

Pandar128E3X

128-Channel Mechanical Lidar User Manual

Classification: Public

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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

Technical support

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

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

Legends and format



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



Notes: Additional information that may be helpful.

Monospace font: field names

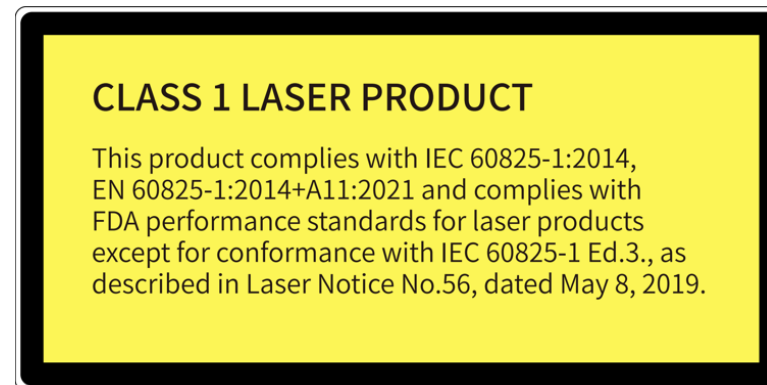
For example: **Distance** represents the Distance field.

■ Safety notice

- 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 liquids, including but not limited to strong acids, strong bases, esters, and ethers.

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 and maintenance

For more product repair or maintenance issues, please contact Hesai or an authorized Hesai service provider.

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.

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.

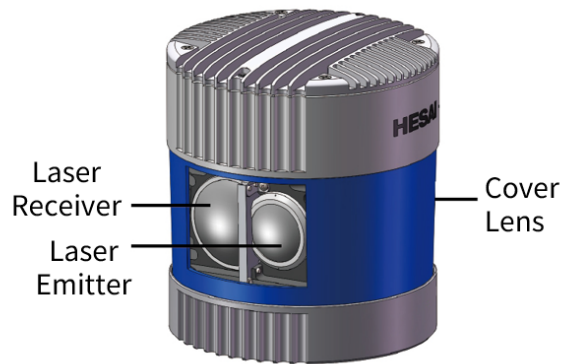


Figure 1. Partial cross-sectional diagram

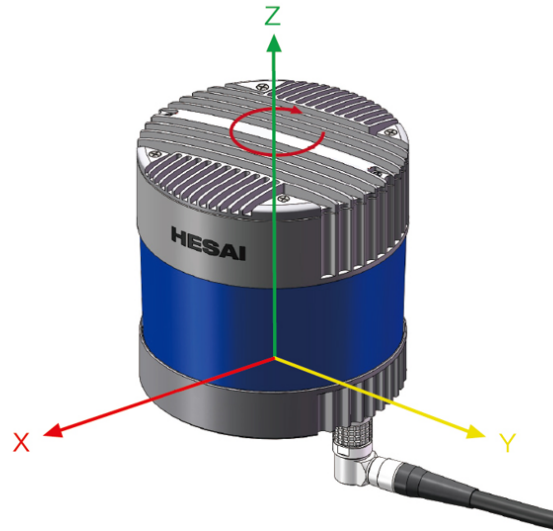


Figure 2. Coordinate system (isometric view)

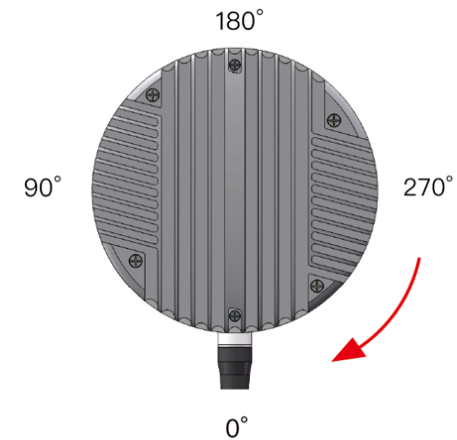


Figure 3. Lidar azimuthal position (top view)

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.

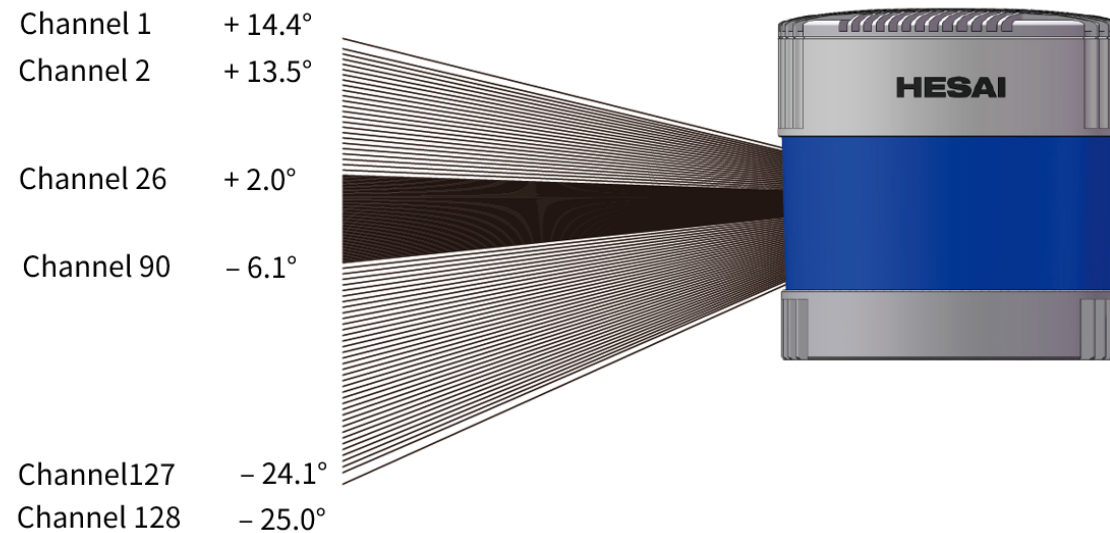


Figure 4. Channel vertical distribution

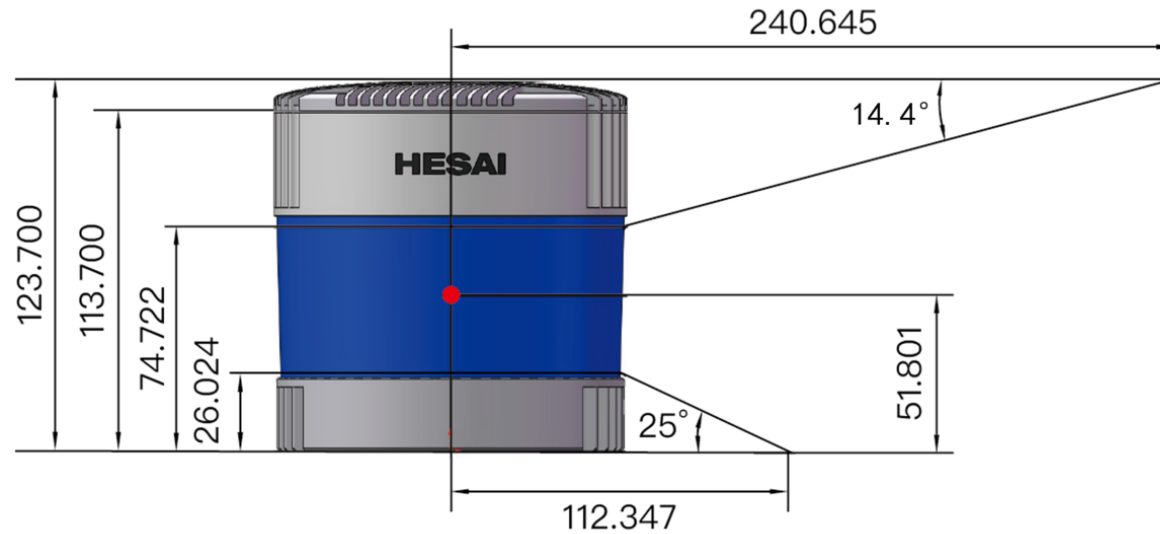


Figure 5. Laser firing position (unit: mm)

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 | Single Return: Last/Strongest/First Dual Return: 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: Φ 118.0/116.0 mm |
| Rated voltage range | DC 9 to 48 V |
| Power consumption ④ | 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 | Single Return: 3 456 000 pts/sec (max) Dual Return: 6 912 000 pts/sec (max) |
| Point cloud data rate | Single Return: 135.22 Mbps (max) Dual Return: 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 ⑤ | $\leq 1 \mu\text{s/s}$ |



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

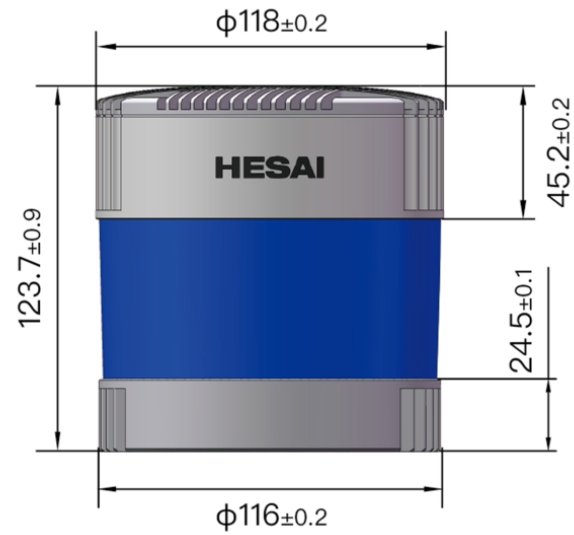


Figure 6. Front view (unit: mm)

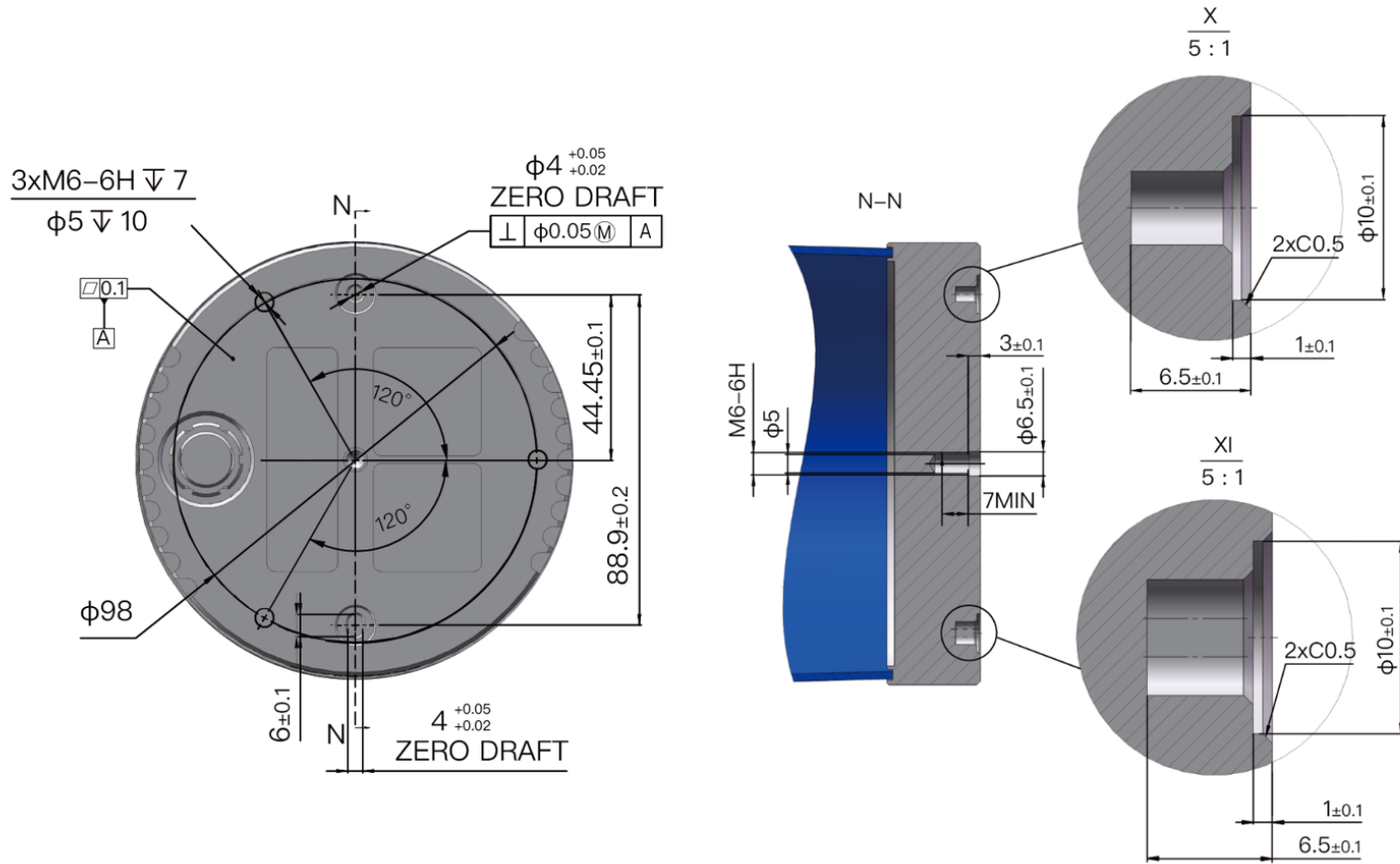


Figure 7. Bottom view (unit: mm)

2.1.2. Quick installation

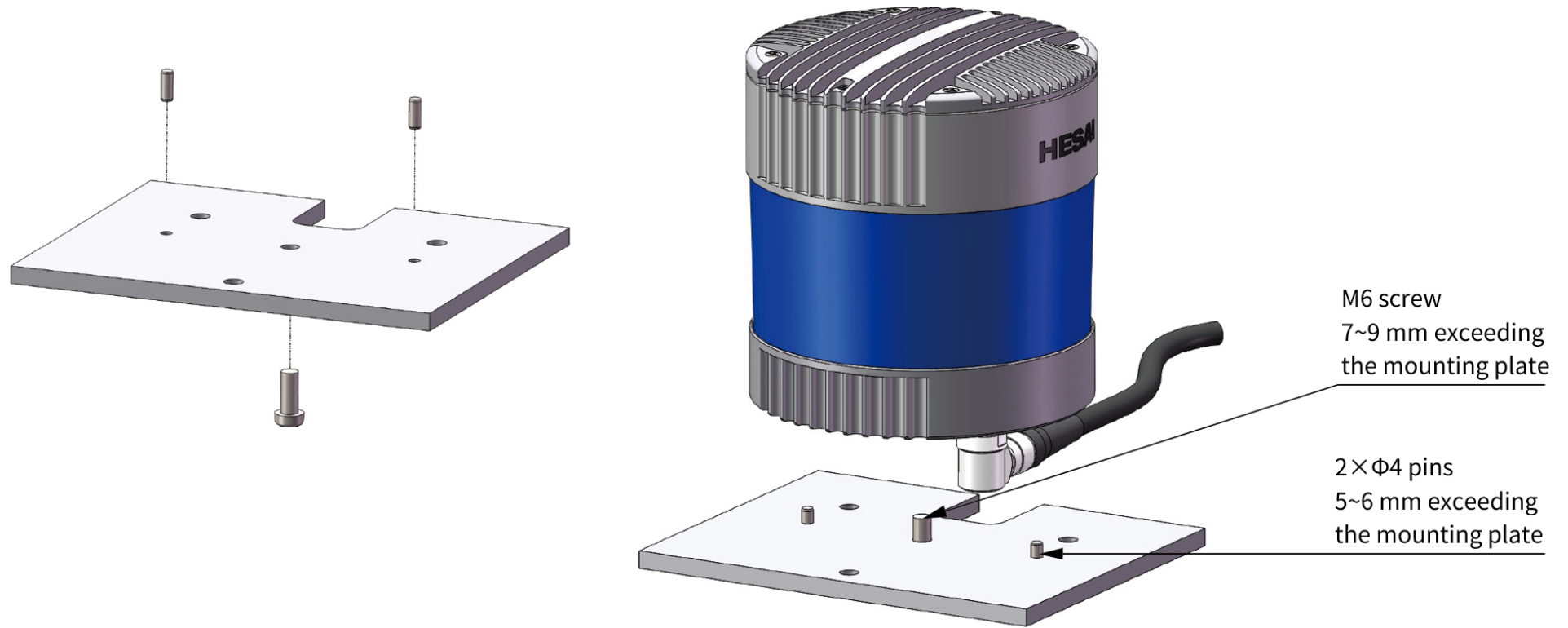


Figure 8. Quick installation

2.1.3. Stable installation

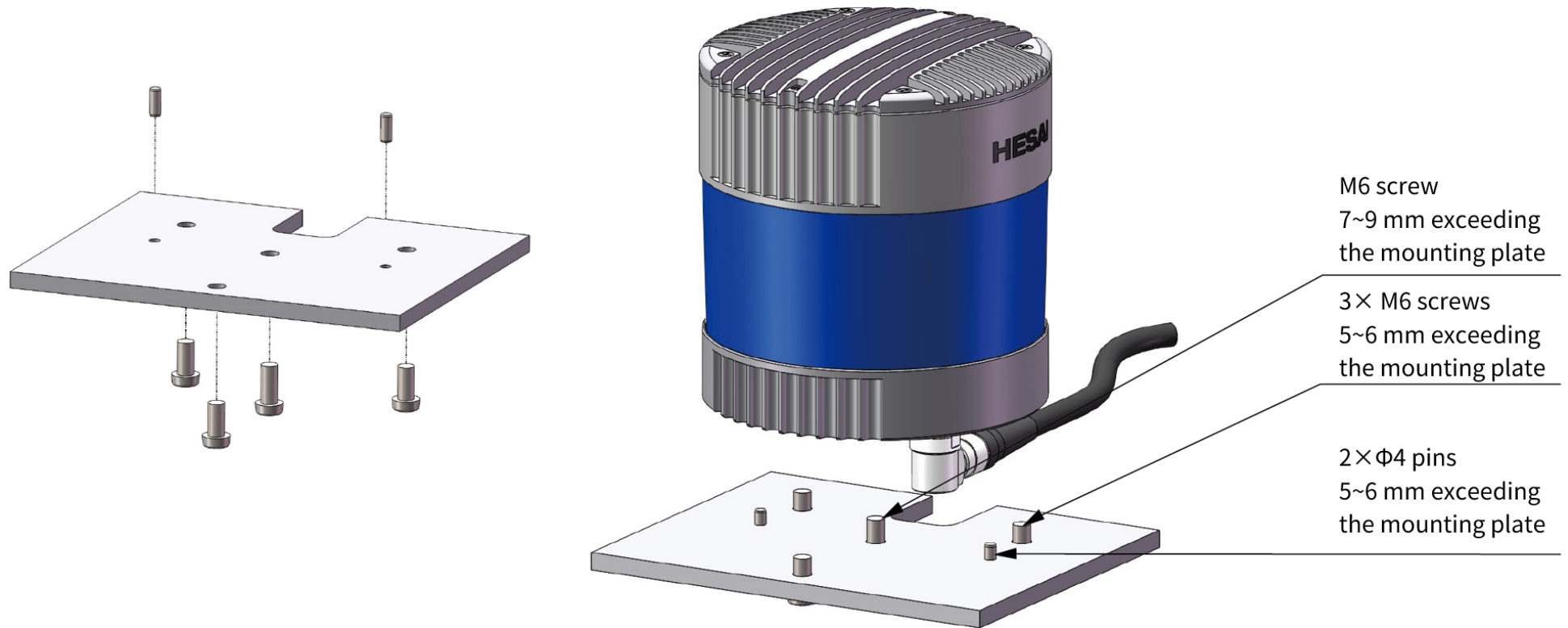


Figure 9. Stable installation

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)

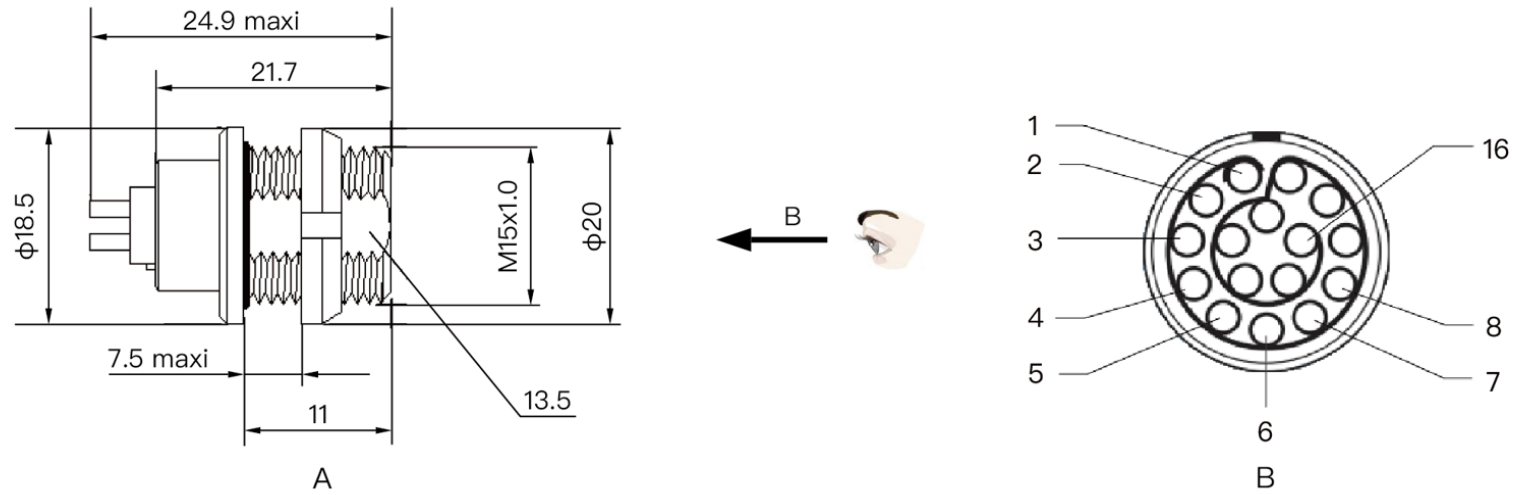


Figure 10. Lemo connector (female socket)


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

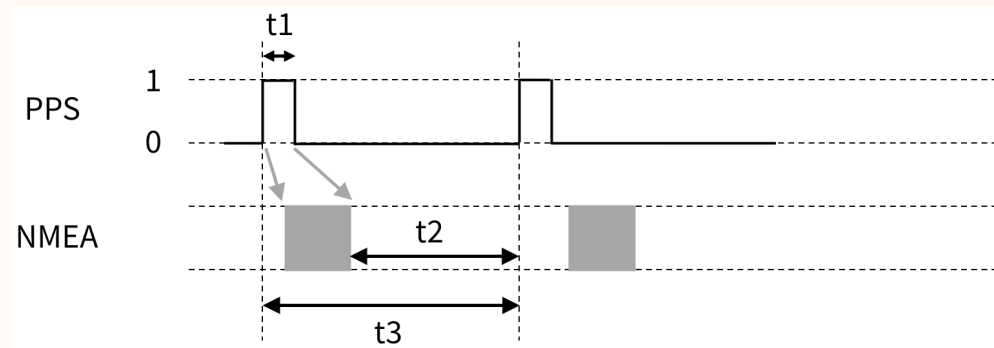
| No. | Signal | Voltage | Wire color |
|----------|-----------------|-------------|------------|
| 1 | Ground (Return) | 0 V | Black |
| 2 | Ground (Return) | 0 V | White |
| 3 | Ethernet_Data- | -1 to 1 V | Blue |
| 4 | Ethernet_Data+ | -1 to 1 V | Blue/White |
| 5 to 8 | — | — | — |
| 9 | GPS Serial 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"> 1. Turn off the power source. 2. Align the red dots on the connector shells. 3. Push the plug straight into the socket. |
| Disconnection | <ol style="list-style-type: none"> 1. Turn off the power source. 2. Pull the release sleeve on the male connector to its outermost position and hold it. 3. Pull the plug from the socket. |

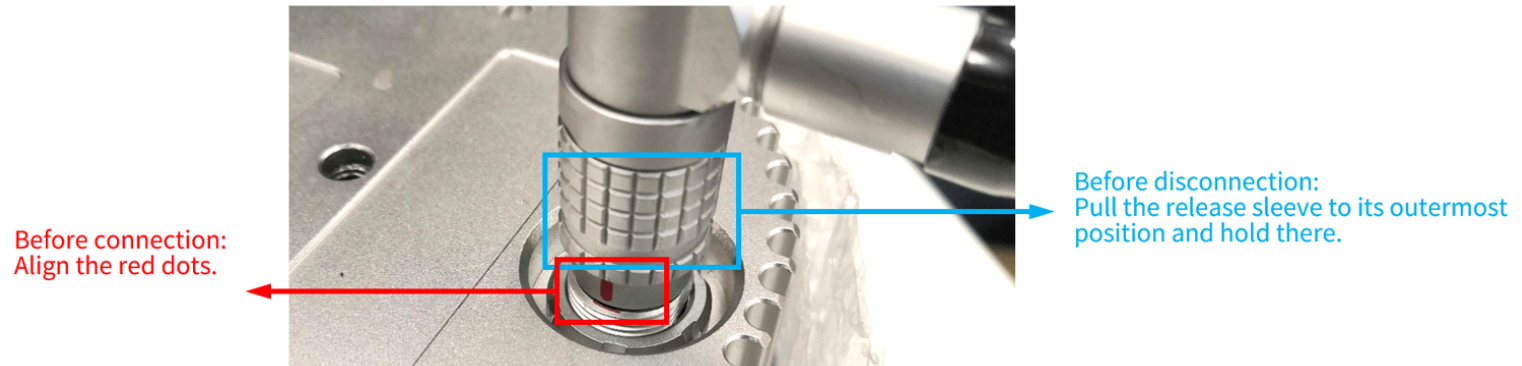


Figure 11. Connection/disconnection



- 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 ± 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.

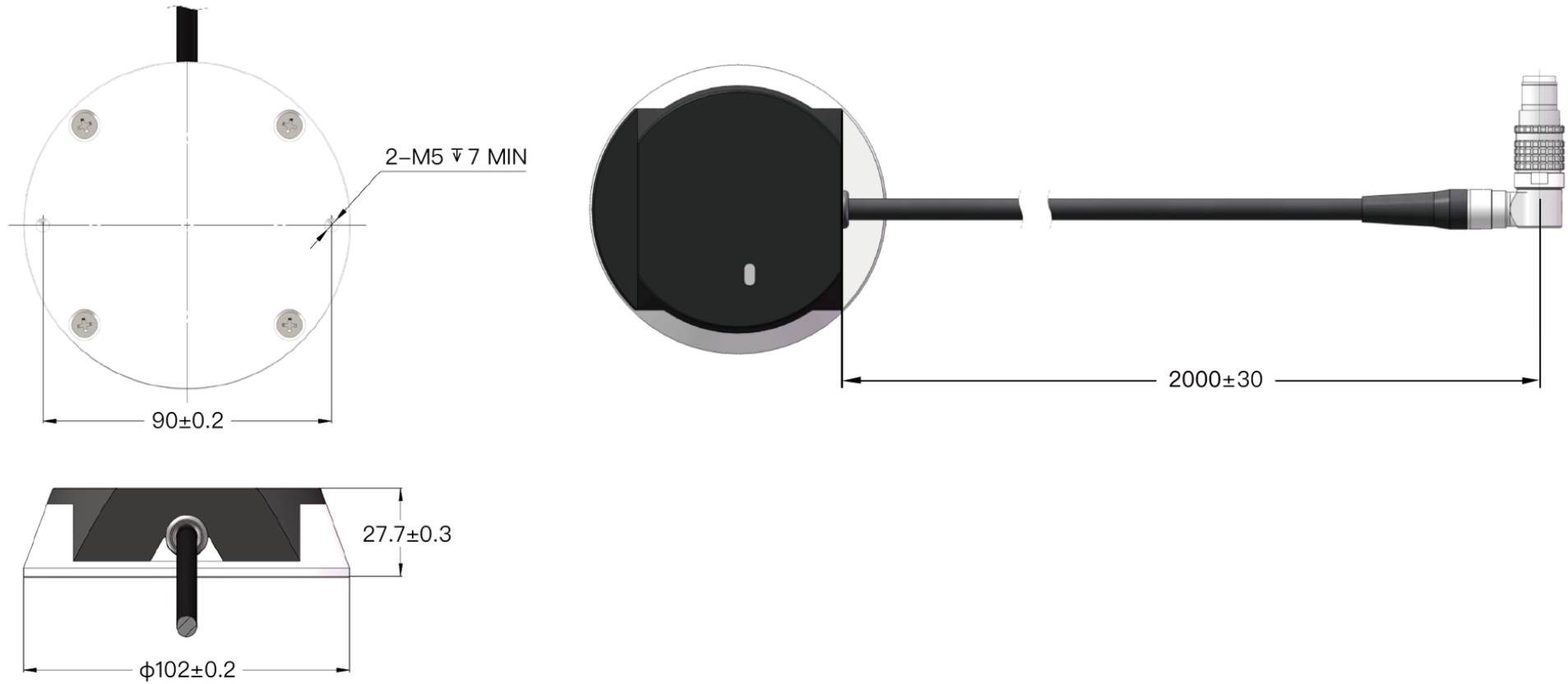


Figure 12. Connection box



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

2.3.1. Ports

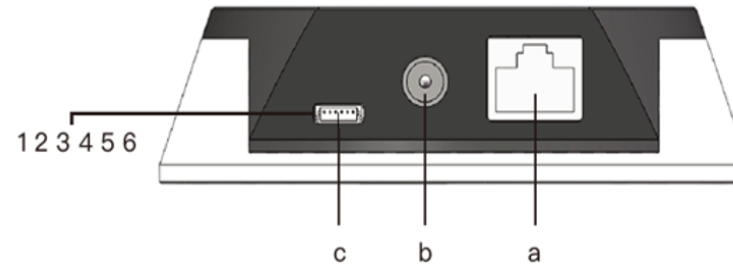


Figure 13. Connection box (front)

| 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 1098"> <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: ≥ 1 ms Signal cycle: 1 s (rising edge to rising edge) |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

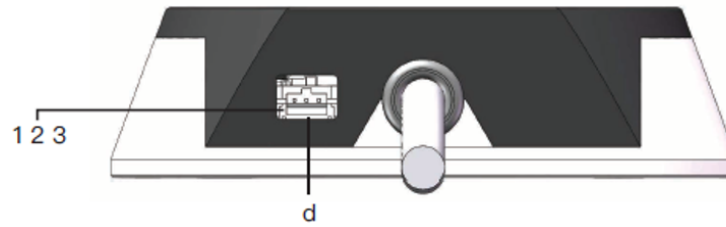


Figure 14. Connection box (back)

| Port No. | Port name | Description | | | | | | | | | | |
|--|------------------------|---|-------------------------|------------------------|--|------------------------|---------|------------|-------------|-------|---------------------|------|
| d | Trigger port | Outputs external trigger signals for multi-sensor synchronization. | | | | | | | | | | |
| | | <table border="1"> <tr> <td>Connector (male socket)</td> <td>Molex, LLC: 5023520300</td> </tr> <tr> <td>Recommended wire connector (female plug)</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 socket) | Molex, LLC: 5023520300 | Recommended wire connector (female plug) | Molex, LLC: 5023510300 | Voltage | 0 to 3.3 V | Signal type | Pulse | Max. output current | 3 mA |
| Connector (male socket) | Molex, LLC: 5023520300 | | | | | | | | | | | |
| Recommended wire connector (female plug) | 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 μ s @ 600 RPM, 4.17 μ s @ 1200 RPM |
| 3 | Output | Trigger-Index | Outputs one pulse when Channel 42 passes the lidar's 180° position (see Figure 3. Lidar azimuthal position (top view)). Pulse width: 2.87 μ s @ 600 RPM, 1.44 μ s @ 1200 RPM |

2.3.2. Connection

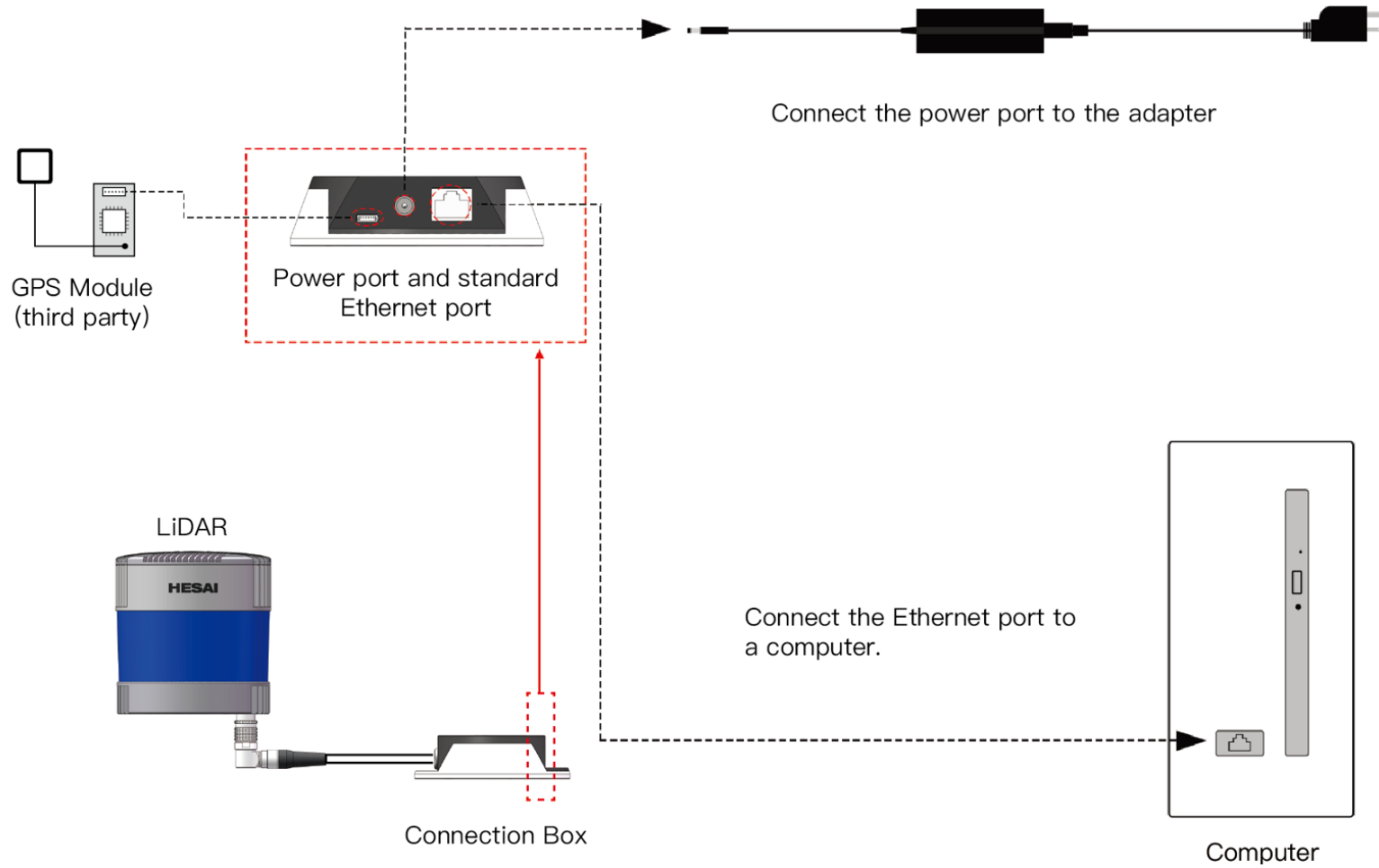


Figure 15. Connection when using GPS

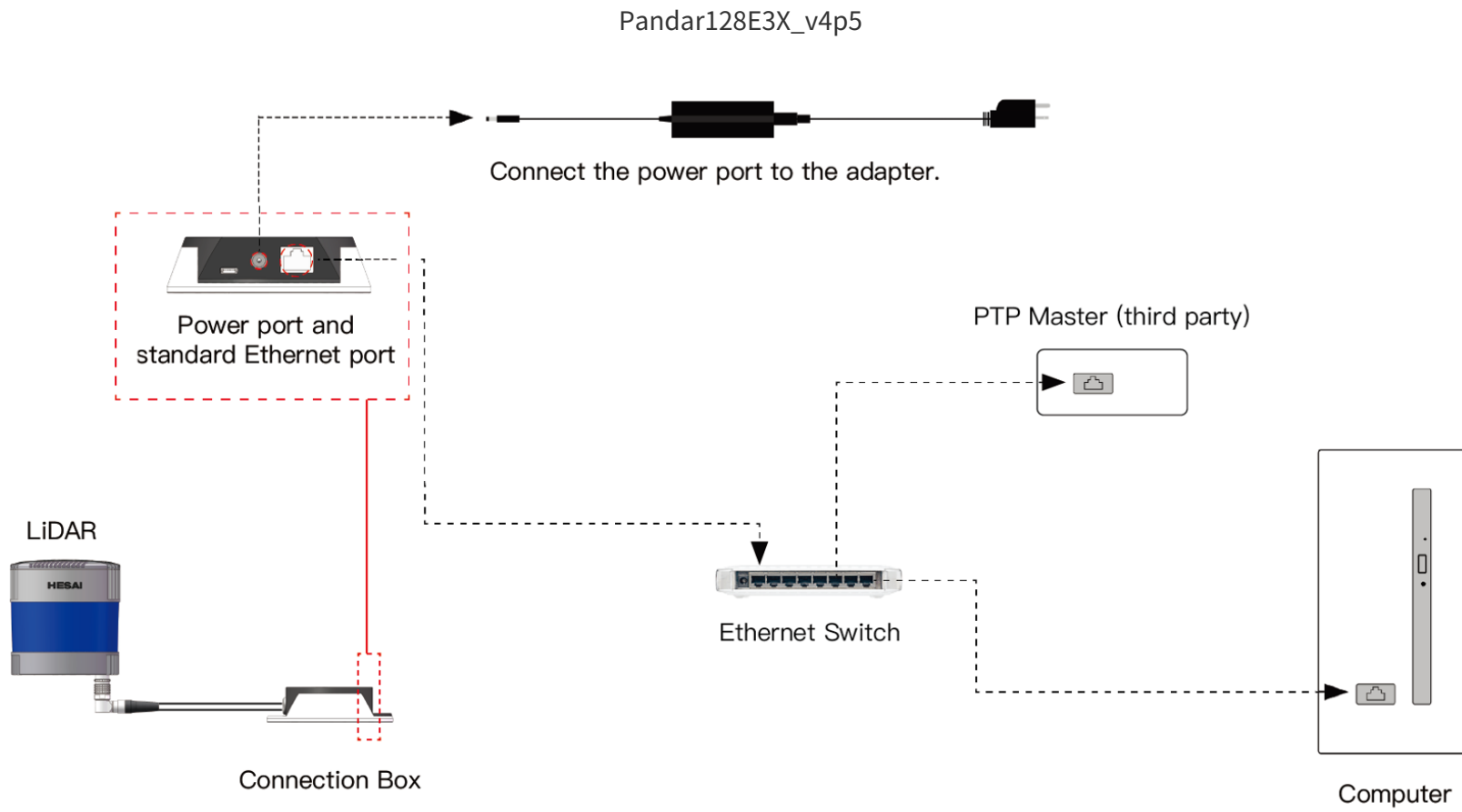



Figure 16. Connection when using PTP

2.4. Network settings on the receiving host

The lidar does not have a power switch. It starts operating once connected to power and the Ethernet.

To receive data on your PC, set the PC's IP address to 192.168.1.X and the subnet mask to 255.255.255.0.

 Range of X: 0 to 255 (except 201, 1 and 255)

| Ubuntu | Windows |
|--|--|
| <ol style="list-style-type: none"> 1. Open the terminal. 2. Input this ifconfig command in the terminal: <code>~\$ sudo ifconfig enp0s20f0u2 192.168.1.X</code> (replace enp0s20f0u2 with the local Ethernet port name.) | <ol style="list-style-type: none"> 1. Go to the "Control Panel". 2. Click "Network and Internet" > "Network and Sharing Center" > "Change adapter settings". 3. Right-click the "Ethernet" interface and select "Properties". 4. Double-click "Internet Protocol Version 4 (TCP/IPv4)". 5. Select "Use the following IP addresses" > Configure the IP address to 192.168.1.X and the subnet mask to 255.255.255.0. |

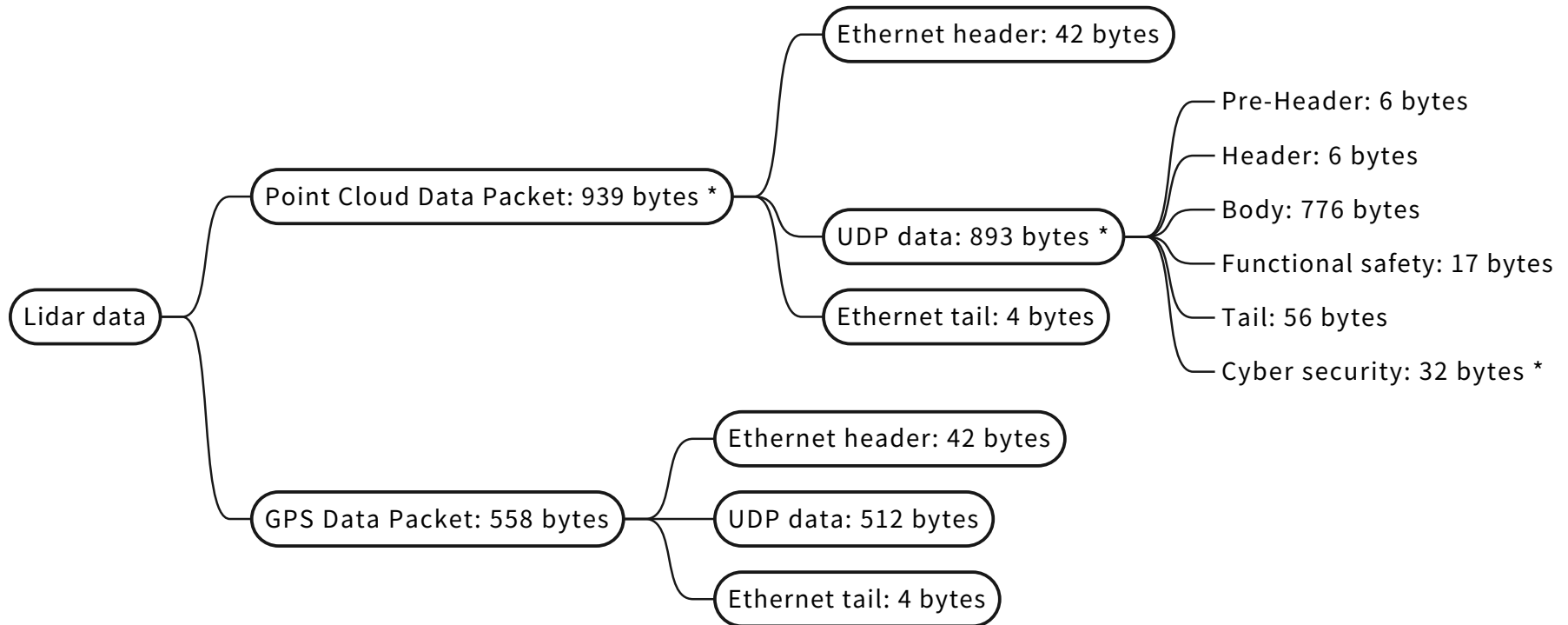
2.5. Tools

| Tool | Purpose | Where to find it |
|---|---|---|
| PandarView 2 (point cloud visualization software) | To record and display point cloud data. | Please contact Hesai technical support. |
| web control、API | To set parameters, check device info or upgrade firmware/software Network parameters: <ul style="list-style-type: none"> • Default Source IPv4 address: 192.168.1.201 • Default PTC port: 9347 | <ul style="list-style-type: none"> • web control: See Section 4 Web control. • API: Please contact Hesai technical support. |

| Tool | Purpose | Where to find it |
|--|------------------------|---|
| Software development kits (SDKs) and ROS drivers | To assist development. | Visit Hesai's official GitHub page: https://github.com/HesaiTechnology |

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 (0x2710, representing 10000) Destination port (0x0940, representing 2368) |
| UDP Length | 2 | Eight bytes more than point cloud UDP data (see Figure 17. Data structure). |
| 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 Each block in the body . |
| 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 Definition of the Distance field . |
| Channel 1: Reflectivity | 1 | Range: 0 to 255 The mapping relation between this field and target reflectivity can be selected using either web control 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 |
|-----------|---|
| ≥ 75 | Object distance = Distance \times Dis Unit ≥ 0.3 m Dis Unit : See Section 3.1.2.2 Header |
| = 0 | No valid point cloud output |

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

| Distance | Description |
|-----------|---|
| ≥ 75 | Object distance = Distance \times Dis Unit ≥ 0.3 m Dis Unit : See Section 3.1.2.2 Header |
| = 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 Appendix A Channel distribution data). 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:  <ul style="list-style-type: none"> • The signal is generated by another lidar unit. • Object distance exceeds the upper limit of the lidar's measurement range. • Pulse intensity is below the threshold. • The signal is filtered out using Retro Multi-Reflection Filtering (see Section 4.2.2 Function). |

 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 Lidar State field to the Reserved 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"> • Used for looking up the laser firing time; see Section B.4 Laser firing time of each channel • Range: 0 to 3 (High Resolution mode), 0 to 1 (Standard or Energy Saving mode) <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 | Coordinated Universal Time (UTC) of this data packet, accurate to the second. In big-endian format: <table border="1" data-bbox="757 486 1809 896"> <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>  To see the definition of absolute time, please refer to Appendix B Absolute time of point cloud data . | 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 "μs time" part of the absolute time of this data packet Unit: μs Range: 0 to 999 999 μs  To see the definition of absolute time, please refer to Appendix B Absolute time of point cloud data . | | | | | | | | | | | | | | |
| Factory Information | 1 | 0x42 | | | | | | | | | | | | | | |

| Field | Byte(s) | Description |
|---------------------------|---------|---|
| UDP Sequence | 4 | Sequence number of this data packet Range: 0 to 0xFF FF FF FF |
| 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) Unit of acceleration: $0.001mg \times 244 = 0.244mg$ (g : standard gravity) |
| IMU Angular Velocity Unit | 2 | Conversion factor of angular velocity Data type: unsigned integer Current value: 1750 (0x06D6) Unit of angular velocity: $0.01 \text{ mdps} \times 1750 = 17.5 \text{ mdps}$ (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 μ s Range: 0 to approx. 29.83 hours |

| Field | Byte(s) | Description | |
|-----------------------------|---------|--|---|
| IMU X Axis Acceleration | 2 | Acceleration of the X-axis, measured by the IMU Data type: signed integer | |
| | | Data type | Signed integer |
| | | Measurement range | $\pm 8g$ |
| | | Unit of acceleration | See the IMU Acceleration Unit 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 | |
| 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 | ± 500 dps |
| | | Unit of angular velocity | See the IMU Angular Velocity Unit field; currently 17.5 mdps. |
| | | Example | When this field is 5, X-axis angular velocity = 5×17.5 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](#).

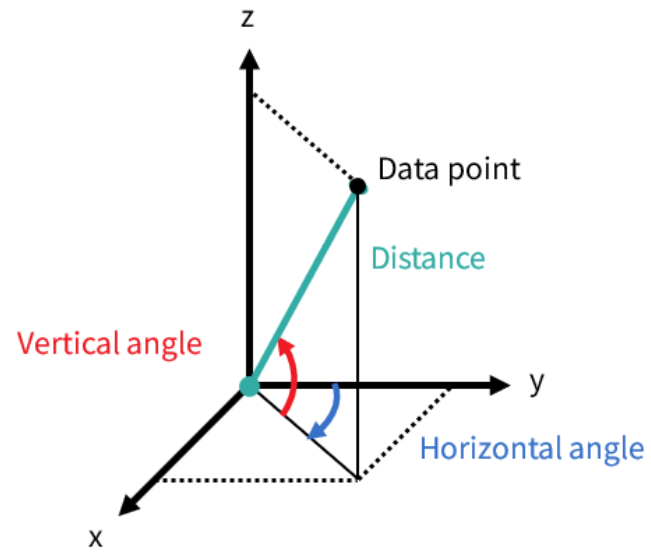
$$\textcircled{2} = \textcircled{5} \times \textcircled{6}$$

- 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 (0x2710, representing 10000) Destination port (0x277E, representing 10110) |
| UDP Length | 2 | 8 bytes more than GPS UDP data; see Figure 17. Data structure |
| 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 | - | | | | | | | | | | | | | | | |
| 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 GPS Mode in Section 4.2.3 Time sync).</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 37 30 38 35 37 30 34 30 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 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 | Device Log |
| 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

| | |
|---------------------------|--|
| GPS | GPS pulse-per-second (PPS) status <ul style="list-style-type: none"> • Lock: Lidar's internal clock is in sync with GPS PPS. • Unlock: Not in sync. |
| NMEA (GPRMC/GPGGA) | NMEA status <ul style="list-style-type: none"> • Lock: After receiving a valid NMEA message. • Unlock: Not receiving a valid NMEA message for over 2 seconds. |
| PTP | PTP status <ul style="list-style-type: none"> • Free Run: No PTP master is selected. • Tracking: Attempting to sync with the selected PTP Master, but the absolute offset exceeds the user-specified limit in Section 4.2.3 Time sync. • Locked: The absolute offset is within the user-specified limit. • 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. |
| P/N | Part Number <ul style="list-style-type: none"> • Cannot be changed. • Format: [Model]-[Configuration] • Lidar units with earlier firmware versions can be upgraded to display P/N. The default P/N is the Product Model (Pandara128E3X). |
| Customer P/N | Customer-Specified Part Number <ul style="list-style-type: none"> • Default: Empty and not displayed. • Format: 1 to 20 characters, digits or hyphen (-). |

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

| Reset All Settings | |
|-------------------------------------|--------------------|
| 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 |
| Save | |

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"> • Make sure the receiving host also supports VLAN; • Check the checkbox and input the lidar's VLAN ID (same as the receiving host's VLAN ID). <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"> • The receiving host shall be in Master mode. • Connect the lidar with or without a connection box. <p>Master mode:</p> <ul style="list-style-type: none"> • Connect the lidar to a Master host, select "Master" and click the [Save] button at the bottom of the Settings page. • Connection to web control will be lost. Then Connect the lidar to a Slave host. • Connection box is not supported. <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 Motor Speed field in Section 3.1.2.5 Tail). The set spin rate is also shown on the Home page (see Section 4.1 Home). |
| Return Mode | Single Return: <ul style="list-style-type: none"> • Last • Strongest • First Dual Return: <ul style="list-style-type: none"> • Last and Strongest (default) • Last and First • First and Strongest | Also shown in Point Cloud Data Packets (see the Return Mode field in Section 3.1.2.5 Tail). |

| Parameter | Options | Description | | | | |
|-----------------|---|--|-------------|---|------------|-----------------------------|
| Sync Angle | 0° to 359° Unit: ° | <p>Phase lock angle</p> <ul style="list-style-type: none"> To activate this function, check the checkbox and input an azimuth. At every full second, the lidar will rotate to that azimuthal position. <p> Lidar azimuthal position is defined in Section 1.2 Basic structure.</p> <p>Definition of the full second (detailed in Section B.1 Source of absolute time):</p> <ul style="list-style-type: none"> When GPS is locked, the full second is defined as the rising edge of the GPS PPS signal.  When PTP is tracking or locked, the full second is retrieved from the PTP master clock. When neither GPS nor PTP is locked, the full second is defined as the rising edge of the lidar's internal 1 Hz signal. <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 Definition of the Distance field . | | | | |
| Reflectivity Mapping | Linear Mapping (default) Nonlinear Mapping #1/#2 | <table border="1"> <tbody> <tr> <td>Linear Mapping</td> <td>The Reflectivity 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 Appendix C Nonlinear reflectivity mapping).</td> </tr> </tbody> </table> | Linear Mapping | The Reflectivity field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%). | Nonlinear Mapping | Increases the contrast in low-reflectivity areas (see Appendix C Nonlinear reflectivity mapping). |
| Linear Mapping | The Reflectivity field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%). | | | | | |
| Nonlinear Mapping | Increases the contrast in low-reflectivity areas (see Appendix C Nonlinear reflectivity mapping). | | | | | |
| 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"> • ambient temperature • horizontal resolution mode (see Section 4.4 High resolution) | | | | | | | | | | | | | | | |
| | | <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 | GPS |
| GPS Mode | GPRMC |
| GPS Destination Port | 10110 |

With PTP selected

| | |
|----------------------------|------------|
| Clock Source | PTP |
| 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 Section 3.2.2 GPS UDP data) |
| 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 μ s (integer) Default: 1 | Upper limit of the absolute offset between Slave and Master when the lidar is in PTP Locked status; see Section 4.1 Home . | | |
| PTP Network Transport | UDP/IP (default) L2 | Network transport protocol | | |
| | | <table border="1"> <tbody> <tr> <td>UDP/IP</td> <td>Available only for the 1588v2 profile</td> </tr> <tr> <td>L2</td> <td>Available for all profiles</td> </tr> </tbody> </table> | UDP/IP | Available only for the 1588v2 profile |
| 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 | |
| | | 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 ▼ |
| Save | |

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 |
| Save | | |

4.3.2. Multi-Section FOV

Input multiple (≤ 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 |
| Save | | |


4.4. High resolution


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

| | |
|-------------|-------------------|
| Mode | High Resolution ▼ |
| Save | |

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

| | |
|----------------|--|
| Upload | To upload the upgrade file This product model supports cybersecurity and only accepts encrypted and signed upgrade files. |
| Restart | Software reboot Afterward, the Start-Up Counts in the Operation Statistics page increments by 1; see Section 4.5 Operation statistics . |

| 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

| | |
|-----------------------|--|
| pandar_control | Lidar's control program |
| diag_ff | Functional safety diagnosis program |
| error | Exceptions that may affect the lidar's normal operation |
| warn | 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 ⓘ | |
| Save | |

Cyber security (master switch): ON

| | |
|--------------------------------|--|
| Cyber Security (Master Switch) | ON |
| Login Control | |
| Authentication | ON |
| Current Password | _____ Forgot Password? |
| New Password | _____ |
| Confirm New Password | _____ |
| Secure Connection | |
| PTC Connection | TLS |
| HTTP Connection | HTTPS |
| Point Cloud Signature | |
| Share Secret Key ⓘ | |
| Save | |

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 http:// 192.168.1.201 redirects to the Home page. | ON https:// 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 | ON (fixed) | 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"> • Default password: 123456 • To effectively implement login control, please change the default password and keep your new password securely. • Before returning a trial/loaner lidar or an RMA lidar to Hesai, please make sure to change the password back to default. |
| New password | - | <p>Format</p> <ul style="list-style-type: none"> • 8 to 30 characters • Containing at least one digit and one letter (case sensitive) • Special characters are allowed |
| Confirm new password | - | - |

If you forget the password:

| | |
|--|---|
| If TLS is selected for PTC Connection | <p>Users should reset the password:</p> <ol style="list-style-type: none"> 1. Click "Forgot password?" and it will redirect to the Reset Password page. 2. Obtain a reset code. 3. Contact technical support and provide the reset code to obtain a verification code. 4. Input the verification code in the Reset Password page and click the [Submit] button. |
| If mTLS is selected for PTC Connection | <p>Users are allowed to change the password (without providing the current password) by sending a PTCS command (see Section 5 Communication protocol).</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"> • Click the [Upload] button to upload a user CA certificate chain. • Before returning a trial/loaner lidar or an RMA lidar to Hesai, click the [Remove] button to remove the uploaded certificate. </td> </tr> </table> | 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"> • Click the [Upload] button to upload a user CA certificate chain. • Before returning a trial/loaner lidar or an RMA lidar to Hesai, click the [Remove] button to remove the uploaded certificate. |
| | | 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"> • Click the [Upload] button to upload a user CA certificate chain. • Before returning a trial/loaner lidar or an RMA lidar to Hesai, click the [Remove] button to remove the uploaded certificate. | | | | | |


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

4.9.3. Point cloud signature

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

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**].

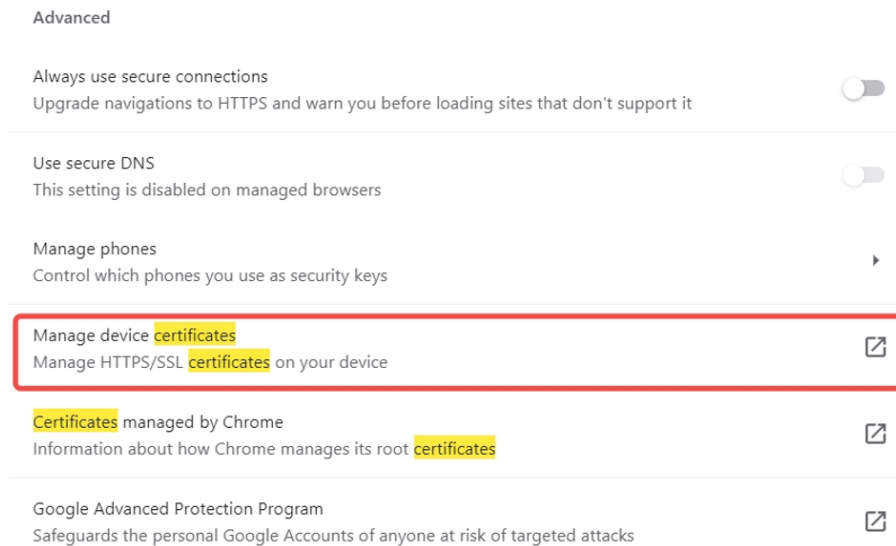


Figure 19. In Chrome

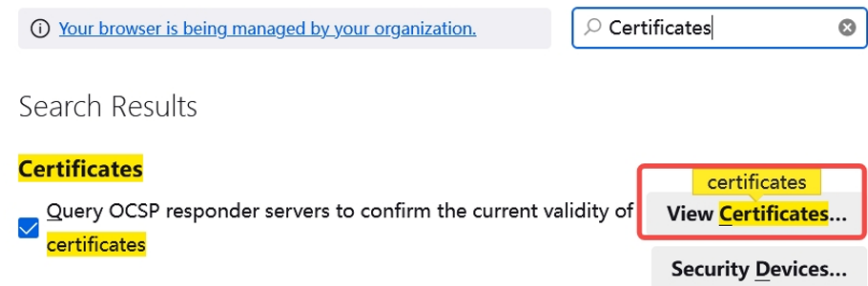


Figure 20. In Firefox

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.

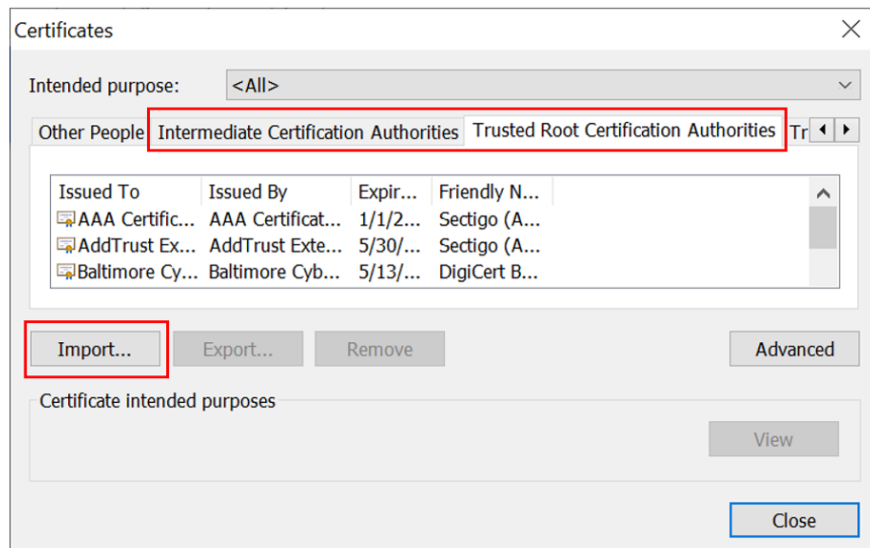


Figure 21. In Chrome

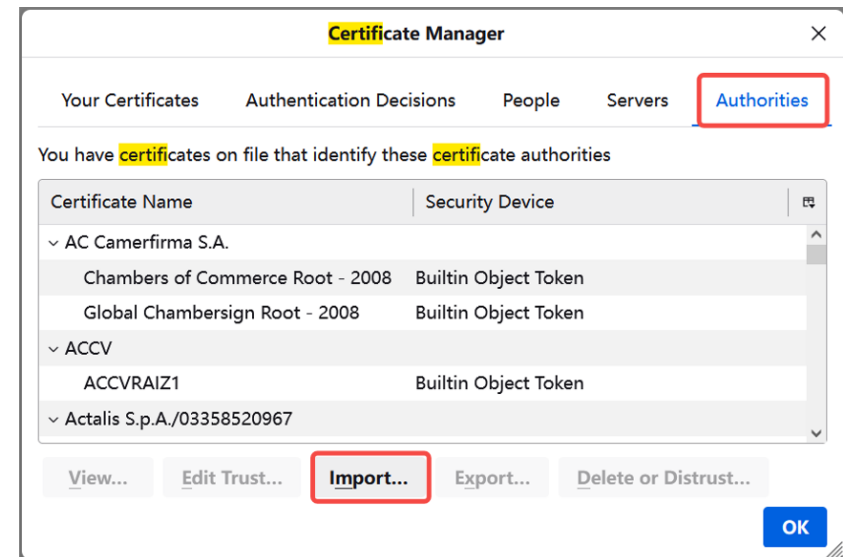


Figure 22. In Firefox

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

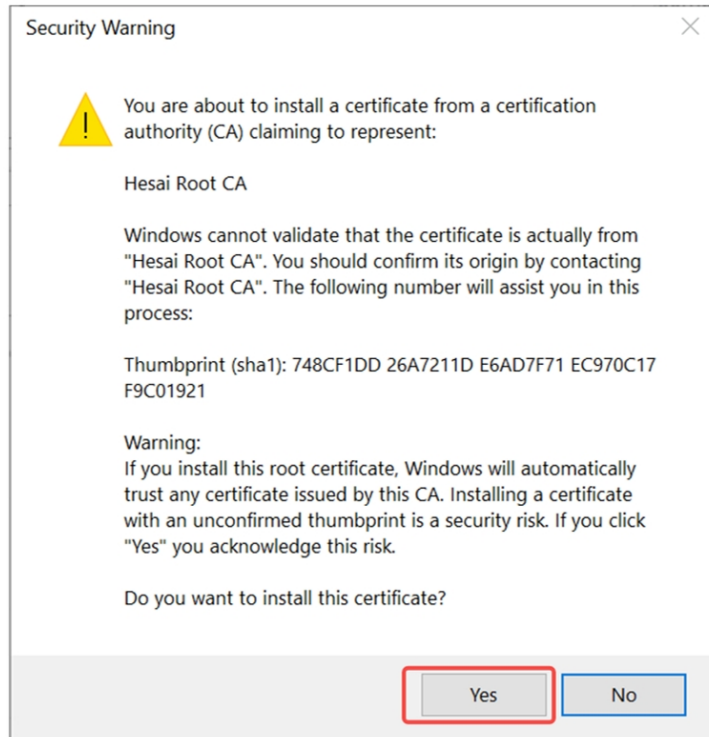


Figure 23. In Chrome

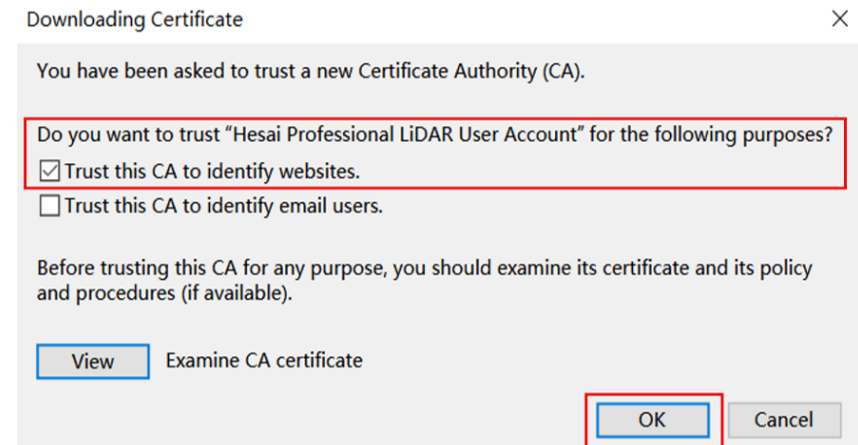


Figure 24. In Firefox

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

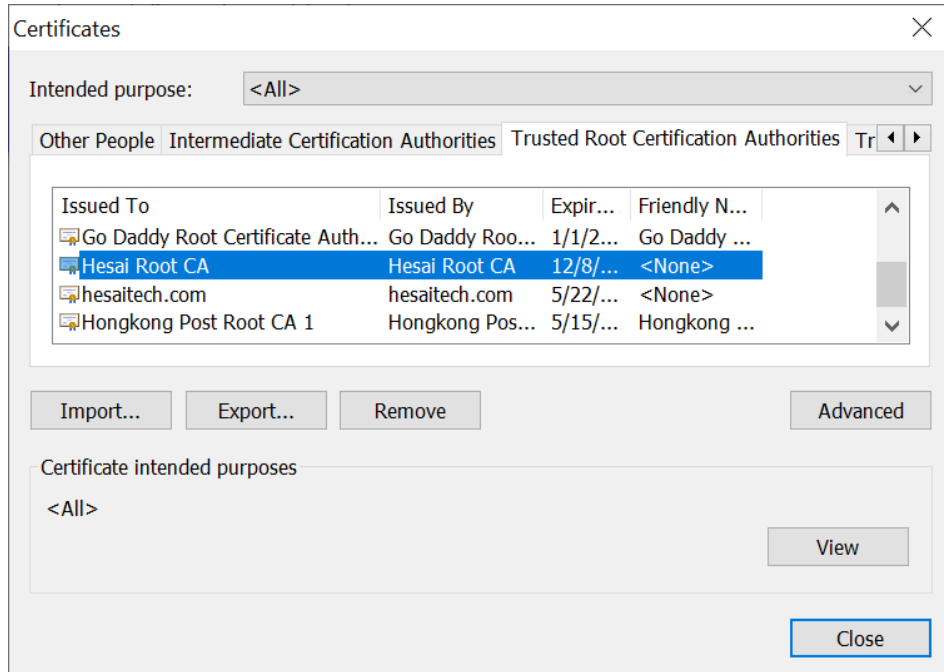


Figure 25. In Chrome

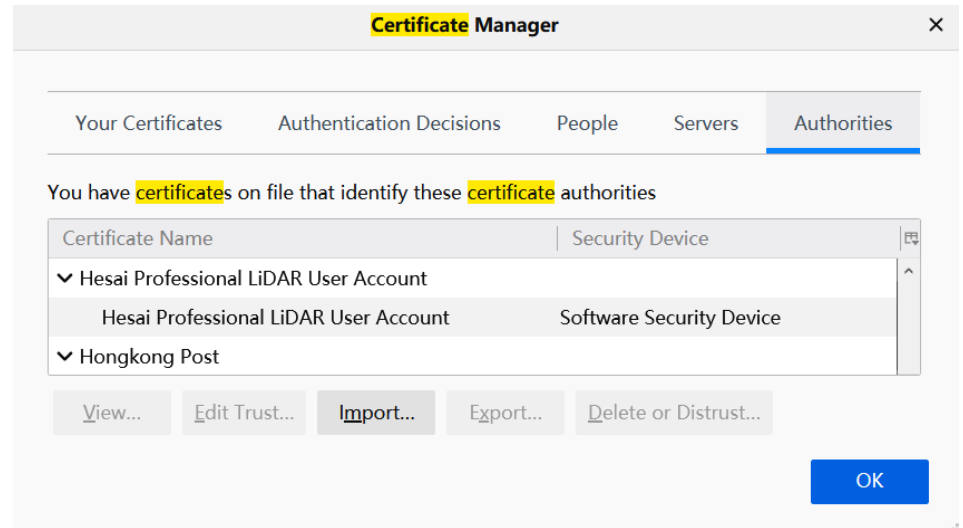
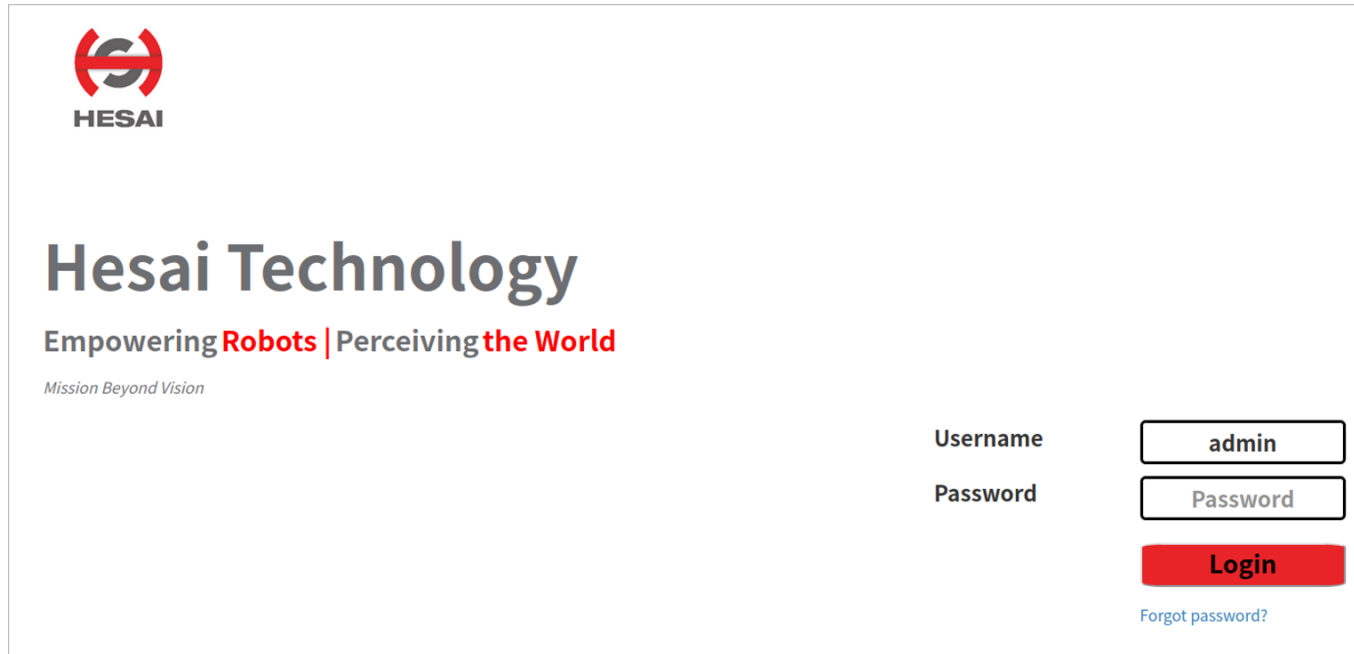


Figure 26. In Firefox

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: 123456 To effectively implement login control, please change the default password (see Section 4.9.1 Login control) 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.

With cybersecurity enabled, the encrypted **HTTPS (HTTP over TLS) API** and **PTCS (PTC over TLS) API** are also available:

- Data format: Same as the cleartext PTC/HTTP API.
- Requirements: TLS version should be 1.3 or above, with OpenSSL 1.1.1 or above.

 The sample code for using PTCS, HTTPS, and point cloud signature can be found at: https://github.com/HesaiTechnology/Cyber_Security

6. Maintenance

Stains on lidar's cover lens, such as dirt, fingerprints, and oil will negatively affect point cloud data quality. Please clean the cover lens in time.




- Turn OFF the power source before cleaning.
- To avoid damaging the optical coating, do NOT apply significant pressure when wiping the cover lens.



Only the stained area of the cover lens needs to be cleaned.

Perform the following steps to remove the stains:

1. Thoroughly wash your hands or wear a pair of powder-free PVC gloves. Hold the metal lid and base of the lidar to avoid touching the cover lens directly.
2. To remove dust, blow dry air onto the cover lens, or use a clean piece of lint-free wipe or soft sponge to lightly brush across the dusty area. If persistent stains exist, perform the following steps; otherwise, the cleaning is done.
3. Add warm, neutral solvent into a spray bottle and spray the cover lens.

| | |
|---------------------|--|
| Solvent type | Mild soap solution  Maximum two tablespoons of soap in 1 quart (1 liter) of water. |
| Solvent temperature | 20 to 25°C |

4. When the stains have loosened, dip a piece of lint-free wipe or soft sponge into the solvent made in Step 3, and gently wipe the cover lens back and forth along its surface.
5. Should another cleaning agent be applied to remove certain stains, repeat Steps 3 and 4.
6. Spray the cover lens with clean water, and gently wipe off the remaining liquid with another piece of lint-free wipe or soft sponge.

7. Troubleshooting

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

| Symptoms | Points to check |
|---|--|
| Indicator light is off on the connection box. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • The power adapter is properly connected and in good condition. • The connection box is intact. • The input voltage and current satisfy the requirements in Section 2.3 Connection box (optional). <p>Afterward, power on the lidar again and check if the symptom persists.</p> |
| Motor is not running. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • The power adapter is properly connected and in good condition. • The input voltage and current satisfy the requirements in Section 1.4 Specifications and Section 2.3 Connection box (optional). • Web control can be accessed (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. <p>Afterward, power on the lidar again and check if the symptom persists.</p> |
| Motor is running, but no output data is received, neither by Wireshark nor by PandarView 2. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • Ethernet cable is properly connected (by unplugging and plugging again). • Destination IP and Azimuth FOV are correctly set and Firmware of Sensor Version is correct; 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. <p>Afterward, power on the lidar again and check if the symptom persists.</p> |

| Symptoms | Points to check |
|---|--|
| Output data can be received by Wireshark but not by PandarView 2. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • 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 (please contact Hesai technical support to obtain it). <p>Afterward, power on the lidar again and check if the symptom persists.</p> |
| Web control cannot be accessed. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • 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. <p>Afterward, follow the steps below:</p> <ol style="list-style-type: none"> 1. Restart the PC or connect the lidar to another PC. 2. Power on the lidar again and check if the symptom persists. |

| Symptoms | Points to check |
|--|---|
| The number of data packets received is abnormal, indicating missing packets. | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none">• Azimuth FOV is properly set; this can be confirmed using either web control or PTC commands.• Spin Rate is steady; this can be confirmed using web control, PandarView 2 or PTC commands or by checking the Motor Speed field in the Point Cloud Data Packet.• The lidar's internal temperature is between -40°C and 110°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). <p>Afterward, follow the steps below:</p> <ol style="list-style-type: none">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. |

| Symptoms | Points to check |
|--|--|
| <p>The point cloud is abnormal, showing obviously misaligned points, flashing points, or incomplete FOV.</p> | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • 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 using web control, PandarView 2 or PTC commands or by checking the Motor Speed field in the Point Cloud Data Packet. • The lidar's internal temperature is between -40°C and 110°C; this can be confirmed using web control, PandarView 2 or PTC commands. <p>Afterward, check for packet loss.</p> <p>If no packet is lost yet the point cloud flashes, please follow the steps below:</p> <ol style="list-style-type: none"> 1. Update PandarView 2 to the latest version (please contact Hesai technical support to obtain it). 2. Restart the PC. <p>If the point cloud is still abnormal, follow the steps below:</p> <ol style="list-style-type: none"> 1. Connect the lidar to another PC and another network. 2. Power on again and check if the symptom persists. |
| <p>GPS cannot be locked.</p> | <p>Make sure that the following conditions are met:</p> <ul style="list-style-type: none"> • 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). <p>Afterward, power on the lidar again and check if the symptom persists.</p> |

Appendix A: Channel distribution data

Notes to the table

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

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](#))

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| 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% | - |

| 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 |

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| 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 |

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| 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 |

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| 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% | - |

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| 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% | - |

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| 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% | - |

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| 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 virtual UTC (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"> 1. Extract the date and time from the previous NMEA message. 2. Add 1 full second. |

| 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 the last synchronized time using the lidar's internal 1 Hz signal. This absolute time will gradually drift from the actual GPS time. |

| PPS status | μ 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

- Users can configure PTP using web control or PTC commands.
- Users can check PTP signal status 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 a virtual UTC (such as 2000-01-01 00:00:00) using the lidar's internal 1 Hz signal. |
| Tracking or Locked | Synchronized | The lidar extracts the actual date and time from the PTP Master's messages. |

| PTP status | Date and time (accurate to the microsecond) | Lidar behavior |
|------------|---|---|
| Frozen | Drifting | When the lidar goes from Tracking/Locked to Frozen, it starts counting from the last synchronized time 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 (μ s) in High Resolution mode | Start time (μ 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 (μ 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 ≤ 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 | - |

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| 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. | | | | | | | | | | | | |
| 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 |

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| 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 | - |

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| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

| 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 |
| Total firings | 96 | 8 | 96 | 8 | 96 | 8 | 96 | 8 | 128 | 16 | 128 | 16 |

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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

| 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 |
| Total firings | | 104 | 8 | Total firings | | 104 | 8 | Total firings | | 104 | 8 | Total firings | | 104 | 8 |

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 | - |

Pandar128E3X_v4p5

| 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 | - |

Pandar128E3X_v4p5

| 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 | - |

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| 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 | - |

| 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 |
| Total firings | | 144 | 16 | Total firings | | 144 | 16 | Total firings | | 144 | 16 | Total firings | | 144 | 16 |

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.

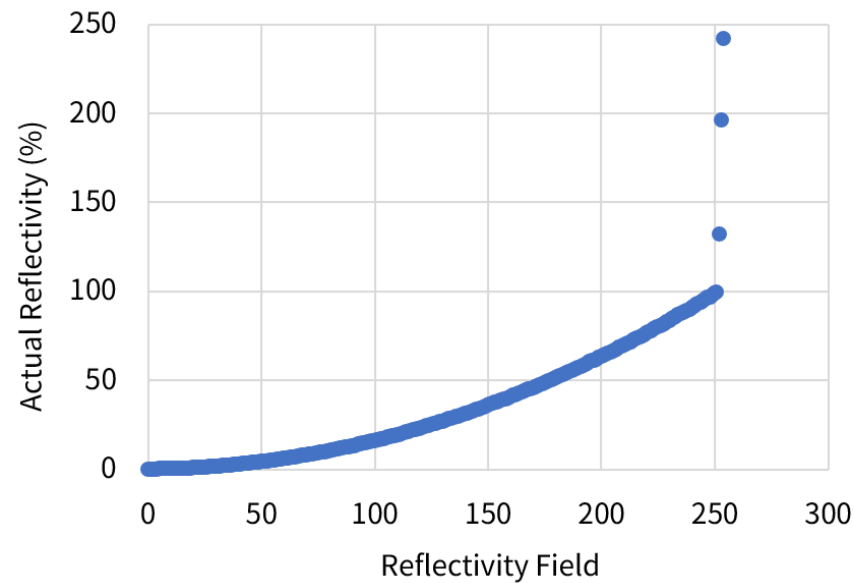


Figure 27. Nonlinear mapping 1#

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 |

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| Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % |
|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|
| 76 | 9.3 | 77 | 9.5 | 78 | 9.7 | 79 | 9.9 |
| 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 |

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| Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % |
|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|
| 156 | 38.75 | 157 | 39.17 | 158 | 39.5 | 159 | 39.83 |
| 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 |

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| Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % | Reflectivity field | Actual reflectivity % |
|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|--------------------|-----------------------|
| 236 | 87.75 | 237 | 88.5 | 238 | 89.25 | 239 | 89.75 |
| 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.

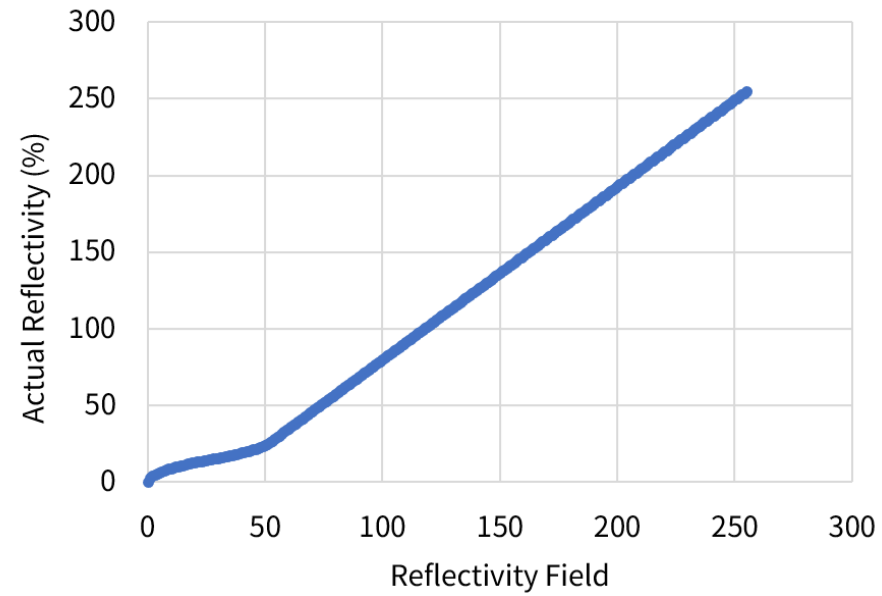


Figure 28. Nonlinear mapping 2#

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 |

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| 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 |

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| 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 |

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| 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 |

Appendix D: Legal notice

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