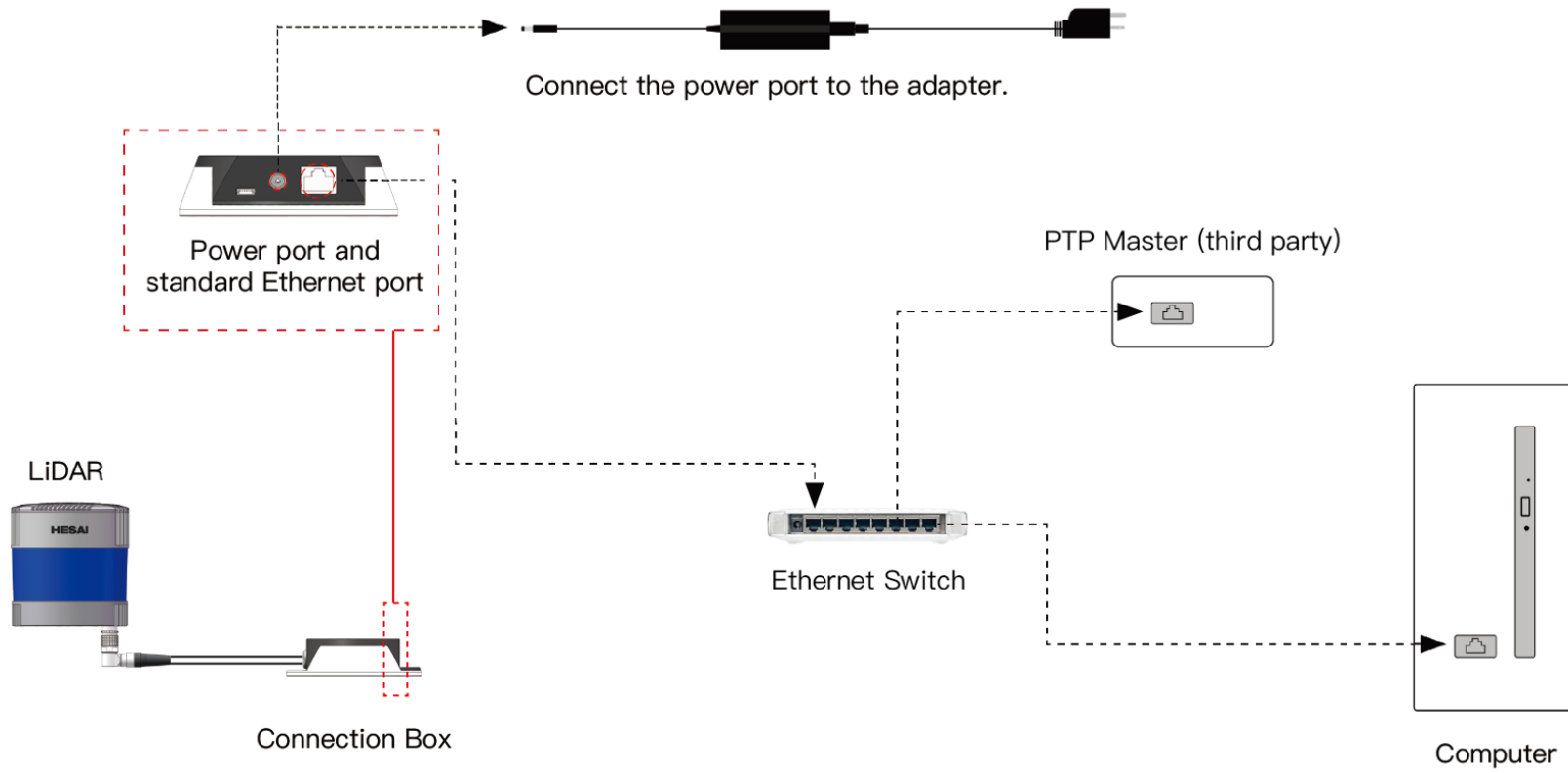


Figure 16. Connection when using PTP

## 2.4. Network settings on the receiving host

The lidar does not have a power switch. It starts transmitting data when all these conditions are met:

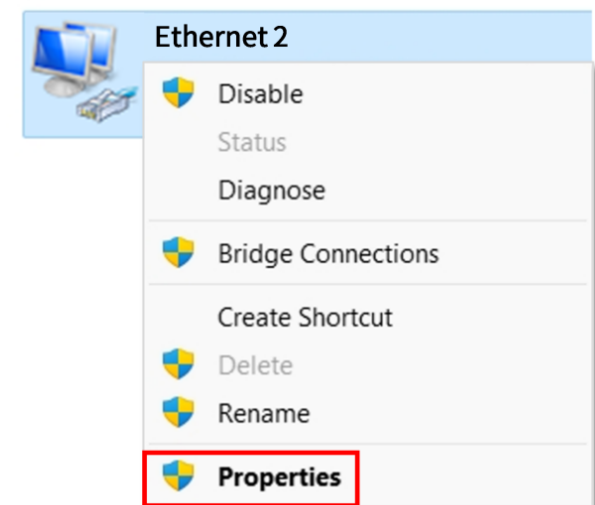
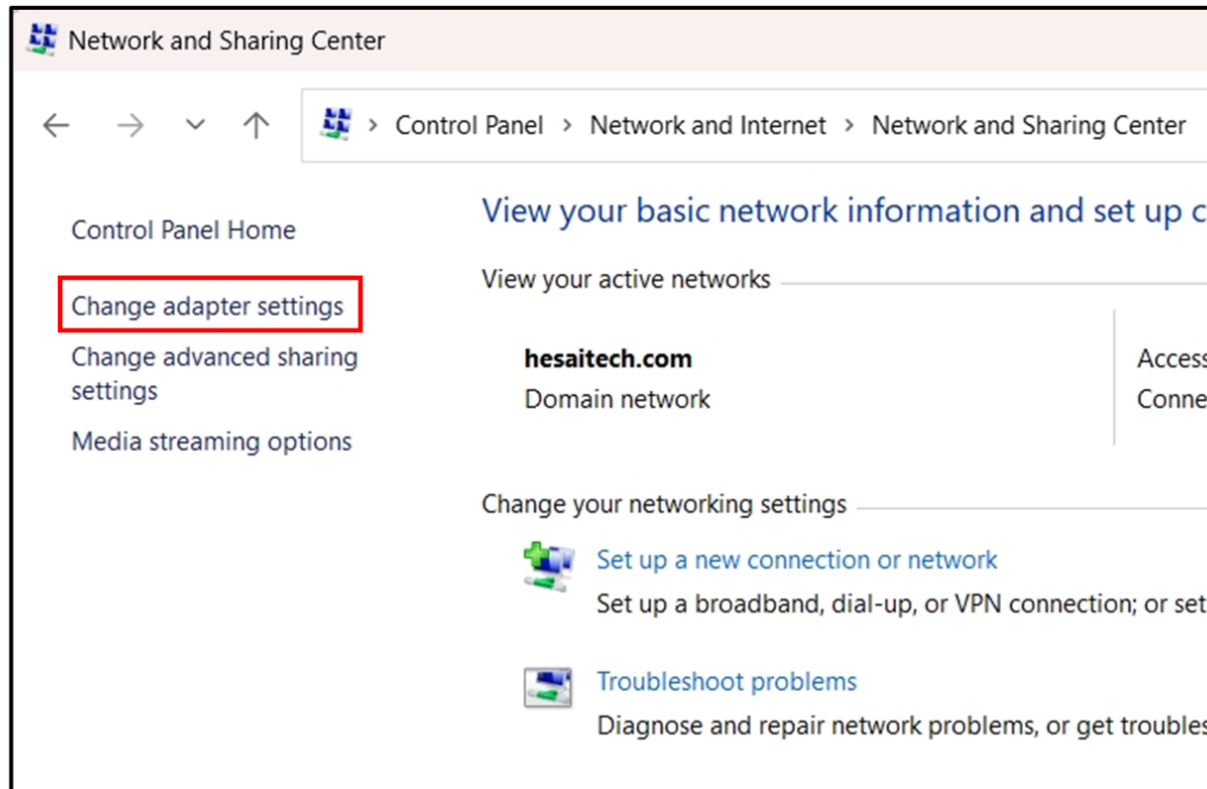
- The lidar is connected to power.
- The lidar is connected to a host computer via Ethernet.
- The network parameters of the receiving host are correctly configured.

### Configure the network parameters of the host computer

Network parameters	Value	Description
IP address	192.168.1.X	<p>Given the lidar's IP address (192.168.1.201) and subnet mask (255.255.255.0), the following can be determined:</p> <ul style="list-style-type: none"> <li>• Network address: 192.168.1.0</li> <li>• Gateway address: 192.168.1.1</li> <li>• Broadcast address: 192.168.1.255</li> </ul> <p>Therefore, <b>X</b> can be selected from 2 to 200 and from 202 to 254.</p>
Subnet mask	255.255.255.0	-
VLAN ID	Range: 1 to 4094	<p>Required only when VLAN tagging is used. Make sure the host computer and the lidar use the same VLAN ID.</p>

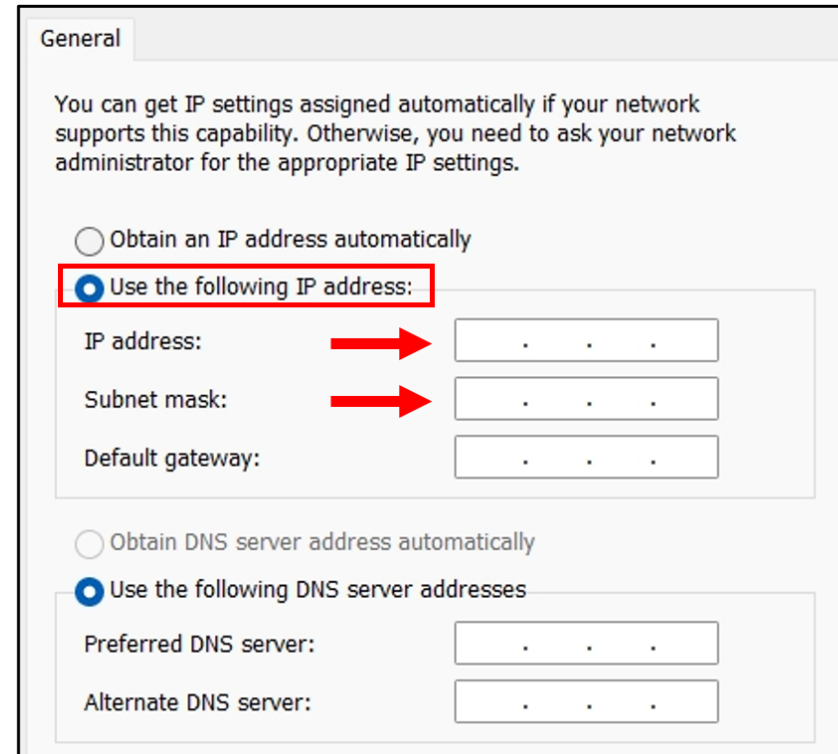
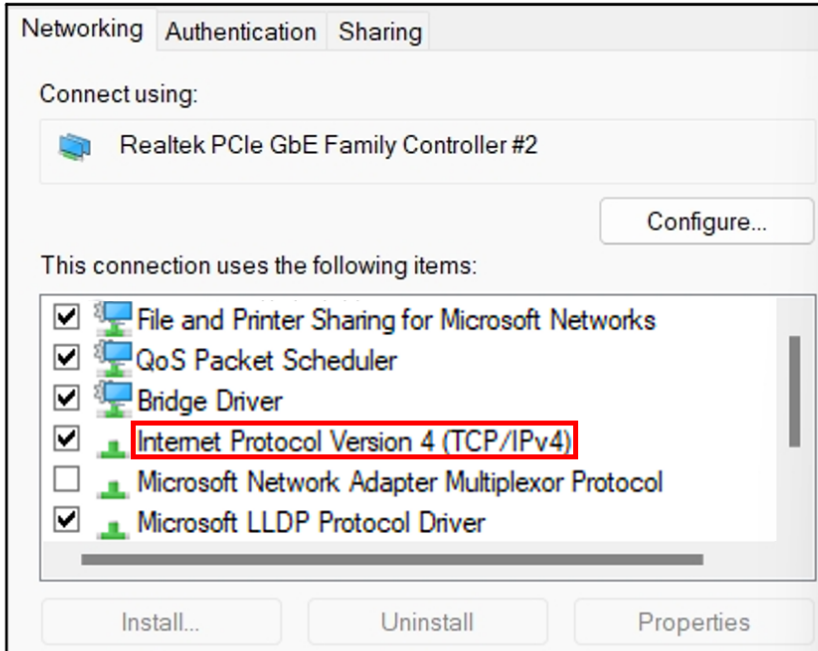
### 2.4.1. In Windows

1. "Control Panel" > "Network and Internet" > "Network and Sharing Center" > "Change Adapter Settings"
2. Right-click on the "Ethernet" or "Ethernet X" which shows Ethernet connection (with no red cross at the bottom left of the icon) > Select "Properties".



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

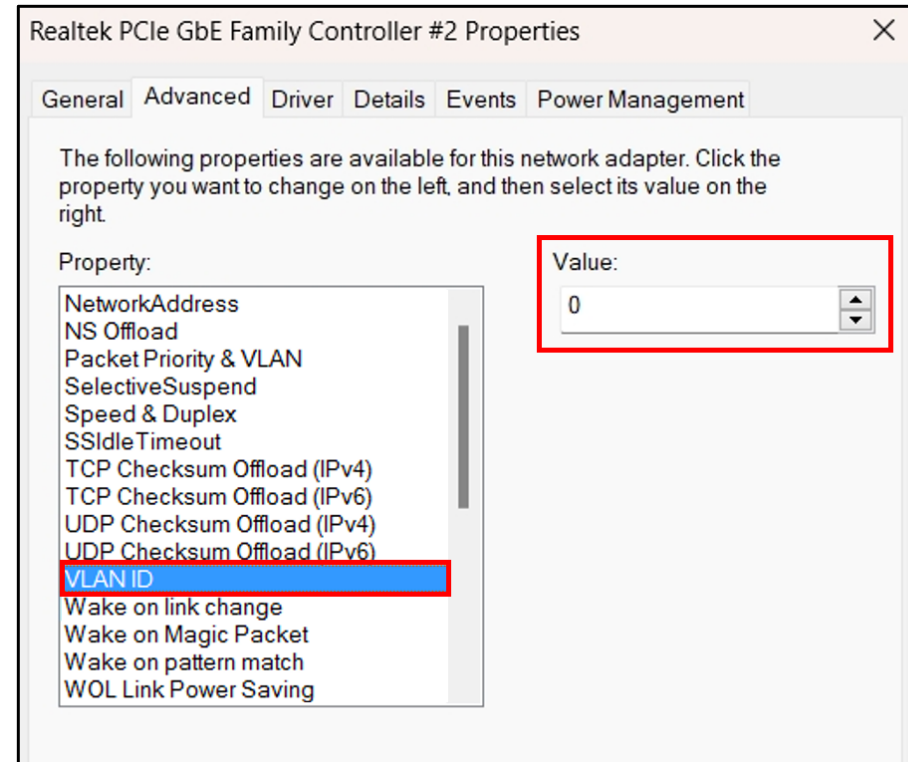
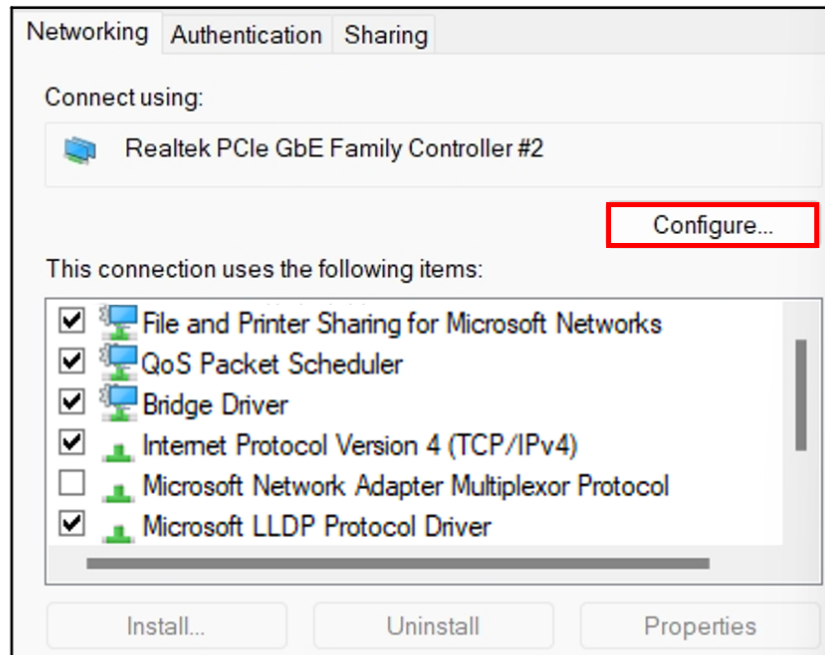




5. To enable VLAN tagging:

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

### 2.4.2.1. When not using VLAN

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.

### 2.4.2.2. When using a VLAN

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.

To check the host computer's network interface name:

**Method 1**

Check the content in brackets after "Ethernet" in the Settings—Network page.



## Method 2


Run `ifconfig` in the terminal.

```
> 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

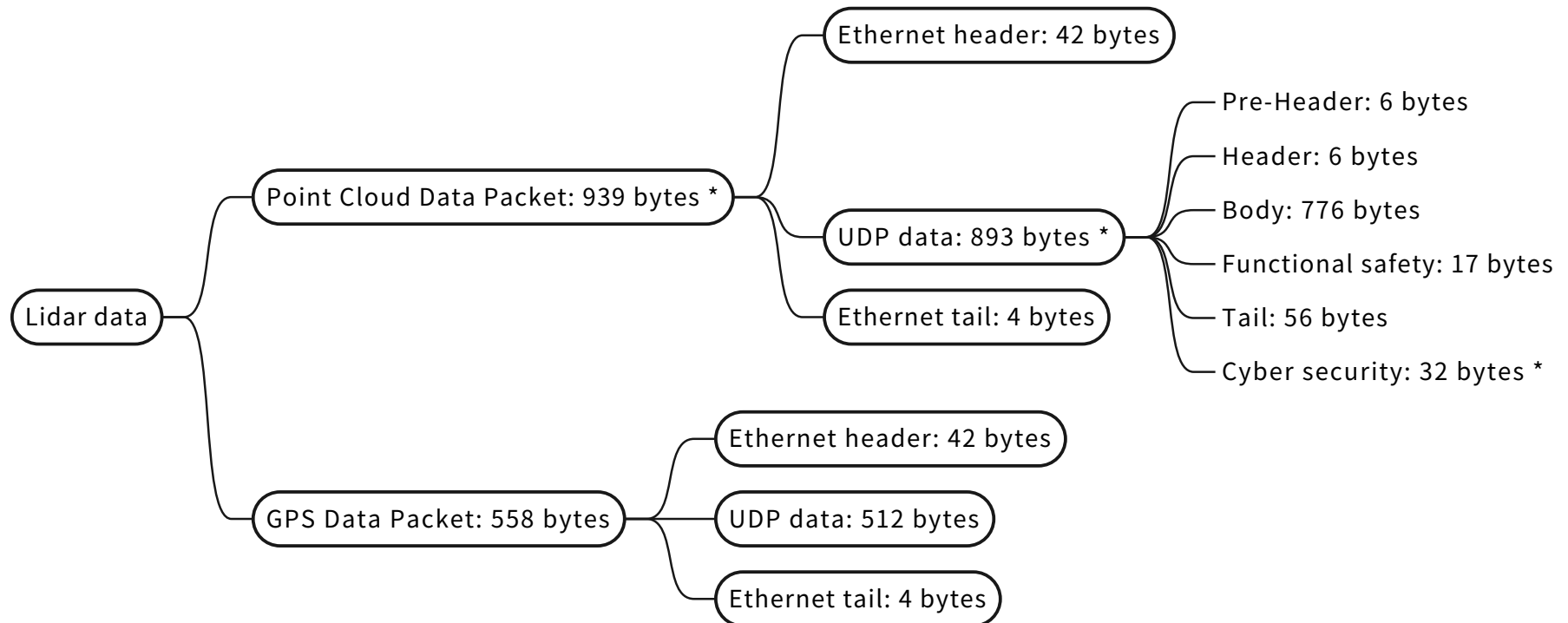
enp5s0: flags=4099<UP,BROADCAST,MULTICAST> mtu 1500
    ether [REDACTED] txqueuelen 1000 (Ethernet)
    RX packets 267706980 bytes 300970909734 (300.9 GB)
    RX errors 0 dropped 0 overruns 0 frame 0
    TX packets 3184 bytes 590575 (590.5 KB)
    TX errors 0 dropped 0 overruns 0 carrier 0 collisions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

## 2.5. Tools

Tool	Purpose	Where to find it
PandarView 2 (point cloud visualization software)	To record and display point cloud data.	Visit <a href="#">the Download page of Hesai's official website</a> or contact Hesai technical support.
web_control、API	To set parameters, check device info or upgrade firmware/software  <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"></div> <div> <p>Network parameters:</p> <ul style="list-style-type: none"> <li>• Default Source IPv4 address: 192.168.1.201</li> <li>• Default PTC port: 9347</li> </ul> </div> </div>	<ul style="list-style-type: none"> <li>• web_control: See <a href="#">Section 4 Web Control</a>.</li> <li>• API: Please contact Hesai technical support.</li> </ul>
Software development kits (SDKs) and ROS drivers	To assist development.	Visit Hesai's official GitHub page: <a href="https://github.com/HesaiTechnology">https://github.com/HesaiTechnology</a>

## 3. Data structure

Unless otherwise specified, all the multi-byte fields are unsigned values in little-endian format.



\* When point cloud signature function is disabled, the Cyber Security part (32 bytes) will be omitted.

Figure 17. Data structure

## 3.1. Point Cloud Data Packet

### 3.1.1. Ethernet header

Default IP address:

Source IP	192.168.1.201
Destination IP	255.255.255.255

#### 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) 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) Destination port (default: 2368)
UDP Length	2	Eight bytes more than point cloud UDP data (see <a href="#">Figure 17. Data structure</a> ).
UDP Checksum	2	Checksum of the Ethernet header



## 3.1.2. Point cloud UDP data

### 3.1.2.1. Pre-Header

Field	Byte(s)	Description
0xEE	1	Start of Packet
0xFF	1	Start of Packet
Protocol Version Major	1	Main class of the point cloud UDP packet structure Current value: 0x01
Protocol Version Minor	1	Subclass of the point cloud UDP packet structure Current value: 0x04
Reserved	2	-

## 3.1.2.2. Header

Field	Byte(s)	Description															
Channel Num	1	Number of laser channels Always 0x80 (128)															
Block Num	1	Number of block(s) per packet Always 0x02 (2)															
First Block Return	1	Reserved															
Dis Unit	1	Always 0x04 (4 mm)															
Return Num	1	Maximum number of returns from each channel 0x02 (2)															
Flags	1	<p>[7:4] is reserved. [3:0] indicates whether this data packet contains the following information (0b1111 by default):</p> <table border="1"> <thead> <tr> <th>Bit</th> <th colspan="2">Value</th> </tr> </thead> <tbody> <tr> <td>[3] Digital signature</td> <td>1 – YES</td> <td>0 – NO</td> </tr> <tr> <td>[2] Functional safety</td> <td>1 – YES</td> <td>0 – NO</td> </tr> <tr> <td>[1] IMU</td> <td>1 – YES</td> <td>0 – NO</td> </tr> <tr> <td>[0] UDP sequence</td> <td>1 – YES</td> <td>0 – NO</td> </tr> </tbody> </table>	Bit	Value		[3] Digital signature	1 – YES	0 – NO	[2] Functional safety	1 – YES	0 – NO	[1] IMU	1 – YES	0 – NO	[0] UDP sequence	1 – YES	0 – NO
Bit	Value																
[3] Digital signature	1 – YES	0 – NO															
[2] Functional safety	1 – YES	0 – NO															
[1] IMU	1 – YES	0 – NO															
[0] UDP sequence	1 – YES	0 – NO															

## 3.1.2.3. Body

Field	Byte(s)	Description
Azimuth 1	2	For Block 1: Current reference angle of the azimuth. Unit: 0.01°

Field	Byte(s)	Description
Block 1	384	For Block 1: Measurements made by each channel (starting from Channel 1) Refer to <a href="#">Each block in the body</a> .
Azimuth 2	2	For Block 2: Current reference angle of the azimuth
Block 2	384	For Block 2: Measurements made by each channel (starting from Channel 1)
CRC 1	4	CRC-32/MPEG-2 checksum of the Body

### Return mode

The available Return mode(s) are listed in the **Return Mode** field in [Section 3.1.2.5 Tail](#).

In Single Return mode, the measurements of each round of firing are stored in one block.

In Dual Return mode, the measurements of each round of firing are stored in two adjacent blocks (see table below), and the **Azimuth** fields of these two blocks are the same.

Return Mode	Block 1	Block 2	Note
Last and Strongest	Last return	Strongest return	If the last return is also the strongest, then Block 2 stores the second strongest return.
Last and First	Last return	First return	If there is only one return, then Block 1 and Block 2 store the same data.
First and Strongest	First return	Strongest return	If the first return is also the strongest, then Block 2 stores the second strongest return.


**Each block in the body:  $3 \times 128 = 384$  bytes**

Field	Byte(s)	Description
Channel 1: Distance	2	See <a href="#">Definition of the Distance field</a> .
Channel 1: Reflectivity	1	Range: 0 to 255 The mapping relation between this field and target reflectivity can be selected using either <code>web_control</code> or PTC commands. Default: linear mapping (0 to 255 linearly represents target reflectivity 0 to 255%)
Channel 2: Distance	2	See above.
Channel 2: Reflectivity	1	See above.
...	...	...
Channel 128: Distance	2	See above.
Channel 128: Reflectivity	1	See above.

#### Definition of the Distance field (when Up-Close Blockage Detection is OFF)

Distance	Description
$\geq 75$	Object distance = <b>Distance</b> $\times$ <b>Dis Unit</b> $\geq 0.3$ m <b>Dis Unit</b> : See <a href="#">Section 3.1.2.2 Header</a>
= 0	No valid point cloud output

**Definition of the Distance field (when Up-Close Blockage Detection is ON)**

Distance	Description
$\geq 75$	Object distance = <b>Distance</b> $\times$ <b>Dis Unit</b> $\geq 0.3$ m <b>Dis Unit</b> : See <a href="#">Section 3.1.2.2 Header</a>
= 0	No laser emission.
= 1	Return signal is received. Object distance: $< 0.3$ m (below the lower limit of the lidar measurement range) Therefore, no valid point cloud output.
= 2	Return signal is received. Object distance is within 0.3 m and 2.85 m (near-field measurement range), but the current channel is not a near-field-enabled channel (see <a href="#">Appendix A Channel distribution data</a> ). Therefore, no valid point cloud output.
= 3	Either no return signal is received, or the return signal is received but rejected. Thus no valid point cloud output.  Common reasons for return signal rejection:  <div data-bbox="609 938 674 1002" style="display: inline-block; vertical-align: middle; margin-right: 10px;">  </div> <ul style="list-style-type: none"> <li>• The signal is generated by another lidar unit.</li> <li>• Object distance exceeds the upper limit of the lidar's measurement range.</li> <li>• Pulse intensity is below the threshold.</li> <li>• The signal is filtered out using Retro Multi-Reflection Filtering (see <a href="#">Section 4.2.2 Function</a>).</li> </ul>

 Users may enable or disable Up-Close Blockage Detection (see [Section 4.2.2 Function](#)).

### 3.1.2.4. Functional safety






- The Functional Safety part of a Point Cloud Data Packet updates only every 5 ms. Therefore, adjacent packets may contain identical Functional Safety data.
- The Lidar States and fault codes are described in the Safety Manual. Please contact Hesai technical support for more information.

Field	Byte(s)	Description
FS Version	1	Version number of the functional safety module (currently 0x00)
Lidar State	1	[7:5] is the current Lidar State.  d-0 (b-000) Initialization d-1 (b-001) Normal d-2 (b-010) Warning d-3 (b-011) Pre-Performance Degradation d-4 (b-100) Performance Degradation d-5 (b-101) Pre-Shutdown d-6 (b-110) Shutdown or Output Untrusted d-7 (b-111) Standby
Fault Code Type		[4:3] is the type of fault code in this data packet. b-00 No fault b-01 Current fault b-10 Past fault (not yet supported)
Rolling Counter		[2:0] indicates whether the fault reporting system gets stuck. Starting from 0, the rolling counter increments by 1 every 5 ms. Range: d-0 (b-000) to d-5 (b-101)
Total Fault Code Num	1	[7:4] is the total number of fault codes in the buffer queue
Fault Code ID		[3:0] is the sequence number of the current fault code in the buffer queue, starting from 1.

Field	Byte(s)	Description
Fault Code	2	The fault code sent by this data packet
Reserved	8	-
CRC 2	4	CRC-32/MPEG-2 checksum of Functional Safety part (from the <b>Lidar State</b> field to the <b>Reserved</b> field).

### 3.1.2.5. Tail

Field	Byte(s)	Description
Reserved	9	-
Azimuth State	2	<p>[15:14] is the azimuth state of Block 1, and [13:12] the azimuth state of Block 2.</p> <ul style="list-style-type: none"> <li>• Used for looking up the laser firing time; see <a href="#">Section B.4 Laser firing time of each channel</a></li> <li>• Range: 0 to 3 (High Resolution mode), 0 to 1 (Standard or Energy Saving mode)</li> </ul> <p>[11:0] is reserved.</p>
Operational State	1	<p>0 — High Resolution  1 — Shutdown  2 — Standard  3 — Energy Saving (reduced ranging capability)</p>
Return Mode	1	<p>0x33 — First  0x37 — Strongest  0x38 — Last  0x39 — Last and Strongest  0x3B — Last and First  0x3C — First and Strongest</p>

Field	Byte(s)	Description														
Motor Speed	2	Unit: RPM  Spin rate of the motor (RPM) = frame rate (Hz) × 60														
Date & Time	6	The whole second part of the Coordinated Universal Time (UTC) of this data packet. <table border="1" data-bbox="757 414 1809 821"> <thead> <tr> <th>Each byte</th> <th>Range (decimal)</th> </tr> </thead> <tbody> <tr> <td>Year (current year minus 1900)</td> <td>≥70</td> </tr> <tr> <td>Month</td> <td>1 to 12</td> </tr> <tr> <td>Day</td> <td>1 to 31</td> </tr> <tr> <td>Hour</td> <td>0 to 23</td> </tr> <tr> <td>Minute</td> <td>0 to 59</td> </tr> <tr> <td>Second</td> <td>0 to 59</td> </tr> </tbody> </table>  The absolute time of a Point Cloud Data Packet is defined in <a href="#">Appendix B Absolute time of point cloud data</a> .	Each byte	Range (decimal)	Year (current year minus 1900)	≥70	Month	1 to 12	Day	1 to 31	Hour	0 to 23	Minute	0 to 59	Second	0 to 59
Each byte	Range (decimal)															
Year (current year minus 1900)	≥70															
Month	1 to 12															
Day	1 to 31															
Hour	0 to 23															
Minute	0 to 59															
Second	0 to 59															
Timestamp	4	The microsecond part of the Coordinated Universal Time (UTC) of this data packet. Unit: μs Range: 0 to 999 999 μs   The absolute time of a Point Cloud Data Packet is defined in <a href="#">Appendix B Absolute time of point cloud data</a> .														
Factory Information	1	Fixed: 0x42														
UDP Sequence	4	Sequence number of this data packet Range: 0 to 0xFF FF FF FF														



Field	Byte(s)	Description								
IMU Temperature	2	Temperature provided by the IMU (inertial measurement unit) Data type: signed integer Unit: 0.01°C								
IMU Acceleration Unit	2	Conversion factor of acceleration Data type: unsigned integer Current value: 244 (0x00F4) <b>Unit of acceleration:</b> $0.001mg \times 244 = 0.244mg$ ( $g$ : standard gravity)								
IMU Angular Velocity Unit	2	Conversion factor of angular velocity Data type: unsigned integer Current value: 1750 (0x06D6) <b>Unit of angular velocity:</b> $0.01 \text{ mdps} \times 1750 = 17.5 \text{ mdps}$ (millidegree per second)								
IMU Timestamp	4	Timestamp of the IMU data Counting from 0 after powering on the lidar or after an overflow. Unit: 25 $\mu$ s Range: 0 to approx. 29.83 hours								
IMU X Axis Acceleration	2	Acceleration of the X-axis, measured by the IMU Data type: signed integer <table border="1" data-bbox="757 1046 2074 1377"> <tbody> <tr> <td>Data type</td> <td>Signed integer</td> </tr> <tr> <td>Measurement range</td> <td><math>\pm 8g</math></td> </tr> <tr> <td>Unit of acceleration</td> <td>See the <b>IMU Acceleration Unit</b> field; currently 0.244mg.</td> </tr> <tr> <td>Example</td> <td>When this field is 5, X-axis acceleration = <math>5 \times 0.244mg = 1.22mg</math>.</td> </tr> </tbody> </table>	Data type	Signed integer	Measurement range	$\pm 8g$	Unit of acceleration	See the <b>IMU Acceleration Unit</b> field; currently 0.244mg.	Example	When this field is 5, X-axis acceleration = $5 \times 0.244mg = 1.22mg$ .
Data type	Signed integer									
Measurement range	$\pm 8g$									
Unit of acceleration	See the <b>IMU Acceleration Unit</b> field; currently 0.244mg.									
Example	When this field is 5, X-axis acceleration = $5 \times 0.244mg = 1.22mg$ .									
IMU Y Axis Acceleration	2	Acceleration of the Y-axis								

Field	Byte(s)	Description	
IMU Z Axis Acceleration	2	Acceleration of the Z-axis	
IMU X Axis Angular Velocity	2	Angular velocity of the X-axis, measured by the IMU.	
		Data type	Signed integer
		Measurement range	$\pm 500$ dps
		Unit of angular velocity	See the <b>IMU Angular Velocity Unit</b> field; currently 17.5 mdps.
Example	When this field is 5, X-axis angular velocity = $5 \times 17.5$ mdps = 87.5 mdps.		
IMU Y Axis Angular Velocity	2	Angular velocity of the Y-axis	
IMU Z Axis Angular Velocity	2	Angular velocity of the Z-axis	
CRC 3	4	CRC-32/MPEG-2 checksum of the Tail	

### 3.1.2.6. Cyber Security (optional)

Field	Byte(s)	Description
Signature	32	Point cloud signature Calculated using point cloud UDP data (from Pre-Header to Tail, appended with UDP Sequence) Algorithm: HMAC-SHA256



This field is added after specifying a Shared Secret Key and starting a session; see [Section 4.9.3 Point cloud signature](#).

### 3.1.3. Ethernet tail

---


Field	Byte(s)	Description
FCS	4	Frame check sequence

### 3.1.4. Point cloud data analysis method


Take **Channel 5** in **Block 2** as an example.

#### 3.1.4.1. Analyze the vertical angle of a data point

The designed vertical angle of Channel 5 is 12.165°, according to [Appendix A Channel distribution data](#).

-  • The accurate vertical angles are recorded in the angle correction file of this lidar; see [Section 1.3 Channel distribution](#).
- 0° is the horizontal direction.
- The upward direction is defined as positive; see [Figure 4. Channel vertical distribution](#).

#### 3.1.4.2. Analyze the horizontal angle of a data point

-  The Y-axis of the lidar coordinate system is 0°. The clockwise direction (in the top view) is defined as positive; see [Figure 3. Lidar azimuthal position \(top view\)](#).

$$\text{Horizontal angle} = \textcircled{1} + \textcircled{2}$$

- ① Angular position at the start time (see [Section B.3 Start time of each block](#)) of the current block
- ② Firing time angular offset of the current firing channel

$$\textcircled{1} = \textcircled{3} + \textcircled{4}$$

- ③ Current reference azimuth of this block  
Can be read from the **Azimuth** field of **Block 2**. See [Section 3.1.2.3 Body](#).
- ④ Horizontal angle offset of the current firing channel  
The offset of **Channel 5** is 1.093°, according to [Appendix A Channel distribution data](#).

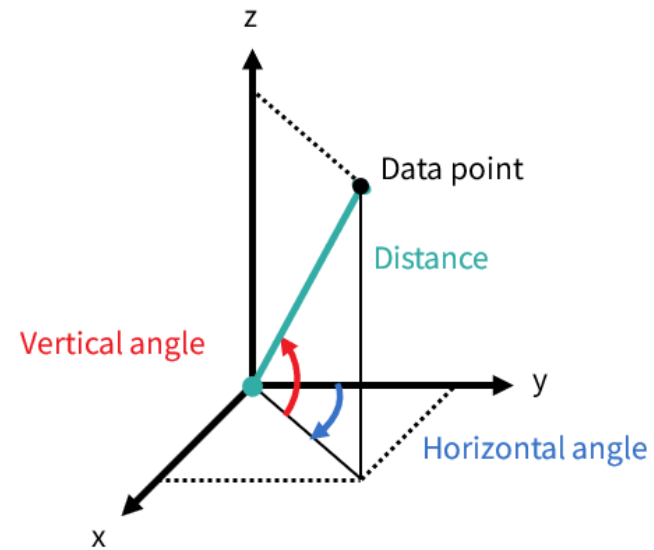
-  The accurate horizontal angle offsets are recorded in the angle correction file of this lidar; see [Section 1.3 Channel distribution](#).

$$\textcircled{2} = \textcircled{5} \times \textcircled{6}$$

- ⑤ Firing time offset of the current firing channel  
See [Section B.4 Laser firing time of each channel](#).
- ⑥ Spin rate of the motor  
See the **Motor Speed** field in [Section 3.1.2.5 Tail](#). The unit should be converted to °/s.

### 3.1.4.3. Analyze the distance of a data point

See the **Distance** field of **Block 2: Channel 5** in [Section 3.1.2.3 Body](#).

**3.1.4.4. Draw the data point in a spherical or rectangular coordinate system****3.1.4.5. Obtain the real-time point cloud data by analyzing and drawing every data point in each frame**

## 3.2. GPS Data Packet

When GPS is selected as the clock source, a GPS Data Packet is triggered every second.

When PTP is selected as the clock source, the lidar does not output GPS Data Packet.

 To select the clock source, refer to [Section 4.2.3 Time sync](#).

All the multi-byte values are unsigned and in little-endian format.

### 3.2.1. Ethernet header


Default IP address:

Source IP	192.168.1.201
Destination IP	255.255.255.255

#### GPS 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) 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) Destination port (default: 10110)
UDP Length	2	8 bytes more than GPS UDP data; see <a href="#">Figure 17. Data structure</a>
UDP Checksum	2	Checksum of the Ethernet header

### 3.2.2. GPS UDP data

Field	Byte(s)	Description															
GPS Time Data	18	GPS time, accurate to the second															
		<table border="1"> <thead> <tr> <th>Field</th> <th>Bytes</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>GPS Header</td> <td>2</td> <td>0xFFEE (0xFF first)</td> </tr> <tr> <td>Date</td> <td>6</td> <td>Year, month, and day in ASCII (2 bytes each, lower byte first)</td> </tr> <tr> <td>Time</td> <td>6</td> <td>Second, minute, and hour in ASCII (2 bytes each, lower byte first)</td> </tr> <tr> <td>Reserved</td> <td>4</td> <td>-</td> </tr> </tbody> </table>	Field	Bytes	Description	GPS Header	2	0xFFEE (0xFF first)	Date	6	Year, month, and day in ASCII (2 bytes each, lower byte first)	Time	6	Second, minute, and hour in ASCII (2 bytes each, lower byte first)	Reserved	4	-
		Field	Bytes	Description													
		GPS Header	2	0xFFEE (0xFF first)													
		Date	6	Year, month, and day in ASCII (2 bytes each, lower byte first)													
Time	6	Second, minute, and hour in ASCII (2 bytes each, lower byte first)															
Reserved	4	-															
NMEA Data	84	<p>NMEA sentence containing date and time ASCII code, valid till 2 bytes after the asterisk (*).</p> <p> Users can select the NMEA sentence to be received (see <b>GPS Mode</b> in <a href="#">Section 4.2.3 Time sync</a>).</p>															
Reserved	404	404 bytes of 0xDF															
GPS Positioning Status	1	ASCII code, obtained from the NMEA sentence															
PPS Lock Flag	1	1 – Locked 0 – Unlocked															
Reserved	4	-															



## 3.2.2.1. GPRMC data format

```
$GPRMC, <01>, <02>, <03>, <04>, <05>, <06>, <07>, <08>, <09>, <10>, <11>, <12>*hh
```

Field No.	Field	Description
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format
<02>	Location Status	A (hex = 41) — Active (valid position) V (hex = 56) — Void (invalid position) NUL (hex = 0) — GPS unlocked
...	...	...
<09>	UTC Date	Date information Typically in ddmmyy (day, month, year) format
...	...	...

The lidar's GPS data interface accepts a variety of GPRMC formats, as long as:

Field <01> (after the first comma separator) is the hour, minute, and second information.  
Field <09> (after the ninth comma separator) is the date information.

For example, the following formats are both acceptable:

```
$GPRMC,072242,A,3027.3680,N,11423.6975,E,000.0,316.7,160617,004.1,W*67
$GPRMC,065829.00,A,3121.86377,N,12114.68322,E,0.027, ,#160617#, , ,A*74
```

## 3.2.2.2. GPGGA data format

```
$GPGGA, <01>, <02>, <03>, <04>, <05>, <06>, <07>, <08>, <09>, <10>, <11>, <12>*hh
```

Field No.	Field	Description																
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format																
...	...	...																
<06>	GPS Fix Quality	Range: 0 to 9 Refer to the description given by the GPS device provider.  Common definitions: <table border="1" data-bbox="757 730 2074 967"> <tbody> <tr> <td>0</td> <td>Invalid</td> <td>4</td> <td>RTK fix</td> </tr> <tr> <td>1</td> <td>GPS fix (SPS)</td> <td>5</td> <td>RTK float</td> </tr> <tr> <td>2</td> <td>DGPS fix</td> <td>6</td> <td>Estimated (dead reckoning)</td> </tr> <tr> <td>3</td> <td>PPS fix</td> <td>-</td> <td>-</td> </tr> </tbody> </table>	0	Invalid	4	RTK fix	1	GPS fix (SPS)	5	RTK float	2	DGPS fix	6	Estimated (dead reckoning)	3	PPS fix	-	-
0	Invalid	4	RTK fix															
1	GPS fix (SPS)	5	RTK float															
2	DGPS fix	6	Estimated (dead reckoning)															
3	PPS fix	-	-															
...	...	...																

The lidar's GPS data interface accepts a variety of GPGGA formats, as long as:

Field <01> (after the first comma separator) is the hour, minute, and second information.

For example, the following formats are both acceptable:

```
$GPGGA, 123519, 4807.038, N, 01131.000, E, 1, 08, 0.9, 545.4, M, 46.9, M, , *47
$GPGGA, 134658.00, 5106.9792, N, 11402.3003, W, 2, 09, 1.0, 1048.47, M, -6.27, M, 08, AAAA*60
```

### 3.2.3. Ethernet tail

Field	Byte(s)	Description
FCS	4	Frame check sequence

### 3.2.4. GPS time data analysis method

> Data (512 bytes)			
0000	04 d4 c4 eb 9b 37 ec 9f 0d 00 48 cb 08 00 45 00	.....7.. ..H...E.	
0010	02 1c c4 23 40 00 80 11 b0 66 c0 a8 01 c9 c0 a8	...#@... .f.....	
0020	01 2d 27 10 27 7e 02 08 00 00 ff ee 30 32 34 30	..'.~... ....0240	
0030	<u>37 30 38 35 37 30 34 30</u> 00 00 00 00 24 47 50 52	70857040 ....\$GPR	
0040	4d 43 00 2c 30 34 30 37 35 37 2e 37 36 2c 56 2c	MC.,0407 57.76,V,	
0050	2c 2c 2c 2c 2c 2c 30 37 30 34 32 30 2c 2c 2c 4e	,,,,,,07 0420,,,N	
0060	2c 56 2a 30 36 36 36 36 36 36 36 36 36 36 36	,V*06666 66666666	

Figure 18. GPS Data packet: GPS time data (example)

#### Date

Field	Data (in ASCII)	Characters	Meaning
Year	0x30 0x32	'0', '2'	20
Month	0x34 0x30	'4', '0'	04
Day	0x37 0x30	'7', '0'	07

#### Time

Field	Data (in ASCII)	Characters	Meaning
Second	0x38 0x35	'8', '5'	58
Minute	0x37 0x30	'7', '0'	07
Hour	0x34 0x30	'4', '0'	04

## 4. Web Control

Web Control is used for setting parameters, checking device info, and upgrading software/firmware.

To access Web Control, follow the steps below:

1. Connect the lidar to your PC using an Ethernet cable.
2. Complete [Section 2.4 Network settings on the receiving host](#).
3. Enter 192.168.1.201 into your web browser.



- Google Chrome and Mozilla Firefox are recommended.
- Firewall port exceptions: Port 9347 (PTC/PTCS), Port 80 (HTTP), Port 443 (HTTPS), and Ports 319 and 320 (PTP 1588v2)

## 4.1. Home

Status	
Spin Rate	600 RPM
GPS	Unlock
NMEA (GPRMC/GPGGA)	Unlock
PTP	Free Run
Device Info	<a href="#">Device Log</a>
Model	Pandar128E3X
S/N	P128XXXXXXXXXXXXXX
MAC Address	XX:XX:XX:XX:XX:XX
P/N	Pandar128E3X-A01
Software Version	1.45.127
Sensor Firmware Version	1.45.141
Controller Firmware Version	1.45.130

 The above Part Number and version numbers may be different from the actual ones. Please refer to the web page of the lidar.

### Buttons and parameters

#### Device Log

Click to download a JSON file that contains the lidar status, device info, all configurable parameters, and the upgrade log.

#### Spin Rate

Spin Rate of the motor (RPM) = frame rate (Hz) × 60

<b>GPS</b>	GPS pulse-per-second (PPS) status <ul style="list-style-type: none"><li>• Lock: Lidar's internal clock is in sync with GPS PPS.</li><li>• Unlock: Not in sync.</li></ul>
<b>NMEA (GPRMC/GPGGA)</b>	NMEA status <ul style="list-style-type: none"><li>• Lock: After receiving a valid NMEA message.</li><li>• Unlock: Not receiving a valid NMEA message for over 2 seconds.</li></ul>
<b>PTP</b>	PTP status <ul style="list-style-type: none"><li>• Free Run: No PTP master is selected.</li><li>• Tracking: Attempting to sync with the selected PTP Master, but the absolute offset exceeds the user-specified limit in <a href="#">Section 4.2.3 Time sync</a>.</li><li>• Locked: The absolute offset is within the user-specified limit.</li><li>• Frozen: The lidar has lost connection to the PTP master and is attempting to recover it. Meanwhile, lidar time will drift from the last synchronized time. When the time drift exceeds the specification, PTP status will change to Free Run.</li></ul>
<b>P/N</b>	Part Number <ul style="list-style-type: none"><li>• Cannot be changed.</li><li>• Format: [Model]-[Configuration]</li><li>• Lidar units with earlier firmware versions can be upgraded to display P/N. The default P/N is the Product Model (Pandar128E3X).</li></ul>
<b>Customer P/N</b>	Customer-Specified Part Number <ul style="list-style-type: none"><li>• Default: Empty and not displayed.</li><li>• Format: 1 to 20 characters, digits or hyphen (-).</li></ul>

Users may send PTC or HTTP commands to:



- enable/disable the display of Customer P/N;
- change Customer P/N.

Refer to [Section 5 Communication protocol](#).

Settings to the Customer P/N:



- are not changed by firmware upgrades/downgrades;
- are not affected by the [ **Reset All Settings** ] button (on the Settings page).



## 4.2. Settings



		<a href="#">Reset All Settings</a>
Control IP		
IPv4 Address		192.168.1.201
IPv4 Mask		255.255.255.0
IPv4 Gateway		192.168.1.1
VLAN	<input type="checkbox"/>	0
Ethernet Communication Mode		Slave
Settings		
Destination IP		255.255.255.255
Lidar Destination Port		2368
Spin Rate		600 RPM
Return Mode		Last and Strongest
Sync Angle	<input type="checkbox"/>	0
Trigger Method		Angle Based
Clock Source		GPS
GPS Mode		GPRMC
GPS Destination Port		10110
Noise Filtering		OFF
Interstitial Points Filtering		OFF
Retro Multi-Reflection Filtering		OFF


Up-Close Blockage Detection	OFF
Reflectivity Mapping	Linear Mapping
Rotation Direction	Clockwise
Operational Mode	Dynamic/Constant
Standby Mode	In Operation/Standby
<a href="#">Save</a>	

### Buttons

- Reset All Settings** Reset all the configurable parameters to factory defaults, including:
- [Settings](#)
  - [Azimuth FOV](#)
  - [High resolution](#)
- Save** Save and execute all the settings on this page.  
Exception: Standby Mode takes effect immediately without having to click this button.



### 4.2.1. Network


Parameter	Options	Description
VLAN	Default: OFF VLAN ID: 1 to 4094	<p>To enable VLAN tagging:</p> <ul style="list-style-type: none"> <li>• Make sure the receiving host also supports VLAN;</li> <li>• Check the checkbox and input the lidar's VLAN ID (same as the receiving host's VLAN ID).</li> </ul> <p>If the lidar's VLAN ID differs from the receiving host's, users will lose access to Web Control. To minimize such risks, the VLAN ID is zero (an invalid value) by default.</p> <p> • When checking the checkbox, users will be alerted to input a valid VLAN ID.</p> <p>• When unchecking the checkbox, the VLAN ID will default to zero.</p> <p> • Once configured, the VLAN ID will not change during firmware upgrades.</p> <p>• When VLAN is enabled, PTP connection will be lost; when VLAN is disabled, PTP connection will automatically recover.</p>

Parameter	Options	Description								
Ethernet Communication Mode	Slave (default) Master	<p>Only for automotive Ethernet (1000BASE-T1).</p> <p>Slave mode (default):</p> <ul style="list-style-type: none"> <li>• The receiving host shall be in Master mode.</li> <li>• Connect the lidar with or without a connection box.</li> </ul> <p>Master mode:</p> <ul style="list-style-type: none"> <li>• Connect the lidar to a Master host, select "Master" and click the [ <b>Save</b> ] button at the bottom of the Settings page.</li> <li>• Connection to Web Control will be lost. Then Connect the lidar to a Slave host.</li> <li>• Connection box is not supported.</li> </ul> <p> If the lidar's Ethernet communication mode is the same as the receiving host's, users will lose access to Web Control. To minimize such risks, please take special care when changing this setting.</p>								
Destination IP	Any except 0.0.0.0, 127.0.0.1, and the lidar's IPv4 address  Default: 255.255.255.255	<table border="1"> <thead> <tr> <th>Communication mode</th> <th>Destination IP</th> </tr> </thead> <tbody> <tr> <td>Broadcast (default)</td> <td>255.255.255.255</td> </tr> <tr> <td>Multicast</td> <td>User-defined</td> </tr> <tr> <td>Unicast</td> <td>Same as the PC's IPv4 address</td> </tr> </tbody> </table>	Communication mode	Destination IP	Broadcast (default)	255.255.255.255	Multicast	User-defined	Unicast	Same as the PC's IPv4 address
Communication mode	Destination IP									
Broadcast (default)	255.255.255.255									
Multicast	User-defined									
Unicast	Same as the PC's IPv4 address									

## 4.2.2. Function

Parameter	Options	Description
Spin Rate	600 RPM (default) 1200 RPM	Spin rate of the motor The accurate spin rate is shown in Point Cloud Data Packets (see the <b>Motor Speed</b> field in <a href="#">Section 3.1.2.5 Tail</a> ). The set spin rate is also shown on the Home page (see <a href="#">Section 4.1 Home</a> ).
Return Mode	Single Return: <ul style="list-style-type: none"><li>• Last</li><li>• Strongest</li><li>• First</li></ul> Dual Return: <ul style="list-style-type: none"><li>• Last and Strongest (default)</li><li>• Last and First</li><li>• First and Strongest</li></ul>	Also shown in Point Cloud Data Packets (see the <b>Return Mode</b> field in <a href="#">Section 3.1.2.5 Tail</a> ).

Parameter	Options	Description				
Sync Angle	0° to 359° Unit: °	<p>Phase lock angle</p> <ul style="list-style-type: none"> <li>To activate this function, check the checkbox and input an azimuth.</li> <li>At every full second, the lidar will rotate to that azimuthal position.</li> </ul> <p> Lidar azimuthal position is defined in <a href="#">Section 1.2 Basic structure</a>.</p> <p>Definition of the full second (detailed in <a href="#">Section B.1 Source of absolute time</a>):</p> <ul style="list-style-type: none"> <li>When GPS is locked, the full second is defined as the rising edge of the GPS PPS signal.</li> <li> When PTP is tracking or locked, the full second is retrieved from the PTP signal. (PPS signal is not required nor used.)</li> <li>When neither GPS nor PTP is locked, the full second is defined as the rising edge of the lidar's internal 1 Hz signal.</li> </ul> <p>To phase-lock multiple lidar units, connect them to the same clock source and set the same sync angle. These lidar units will rotate to the same azimuthal position at every full second.</p>				
Trigger Method	Angle-Based (default) Time-Based	<p>The way laser firings are triggered</p> <table border="1"> <tbody> <tr> <td>Angle-based</td> <td>Lasers fire every 0.1° at 10 Hz (or 0.2° at 20 Hz).</td> </tr> <tr> <td>Time-based</td> <td>Lasers fire every 27.78 μs.</td> </tr> </tbody> </table>	Angle-based	Lasers fire every 0.1° at 10 Hz (or 0.2° at 20 Hz).	Time-based	Lasers fire every 27.78 μs.
Angle-based	Lasers fire every 0.1° at 10 Hz (or 0.2° at 20 Hz).					
Time-based	Lasers fire every 27.78 μs.					
Noise Filtering	OFF (default) ON	To reduce the scattered false positives (i.e. noise points) in point cloud data.				

Parameter	Options	Description				
Interstitial Points Filtering	OFF (default) ON	To reduce the interstitial points in point cloud data.   Definition of interstitial points: When a beam partially hits a front target's edge and further hits a rear target, the return signal can result in a false point located between both targets.				
Retro Multi-Reflection Filtering	OFF (default) ON	To reduce the false positives at twice the distance of a retroreflector.				
Up-Close Blockage Detection	OFF (default) ON	See <a href="#">Definition of the Distance field</a> .				
Reflectivity Mapping	Linear Mapping (default) Nonlinear Mapping #1/#2	<table border="1"> <tbody> <tr> <td>Linear Mapping</td> <td>The <b>Reflectivity</b> field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%).</td> </tr> <tr> <td>Nonlinear Mapping</td> <td>Increases the contrast in low-reflectivity areas (see <a href="#">Appendix C Nonlinear reflectivity mapping</a>).</td> </tr> </tbody> </table>	Linear Mapping	The <b>Reflectivity</b> field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%).	Nonlinear Mapping	Increases the contrast in low-reflectivity areas (see <a href="#">Appendix C Nonlinear reflectivity mapping</a> ).
Linear Mapping	The <b>Reflectivity</b> field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%).					
Nonlinear Mapping	Increases the contrast in low-reflectivity areas (see <a href="#">Appendix C Nonlinear reflectivity mapping</a> ).					
Rotation Direction	Clockwise (default) Counterclockwise	Direction of motor rotation				

Parameter	Options	Description															
Operational Mode	Dynamic (default) Constant	After selecting Operational Mode, the Operational States will shift automatically according to: <ul style="list-style-type: none"> <li>• ambient temperature</li> <li>• horizontal resolution mode (see <a href="#">Section 4.4 High resolution</a>)</li> </ul>															
		<table border="1"> <thead> <tr> <th>Operational Mode</th> <th>Horizontal Resolution Mode</th> <th>Operational States (in the order of priority)</th> </tr> </thead> <tbody> <tr> <td rowspan="2">Dynamic</td> <td>Standard</td> <td>Standard, Energy Saving, and Shutdown</td> </tr> <tr> <td>High Resolution</td> <td>High Resolution, Standard, Energy Saving, and Shutdown</td> </tr> <tr> <td rowspan="2">Constant</td> <td>Standard</td> <td>Standard and Shutdown</td> </tr> <tr> <td>High Resolution</td> <td>High Resolution and Shutdown</td> </tr> </tbody> </table>	Operational Mode	Horizontal Resolution Mode	Operational States (in the order of priority)	Dynamic	Standard	Standard, Energy Saving, and Shutdown	High Resolution	High Resolution, Standard, Energy Saving, and Shutdown	Constant	Standard	Standard and Shutdown	High Resolution	High Resolution and Shutdown		
		Operational Mode	Horizontal Resolution Mode	Operational States (in the order of priority)													
		Dynamic	Standard	Standard, Energy Saving, and Shutdown													
			High Resolution	High Resolution, Standard, Energy Saving, and Shutdown													
		Constant	Standard	Standard and Shutdown													
			High Resolution	High Resolution and Shutdown													
		Definition of Operational States:															
		<table border="1"> <thead> <tr> <th>Operational States</th> <th>Horizontal Resolution Mode</th> <th>Laser Power</th> </tr> </thead> <tbody> <tr> <td>High Resolution</td> <td>High Resolution</td> <td>Normal</td> </tr> <tr> <td>Standard</td> <td>Standard</td> <td>Normal</td> </tr> <tr> <td>Energy Saving</td> <td>Standard</td> <td>Half of normal value (reduced ranging capability)</td> </tr> <tr> <td>Shutdown</td> <td colspan="2">Motor not running and lasers not firing.</td> </tr> </tbody> </table>	Operational States	Horizontal Resolution Mode	Laser Power	High Resolution	High Resolution	Normal	Standard	Standard	Normal	Energy Saving	Standard	Half of normal value (reduced ranging capability)	Shutdown	Motor not running and lasers not firing.	
		Operational States	Horizontal Resolution Mode	Laser Power													
High Resolution	High Resolution	Normal															
Standard	Standard	Normal															
Energy Saving	Standard	Half of normal value (reduced ranging capability)															
Shutdown	Motor not running and lasers not firing.																
Standby Mode	In Operation (default) Standby	In Standby mode, the motor stops running and lasers stop firing.															



### 4.2.3. Time sync

#### With GPS selected

Clock Source	<b>GPS</b>
GPS Mode	GPRMC
GPS Destination Port	10110

#### With PTP selected

Clock Source	<b>PTP</b>
Profile	1588v2
Time Offset for Lidar Lock	1
PTP Network Transport	UDP/IP
PTP Domain Number	0
PTP logAnnounceInterval	1
PTP logSyncInterval	1
PTP logMinDelayReqInterval	0

Parameter	Options	Description
Clock Source	GPS (default) PTP	External source of absolute time

**4.2.3.1. With GPS selected**

Parameter	Options	Description
GPS Mode	GPRMC (default) GPGGA	Format of the NMEA data received from the external GPS module (see <a href="#">Section 3.2.2 GPS UDP data</a> )
Destination Port	Default: 10110	Port used for sending GPS Data packets

**4.2.3.2. With PTP selected**

The lidar does NOT output GPS Data Packets.

Parameter	Options	Description	
Profile	1588v2 (default) 802.1AS 802.1AS Automotive	IEEE timing and synchronization standard	
Time Offset for Lidar Lock	1 to 100 $\mu$ s (integer) Default: 1	Upper limit of the absolute offset between Slave and Master when the lidar is in PTP Locked status; see <a href="#">Section 4.1 Home</a> .	
PTP Network Transport	UDP/IP (default) L2	Network transport protocol	
		UDP/IP	Available only for the 1588v2 profile
		L2	Available for all profiles
Domain Number	0 to 127 (integer) Default: 0	Domain attribute of the local clock	

When using the 1588v2 profile, these additional parameters can be configured:

Parameter	Options	Description
PTP logAnnounceInterval	-2 to 3 Default: 1	Time interval between Announce messages Default: 1 ( $2^1 = 2$ seconds)
PTP logSyncInterval	-7 to 3 Default: 1	Time interval between Sync messages Default: 1 ( $2^1 = 2$ seconds)
PTP logMinDelayReqInterval	-7 to 3 Default: 0	Minimum permitted mean time between Delay_Req messages Default: 0 ( $2^0 = 1$ second)

When using the 802.1AS or 802.1AS Automotive profile:

Parameter	Options	Description				
Switch Type	TSN (default) Non-TSN	Type of the network switch <table border="1" data-bbox="913 783 2072 903"> <tbody> <tr> <td>TSN</td> <td>Time Sensitive Network, using Peer-to-Peer delay mechanism</td> </tr> <tr> <td>Non-TSN</td> <td>Using End-to-End delay mechanism</td> </tr> </tbody> </table>	TSN	Time Sensitive Network, using Peer-to-Peer delay mechanism	Non-TSN	Using End-to-End delay mechanism
TSN	Time Sensitive Network, using Peer-to-Peer delay mechanism					
Non-TSN	Using End-to-End delay mechanism					

## 4.3. Azimuth FOV

Azimuth FOV Setting	For all channels ▼
<a href="#">Save</a>	

### Buttons

**Save** Save and execute all the settings on this page.

Parameter	Options	Description
Azimuth FOV Setting	For all channels (default) Multi-section FOV	Configuration mode of the azimuth FOV The lidar outputs valid data only within the specified azimuth FOV ranges.



- The angles in degrees are accurate to the first decimal place.
- If the Start Angle is larger than the End Angle, then the actual range is the union of [Start Angle, 360°) and [0°, End Angle).  
For instance, when the angle range is set to be [270°, 90°), the actual azimuth FOV is [270°, 360°) ∪ [0°, 90°).

### 4.3.1. For all channels

Input a start angle and an end angle to form a continuous angle range [Start, End].

This range applies to all channels.

Azimuth FOV Setting		For all channels
Azimuth FOV for all channels	Start:	0.0
	End:	360.0
<a href="#">Save</a>		

### 4.3.2. Multi-Section FOV

Input multiple ( $\leq 5$ ) sets of Start Angles and End Angles to form multiple continuous angle ranges.

These ranges apply to all channels.

Azimuth FOV Setting		Multi-section FOV	
Multi-section FOV	Start Angle	End Angle	
Azimuth FOV 1	0.0	0.0	
Azimuth FOV 2	0.0	0.0	
Azimuth FOV 3	0.0	0.0	
Azimuth FOV 4	0.0	0.0	
Azimuth FOV 5	0.0	0.0	
<a href="#">Save</a>			


## 4.4. High resolution


Configure on-the-fly the horizontal resolution of far-field measurement.

Mode	High Resolution ▼
<b>Save</b>	

### Buttons

**Save** Save and execute all the settings on this page.

Parameter	Options	Description			
Mode	Standard (default) High Resolution	Mode	Frame rate	Horizontal resolution of far-field measurement	
		Standard	10 Hz	0.2° for all channels	
			20 Hz	0.4° for all channels	
		High Resolution	10 Hz	0.1° for the 64 high-res channels (Channel 26 to Channel 89) 0.2° for the other channels	
				20 Hz	0.2° for the 64 high-res channels (Channel 26 to Channel 89) 0.4° for the other channels
		 Channel number counts from 1, top to bottom.			

-  The horizontal resolution of near-field measurement is always 0.4° at 10 Hz (and 0.8° at 20 Hz).
- The definition of near/far-field measurement is in [Appendix A Channel distribution data](#).

## 4.5. Operation statistics

Start-Up Counts	510
Internal Temperature	32.10°C
Internal Humidity	50.0% RH
System Uptime	0 h 5 min
Total Operation Time	559 h 43 min
Internal Temperature	Operation Time
< -40°C	0 h 1 min
-40 to -20°C	0 h 46 min
-20 to 0°C	0 h 49 min
0 to 20°C	8 h 40 min
20 to 40°C	38 h 20 min
40 to 60°C	393 h 17 min
60 to 80°C	109 h 50 min
80 to 100°C	6 h 16 min
100 to 120°C	1 h 44 min
> 120°C	0 h 0 min

## 4.6. Monitor

These electrical parameters (measured at the lidar's external connector) are displayed in real time:

- Lidar Input Current
- Lidar Input Voltage
- Lidar Input Power



## 4.7. Upgrade

### Preparation

- Please contact Hesai technical support to receive the upgrade file.
- During the upgrade, it is recommended to place a protective cover or other opaque material over the lidar's cover lens.

### Upgrade

- Click the [ **Upload** ] button and select an upgrade file.
- When the upgrade is complete, the lidar will automatically reboot, and the past versions will be logged in the Upgrade Log.

### Buttons

<b>Upload</b>	To upload the upgrade file
<b>Restart</b>	Software reboot Afterward, the Start-Up Counts in the Operation Statistics page increments by 1; see <a href="#">Section 4.5 Operation statistics</a> .

Parameter	Current version
Software version	1.45.127
Firmware of sensor version	1.45.141
Firmware of controller version	1.45.130
Upgrade Log	-



The above version numbers may be different from the actual ones. Please refer to the web page of the lidar.

## 4.8. Log

The process logs on this page are used for software troubleshooting.

### Parameters

<b>pandar_control</b>	Lidar's control program
<b>diag_ff</b>	Functional safety diagnosis program
<b>error</b>	Exceptions that may affect the lidar's normal operation
<b>warn</b>	Exceptions that do not affect the lidar's normal operation

## 4.9. Security

### Cyber security (Master Switch): OFF

Cyber Security (Master Switch)	OFF
Login Control	
Authentication	OFF
Secure Connection	
PTC Connection	Non-TLS
HTTP Connection	HTTP
Point Cloud Signature	
Share Secret Key ⓘ	
<a href="#">Save</a>	

### Cyber security (master switch): ON

Cyber Security (Master Switch)	ON
Login Control	
Authentication	ON
Current Password	_____ <a href="#">Forgot Password?</a>
New Password	_____
Confirm New Password	_____
Secure Connection	
PTC Connection	TLS
HTTP Connection	HTTPS
Point Cloud Signature	
Share Secret Key ⓘ	
<a href="#">Save</a>	

As shown in the previous page, the available settings depend on the Cyber Security Master Switch:

	Cyber Security (Master Switch): OFF (default)	Cyber Security (Master Switch): ON
Login control	OFF <b>http://</b> 192.168.1.201 redirects to the Home page.	ON <b>https://</b> 192.168.1.201 redirects to the Login page.
Secure connection	OFF PTC and HTTP (cleartext communication)	ON PTCS and HTTPS (encrypted communication; configuration required)
Point cloud signature	Setting the Shared Secret Key in cleartext poses data breach risks and is not recommended.	Users can change the shared secret key.



- Point cloud signature is deactivated by default. Its activation/deactivation is controlled by PTC commands (see [Section 5 Communication protocol](#)), regardless of the Cyber Security Master Switch. This webpage only sets the Shared Secret Key of point cloud signature.
- Firmware and software upgrades are always encrypted and signed, regardless of the Cyber Security Master Switch.

### 4.9.1. Login control

When the Cyber Security Master Switch is ON:

Parameter	Options	Description
Authentication	Fixed: ON	Login control
Current password	-	<p>When turning on/off the Cyber Security Master Switch or when changing the password, input here.</p> <ul style="list-style-type: none"> <li>• Default password: <b>123456</b></li> <li>• To effectively implement login control, please change the default password and keep your new password securely.</li> <li>• Before returning a trial/loaner lidar or an RMA lidar to Hesai, please make sure to change the password back to default.</li> </ul>
New password	-	<p>Format</p> <ul style="list-style-type: none"> <li>• 8 to 30 characters</li> <li>• Containing at least one digit and one letter (case sensitive)</li> <li>• Special characters are allowed</li> </ul>
Confirm new password	-	-

If you forget the password:

If TLS is selected for PTC Connection	<p>Users should <b>reset the password</b>:</p> <ol style="list-style-type: none"> <li>1. Click "Forgot password?" and it will redirect to the Reset Password page.</li> <li>2. Obtain a reset code.</li> <li>3. Contact technical support and provide the reset code to obtain a verification code.</li> <li>4. Input the verification code in the Reset Password page and click the [ <b>Submit</b> ] button.</li> </ol>
If mTLS is selected for PTC Connection	<p>Users are allowed to <b>change the password</b> (without providing the current password) by sending a PTCS command (see <a href="#">Section 5 Communication protocol</a>).</p>

## 4.9.2. Secure connection

When the Cyber Security Master Switch is ON:

### TLS

Secure Connection	
PTC Connection	TLS
HTTP Connection	HTTPS

### mTLS

Secure Connection	
PTC Connection	mTLS
Client CA Certificate	No file
Certificate Status	Invalid
Change Certificate	<input type="button" value="Upload"/> <input type="button" value="Remove"/>
HTTP Connection	HTTPS

Parameter	Options	Description		
PTC connection	TLS (default) mTLS	PTC connection mode		
		<table border="1"> <tr> <td>TLS (one-way auth)</td> <td>Only the user authenticates the lidar.</td> </tr> <tr> <td>mTLS (two-way authentication)</td> <td>           The user and the lidar authenticate each other.            Recommended for enhanced security.           <ul style="list-style-type: none"> <li>Click the [ <b>Upload</b> ] button to upload a user CA certificate chain.</li> <li>Before returning a trial/loaner lidar or an RMA lidar to Hesai, click the [ <b>Remove</b> ] button to remove the uploaded certificate.</li> </ul> </td> </tr> </table>	TLS (one-way auth)	Only the user authenticates the lidar.
TLS (one-way auth)	Only the user authenticates the lidar.			
mTLS (two-way authentication)	The user and the lidar authenticate each other. Recommended for enhanced security. <ul style="list-style-type: none"> <li>Click the [ <b>Upload</b> ] button to upload a user CA certificate chain.</li> <li>Before returning a trial/loaner lidar or an RMA lidar to Hesai, click the [ <b>Remove</b> ] button to remove the uploaded certificate.</li> </ul>			

Parameter	Options	Description
HTTP Connection	Fixed: HTTPS	<p>HTTP connection mode</p> <p>After configuring the HTTPS environment (see <a href="#">Section 4.9.4 Configure HTTPS environment</a>):</p> <ul style="list-style-type: none"><li>• The current URL switches from <b>http://192.168.1.201</b> to <b>https://192.168.1.201</b>.</li><li>• Communication becomes encrypted.</li></ul>


### 4.9.3. Point cloud signature

Parameter	Options	Description
Shared secret key	-	<p>Used for negotiating a session key</p> <ul style="list-style-type: none"><li>• Default key: <b>12345678</b></li><li>• To avoid data breach risks, please change the default key and keep your new key securely.</li></ul> <p>Format: 8 to 32 digits or letters (case sensitive)</p>



## 4.9.4. Configure HTTPS environment

Before using HTTPS, import the lidar CA certificate chain into your browser.

 Without this step, HTTPS will not be activated, and a browser warning ("Not Secure") will appear when accessing Web Control.

Follow the steps below to set up certificates in Chrome or Firefox (Windows 10).

1. Go to the "Settings".
2. Input "Certificates" in the search bar.
  - **Chrome:** Select "Security" > "Manage device certificates".
  - **Firefox:** Select [ **View Certificates** ].

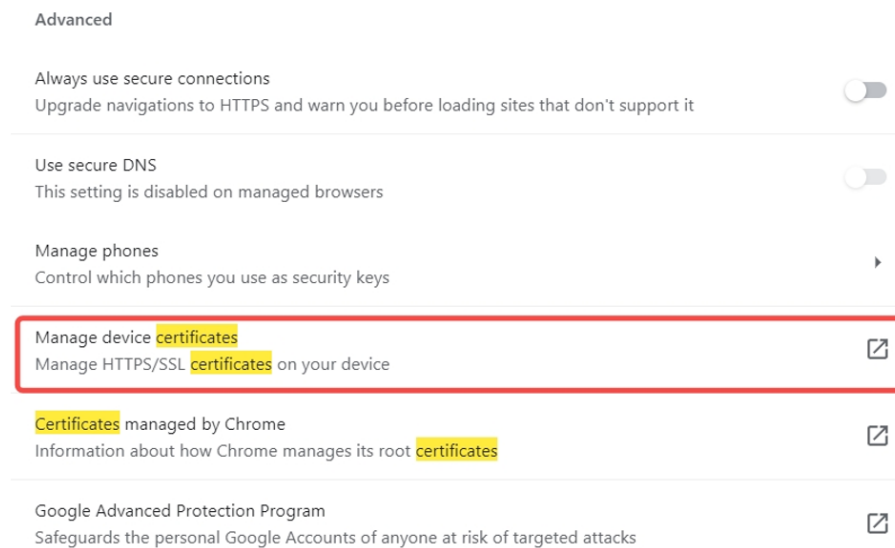


Figure 19. In Chrome

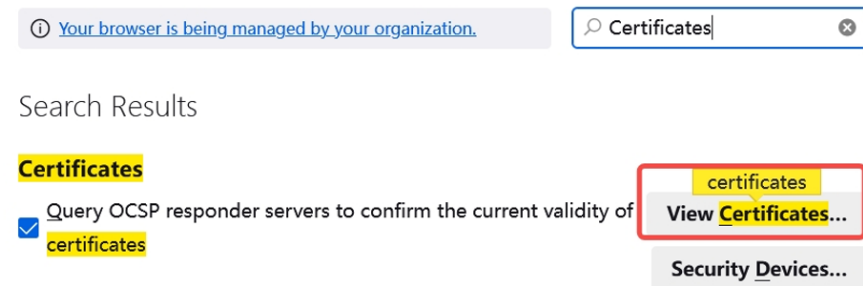


Figure 20. In Firefox

### 3. Upload intermediate and root certificates

- **Chrome:**

- Click [ **Intermediate Certificate Authorities** ] tab > Click [ **Import** ] to upload the intermediate certificate.
- Click [ **Trusted Root Certification Authorities** ] tab > Click [ **Import** ] to upload the root certificate.

- **Firefox:**

Click [ **Authorities** ] tab > Click [ **Import** ] to upload the intermediate and root certificates, or upload the certificate chain file only.

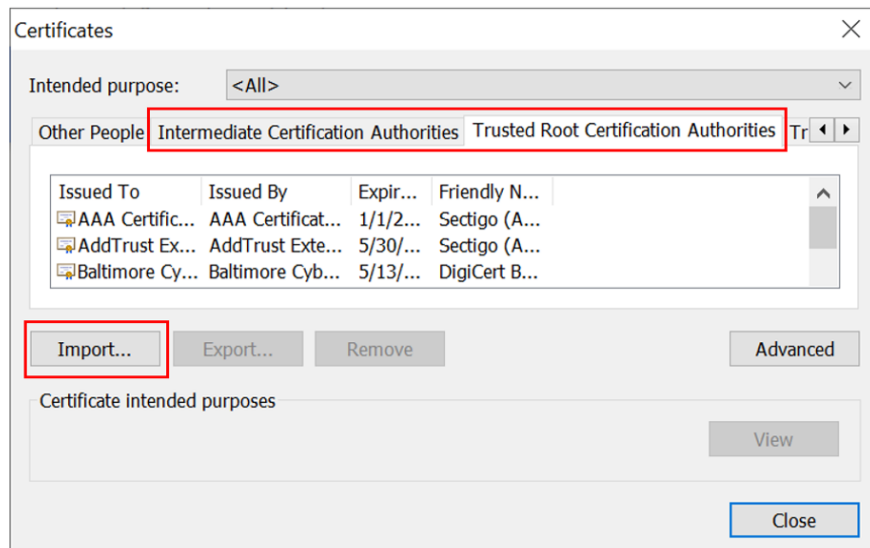


Figure 21. In Chrome

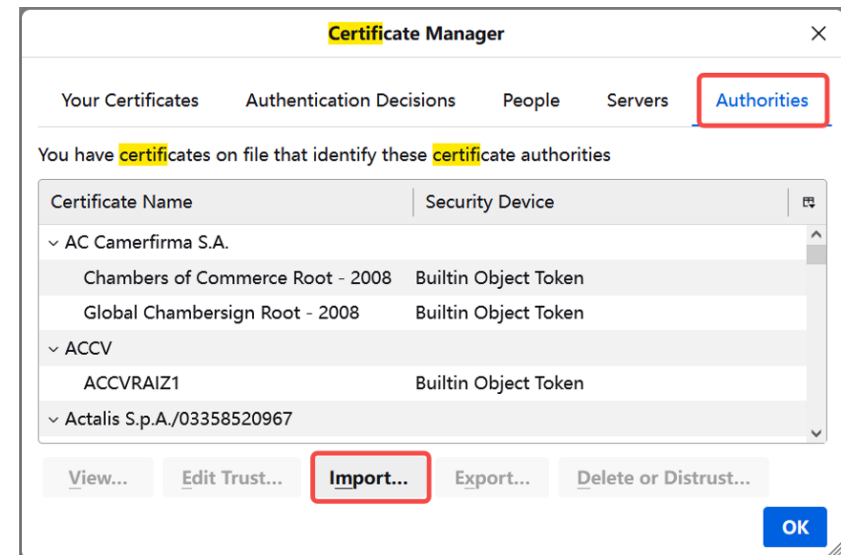


Figure 22. In Firefox

4. If a "Security Warning" or "Downloading Certificate" dialog box appears:
- **Chrome:** Click [ **Yes** ].
  - **Firefox:** Select "Trust this CA to identify websites" > Click [ **OK** ].

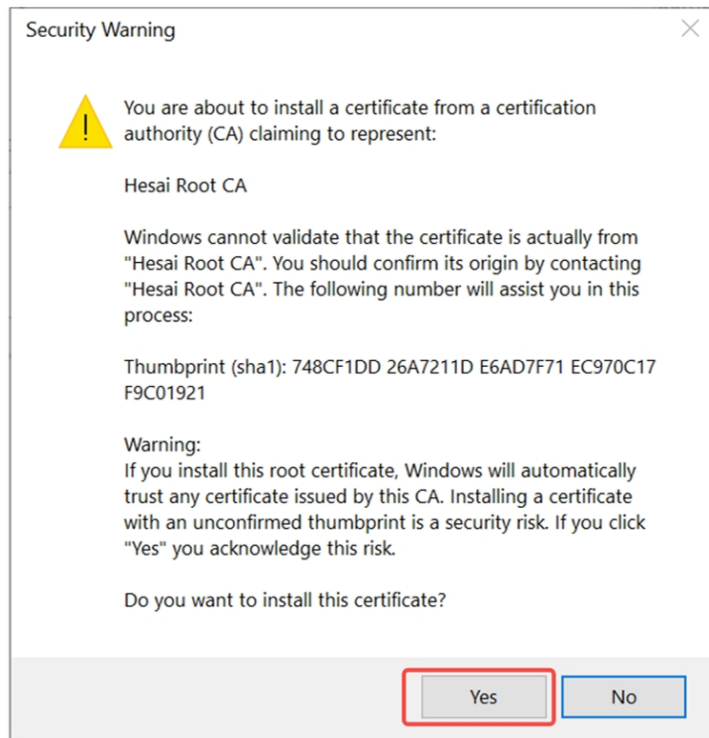


Figure 23. In Chrome

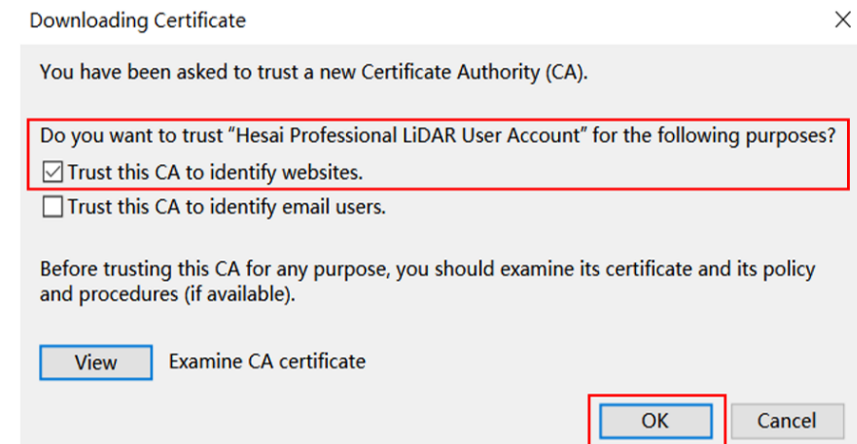


Figure 24. In Firefox

5. The newly-added CAs will appear in the list. Double-click to view more detailed information.

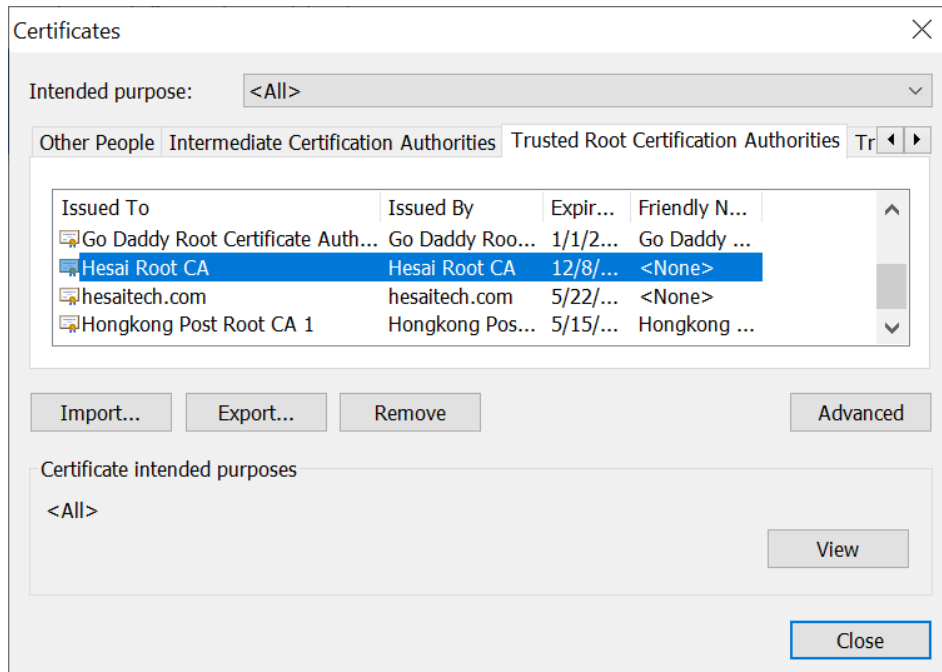


Figure 25. In Chrome

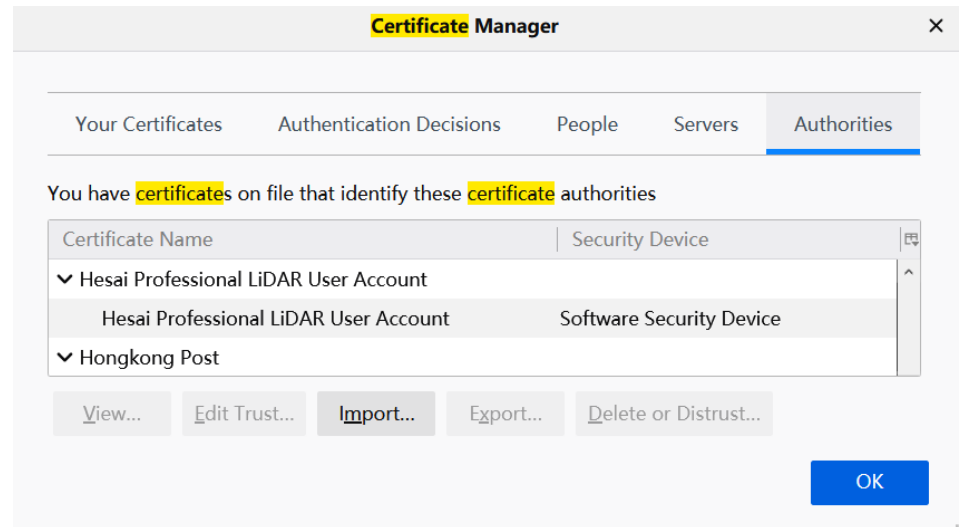
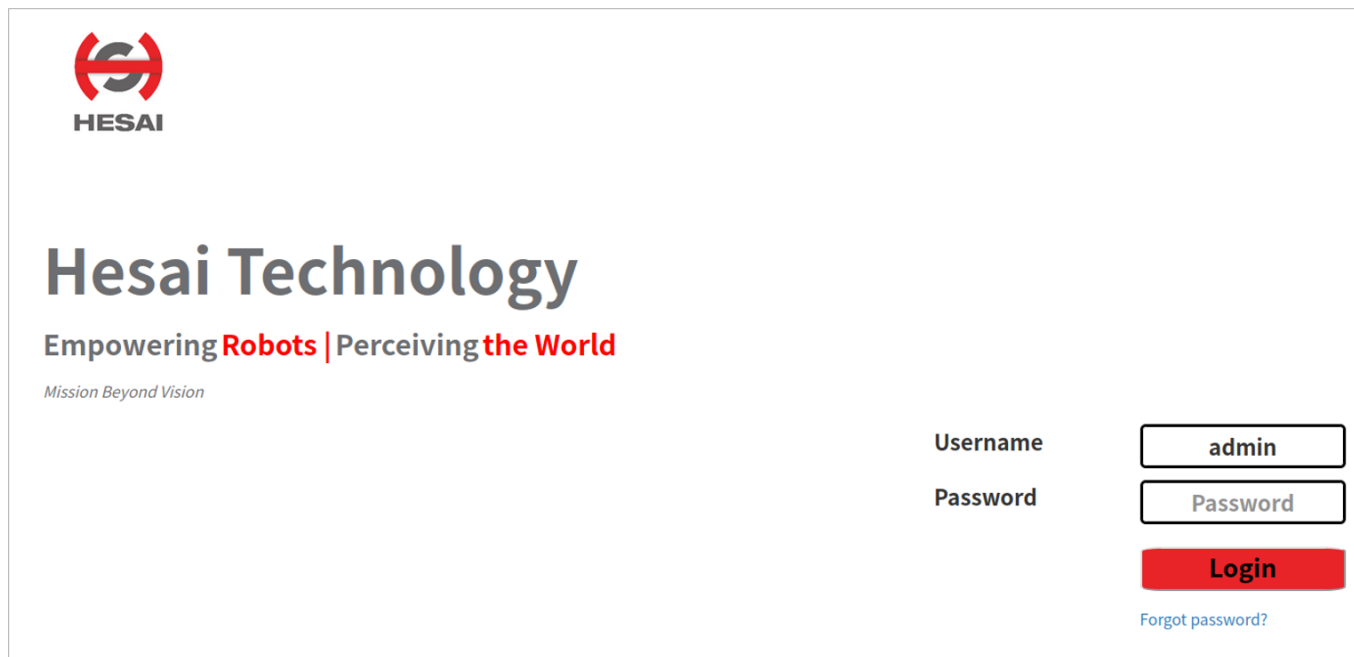


Figure 26. In Firefox

## 4.10. Login


When the Cyber Security Master Switch on the [Security](#) page is ON, login control will be activated and the current URL will redirect to the Login page.



Parameter	Options	Description
Username	admin	-
Password	-	Default: <b>123456</b> To effectively implement login control, please change the default password (see <a href="#">Section 4.9.1 Login control</a> ) and keep your new password securely.

## 5. Communication protocol

**HTTP API** and **Pandar TCP Commands (PTC) API** can be used to communicate with Hesai lidars.

 To acquire the API reference manuals, please contact Hesai technical support.

## 6. Maintenance

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

- Do NOT wipe the cover lens when it is dry, nor use abrasive cleaners. Doing so can damage the optical coating.
- Do NOT use organic cleaners, which can damage the cover lens 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.
  - Do NOT use automatic car wash equipment to clean the lidar. Before washing the car or performing related operations, protect the cover lens to prevent any contact with organic cleaners.
- Do NOT apply excessive force to the lidar, as this can damage the cover lens.
- If a pressure washer is used to clean the cover lens, make sure the distance between the nozzle and the cover lens remains at least 60 cm.
- After prolonged exposure to strong sunlight and high temperatures, the cover lens should NOT be cleaned immediately.
- If snow or ice accumulates on the cover lens, 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 cover lens.



Please regularly check the cover lens, considering your car use frequency, parking environment, and climate conditions.



- If foreign objects (such as dust, fingerprints, or oil stains) are found on the cover lens, 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 cover lens, 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 cover lens 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 cover lens 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).



## 7. Troubleshooting

If the following procedures cannot solve your problem, please contact Hesai technical support.

### Indicator light is off on the connection box.

Make sure that the following conditions are met:

- The power adapter is properly connected and in good condition.
- The connection box is intact.
- The input voltage and input current satisfy the requirements in [Section 2.3 Connection box \(optional\)](#).

Afterward, power on the lidar again and check if the symptom persists.

### Motor is not running.

Make sure that the following conditions are met:

- The power adapter is properly connected and in good condition.
- The input voltage and input current satisfy the requirements in [Section 1.4 Specifications](#).
- The lidar can be accessed using web\_control (see [Cannot open Web Control](#)).
- The lidar is not in standby mode; this can be confirmed using Web Control or PTC commands.
- If a connection box is used, the connection box is intact.

Afterward, power on the lidar again and check if the symptom persists.

### Motor is running, but no output data is received, neither by Wireshark nor by PandarView 2.

Make sure that the following conditions are met:

- Ethernet cable is properly connected (by unplugging and plugging again).
- Destination IP is correctly set; this can be confirmed using Web Control or PTC commands.
- Firmware version is correct; this can be confirmed using Web Control or PTC commands.

- Azimuth FOV is correctly set; this can be confirmed using Web Control or PTC commands.
- The lidar is emitting laser light; this can be confirmed using an infrared camera, an infrared sensor card, or a phone camera without an infrared filter.
- If a connection box is used, replace the current Ethernet cable with another cable of at least Cat 6; Cat 7 or higher is recommended.

Afterward, power on the lidar again and check if the symptom persists.

#### Output data can be received by Wireshark but not by PandarView 2.

Make sure that the following conditions are met:

- Lidar Destination Port is correctly set; this can be confirmed using Web Control or PTC commands.
- If VLAN is enabled, the PC's VLAN ID should be the same as the lidar's; this can be checked using Web Control or PTC commands.
- The PC's firewall is disabled, or PandarView 2 is added to the firewall exceptions.
- The latest PandarView 2 is installed (see [Downloads page of Hesai's official website](#) or contact Hesai technical support).

Afterward, power on the lidar again and check if the symptom persists.

#### Cannot open Web Control.

Make sure that the following conditions are met:

- Ethernet cable is properly connected (by unplugging and plugging again).
- The lidar's IP is in the same subnet with the PC's (WireShark may be used to check the lidar's IP that broadcasts data packets).
- If VLAN is enabled, the PC's VLAN ID should be the same as the lidar's; this can be checked using Web Control or PTC commands.

Afterward, follow the steps below:

1. Restart the PC or connect the lidar to another PC.
2. Power on the lidar again and check if the symptom persists.

The point cloud is abnormal, showing obviously misaligned points, flashing points, or incomplete FOV.

Make sure that the following conditions are met:

- The lidar's cover lens is clean. If not, refer to [Section 6 Maintenance](#) for the cleaning method.
- The lidar's angle correction file is imported (refer to PandarView 2 User Manual).
- Azimuth FOV is properly set; this can be confirmed using Web Control or PTC commands.
- Spin Rate is steady; this can be confirmed by checking the **Motor Speed** field in the Point Cloud Data Packet, or by using Web Control, PandarView 2 or PTC commands.
- The lidar's internal temperature is between  $-40^{\circ}\text{C}$  and  $110^{\circ}\text{C}$ ; this can be confirmed using Web Control, PandarView 2 or PTC commands.

Afterward, check for packet loss.

If no packet is lost yet the point cloud flashes, please follow the steps below:

1. Update PandarView 2 to the latest version (see [Downloads page of Hesai's official website](#) or contact Hesai technical support).
2. Restart the PC.

If the point cloud is still abnormal, follow the steps below:

1. Connect the lidar to another PC and another network.
2. Power on again and check if the symptom persists.

The number of data packets received is abnormal, indicating missing packets.

Make sure that the following conditions are met:

- Azimuth FOV is properly set; this can be confirmed using Web Control or PTC commands.
- Spin Rate is steady; this can be confirmed by checking the **Motor Speed** field in the Point Cloud Data Packet, or by using Web Control, PandarView 2 or PTC commands.
- The lidar's internal temperature is between  $-40^{\circ}\text{C}$  and  $110^{\circ}\text{C}$ ; this can be confirmed using Web Control, PandarView 2 or PTC commands.
- Ethernet is not overloaded.
- No switch is connected to the network (the data transmitted from other devices may cause network congestion and packet loss).

Afterward, follow the steps below:

1. Connect the PC to no other devices but the lidar and check for packet loss.
2. Power on the lidar again and check if the symptom persists.

### GPS cannot be locked.

Make sure that the following conditions are met:

- GPS receiver is properly connected.
- PPS signal is connected to the lidar.
- GPS Destination Port is correctly set; this can be confirmed using Web Control or PTC commands.
- The GPS signals satisfy the electrical requirements in [Section 2.2 Electrical interface](#) and [Section 2.3 Connection box \(optional\)](#).

Afterward, power on the lidar again and check if the symptom persists.

## Appendix A: Channel distribution data

### Notes to the table

<b>Channel number</b>	Counts from 1, top to bottom.
<b>Angular position</b>	<p>The design values of each channel's horizontal (azimuth) angle offset and vertical (elevation) angle.</p> <ul style="list-style-type: none"> <li>• The accurate values are recorded in this lidar unit's angle correction file.</li> <li>• To analyze point cloud data, refer to <a href="#">Section 3.1.4 Point cloud data analysis method</a>.</li> </ul>
<b>Instrumented range</b>	Actual measurement range, confined by the allocated Time of Flight (ToF) for each channel
<b>Near- and mid-field enabled</b>	<p>The 32 channels with <b>min. instrumented range</b> = 0.3 m are <b>near-field-enabled channels</b>.</p> <ul style="list-style-type: none"> <li>• All channels fire laser pulses that detect far-field objects (&gt; 2.7 m). Additionally, the <b>near-field-enabled channels</b> also fire laser pulses that only detect the near-field objects (0.3 to 2.85 m) at times separate from these channels' far-field firings.</li> <li>• The horizontal resolution of near-field measurement is always 0.4° at 10 Hz and 0.8° at 20 Hz.</li> </ul>
<b>Max. range @10% reflectivity</b>	<ul style="list-style-type: none"> <li>• Probability of Detection (PoD) = 70%</li> <li>• The values in brackets only indicate ranging capability, while the actual measurement range is cut off to <b>max. instrumented range</b>.</li> <li>• Channels 98 to 128 only provide near- and mid-field detection, since these channels typically point to the ground.</li> </ul>
<b>Far-field enhanced</b>	Channels 34 to 65 are <b>far-field-enhanced channels</b> , able to detect 200 m @10% reflectivity (see data in <b>max. range @10% reflectivity</b> ).

**Min. detectable reflectivity at max. instrumented range**

Probability of Detection (PoD) = 70%

**High-resolution**

Channels 26 to 90 are high-res channels, characterized by

- 0.125° vertical resolution
- enhanced horizontal resolution in High Resolution Mode (see [Section 4.4 High resolution](#))

Appendix A: Channel distribution data

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
1	3.257°	14.436°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
2	3.263°	13.535°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
3	1.091°	13.082°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
4	3.268°	12.624°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
5	1.093°	12.165°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
6	3.273°	11.702°	0.3 m	100 m	YES	(120 m)	-	100 m @ 6%	-
7	1.094°	11.239°	2.7 m	100 m	-	(120 m)	-	100 m @ 6%	-
8	3.278°	10.771°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
9	1.095°	10.305°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
10	3.283°	9.830°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
11	1.096°	9.356°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
12	3.288°	8.880°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
13	1.097°	8.401°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
14	3.291°	7.921°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
15	1.098°	7.438°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
16	-1.101°	6.953°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
17	1.100°	6.467°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
18	-1.104°	5.978°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-

Appendix A: Channel distribution data

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
19	-3.306°	5.487°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
20	-1.106°	4.996°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
21	-3.311°	4.501°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
22	-1.109°	4.007°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
23	-3.318°	3.509°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
24	-1.111°	3.013°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
25	-3.324°	2.512°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
26	-1.113°	2.013°	0.3 m	200 m	YES	140 m	-	200 m @ 37%	YES
27	7.72°	1.885°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
28	5.535°	1.761°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
29	3.325°	1.637°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
30	-3.33°	1.511°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
31	1.107°	1.386°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
32	-5.538°	1.258°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
33	-7.726°	1.13°	0.3 m	200 m	YES	140 m	-	200 m @ 37%	YES
34	-1.115°	1.008°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
35	7.731°	0.88°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
36	5.543°	0.756°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES



Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
37	3.329°	0.63°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
38	-3.336°	0.505°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
39	1.108°	0.379°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
40	-5.547°	0.251°	0.3 m	200 m	YES	200 m	YES	200 m @ 10%	YES
41	-7.738°	0.124°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
42	-1.117°	0.000°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
43	7.743°	-0.129°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
44	5.551°	-0.254°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
45	3.335°	-0.380°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
46	-3.342°	-0.506°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
47	1.110°	-0.632°	0.3 m	200 m	YES	200 m	YES	200 m @ 10%	YES
48	-5.555°	-0.760°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
49	-7.750°	-0.887°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
50	-1.119°	-1.012°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
51	7.757°	-1.141°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
52	5.560°	-1.266°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
53	3.340°	-1.393°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
54	-3.347°	-1.519°	0.3 m	200 m	YES	200 m	YES	200 m @ 10%	YES

Appendix A: Channel distribution data

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
55	1.111°	-1.646°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
56	-5.564°	-1.773°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
57	-7.762°	-1.901°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
58	-1.121°	-2.027°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
59	7.768°	-2.155°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
60	5.569°	-2.282°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
61	3.345°	-2.409°	0.3 m	200 m	YES	200 m	YES	200 m @ 10%	YES
62	-3.353°	-2.535°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
63	1.113°	-2.663°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
64	-5.573°	-2.789°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
65	-7.775°	-2.916°	2.7 m	200 m	-	200 m	YES	200 m @ 10%	YES
66	-1.123°	-3.044°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
67	7.780°	-3.172°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
68	5.578°	-3.299°	0.3 m	200 m	YES	140 m	-	200 m @ 37%	YES
69	3.351°	-3.425°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
70	-3.358°	-3.552°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
71	1.115°	-3.680°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
72	-5.582°	-3.806°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
73	-7.787°	-3.933°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
74	-1.125°	-4.062°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
75	7.792°	-4.190°	0.3 m	200 m	YES	140 m	-	200 m @ 37%	YES
76	5.586°	-4.318°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
77	3.356°	-4.444°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
78	-3.363°	-4.571°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
79	1.116°	-4.699°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
80	-5.591°	-4.824°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
81	-7.799°	-4.951°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
82	-1.127°	-5.081°	0.3 m	200 m	YES	140 m	-	200 m @ 37%	YES
83	7.804°	-5.209°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
84	5.595°	-5.336°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
85	3.360°	-5.463°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
86	-3.369°	-5.589°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
87	1.118°	-5.718°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
88	-5.599°	-5.843°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
89	-7.811°	-5.968°	2.7 m	200 m	-	140 m	-	200 m @ 37%	YES
90	-1.129°	-6.100°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
91	-3.374°	-6.607°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
92	-1.130°	-7.117°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
93	-3.379°	-7.624°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
94	-1.132°	-8.134°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
95	-3.383°	-8.640°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
96	3.381°	-9.149°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
97	-3.388°	-9.652°	2.7 m	100 m	-	(140 m)	-	100 m @ 3%	-
98	3.386°	-10.160°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
99	1.129°	-10.665°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
100	3.390°	-11.170°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
101	1.129°	-11.672°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
102	3.395°	-12.174°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
103	1.131°	-12.673°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
104	3.401°	-13.173°	2.7 m	100 m	-	100 m	-	100 m @ 10%	-
105	1.133°	-13.67°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
106	3.406°	-14.166°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
107	1.135°	-14.66°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
108	3.410°	-15.154°	0.3 m	100 m	YES	50 m	-	100 m @ 120%	-

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
109	1.137°	-15.645°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
110	3.416°	-16.135°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
111	1.139°	-16.622°	0.3 m	100 m	YES	50 m	-	100 m @ 120%	-
112	-1.142°	-17.106°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
113	1.142°	-17.592°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
114	-1.143°	-18.072°	0.3 m	100 m	YES	50 m	-	100 m @ 120%	-
115	-3.426°	-18.548°	2.7 m	100 m	-	50 m	-	100 m @ 120%	-
116	-1.143°	-19.030°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
117	-3.429°	-19.501°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-
118	-1.145°	-19.978°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
119	-3.433°	-20.445°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
120	-1.145°	-20.918°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-
121	-3.436°	-21.379°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
122	-1.146°	-21.848°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
123	-3.440°	-22.304°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-
124	-1.146°	-22.768°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
125	-3.443°	-23.219°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
126	-1.146°	-23.678°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced ?	Min. detectable reflectivity at max. instrumented range	High-res?
	Horiz. offset	Vertical	Min	Max					
127	-3.446°	-24.123°	2.7 m	100 m	-	25 m	-	100 m @ 1600%	-
128	-3.449°	-25.016°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	—

## Appendix B: Absolute time of point cloud data

### B.1. Source of absolute time

The lidar retrieves the current absolute time by connecting to an external clock source.

#### B.1.1. GPS as the clock source

The lidar connects to a third-party GPS module to obtain pulse-per-second (PPS) signals and NMEA sentences.

- NMEA sentence (\$GPRMC or \$GPGGA) can be selected using Web Control or PTC commands.
- The signal status of GPS PPS and NMEA can be checked using Web Control or PTC commands.
- The timing requirements of PPS and NMEA are shown in [Section 2.2.1 Pin description](#).
- Each rising edge of the lidar's internal 1 Hz signal triggers a GPS Data Packet. The data format is detailed in [Section 3.2 GPS Data Packet](#).
- The timing requirements of PPS and NMEA are shown in [Section 2.2.1 Pin description](#).
- Each rising edge of the lidar's internal 1 Hz signal triggers a GPS Data Packet. The data format is detailed in [Section 3.2 GPS Data Packet](#).

The absolute time is updated as follows:

NMEA status	Date and time (accurate to the second)	Lidar behavior
Unlocked (Initial)	Virtual	Since the lidar has not been locked before, it starts counting from a <b>virtual UTC</b> (such as 2000-01-01 00:00:00) using the lidar's internal 1 Hz signal.
Locked	Synchronized	At each rising edge of the internal 1 Hz signal, the lidar obtains the actual date and time by performing these two steps: <ol style="list-style-type: none"> <li>1. Extract the date and time from the previous NMEA message.</li> <li>2. Add 1 full second.</li> </ol>

NMEA status	Date and time (accurate to the second)	Lidar behavior
Unlocked (Lost)	Drifting	When the lidar goes from Locked to Unlocked, it starts counting from <b>the last synchronized time</b> using the lidar's internal 1 Hz signal. This absolute time will gradually drift from the actual GPS time.

PPS status	$\mu$ s time	Lidar behavior
Unlocked (Initial)	Not synchronized	The lidar's internal 1 Hz signal is not aligned with the GPS second.
Locked	Synchronized	The rising edge of the lidar's internal 1 Hz signal is aligned with the rising edge of the PPS signal (i.e. the start of each GPS second).
Unlocked (Lost)	Drifting	The lidar counts the absolute time using the internal 1 Hz signal. This absolute time will gradually drift from the actual GPS second.

### B.1.2. PTP as the clock source

The lidar connects to a third-party PTP master to obtain PTP signal.



- PPS signal is not required nor used.
- PTP can be configured using Web Control or PTC commands.
- The status of PTP signal can be found using Web Control or PTC commands.
- The lidar does not output GPS Data Packets.

The absolute time is updated as follows:

PTP status	Date and time (accurate to the microsecond)	Lidar behavior
Free run	Virtual	Since the lidar has not been locked before, it starts counting from <b>a virtual UTC</b> (such as 2000-01-01 00:00:00) using the lidar's internal 1 Hz signal.



PTP status	Date and time (accurate to the microsecond)	Lidar behavior
Tracking or Locked	Synchronized	The lidar extracts the actual date and time from the PTP Master's messages.
Frozen	Drifting	When the lidar goes from Tracking/Locked to Frozen, it starts counting from <b>the last synchronized time</b> using the lidar's internal 1 Hz signal. This absolute time will gradually drift from the actual PTP time.



- PTP is a Plug & Play protocol; the lidar works as a PTP slave device and requires no additional setup.
- The **Timestamps** and **Date & Time** fields in Point Cloud Data Packets strictly follow the PTP master device. Certain PTP master devices may have a specified offset from the lidar's time output. Please verify the configuration and calibration of your PTP master device.

## B.2. Absolute time of Point Cloud Data Packets

The absolute time of Point Cloud Data Packets is  $t_0 = t_s + t_{ms}$ , where:

- $t_s$  is the whole second part (see the **Date & Time** field).
- $t_{ms}$  is the microsecond part (see the **Timestamp** field).

The definition of the above fields is in [Section 3.1.2.5 Tail](#).

## B.3. Start time of each block

Given the absolute time of Point Cloud Data Packets as  $t_0$ , the start time of each block (i.e., the time when the first firing starts) can be calculated.

### Single return mode

Block	Start time ( $\mu\text{s}$ ) in High Resolution mode	Start time ( $\mu\text{s}$ ) in Standard mode
Block 1	$t_0 + 3.148 - 27.778$	$t_0 + 3.148 - 27.778 \times 2$
Block 2	$t_0 + 3.148$	$t_0 + 3.148$



High Resolution mode and Standard mode are defined in [Section 4.4 High resolution](#).

### Dual return mode

Block	Start time ( $\mu\text{s}$ )
Block 1 & Block 2	$t_0 + 3.148$

## B.4. Laser firing time of each channel

Given the start time (see [Section B.3 Start time of each block](#)) of **Block m** as  $T(m)$ ,  $m \in \{1, 2\}$ , the laser firing time of **Channel n: Block m** is:

$$t(m, n) = T(m) + \Delta t(n), n \in \{1, 2, \dots, 128\}.$$

### Steps to look up firing time offsets $\Delta t(n)$

1. Check the **Operational State** field in the **Tail** of the Point Cloud Data Packet.  
Operation States: High Resolution, Standard, Energy Saving, Shutdown
2. Check the **Azimuth State** field in the **Tail** of the Point Cloud Data Packet, and obtain the azimuth state of Block m.
  - Range in High Resolution mode: 0, 1, 2, 3
  - Range in Standard or Energy Saving mode: 0, 1
3. Check the **Distance** field of Channel n in Block m, in the **Body** of the Point Cloud Data Packet.
  - If object distance  $> 2.85$  m, the data point is generated from a far-field firing.
  - If object distance  $\leq 2.85$  m, the data point is generated from a near-field firing.
4. Look up  $\Delta t(n)$  in the tables below  
Unit: ns

In the ascending order of channel number

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
Firing type	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
1	4436	5201	-	-	4436	-	-	-	4436	5201	4436	-
2	-	-	776	-	-	-	776	-	28554	-	28554	-
3	776	1541	-	-	776	-	-	-	776	1541	776	-
4	2431	-	-	-	2781	-	-	-	2431	-	2781	-
5	4436	-	-	-	4436	-	-	-	4436	-	4436	-
6	-	-	2781	4026	-	-	2431	-	30559	31804	30209	-
7	6441	-	-	-	6091	-	-	-	6441	-	6091	-
8	-	-	4786	-	-	-	4086	-	32564	-	31864	-
9	-	-	6441	7206	-	-	6091	-	34219	34984	33869	-
10	776	-	-	-	776	-	-	-	776	-	776	-
11	2431	-	-	-	2781	-	-	-	2431	-	2781	-
12	6441	-	-	-	6091	7336	-	-	6441	-	6091	7336
13	-	-	776	-	-	-	776	-	28554	-	28554	-
14	-	-	6441	-	-	-	6091	-	34219	-	33869	-
15	-	-	2781	3546	-	-	2431	-	30559	31324	30209	-
16	-	-	776	-	-	-	776	-	28554	-	28554	-

B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
17	-	-	4786	-	-	-	4086	-	32564	-	31864	-
18	6441	7206	-	-	6091	-	-	-	6441	7206	6091	-
19	-	-	4786	-	-	-	4086	-	32564	-	31864	-
20	776	-	-	-	776	-	-	-	776	-	776	-
21	2431	3196	-	-	2781	-	-	-	2431	3196	2781	-
22	-	-	2781	-	-	-	2431	-	30559	-	30209	-
23	-	-	6441	-	-	-	6091	-	34219	-	33869	-
24	-	-	4786	-	-	-	4086	4851	32564	-	31864	32629
25	4436	-	-	-	4436	-	-	-	4436	-	4436	-
26	10381	-	10731	12126	10381	-	10031	-	38509	39904	37809	-
27	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
28	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
29	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
30	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
31	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
32	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
33	12666	-	13016	-	12666	14061	12316	-	12666	-	12666	14061

#### B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
Azimuth State	0		1		2		3		0		1	
Firing type	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
34	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
35	10381	-	10731	-	10381	-	10031	-	38509	-	37809	-
36	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
37	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
38	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
39	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
40	14951	27056	15301	-	14951	-	14601	-	43079	27056	42379	-
41	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
42	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
43	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
44	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
45	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
46	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
47	10381	-	10731	27406	10381	-	10031	-	38509	55184	37809	-
48	10381	-	10731	-	10381	-	10031	-	38509	-	37809	-
49	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
50	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-

#### B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
51	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
52	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
53	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
54	12666	-	13016	-	12666	27056	12316	-	12666	-	12666	27056
55	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
56	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
57	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
58	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
59	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
60	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
61	10381	-	10731	-	10381	-	10031	26706	38509	-	37809	54484
62	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
63	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
64	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
65	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
66	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
67	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-

#### B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
68	10381	-	10731	-	10381	-	10031	11426	38509	-	37809	39204
69	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
70	10381	-	10731	-	10381	-	10031	-	38509	-	37809	-
71	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
72	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
73	10381	-	10731	-	10381	-	10031	-	38509	-	37809	-
74	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
75	21806	23201	22156	-	21806	-	21456	-	21806	23201	21806	-
76	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
77	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
78	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-
79	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
80	19521	-	19871	-	19521	-	19171	-	19521	-	19521	-
81	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
82	24091	-	24441	-	24091	-	23741	25136	52219	-	51519	52914
83	24091	-	24441	-	24091	-	23741	-	52219	-	51519	-
84	17236	-	17586	-	17236	-	16886	-	17236	-	17236	-



#### B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
85	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
86	8096	-	8446	-	8096	-	7746	-	36224	-	35524	-
87	12666	-	13016	-	12666	-	12316	-	12666	-	12666	-
88	21806	-	22156	-	21806	-	21456	-	21806	-	21806	-
89	14951	-	15301	-	14951	-	14601	-	43079	-	42379	-
90	2431	3676	-	-	2781	-	-	-	2431	3676	2781	-
91	776	-	-	-	776	-	-	-	776	-	776	-
92	4436	-	-	-	4436	-	-	-	4436	-	4436	-
93	6441	-	-	-	6091	6856	-	-	6441	-	6091	6856
94	-	-	6441	-	-	-	6091	-	34219	-	33869	-
95	-	-	2781	-	-	-	2431	-	30559	-	30209	-
96	776	-	-	-	776	2021	0	-	776	-	776	2021
97	-	-	776	-	-	-	776	-	28554	-	28554	-
98	2431	-	-	-	2781	-	-	-	2431	-	2781	-
99	2431	-	-	-	2781	3546	-	-	2431	-	2781	3546
100	4436	-	-	-	4436	-	-	-	4436	-	4436	-
101	-	-	4786	-	-	-	4086	-	32564	-	31864	-

B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
	0		1		2		3		0		1	
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
102	-	-	776	2021	-	-	776	-	28554	29799	28554	-
103	-	-	2781	-	-	-	2431	-	30559	-	30209	-
104	6441	-	-	-	6091	-	-	-	6441	-	6091	-
105	4436	5681	-	-	4436	-	-	-	4436	5681	4436	-
106	-	-	2781	-	-	-	2431	-	30559	-	30209	-
107	-	-	776	-	-	-	776	-	28554	-	28554	-
108	-	-	4786	-	-	-	4086	5331	32564	-	31864	33109
109	6441	-	-	-	6091	-	-	-	6441	-	6091	-
110	-	-	6441	-	-	-	6091	-	34219	-	33869	-
111	-	-	6441	7686	-	-	6091	-	34219	35464	33869	-
112	-	-	4786	-	-	-	4086	-	32564	-	31864	-
113	776	-	-	-	776	-	-	-	776	-	776	-
114	4436	-	-	-	4436	5201	-	-	4436	-	4436	5201
115	-	-	4786	-	-	-	4086	-	32564	-	31864	-
116	2431	-	-	-	2781	-	-	-	2431	-	2781	-
117	-	-	2781	-	-	-	2431	3196	30559	-	30209	30974
118	-	-	6441	-	-	-	6091	-	34219	-	33869	-

#### B.4. Laser firing time of each channel

Operational State	High Resolution								Standard or Energy-Saving			
Azimuth State	0		1		2		3		0		1	
Firing type	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near
Channel No.												
119	776	-	-	-	776	-	-	-	776	-	776	-
120	-	-	776	1541	-	-	776	-	28554	29319	28554	-
121	4436	-	-	-	4436	-	-	-	4436	-	4436	-
122	6441	-	-	-	6091	-	-	-	6441	-	6091	-
123	-	-	6441	-	-	-	6091	6856	34219	-	33869	34634
124	-	-	2781	-	-	-	2431	-	30559	-	30209	-
125	2431	-	-	-	2781	-	-	-	2431	-	2781	-
126	776	-	-	-	776	1541	-	-	776	-	776	1541
127	6441	-	-	-	6091	-	-	-	6441	-	6091	-
128	-	-	776	-	-	-	776	1541	28554	-	28554	29319
<b>Total firings</b>	<b>96</b>	<b>8</b>	<b>96</b>	<b>8</b>	<b>96</b>	<b>8</b>	<b>96</b>	<b>8</b>	<b>128</b>	<b>16</b>	<b>128</b>	<b>16</b>

In the ascending order of firing sequence (High Resolution state)

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
3	776	1	-	2	776	1	-	3	776	1	-	2	776	1	-
10	776	1	-	13	776	1	-	10	776	1	-	13	776	1	-
20	776	1	-	16	776	1	-	20	776	1	-	16	776	1	-
91	776	1	-	97	776	1	-	91	776	1	-	97	776	1	-
96	776	1	-	102	776	1	-	96	776	1	-	102	776	1	-
113	776	1	-	107	776	1	-	113	776	1	-	107	776	1	-
119	776	1	-	120	776	1	-	119	776	1	-	120	776	1	-
126	776	1	-	128	776	1	-	126	776	1	-	128	776	1	-
3	1541	2	YES	120	1541	2	YES	126	1541	2	YES	128	1541	2	YES
4	2431	3	-	102	2021	3	YES	96	2021	3	YES	6	2431	3	-
11	2431	3	-	6	2781	4	-	4	2781	4	-	15	2431	3	-
21	2431	3	-	15	2781	4	-	11	2781	4	-	22	2431	3	-
90	2431	3	-	22	2781	4	-	21	2781	4	-	95	2431	3	-
98	2431	3	-	95	2781	4	-	90	2781	4	-	103	2431	3	-
99	2431	3	-	103	2781	4	-	98	2781	4	-	106	2431	3	-
116	2431	3	-	106	2781	4	-	99	2781	4	-	117	2431	3	-
125	2431	3	-	117	2781	4	-	116	2781	4	-	124	2431	3	-

#### B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
21	3196	4	YES	124	2781	4	-	125	2781	4	-	117	3196	4	YES
90	3676	5	YES	15	3546	5	YES	99	3546	5	YES	8	4086	5	-
1	4436	6	-	6	4026	6	YES	1	4436	6	-	17	4086	5	-
5	4436	6	-	8	4786	7	-	5	4436	6	-	19	4086	5	-
25	4436	6	-	17	4786	7	-	25	4436	6	-	24	4086	5	-
92	4436	6	-	19	4786	7	-	92	4436	6	-	101	4086	5	-
100	4436	6	-	24	4786	7	-	100	4436	6	-	108	4086	5	-
105	4436	6	-	101	4786	7	-	105	4436	6	-	112	4086	5	-
114	4436	6	-	108	4786	7	-	114	4436	6	-	115	4086	5	-
121	4436	6	-	112	4786	7	-	121	4436	6	-	24	4851	6	YES
1	5201	7	YES	115	4786	7	-	114	5201	7	YES	108	5331	7	YES
105	5681	8	YES	9	6441	8	-	7	6091	8	-	9	6091	8	-
7	6441	9	-	14	6441	8	-	12	6091	8	-	14	6091	8	-
12	6441	9	-	23	6441	8	-	18	6091	8	-	23	6091	8	-
18	6441	9	-	94	6441	8	-	93	6091	8	-	94	6091	8	-
93	6441	9	-	110	6441	8	-	104	6091	8	-	110	6091	8	-
104	6441	9	-	111	6441	8	-	109	6091	8	-	111	6091	8	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
109	6441	9	-	118	6441	8	-	122	6091	8	-	118	6091	8	-
122	6441	9	-	123	6441	8	-	127	6091	8	-	123	6091	8	-
127	6441	9	-	9	7206	9	YES	93	6856	9	YES	123	6856	9	YES
18	7206	10	YES	111	7686	10	YES	12	7336	10	YES	32	7746	10	-
32	8096	11	-	32	8446	11	-	32	8096	11	-	45	7746	10	-
45	8096	11	-	45	8446	11	-	45	8096	11	-	50	7746	10	-
50	8096	11	-	50	8446	11	-	50	8096	11	-	51	7746	10	-
51	8096	11	-	51	8446	11	-	51	8096	11	-	65	7746	10	-
65	8096	11	-	65	8446	11	-	65	8096	11	-	76	7746	10	-
76	8096	11	-	76	8446	11	-	76	8096	11	-	79	7746	10	-
79	8096	11	-	79	8446	11	-	79	8096	11	-	86	7746	10	-
86	8096	11	-	86	8446	11	-	86	8096	11	-	26	10031	11	-
26	10381	12	-	26	10731	12	-	26	10381	12	-	35	10031	11	-
35	10381	12	-	35	10731	12	-	35	10381	12	-	47	10031	11	-
47	10381	12	-	47	10731	12	-	47	10381	12	-	48	10031	11	-
48	10381	12	-	48	10731	12	-	48	10381	12	-	61	10031	11	-
61	10381	12	-	61	10731	12	-	61	10381	12	-	68	10031	11	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
68	10381	12	-	68	10731	12	-	68	10381	12	-	70	10031	11	-
70	10381	12	-	70	10731	12	-	70	10381	12	-	73	10031	11	-
73	10381	12	-	73	10731	12	-	73	10381	12	-	68	11426	12	YES
28	12666	13	-	26	12126	13	YES	28	12666	13	-	28	12316	13	-
33	12666	13	-	28	13016	14	-	33	12666	13	-	33	12316	13	-
34	12666	13	-	33	13016	14	-	34	12666	13	-	34	12316	13	-
43	12666	13	-	34	13016	14	-	43	12666	13	-	43	12316	13	-
53	12666	13	-	43	13016	14	-	53	12666	13	-	53	12316	13	-
54	12666	13	-	53	13016	14	-	54	12666	13	-	54	12316	13	-
72	12666	13	-	54	13016	14	-	72	12666	13	-	72	12316	13	-
87	12666	13	-	72	13016	14	-	87	12666	13	-	87	12316	13	-
27	14951	14	-	87	13016	14	-	33	14061	14	YES	27	14601	14	-
29	14951	14	-	27	15301	15	-	27	14951	15	-	29	14601	14	-
39	14951	14	-	29	15301	15	-	29	14951	15	-	39	14601	14	-
40	14951	14	-	39	15301	15	-	39	14951	15	-	40	14601	14	-
60	14951	14	-	40	15301	15	-	40	14951	15	-	60	14601	14	-
62	14951	14	-	60	15301	15	-	60	14951	15	-	62	14601	14	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
74	14951	14	-	62	15301	15	-	62	14951	15	-	74	14601	14	-
89	14951	14	-	74	15301	15	-	74	14951	15	-	89	14601	14	-
37	17236	15	-	89	15301	15	-	89	14951	15	-	37	16886	15	-
42	17236	15	-	37	17586	16	-	37	17236	16	-	42	16886	15	-
57	17236	15	-	42	17586	16	-	42	17236	16	-	57	16886	15	-
59	17236	15	-	57	17586	16	-	57	17236	16	-	59	16886	15	-
63	17236	15	-	59	17586	16	-	59	17236	16	-	63	16886	15	-
64	17236	15	-	63	17586	16	-	63	17236	16	-	64	16886	15	-
78	17236	15	-	64	17586	16	-	64	17236	16	-	78	16886	15	-
84	17236	15	-	78	17586	16	-	78	17236	16	-	84	16886	15	-
30	19521	16	-	84	17586	16	-	84	17236	16	-	30	19171	16	-
31	19521	16	-	30	19871	17	-	30	19521	17	-	31	19171	16	-
41	19521	16	-	31	19871	17	-	31	19521	17	-	41	19171	16	-
52	19521	16	-	41	19871	17	-	41	19521	17	-	52	19171	16	-
66	19521	16	-	52	19871	17	-	52	19521	17	-	66	19171	16	-
67	19521	16	-	66	19871	17	-	66	19521	17	-	67	19171	16	-
77	19521	16	-	67	19871	17	-	67	19521	17	-	77	19171	16	-



B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
80	19521	16	-	77	19871	17	-	77	19521	17	-	80	19171	16	-
44	21806	17	-	80	19871	17	-	80	19521	17	-	44	21456	17	-
46	21806	17	-	44	22156	18	-	44	21806	18	-	46	21456	17	-
49	21806	17	-	46	22156	18	-	46	21806	18	-	49	21456	17	-
58	21806	17	-	49	22156	18	-	49	21806	18	-	58	21456	17	-
71	21806	17	-	58	22156	18	-	58	21806	18	-	71	21456	17	-
75	21806	17	-	71	22156	18	-	71	21806	18	-	75	21456	17	-
85	21806	17	-	75	22156	18	-	75	21806	18	-	85	21456	17	-
88	21806	17	-	85	22156	18	-	85	21806	18	-	88	21456	17	-
75	23201	18	YES	88	22156	18	-	88	21806	18	-	36	23741	18	-
36	24091	19	-	36	24441	19	-	36	24091	19	-	38	23741	18	-
38	24091	19	-	38	24441	19	-	38	24091	19	-	55	23741	18	-
55	24091	19	-	55	24441	19	-	55	24091	19	-	56	23741	18	-
56	24091	19	-	56	24441	19	-	56	24091	19	-	69	23741	18	-
69	24091	19	-	69	24441	19	-	69	24091	19	-	81	23741	18	-
81	24091	19	-	81	24441	19	-	81	24091	19	-	82	23741	18	-
82	24091	19	-	82	24441	19	-	82	24091	19	-	83	23741	18	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	1			Azimuth State	2			Azimuth State	3		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
83	24091	19	-	83	24441	19	-	83	24091	19	-	82	25136	19	YES
40	27056	20	YES	47	27406	20	YES	54	27056	20	YES	61	26706	20	YES
<b>Total firings</b>		<b>104</b>	<b>8</b>	<b>Total firings</b>		<b>104</b>	<b>8</b>	<b>Total firings</b>		<b>104</b>	<b>8</b>	<b>Total firings</b>		<b>104</b>	<b>8</b>

## In the ascending order of firing sequence (Standard and Energy-Saving states)

Azimuth State	0			Azimuth State	0			Azimuth State	1			Azimuth State	1		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
119	776	1	-	90	3676	5	YES	119	776	1	-	99	3546	5	YES
126	776	1	-	121	4436	6	-	126	776	1	-	121	4436	6	-
91	776	1	-	114	4436	6	-	91	776	1	-	114	4436	6	-
20	776	1	-	25	4436	6	-	20	776	1	-	25	4436	6	-
3	776	1	-	92	4436	6	-	3	776	1	-	92	4436	6	-
10	776	1	-	5	4436	6	-	10	776	1	-	5	4436	6	-
113	776	1	-	1	4436	6	-	113	776	1	-	1	4436	6	-
96	776	1	-	105	4436	6	-	96	776	1	-	105	4436	6	-
3	1541	2	YES	100	4436	6	-	126	1541	2	YES	100	4436	6	-
125	2431	3	-	1	5201	7	YES	96	2021	3	YES	114	5201	7	YES
116	2431	3	-	105	5681	8	YES	125	2781	4	-	127	6091	8	-
21	2431	3	-	127	6441	9	-	116	2781	4	-	122	6091	8	-
90	2431	3	-	122	6441	9	-	21	2781	4	-	93	6091	8	-
11	2431	3	-	93	6441	9	-	90	2781	4	-	18	6091	8	-
4	2431	3	-	18	6441	9	-	11	2781	4	-	7	6091	8	-
99	2431	3	-	7	6441	9	-	4	2781	4	-	12	6091	8	-
98	2431	3	-	12	6441	9	-	99	2781	4	-	109	6091	8	-

#### B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	0			Azimuth State	1			Azimuth State	1		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
21	3196	4	YES	109	6441	9	-	98	2781	4	-	104	6091	8	-
104	6441	9	-	41	19521	13	-	93	6856	9	YES	59	17236	13	-
18	7206	10	YES	80	19521	13	-	12	7336	10	YES	41	19521	14	-
33	12666	11	-	30	19521	13	-	33	12666	11	-	80	19521	14	-
72	12666	11	-	66	19521	13	-	72	12666	11	-	30	19521	14	-
54	12666	11	-	31	19521	13	-	54	12666	11	-	66	19521	14	-
34	12666	11	-	77	19521	13	-	34	12666	11	-	31	19521	14	-
87	12666	11	-	52	19521	13	-	87	12666	11	-	77	19521	14	-
53	12666	11	-	67	19521	13	-	53	12666	11	-	52	19521	14	-
28	12666	11	-	49	21806	14	-	28	12666	11	-	67	19521	14	-
43	12666	11	-	88	21806	14	-	43	12666	11	-	49	21806	15	-
57	17236	12	-	46	21806	14	-	33	14061	12	YES	88	21806	15	-
64	17236	12	-	58	21806	14	-	57	17236	13	-	46	21806	15	-
78	17236	12	-	71	21806	14	-	64	17236	13	-	58	21806	15	-
42	17236	12	-	85	21806	14	-	78	17236	13	-	71	21806	15	-
63	17236	12	-	44	21806	14	-	42	17236	13	-	85	21806	15	-
37	17236	12	-	75	21806	14	-	63	17236	13	-	44	21806	15	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	0			Azimuth State	1			Azimuth State	1		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
84	17236	12	-	75	23201	15	YES	37	17236	13	-	75	21806	15	-
59	17236	12	-	40	27056	16	YES	84	17236	13	-	54	27056	16	YES
128	28554	17	-	15	31324	21	YES	128	28554	17	-	115	31864	21	-
120	28554	17	-	6	31804	22	YES	120	28554	17	-	112	31864	21	-
97	28554	17	-	115	32564	23	-	97	28554	17	-	19	31864	21	-
16	28554	17	-	112	32564	23	-	16	28554	17	-	24	31864	21	-
13	28554	17	-	19	32564	23	-	13	28554	17	-	17	31864	21	-
2	28554	17	-	24	32564	23	-	2	28554	17	-	8	31864	21	-
107	28554	17	-	17	32564	23	-	107	28554	17	-	101	31864	21	-
102	28554	17	-	8	32564	23	-	102	28554	17	-	108	31864	21	-
120	29319	18	YES	101	32564	23	-	128	29319	18	YES	24	32629	22	YES
102	29799	19	YES	108	32564	23	-	117	30209	19	-	108	33109	23	YES
117	30559	20	-	123	34219	24	-	124	30209	19	-	123	33869	24	-
124	30559	20	-	118	34219	24	-	95	30209	19	-	118	33869	24	-
95	30559	20	-	23	34219	24	-	22	30209	19	-	23	33869	24	-
22	30559	20	-	94	34219	24	-	15	30209	19	-	94	33869	24	-
15	30559	20	-	9	34219	24	-	6	30209	19	-	9	33869	24	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	0			Azimuth State	1			Azimuth State	1		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
6	30559	20	-	14	34219	24	-	103	30209	19	-	14	33869	24	-
103	30559	20	-	111	34219	24	-	106	30209	19	-	111	33869	24	-
106	30559	20	-	110	34219	24	-	117	30974	20	YES	110	33869	24	-
9	34984	25	YES	74	43079	30	-	123	34634	25	YES	39	42379	29	-
111	35464	26	YES	39	43079	30	-	65	35524	26	-	29	42379	29	-
65	36224	27	-	29	43079	30	-	32	35524	26	-	60	42379	29	-
32	36224	27	-	60	43079	30	-	86	35524	26	-	27	42379	29	-
86	36224	27	-	27	43079	30	-	50	35524	26	-	81	51519	30	-
50	36224	27	-	81	52219	31	-	79	35524	26	-	56	51519	30	-
79	36224	27	-	56	52219	31	-	45	35524	26	-	38	51519	30	-
45	36224	27	-	38	52219	31	-	76	35524	26	-	82	51519	30	-
76	36224	27	-	82	52219	31	-	51	35524	26	-	55	51519	30	-
51	36224	27	-	26	38509	28	-	73	37809	27	-	26	38509	28	-
73	38509	28	-	47	38509	28	-	48	37809	27	-	47	38509	28	-
48	38509	28	-	61	38509	28	-	70	37809	27	-	61	38509	28	-
70	38509	28	-	68	38509	28	-	26	37809	27	-	68	38509	28	-
26	39904	29	YES	35	38509	28	-	89	42379	29	-	35	38509	28	-

B.4. Laser firing time of each channel

Azimuth State	0			Azimuth State	0			Azimuth State	1			Azimuth State	1		
Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field	Channel No.	$\Delta t(n)$	Firing sequence	Near-field
89	43079	30	-	55	52219	31	-	40	42379	29	-	55	52219	31	-
40	43079	30	-	69	52219	31	-	62	42379	29	-	69	52219	31	-
62	43079	30	-	36	52219	31	-	74	42379	29	-	36	52219	31	-
83	52219	31	-	47	55184	32	YES	83	52219	31	-	47	55184	32	YES
<b>Total firings</b>		<b>144</b>	<b>16</b>	<b>Total firings</b>		<b>144</b>	<b>16</b>	<b>Total firings</b>		<b>144</b>	<b>16</b>	<b>Total firings</b>		<b>144</b>	<b>16</b>

## Appendix C: Nonlinear reflectivity mapping

By default, the **Reflectivity** field in Point Cloud Data Packets (see [Section 3.1.2.3 Body](#)) linearly represents target reflectivity.

- Range of the **Reflectivity** field value: 0 to 255
- Range of target reflectivity: 0 to 255%

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

### C.1. Nonlinear Mapping 1#

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

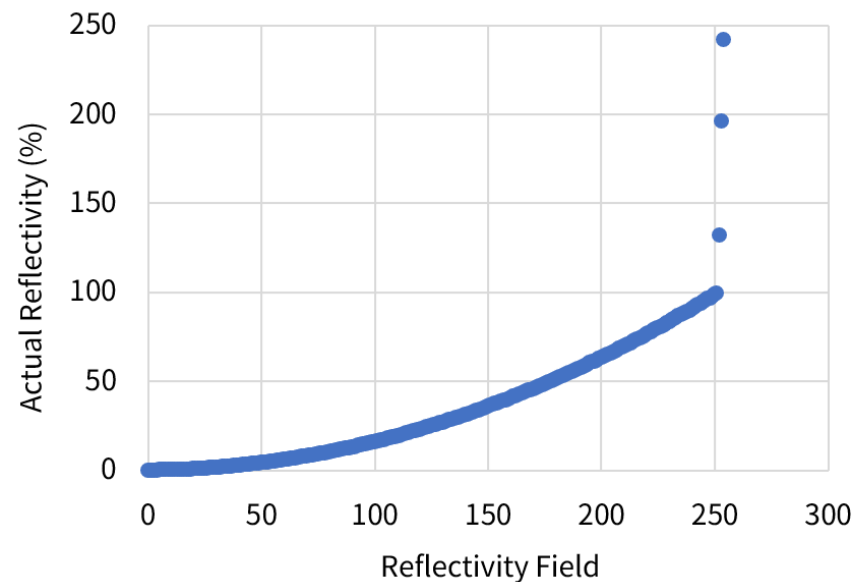


Figure 27. Nonlinear mapping 1#

#### Nonlinear mapping 1#



Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
0	0	1	0.01	2	0.02	3	0.03
4	0.04	5	0.05	6	0.08	7	0.11
8	0.13	9	0.15	10	0.19	11	0.23
12	0.26	13	0.29	14	0.34	15	0.39
16	0.44	17	0.5	18	0.56	19	0.61
20	0.67	21	0.75	22	0.81	23	0.87
24	0.95	25	1.05	26	1.15	27	1.25
28	1.35	29	1.45	30	1.55	31	1.65
32	1.75	33	1.85	34	1.95	35	2.06
36	2.19	37	2.31	38	2.44	39	2.56
40	2.69	41	2.81	42	2.94	43	3.07
44	3.21	45	3.36	46	3.5	47	3.64
48	3.79	49	3.93	50	4.08	51	4.25
52	4.42	53	4.58	54	4.75	55	4.92
56	5.1	57	5.3	58	5.5	59	5.7
60	5.9	61	6.1	62	6.3	63	6.5
64	6.7	65	6.9	66	7.1	67	7.3
68	7.5	69	7.7	70	7.9	71	8.12
72	8.37	73	8.62	74	8.87	75	9.1
76	9.3	77	9.5	78	9.7	79	9.9

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
80	10.17	81	10.5	82	10.83	83	11.12
84	11.37	85	11.62	86	11.87	87	12.12
88	12.37	89	12.62	90	12.87	91	13.17
92	13.5	93	13.83	94	14.17	95	14.5
96	14.83	97	15.12	98	15.37	99	15.62
100	15.87	101	16.17	102	16.5	103	16.83
104	17.17	105	17.5	106	17.83	107	18.17
108	18.5	109	18.83	110	19.17	111	19.5
112	19.83	113	20.25	114	20.75	115	21.17
116	21.5	117	21.83	118	22.17	119	22.5
120	22.83	121	23.25	122	23.75	123	24.17
124	24.5	125	24.83	126	25.25	127	25.75
128	26.17	129	26.5	130	26.83	131	27.25
132	27.75	133	28.17	134	28.5	135	28.83
136	29.25	137	29.75	138	30.25	139	30.75
140	31.17	141	31.5	142	31.83	143	32.25
144	32.75	145	33.25	146	33.75	147	34.25
148	34.75	149	35.25	150	35.75	151	36.25
152	36.75	153	37.25	154	37.75	155	38.25
156	38.75	157	39.17	158	39.5	159	39.83

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
160	40.5	161	41.25	162	41.75	163	42.25
164	42.75	165	43.25	166	43.75	167	44.25
168	44.75	169	45.25	170	45.75	171	46.25
172	46.75	173	47.25	174	47.75	175	48.25
176	48.75	177	49.5	178	50.25	179	50.75
180	51.25	181	51.75	182	52.25	183	52.75
184	53.5	185	54.25	186	54.75	187	55.25
188	55.75	189	56.5	190	57.25	191	57.75
192	58.25	193	58.75	194	59.5	195	60.25
196	60.75	197	61.25	198	61.75	199	62.5
200	63.25	201	63.75	202	64.5	203	65.25
204	65.75	205	66.25	206	66.75	207	67.5
208	68.25	209	68.75	210	69.5	211	70.25
212	70.75	213	71.5	214	72.25	215	72.75
216	73.5	217	74.25	218	74.75	219	75.5
220	76.5	221	77.25	222	77.75	223	78.5
224	79.25	225	79.75	226	80.5	227	81.25
228	81.75	229	82.5	230	83.5	231	84.25
232	84.75	233	85.5	234	86.5	235	87.25
236	87.75	237	88.5	238	89.25	239	89.75

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
240	90.5	241	91.5	242	92.5	243	93.25
244	93.75	245	94.5	246	95.5	247	96.25
248	96.75	249	97.5	250	98.5	251	99.5
252	132	253	196	254	242	-	-

## C.2. Nonlinear mapping 2#

This mapping increases the resolution of low-reflectivity objects, especially lane markings.

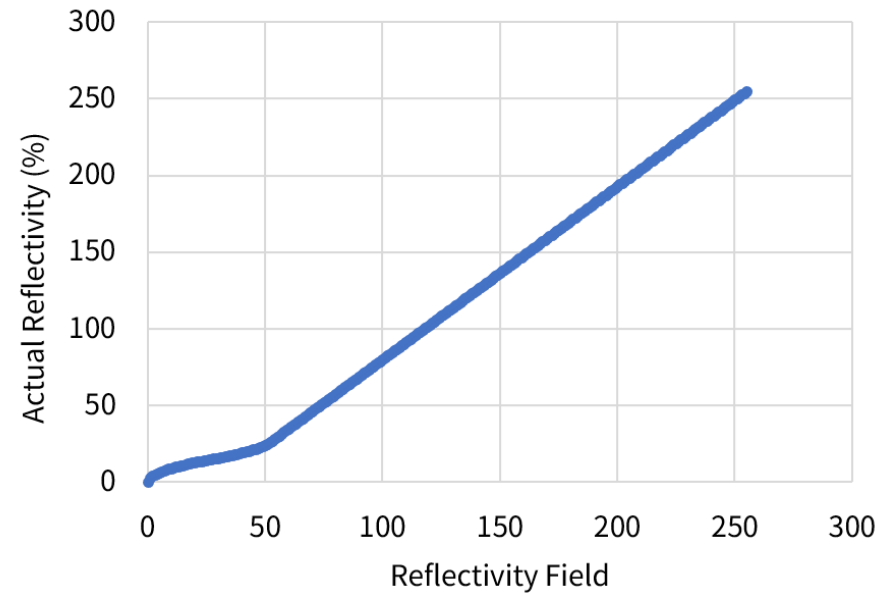


Figure 28. Nonlinear mapping 2#

## Nonlinear mapping 2#

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
0	0	1	2.89	2	4.08	3	5
4	5.77	5	6.45	6	7.07	7	7.64
8	8.16	9	8.66	10	9.13	11	9.57
12	10	13	10.41	14	10.8	15	11.18
16	11.55	17	11.9	18	12.25	19	12.58
20	12.91	21	13.23	22	13.54	23	13.84
24	14.14	25	14.43	26	14.72	27	15
28	15.28	29	15.57	30	15.86	31	16.16
32	16.46	33	16.77	34	17.09	35	17.42
36	17.75	37	18.1	38	18.45	39	18.82
40	19.2	41	19.59	42	20	43	20.43
44	20.87	45	21.34	46	21.84	47	22.36
48	22.93	49	23.55	50	24.23	51	25
52	25.92	53	27.09	54	28.22	55	29.35
56	30.47	57	31.6	58	32.73	59	33.86
60	34.99	61	36.12	62	37.25	63	38.37
64	39.5	65	40.63	66	41.76	67	42.89
68	44.02	69	45.15	70	46.28	71	47.4
72	48.53	73	49.66	74	50.79	75	51.92

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
76	53.05	77	54.18	78	55.3	79	56.43
80	57.56	81	58.69	82	59.82	83	60.95
84	62.08	85	63.21	86	64.33	87	65.46
88	66.59	89	67.72	90	68.85	91	69.98
92	71.11	93	72.23	94	73.36	95	74.49
96	75.62	97	76.75	98	77.88	99	79.01
100	80.14	101	81.26	102	82.39	103	83.52
104	84.65	105	85.78	106	86.91	107	88.04
108	89.16	109	90.29	110	91.42	111	92.55
112	93.68	113	94.81	114	95.94	115	97.07
116	98.19	117	99.32	118	100.45	119	101.58
120	102.71	121	103.84	122	104.97	123	106.09
124	107.22	125	108.35	126	109.48	127	110.61
128	111.74	129	112.87	130	114	131	115.12
132	116.25	133	117.38	134	118.51	135	119.64
136	120.77	137	121.9	138	123.02	139	124.15
140	125.28	141	126.41	142	127.54	143	128.67
144	129.8	145	130.93	146	132.05	147	133.18
148	134.31	149	135.44	150	136.57	151	137.7
152	138.83	153	139.95	154	141.08	155	142.21

Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
156	143.34	157	144.47	158	145.6	159	146.73
160	147.86	161	148.98	162	150.11	163	151.24
164	152.37	165	153.5	166	154.63	167	155.76
168	156.88	169	158.01	170	159.14	171	160.27
172	161.4	173	162.53	174	163.66	175	164.79
176	165.91	177	167.04	178	168.17	179	169.3
180	170.43	181	171.56	182	172.69	183	173.81
184	174.94	185	176.07	186	177.2	187	178.33
188	179.46	189	180.59	190	181.72	191	182.84
192	183.97	193	185.1	194	186.23	195	187.36
196	188.49	197	189.62	198	190.74	199	191.87
200	193	201	194.13	202	195.26	203	196.39
204	197.52	205	198.65	206	199.77	207	200.9
208	202.03	209	203.16	210	204.29	211	205.42
212	206.55	213	207.67	214	208.8	215	209.93
216	211.06	217	212.19	218	213.32	219	214.45
220	215.58	221	216.7	222	217.83	223	218.96
224	220.09	225	221.22	226	222.35	227	223.48
228	224.6	229	225.73	230	226.86	231	227.99
232	229.12	233	230.25	234	231.38	235	232.51



Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %	Reflectivity field	Actual reflectivity %
236	233.63	237	234.76	238	235.89	239	237.02
240	238.15	241	239.28	242	240.41	243	241.53
244	242.66	245	243.79	246	244.92	247	246.05
248	247.18	249	248.31	250	249.44	251	250.56
252	251.69	253	252.82	254	253.95	255	255.08

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