HESAI

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Pandar128E3X

128-Channel Mechanical Lidar User Manual

HESAI Wechat

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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:

- Visit the Download page of Hesai's official website: https://www.hesaitech.com/downloads/
- Or contact your sales representative at Hesai
- Or contact Hesai's technical support team: 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 (Please leave your questions under the corresponding GitHub projects.)

■ Legends

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

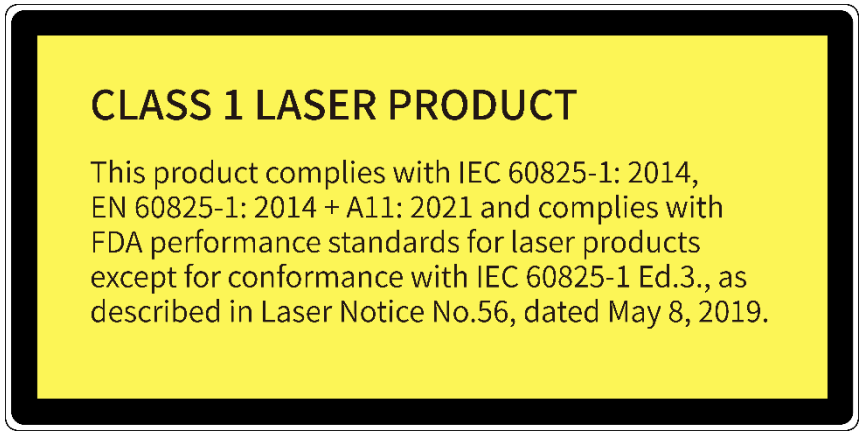
Notes: additional information that may be helpful.

Safety Notice

- Please check the certification information on the product's nameplate and read through the corresponding certification warnings. If specific users require not to present certification information on the nameplate, please follow the agreed-to arrangements.
- If you incorporate this lidar product into your product(s), you are required to provide this user manual (or the means to access 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 parts.

Abnormalities

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

- You suspect that the product malfunctions or is damaged. For example, the product produces significant noise or is visibly vibrating.
- You or other people in the nearby environment feel discomfort.
- Any device or equipment in the nearby environment malfunctions.

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

Prohibition of Disassembly

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

■ Operating Environment

Radio Frequency Interference

- Please check the certification information on the product's nameplate and read through the corresponding certification warnings. If specific users require not to present 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 may exist in the product's operating environment, please contact Hesai's technical support team to obtain the shock and vibration limits of this 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 high concentrations of flammable chemicals, vapors, or particulates (including particles, dust, and metal powder) in the air.
- Do NOT expose the product to high concentrations of industrial chemicals, including liquefied gases that are easily vaporized (such as helium). Such exposure can damage or weaken the product's function.

Ingress Protection

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

Operating Temperature

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

Recommended Storage Conditions

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

Light Interference

Certain precision optical instruments may be interfered by the laser light emitted from the product. Please check all the instructions of these instruments and take preventive measures if necessary. For example, certain product models are equipped with protective covers, which can be used to block laser light emission when the product is temporarily not used for measurement.

■ 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 other people in the nearby environment wear medical devices (such as cochlear implants, heart pacemakers, and defibrillators), make sure to consult the physicians and medical device manufacturers for medical advice, such as determining whether it is safe to work near the product.
- If you suspect that the product is interfering with your medical device, stop using the product immediately.

■ Installation and Operation

Power Supply

- You are recommended to use only the cables and power adapters provided by Hesai Technology.
- 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 the *Specifications* section and the *Power Supply Requirements* section); for technical support, please contact Hesai Technology. Do NOT use off-spec or damaged cables or adapters.

Electrical Interface

- Before powering on the product, make sure the electrical interfaces are dry and clean. Do NOT power on the product in a humid environment.
- Please check the *Interfaces* section in the product's user manual 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.
- To prevent breakdown, turn off the power source before connection and disconnection.

Eye Safety

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

- IEC/EN 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.

Please follow the standard laser safety guidelines accordingly.

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

For maximum self-protection, it is strongly warned NOT to 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 / optical window can be regarded as the product's laser emitting window; looking at the cover lens / optical window can be regarded as looking into transmitting laser.

Product Enclosure

- The product contains metal, glass, plastic, as well as sensitive electronic components. In case the product has been dropped and 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.
- Before operating the product, make sure it is properly and securely mounted. The mounting should prevent the product from leaving its mounting position in case of external forces (such as collisions, high winds, and stone impacts).
- 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.

Product Enclosure: Cover lens / optical window

- Do NOT apply protective film, wax or any other substance on the cover lens / optical window.
- To keep the product's cover lens / optical window from fingerprints and other stains, do NOT touch the cover lens / optical window with bare hands. If the cover lens / optical window is already stained, please refer to the cleaning method in the *Sensor Maintenance* section of the user manual.
- To prevent scratches, do NOT touch the product's cover lens / optical window with hard or sharp objects. If scratches already exist, stop using the product and contact Hesai technical support. Severe scratches may affect the quality of the product's point cloud data.
- Before installing any exterior part, please ensure that each exterior part and its movable area do not overlap the detection blind zone of lidar product. For questions on determining the detection blind zone, contact Hesai technical support.

Hot Surface

During operation or a time period after 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, do NOT touch the product's enclosure with flammable materials.

Certain product models support active heating of the cover lens / optical window to reduce the impact of ice and frost. Users can turn off this function.

- While active heating is ON, please avoid direct skin contact with the cover lens / optical window.
- For the location of the cover lens, please refer to the Introduction section in the product's user manual.

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, and cleaning equipment. Please refer to all relevant specifications in the product's user manual, or contact Hesai technical support. Using off-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 Technology. Make sure to observe all the instructions provided for that upgrade file.

Custom Firmware and Software

- Before using a custom version of firmware and software, please thoroughly understand the differences in functions and in performance between this custom version and the standard version.
- Make sure to strictly follow all the instructions and safety precautions provided for that custom 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 features, include but are not limited to: Noise Filtering, Interstitial Points Filtering, Retro Multi-Reflection Filtering, and Non-Linear Reflectivity Mapping.

These features 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 features. Moreover, users are responsible for analyzing the product's intended application scenarios and evaluating the risk of enabling one or more of these features in combination.

The supported features for this product model can be found on web control.

■ Repair and Maintenance

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

Repair

Unless expressly agreed to in writing by Hesai Technology, do NOT by yourself or entrust any third party to disassemble, repair, modify, or retrofit the product. Such a breach:

- can result in product damage (including but not limited to water resistance failure), property loss, and/or personal injuries;
- shall constitute a breach of warranty.

1 Introduction

This manual describes the specifications, installation, and data format of Pandar128E3X.

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

Figure 1.1 Distance Measurement Using Time of Flight

1.2 Lidar Structure

The basic structure is shown in Figure 1.2. Multiple pairs of laser emitters and receivers are attached to a motor that rotates horizontally.

Figure 1.2 Partial Cross-Sectional Diagram

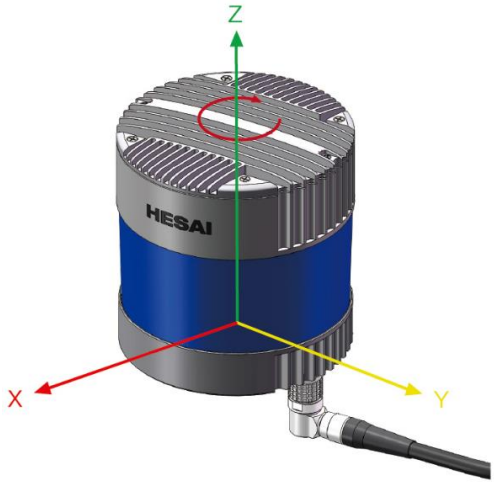


Figure 1.3 Coordinate System (Isometric View)

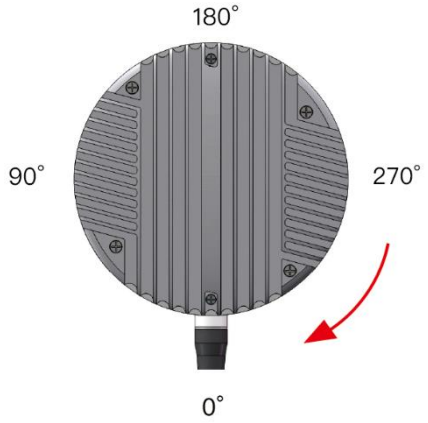


Figure 1.4 Default Rotation Direction (Top View)

The lidar's coordinate system is illustrated in Figure 1.3. Z-axis is the axis of rotation.
By default, the lidar rotates clockwise in the top view. To select counterclockwise rotation, see Section 4.2 (Web Control - Settings).
The origin's exact position is shown in Figure 1.6, as a red dot. All measurements are relative to the origin.

Lidar azimuthal position is defined in Figure 1.4. 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 field in the corresponding data block in the Point Cloud Data Packet will be 90°.

1.3 Channel Distribution

The vertical resolution is

- 0.125° from Channel 26 to Channel 90
- 0.5° from Channel 2 to Channel 26, as well as from Channel 90 to Channel 127
- 1° between Channel 1 and Channel 2, as well as between Channel 127 and Channel 128
- detailed in Appendix I (Channel Distribution)

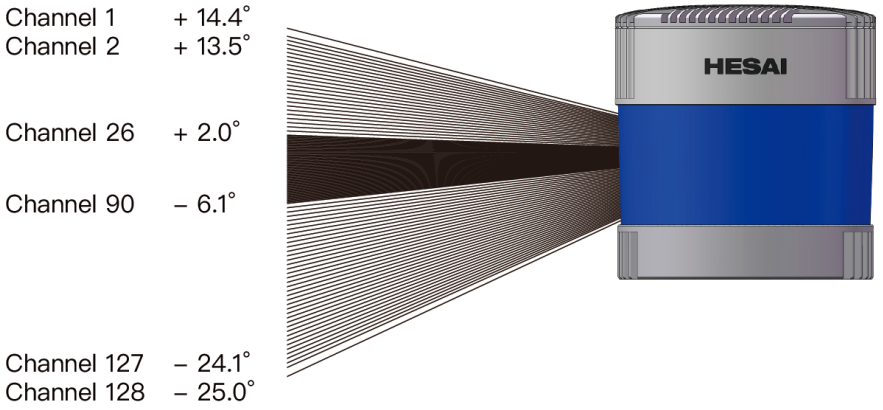


Figure 1.5 Channel Vertical Distribution

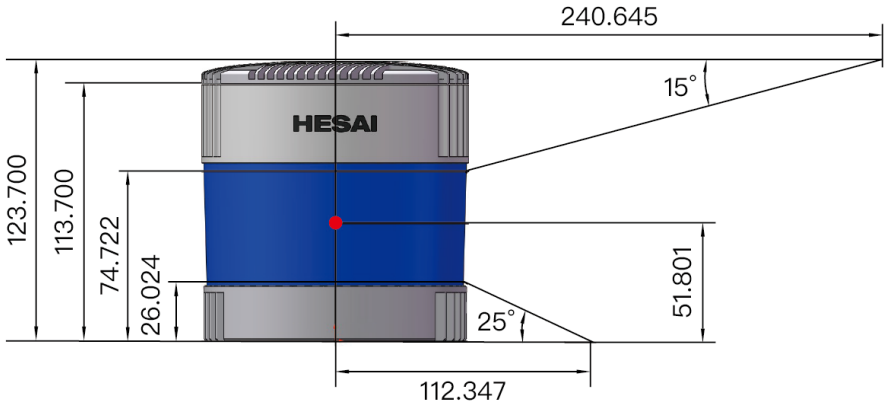


Figure 1.6 Laser Firing Position (Unit: mm)

Each channel has an intrinsic angle offset, both horizontally and vertically.

The offsetted angles are recorded in this lidar unit's angle correction file, which is provided when shipping the unit.

In case you need to obtain the file again:

- send PTC command 0x05, as described in Hesai TCP API Protocol (Section 5);
- or export the file using PandarView 2 (see the PandarView 2 user manual).

1.4 Specifications

SENSOR		
Scanning Method	Mechanical Rotation	
Channel	128	
Range Capability ①③	0.3 to 200 m (at 10% reflectivity)	
Range 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)
FOV (Horizontal)	360°	
Resolution (Horizontal) ③	Configurable on-the-fly	
	0.1°/0.2°	(10 Hz)
	0.2°/0.4°	(20 Hz)
FOV (Vertical)	40°	(-25° to +15°)
Resolution (Vertical)	0.125°	(-6° to +2°)
	0.5°	(+2° to +14°, -6° to -24°)
	1°	(+14° to +15°, -24° to -25°)
Frame Rate	10 Hz, 20 Hz	
Return Modes	Single Return (Last/Strongest/First)	
	Dual Return (Last & Strongest)	
	Dual Return (Last & First)	
	Dual Return (First & Strongest)	

Specifications are subject to change. Please refer to the latest version. (Continued on the next page)

MECHANICAL/ELECTRICAL/OPERATIONAL		
Wavelength	905 nm	
Laser Class	Class 1 Eye Safe	
Ingress Protection	IP6K7 & IP6K9K	
Dimensions	Height:	123.7 mm
	Top/Bottom:	Φ118.0 / 116.0 mm
Rated Voltage Range	DC 9 to 48 V	
Power Consumption ④	27 W / 23 W	
	(at 10 Hz，high-res/standard mode)	
Operating Temperature	-40°C to 85°C	
Storage Temperature	-40°C to 95°C	
Weight	1.63 kg	

DATA I/O		
Data Transmission	1000Base-T or Automotive 1000Base-T1	
	Slave Mode by default	
Measurements	Distance, Azimuth Angle, Intensity	
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:	134.64 Mbps (max)
	Dual Return:	269.28 Mbps (max)
Clock Source	GPS / PTP	
PTP Clock Accuracy	⩽1 μs	
PTP Clock Drift ⑤	⩽1 μs/s	

(Continued)

① Range Capability
- Measured under 100 klux ambient illuminance.

② Range Accuracy
- May vary with range, temperature, and target reflectivity.

③ The range capability and horizontal resolution of each channel is shown in Appendix I (Channel Distribution).

④ Power Consumption
- Not including accessories such as the connection box.
- The external power supply should be able to provide at least 27 W.
- See Section 4.4 for details.

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

2.1 Mechanical Installation

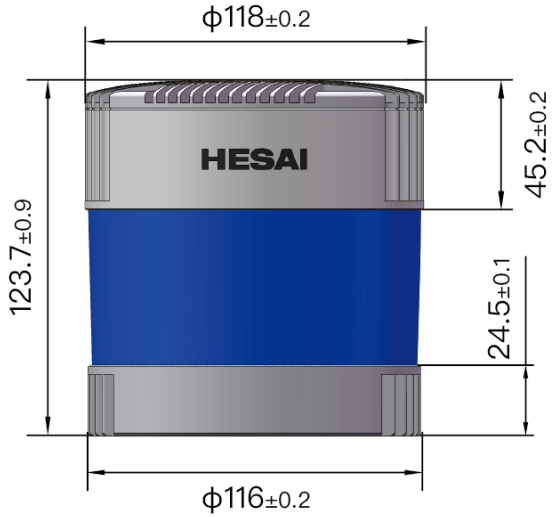


Figure 2.1 Front View (Unit: mm)

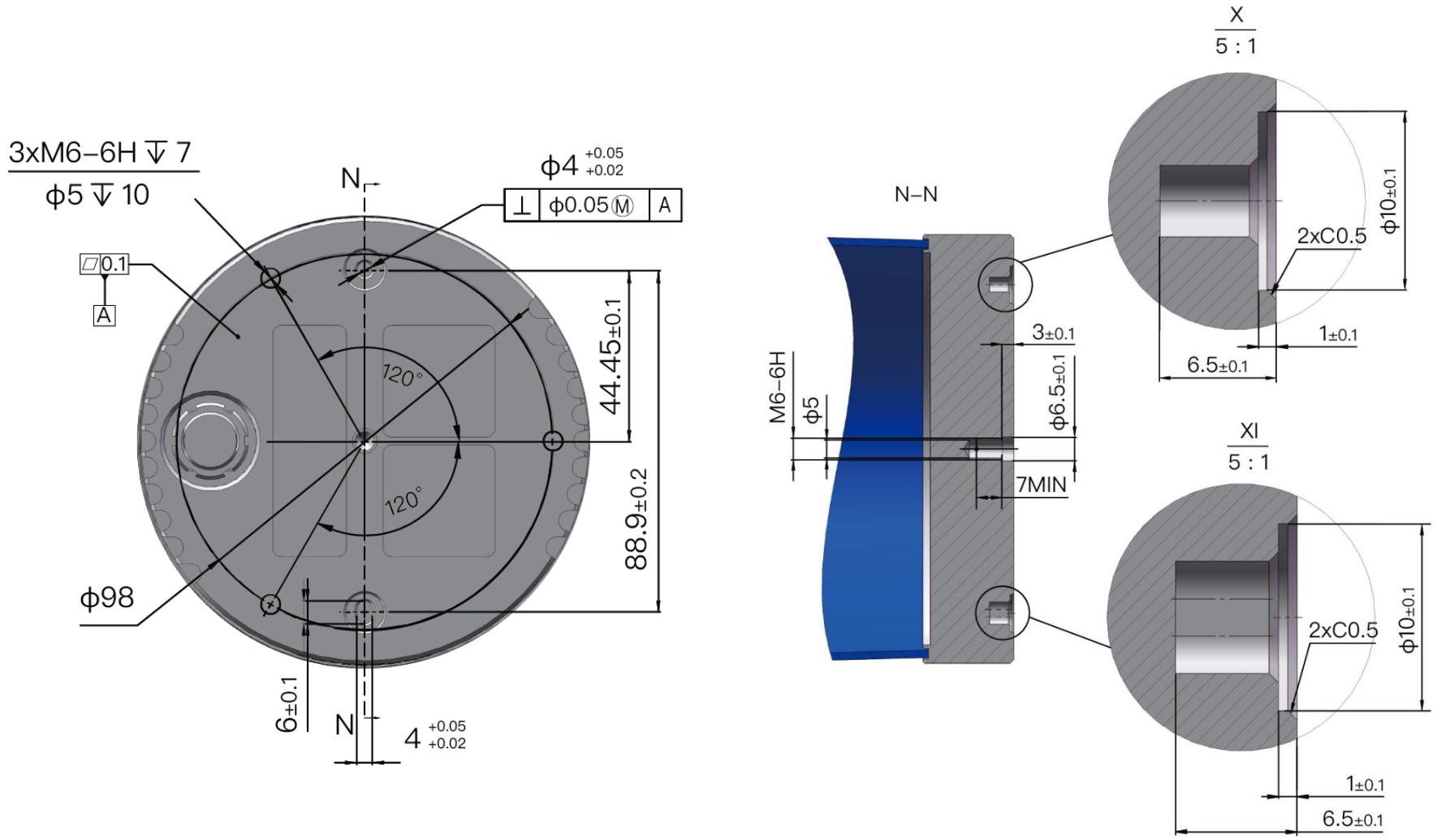


Figure 2.2 Bottom View (Unit: mm)

2.1.1 Quick Installation

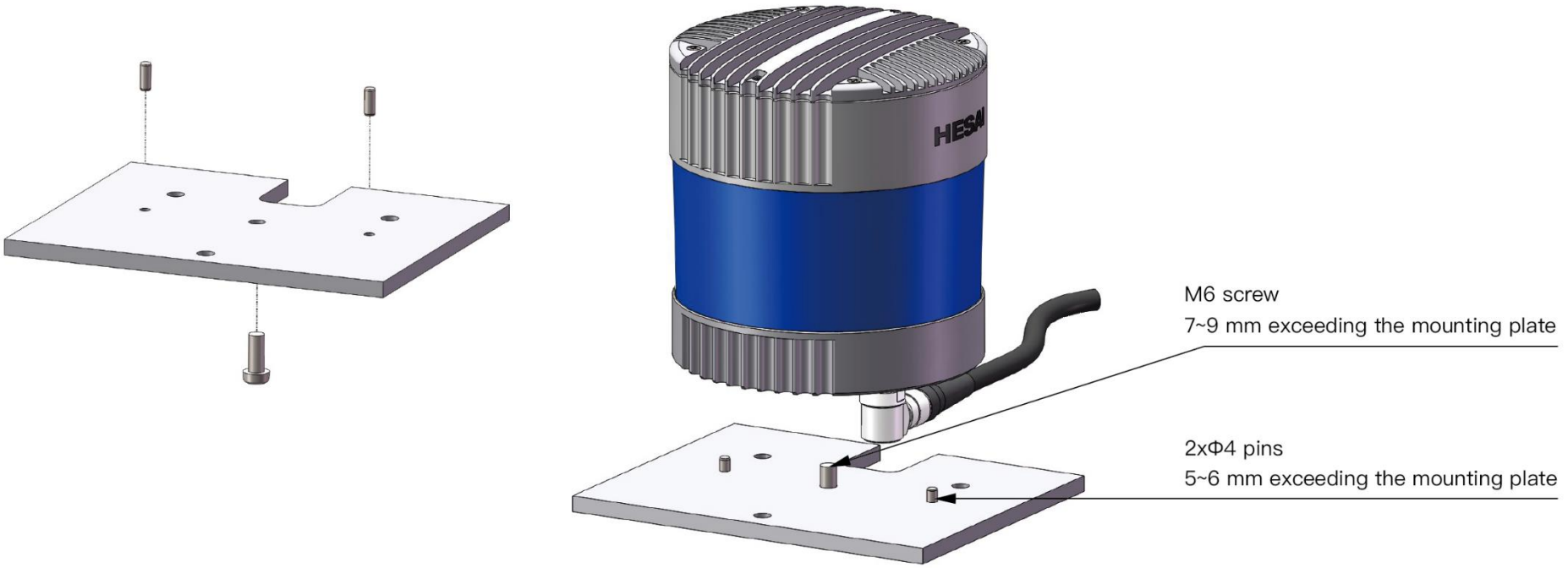


Figure 2.3 Quick Installation

2.1.2 Stable Installation

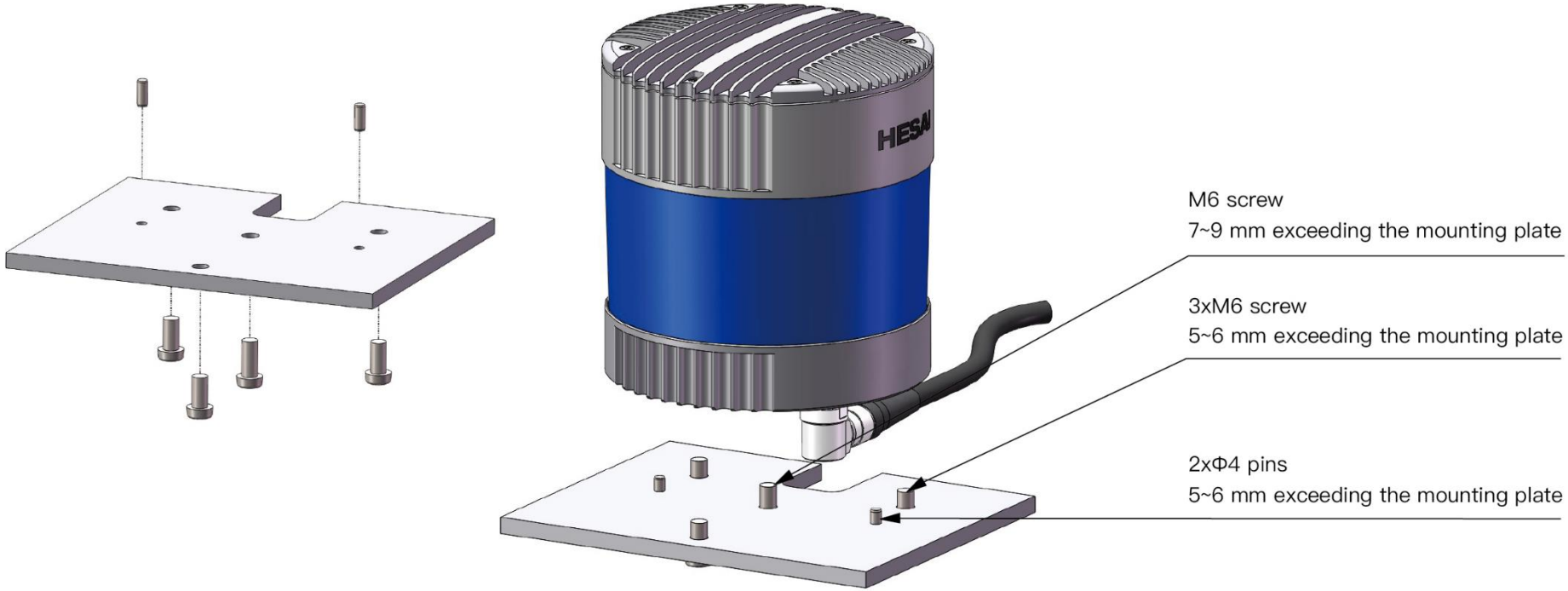


Figure 2.4 Stable Installation

2.1.3 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 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
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 Interfaces

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

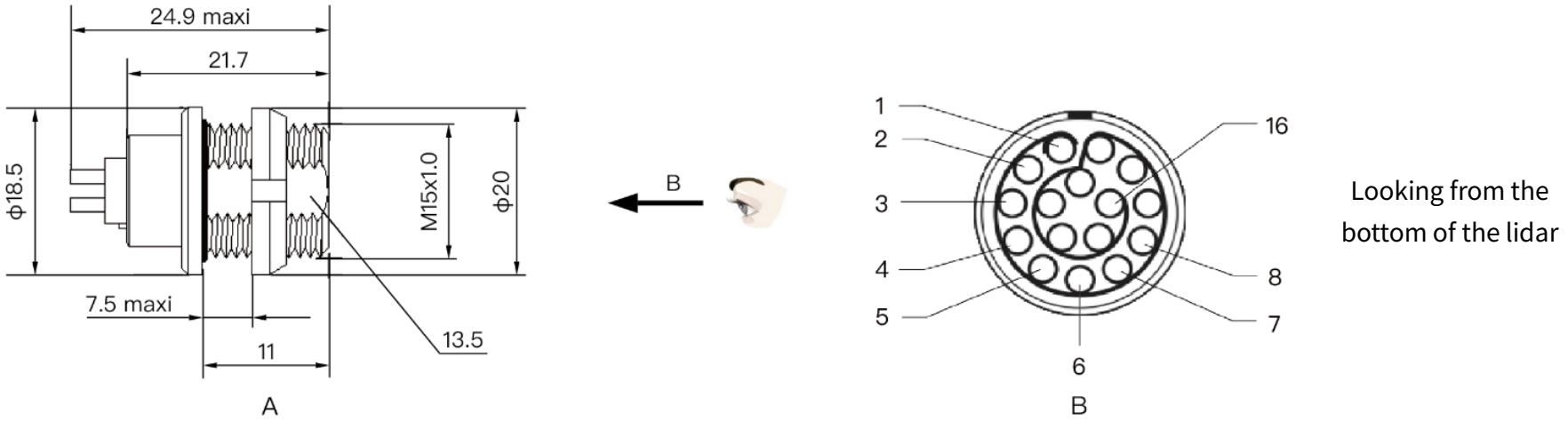


Figure 2.5 Lemo Connector (Female Socket)

2.2.1 Pin Description

■ 1000Base-T

No.	Signal	Voltage
1	Ground (Return)	0 V
2	Ground (Return)	0 V
3	Ethernet BI_DC-	-1 to 1 V
4	Ethernet BI_DC+	-1 to 1 V
5	Ethernet BI_DB-	-1 to 1 V
6	Ethernet BI_DB+	-1 to 1 V
7	Ethernet BI_DA-	-1 to 1 V
8	Ethernet BI_DA+	-1 to 1 V

No.	Signal	Voltage
9	GPS Serial Data	-13 to +13 V
10	Power	9 to 48 V
11	Power	9 to 48 V
12	GPS PPS	3.3 / 5 V
13	Ethernet BI_DD-	-1 to 1 V
14	Ethernet BI_DD+	-1 to 1 V
15	Index	0 to 3.3 V
16	Encoder	0 to 3.3 V

■ Automotive 1000Base-T1

No.	Signal	Voltage
1	Ground (Return)	0 V
2	Ground (Return)	0 V
3	Ethernet_Data-	-1 to 1 V
4	Ethernet_Data+	-1 to 1 V
5	-	-
6	-	-
7	-	-
8	-	-

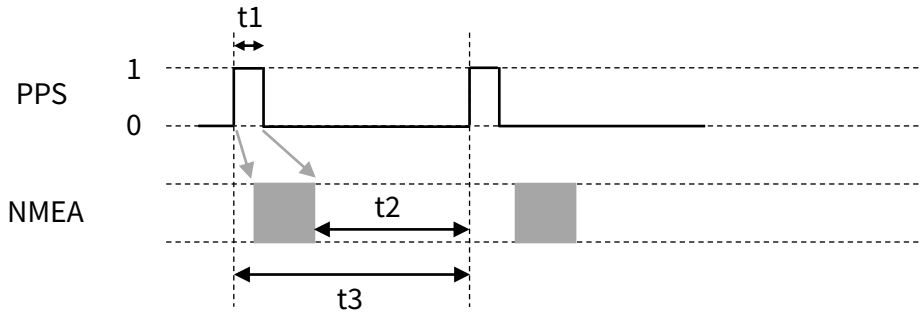
No.	Signal	Voltage
9	GPS Serial Data	-13 to +13 V
10	Power	9 to 48 V
11	Power	9 to 48 V
12	GPS PPS	3.3 / 5 V
13	-	-
14	-	-
15	Index	0 to 3.3 V
16	Encoder	0 to 3.3 V

For the GPS PPS signal, pulse width is recommended to be over 1 ms, and the cycle is 1 s (rising edge to rising edge)

⚠ 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
- avoid touching the GPS wire or GPS port with bare hands

💡 The timing requirements of GPS PPS and GPS Serial Data (NMEA) are shown below:



PPS cycle	t3 = 1 s ±50 μs (rising edge to rising edge)
PPS pulse width	t1 ⩾ 1 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 figure above. NMEA signal ends before the PPS rising edge of the next second; t2 ⩾ 100 ms.

2.2.2 Connector Use

Connection	Disconnection
• Turn off the power source • Align the red dots on the connector shells • Push the plug straight into the socket	• Turn off the power source • Pull the release sleeve on the male connector to its outermost position and hold there • Pull the plug from the socket

Warnings

• DO NOT attempt to force open a connection by pulling on the cables or the shells, or by twisting the connectors in any way. Doing so can loosen the connectors' shells, or even damage the contacts.

• In case a 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.

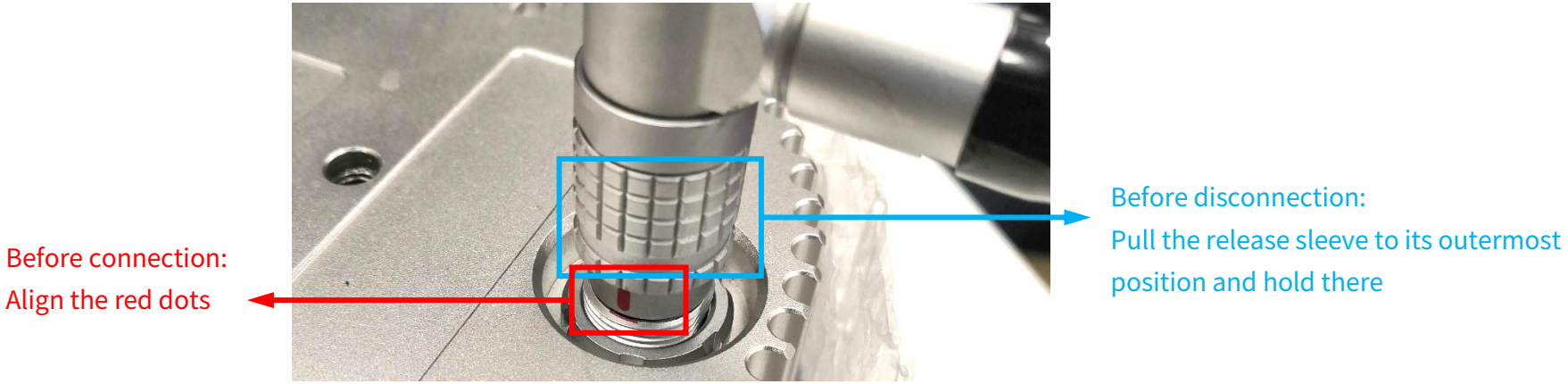


Figure 2.6 Lemo Connection/Disconnection

2.2.3 Cables

OD (outside diameter) = 7.70±0.30 mm

Minimum bend radius: 5 * OD

2.3 Connection Box (Optional)

Users may connect the lidar directly or using the connection box.

The connection box has a power port, a GPS port, and a standard Ethernet port.

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

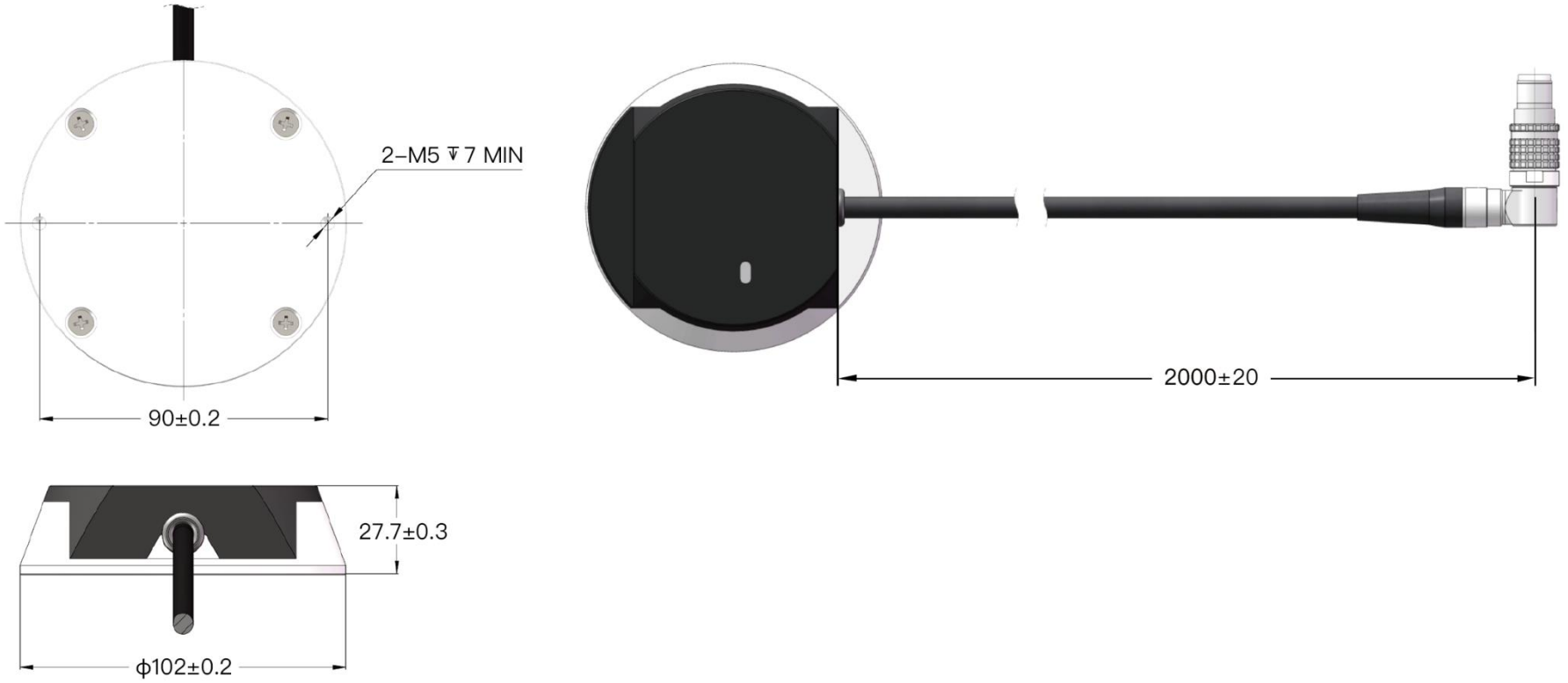


Figure 2.7 Connection Box (Unit: mm)

■ 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

No.	Signal	Voltage	Wire Color
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	-	-	
6	-	-	
7	-	-	
8	-	-	

No.	Signal	Voltage	Wire Color
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	-	-	
14	-	-	
15	Index	0 to 3.3 V	Gray
16	Encoder	0 to 3.3 V	Gray/White

2.3.1 Connection Box Interfaces

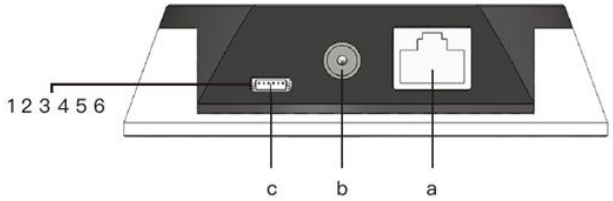


Figure 2.8 Connection Box (Front)

Port #	Port Name	Description
a	Standard Ethernet Port	RJ45, 1000 Mbps Ethernet
b	Power Port	Connects to a DC-005 DC power adapter. External power supply: 9 to 48 V, 27 W
c	GPS Port	Connector part number: JST, SM06B-SRSS-TB Recommended connector for the external GPS module: JST, SHR-06V-S-B Voltage standard: RS232 Baud rate: 9600 bps

The GPS port pin numbers are 1 to 6 from left to right, defined as follows:

Pin #	Direction	Pin Description	Requirements
1	Input	PPS (pulse-per-second) signal for synchronization	TTL level 3.3/5 V Recommended pulse width: ⩾1 ms Cycle: 1 s (from rising edge to rising edge)
2	Output	Power for the external GPS module	5 V
3	Output	Ground for the external GPS module	-
4	Input	Receiving serial data from the external GPS module	RS232 level
5	Output	Ground for the external GPS module	-
6	-	Reserved	-

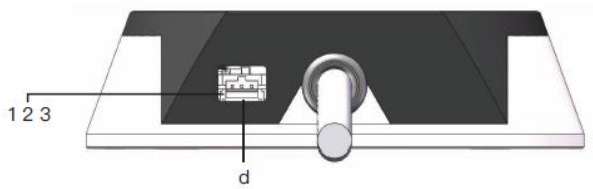


Figure 2.9 Connecting Box (Back)

Port #	Port Name	Description
d	Trigger Port	Outputs external trigger signals for multi-sensor synchronization. Connector (plug): Molex, LLC 5023520300 Recommended wire connector (plug): Molex, LLC 5023510300 Voltage: 0 to 3.3 V Signal type: pulse Max. current output level: 12 mA

Pin Description for the trigger port:

Pin #	Direction	Pin Description
1	Input	GND, to ground the external trigger signal
2	Output-Encoder	Trigger signal: outputs one pulse when the lidar rotates 0.05° Pulse width: 8.31 μs @ 600 RPM, 4.17 μs @ 1200 RPM
3	Output-Index	Trigger signal: outputs one pulse when Channel 42 passes the lidar's 180° position (see Figure 1.4) Pulse width: 2.87 μs @ 600 RPM, 1.44 μs @ 1200 RPM

2.3.2 Connection

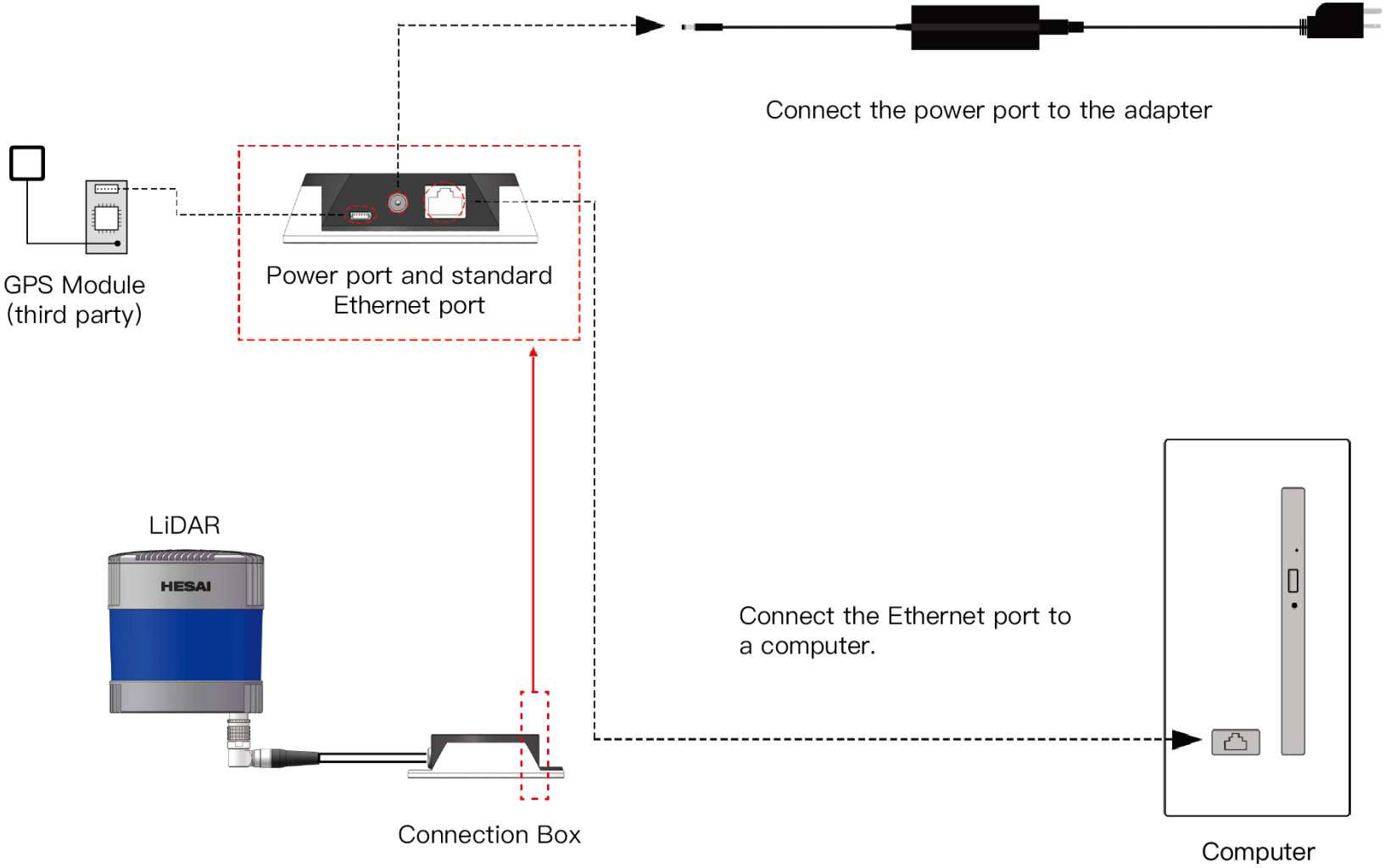


Figure 2.10 Connection with GPS

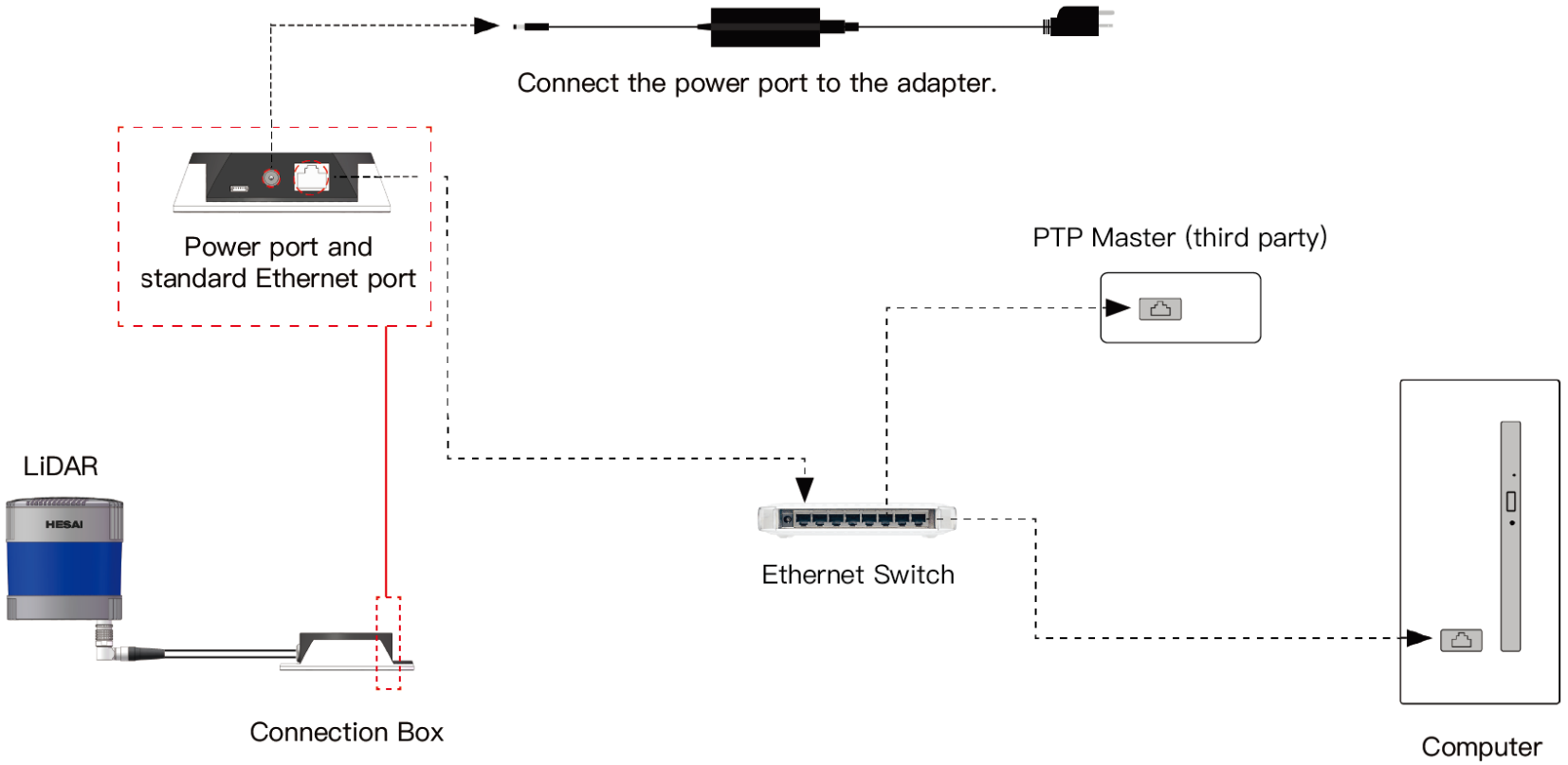


Figure 2.11 Connection with PTP

2.4 Get Ready to Use

Before operating the lidar, strip away the protective cover outside the cover lens.

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 192.168.1.100 and subnet mask to 255.255.255.0

For Ubuntu:	For Windows:
Input this ifconfig command in the terminal: ~$ sudo ifconfig enp0s20f0u2 192.168.1.100 (replace enp0s20f0u2 with the local Ethernet port name)	Open the Network Sharing Center, click on "Ethernet" In the "Ethernet Status" box, click on "Properties" Double-click on "Internet Protocol Version 4 (TCP/IPv4)" Configure the IP address to 192.168.1.100 and subnet mask to 255.255.255.0

To record and display point cloud data (see PandarView 2 User Manual).

To set parameters, check device info, or upgrade firmware/software (see Section 4 Web Control)

To obtain the SDKs (Software Development Kits) for your product model,

- please find the download link at: www.hesaitech.com/en/download (Product Documentation → select product model)
- or visit Hesai's official GitHub page: https://github.com/HesaiTechnology

3 Data Structure

The lidar outputs two types of UDP packets: Point Cloud Data Packets and GPS Data Packets.
Unless otherwise specified, all the multi-byte fields are unsigned values in little endian format.

The Cyber Security field (32 bytes) in Point Cloud UDP Data is present only when point cloud signature is enabled.

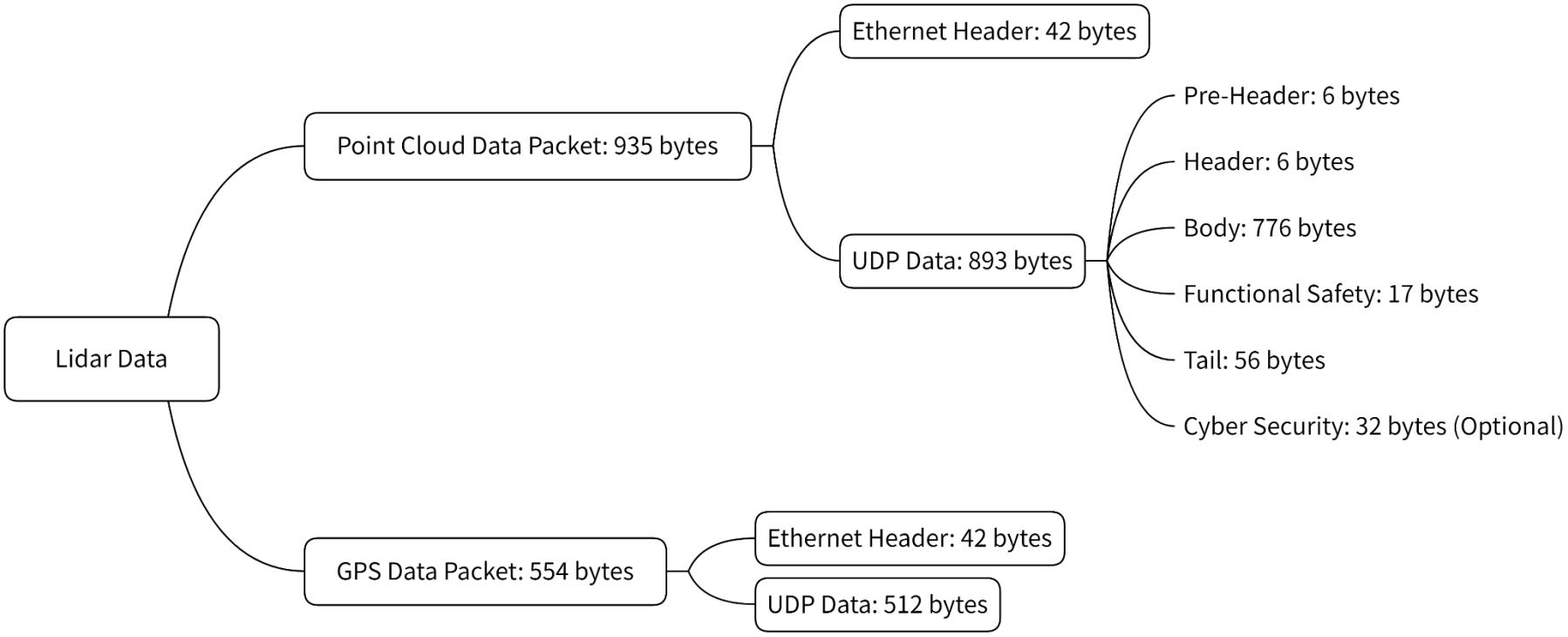


Figure 3.1 Data Structure

3.1 Point Cloud Data Packet

3.1.1 Ethernet Header

Each lidar has a unique MAC address. The source IP is 192.168.1.201 by default, and the destination IP is 255.255.255.255 (broadcast).

Point Cloud Ethernet Header: 42 bytes		
Field	Bytes	Description
Ethernet II MAC	12	Destination: broadcast (0xFF: 0xFF: 0xFF: 0xFF: 0xFF: 0xFF) Source: (xx:xx:xx:xx:xx:xx)
Ethernet Data Packet Type	2	0x08, 0x00
Internet Protocol	20	Shown in the figure below
UDP Port Number	4	UDP source port (0x2710, representing 10000) Destination port (0x0940, representing 2368)
UDP Length	2	8 bytes more than the size of the Point Cloud UDP Data
UDP Checksum	2	Shown in the figure below

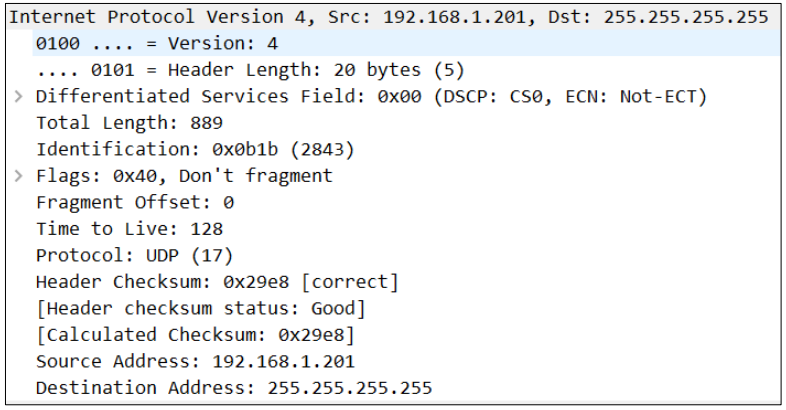


Figure 3.2 Point Cloud Ethernet Header - Internet Protocol

3.1.2 UDP Data

■ **Pre-Header: 6 bytes**

Field	Bytes	Description
0xEE	1	SOP (start of packet)
0xFF	1	SOP (start of packet)
Protocol Version Major	1	Main class of the point cloud UDP packet structure Currently 0x01
Protocol Version Minor	1	Subclass of the point cloud UDP packet structure Currently 0x04
Reserved	2	-

■ **Header: 6 bytes**

Field	Bytes	Description
Laser Num	1	0x80 (128 channels)
Block Num	1	0x02 (2 blocks per packet)
First Block Return	1	Reserved
Dis Unit	1	0x04 (4 mm)
Return Num	1	0x02 (each channel can generate two returns maximum)
Flags	1	[7:4] is reserved [3:0] shows whether this data packet contains the following information [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

■ **Body: 776 bytes (2 blocks)**

Field	Bytes	Description
Azimuth 1	2	For Block 1: current reference angle of the rotor Unit: 0.01°
Block 1	384	For Block 1: measurements made by each channel, starting form Channel 1 See table below
Azimuth 2	2	For Block 2
Block 2	384	
CRC 1	4	CRC-32/MPEG-2 checksum of the Body For more on the CRC-32/MPEG-2 computation algorithm, refer to: https://www.mathworks.com/matlabcentral/fileexchange/72226-crc-32-mpeg-2-computation-algorithm

Each Block in the Body: 3 * 128 = 384 bytes			
Field	Bytes	Description	
Channel XX	3	2-byte Distance	See definition in the next page.
		1-byte Reflectivity	Range: 0 to 255 The mapping from this field to target reflectivity can be selected in Section 4.2 (Web Control – Settings).

Three single-return modes and three dual-return modes are available (see the Return Mode field in the Tail of Point Cloud UDP Data).
In a dual-return mode,

- the measurements from each round of firing are stored in two adjacent blocks (see table below);
- the Azimuth of these two blocks are the same.

Return Mode field	Block 1	Block 2	Note
0x39	Last return	Strongest return	If the last return is also the strongest, then Block 2 stores the second strongest return.
0x3B	Last return	First return	If there is only one return, then Block 1 and Block 2 store the same data.
0x3C	First return	Strongest return	If the first return is also the strongest, then Block 2 stores the second strongest return.

The Distance field is defined below:

Up-Close Blockage Detection = **OFF**	Description
Distance≥75	Distance Value = Distance * Dis Unit ≥ 0.3 m Dis Unit: See "Header" in this section
Distance = 0	No valid point cloud output

Up-Close Blockage Detection = **ON**	Description
Distance≥75	Distance Value = Distance * Dis Unit ≥ 0.3 m Dis Unit: See "Header" in this section
Distance = 0	No laser emission.
Distance = 1	Return signal from this lidar unit is received. Object distance: < 0.3 m (below the lower limit of the lidar measurement range) Therefore, no valid point cloud output.
Distance = 2	Return signal from this lidar unit is received. Object distance: 0.3 to 2.85 m (near-field measurement range) The current channel is not a NF (near field)-enabled channel (see Appendix I, Channel Distribution). Therefore, no valid point cloud output.
Distance = 3	Either no return signal is received, or return signal is received but rejected. Thus no valid point cloud output. Common reasons for return signal rejection: • 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. See Retro Multi-Reflection Filtering in Section 4.2 (Web Control: Settings)

Users can enable or disenable Up-Close Blockage Detection (see Section 4.2 Web Control - Settings).

■ **Functional Safety: 17 bytes**

Field	Bytes	Description
FS Version	1	Version number of the functional safety module (currently 0x00)
Lidar State	1	[7:5] is the lidar's current state: d-0 (b-000) Init 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
Fault Code Type		[4:3] is the type of the fault code in this data packet b-01: current fault b-10: past fault
Rolling Counter		[2:0] indicates whether the fault reporting system gets stuck Starting from 0, the rolling counter increments by 1 every time the fault message is updated Normally, the fault message is updated every 5 ms
Total Fault Code Num	1	[7:4] counts the total number of fault codes in this queue
Fault Code ID		[3:0] is the sequence number of the fault code in this queue, starting from 1
Fault Code	2	Fault code sent by this data packet
Reserved	8	-
CRC 2	4	CRC-32/MPEG-2 checksum of Functional Safety (from the Lidar State field to the Reserved field)

The lidar states and fault codes are described in the Safety Manual. Please contact Hesai technical support for more information.

■ **Tail: 56 bytes**

Field	Bytes	Description
Reserved	9	-
Azimuth State	2	Azimuth states are used to determine the laser firing time of a channel, see Appendix II. [15:14] is the azimuth state of Block 1, and [13:12] the azimuth state of Block 2. Range: 0 to 3 (High Resolution mode), 0 to 1 (Standard mode, Energy Saving mode) [11:0] is reserved
Operational State	1	0 - High Resolution 1 - Shutdown 2 - Standard 3 - Energy Saving (reduced range capability)
Return Mode	1	0x33 - First Return 0x37 - Strongest Return 0x38 - Last Return 0x39 - Dual Return (Last, Strongest) 0x3B - Dual Return (Last, First) 0x3C - Dual Return (First, Strongest)
Motor Speed	2	Unit: rpm

<table>
<tr><th>Field</th><th>Bytes</th><th>Description</th></tr>
<tr><td>Date & Time</td><td>6</td><td>Absolute UTC time of this data packet (defined in Appendix II – Absolute time of Point Cloud Data), accurate to the second.

<table><tr><th>Each Byte</th><th>Range (Decimal)</th></tr><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></table></td></tr>
<tr><td>Timestamp</td><td>4</td><td>The "μs time" part of the absolute time of this data packet (defined in Appendix II)
Unit: μs
Range: 0 to 1000000 μs (1 s)</td></tr>
<tr><td>Factory Information</td><td>1</td><td>0x42</td></tr>
<tr><td>UDP Sequence</td><td>4</td><td>Sequence number of this UDP packet
0 to 0xFF FF FF FF</td></tr>
<tr><td>IMU Temperature</td><td>2</td><td>Temperature provided by the IMU (inertial measurement unit), as a signed integer
Unit: 0.01°C</td></tr>
<tr><td>IMU Acceleration Unit</td><td>2</td><td>Conversion factor of acceleration, as an unsigned integer
Currently 244 (0xF4)
Unit of acceleration: 0.001mg * 244 = 0.244mg (g: standard gravity)</td></tr>
<tr><td>IMU Angular Velocity Unit</td><td>2</td><td>Conversion factor of angular velocity, as an unsigned integer
Currently 1750 (0x6D6)
Unit of angular velocity: 0.01 mdps * 1750 = 17.5 mdps (millidegree per second)</td></tr>
</table>

Field	Bytes	Description
IMU Timestamp	4	Timestamp of the IMU data Counting from 0 after powering on the lidar or after an overflow Unit: 25 μs Range: 0 to approx. 1.24 days
IMU X Axis Acceleration	2	Acceleration of the X-axis, measured by the IMU as a signed integer Measurement range: ±8*g* Unit of acceleration: currently 0.244*mg*, see the IMU Acceleration Unit field **E.g.** When IMU_X_Axis_Acceleration_2_bytes = 5, X-axis acceleration = 5 * 0.244*mg* = 1.22*mg*
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 as a signed integer Measurement range: ±500 dps Unit of angular velocity: currently 17.5 mdps, see the IMU Angular Velocity Unit field **E.g.** When IMU_X_Axis_Angular_Velocity_2_bytes = 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

■ **Cyber Security (Optional): 32 bytes**

Field	Bytes	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 4.1.4 (Web Control - Cybersecurity Config - Point Cloud Signature).

3.1.3 Point Cloud Data Analysis

Take Channel 5 in Block 2 as an example:

■ **Analyze the vertical angle of a data point**

The designed vertical angle of Channel 5 is 12.165°, according to Appendix I (Channel Distribution)

Notes

- The accurate vertical angle is recorded in this lidar's unit's angle correction file, see Section 1.3 (Channel Distribution).
- 0° is the horizontal direction; define upward as positive (see Figure 1.5).
- Channel # counts from 1, top to bottom.

■ **Analyze the horizontal angle of a data point**

Y-axis is the 0° position; define clockwise in the top view as positive (see Figure 1.4).

Horizontal angle = ① + ②

① Angular position of current block (see Appendix II for definition)

② Firing time angular offset of the current firing channel

① = ③ + ④

③ Rotor reference angle during the current round of firing

In the Azimuth field of Block 2.

④ Horizontal angle offset of the current firing channel

The designed offset for Channel 5 is 1.093°, according to Appendix I (Channel Distribution Table).

The accurate horizontal angle offset is recorded in this lidar's unit's angle correction file, see Section 1.3 (Channel Distribution).

② = ⑤ * ⑥

⑤ Firing time offset of the current firing channel

Look up the table in Appendix II (Absolute Time of Point Cloud Data).

⑥ Spin rate of the motor

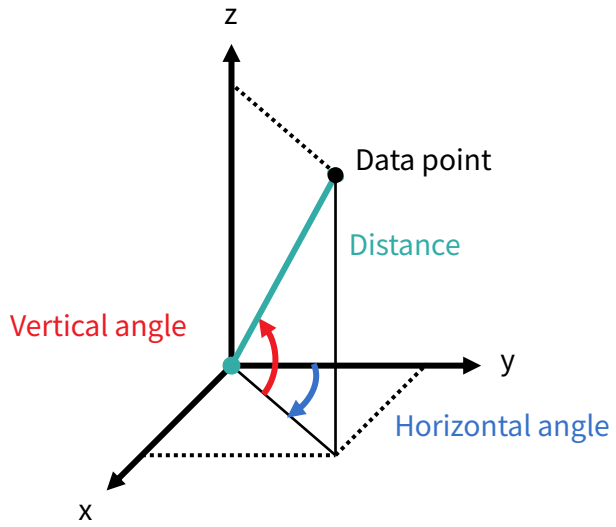
See Section 4.1 (Web Control – Home).

■ Analyze the distance of a data point

Actual distance in real world millimeters = distance measurement * Distance Unit

- Distance measurement: Distance field of Channel 5 in Block 2
- Distance Unit: 4 mm

■ Draw the data point in a polar or rectangular coordinate system



■ 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 (see Section 4.2 Web Control - Settings), GPS Data Packets are triggered every second.
When PTP is selected as the clock source, the Lidar does not output GPS Data Packet.

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

3.2.1 Ethernet Header

The source IP is 192.168.1.201 by default.

The destination IP address is 255.255.255.255 and in broadcast form.

GPS Ethernet Header: 42 bytes		
Field	Bytes	Description
Ethernet II MAC	12	Destination: broadcast (0xFF: 0xFF: 0xFF: 0xFF: 0xFF: 0xFF) Source: (xx:xx:xx:xx:xx:xx)
Ethernet Data Packet Type	2	0x08, 0x00
Internet Protocol	20	Shown in the figure below
UDP Port Number	4	UDP source port (0x2710, represents 10000) Destination port (0x277E, represents 10110)
UDP Length	2	0x208, representing 520 bytes (8 bytes more than the size of the GPS UDP Data, shown in Figure 3.1)
UDP Checksum	2	-

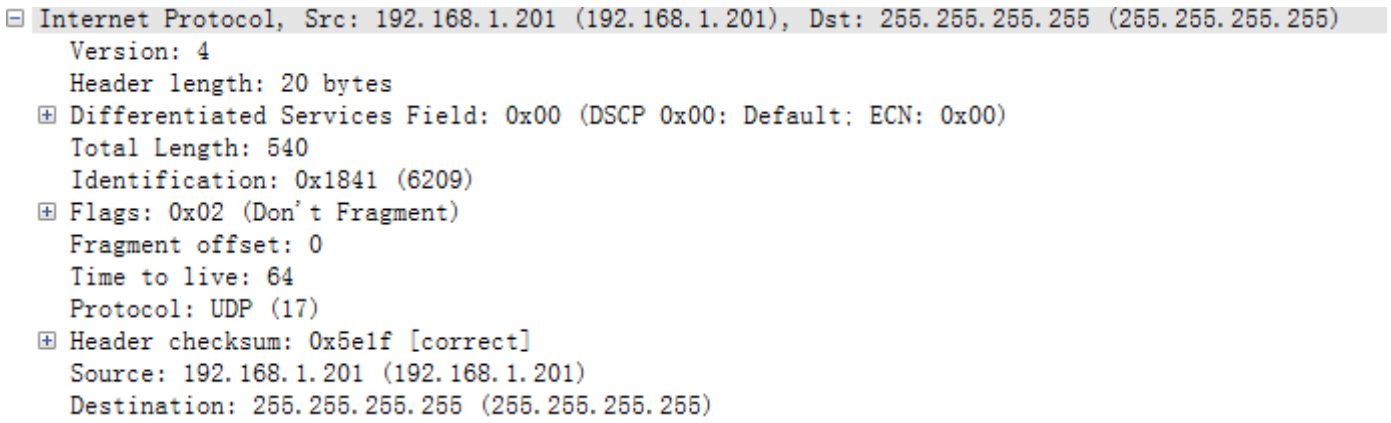


Figure 3.3 GPS Ethernet Header - Internet Protocol

3.2.2 UDP Data

<table>
<tr><th colspan="5">GPS UDP data: 512 bytes</th></tr>
<tr><th>Field</th><th>Bytes</th><th colspan="3">Description</th></tr>
<tr><td rowspan="4">GPS Time Data</td><td rowspan="4">18</td><td>Header</td><td>2 bytes</td><td>0xFFEE (0xFF first)</td></tr>
<tr><td>Date</td><td>6 bytes</td><td>Year, month, and day (2 bytes each, lower byte first) in ASCII</td></tr>
<tr><td>Time</td><td>6 bytes</td><td>Second, minute, and hour (2 bytes each, lower byte first) in ASCII</td></tr>
<tr><td>Reserved</td><td>4 bytes</td><td>-</td></tr>
<tr><td>GPRMC/GPGGA Data</td><td>84</td><td colspan="3">NMEA sentence that contains date and time
ASCII code, valid till 2 bytes after the asterisk (*)
The lidar can receive either GPRMC or GPGGA (see Section 4.2 Web Control - Settings)</td></tr>
<tr><td>Reserved</td><td>404</td><td colspan="3">404 bytes of 0xDF</td></tr>
<tr><td>GPS Positioning Status</td><td>1</td><td colspan="3">ASCII code, obtained from $GPRMC or $GPGGA
<table><tr><th>When $GPRMC is selected:</th><th>When $GPGGA is selected:</th></tr><tr><td>Output A, V, or NUL
• A (hex = 41) = Active
• V (hex = 56) = Void
• NUL (hex = 0) = GPS being unlocked</td><td>Output 0 to 9, as defined by the GPS device manufacturer. Commonly used definitions:
• 0 = invalid
• 1 = GPS fix (SPS)
• 2 = DGPS fix
• 4 = RTK fixed
• 5 = RTK float
• 6 = estimated (dead reckoning)</td></tr></table></td></tr>
<tr><td>PPS Lock Flag</td><td>1</td><td colspan="3">1 - locked 0 - unlocked</td></tr>
<tr><td>Reserved</td><td>4</td><td colspan="3">-</td></tr>
</table>

■ GPRMC Data Format

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

Field #	Field	Description
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format
<02>	Location Status	A (hex = 41) for Valid Position V (hex = 56) for Invalid Position NUL (hex = 0) for GPS being unlocked
...		
<09>	UTC Date	Date information Typically in ddmmyy (day, month, year) format
...		

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

<01> is the hour, minute, and second information
<09> is the date information.

For example, the following two 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
```

■ GPGGA Data Format

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

Field #	Field	Description
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format
...		
<06>	GPS Fix Quality	0 = invalid 1 = GPS fix (SPS) 2 = DGPS fix 3 = PPS fix 6 = estimated (dead reckoning)
...		

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

<01> is the hour, minute, and second information

For example, the following two 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 GPS Data Analysis

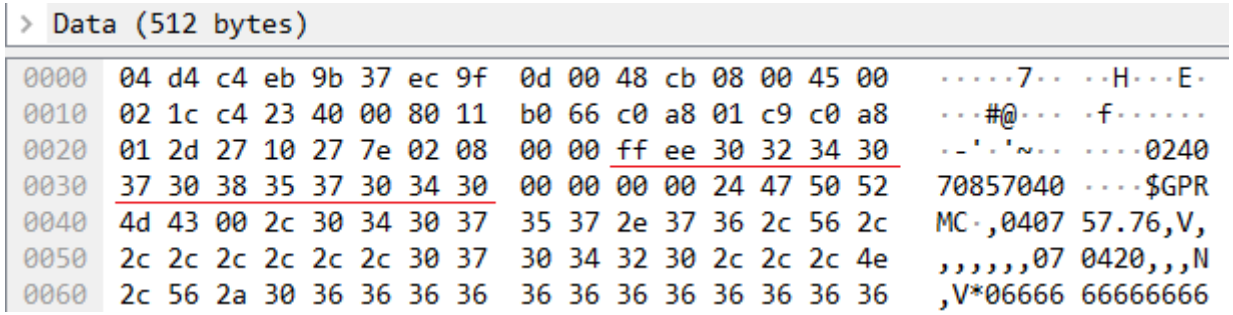


Figure 3.4 GPS Data Packet - UDP Data (Example)

Date

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

Time

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

µs Time

4 bytes, in units of µs, using the same clock source as the GPS Timestamp in Point Cloud Data Packets

Reset to 0 at the rising edge of each PPS signal

4 Web Control

Web control is used for setting parameters, checking device info, and upgrading.

To access web control

1) Connect the lidar to your PC using an Ethernet cable
2) Set the IP address according to Section 2.4 (Get Ready to Use)
3) Enter this URL into your web browser: 192.168.1.201

 Google Chrome and Mozilla Firefox are recommended.

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	P128XXXXXXXXXXXXX
MAC Address	XX:XX:XX:XX:XX:XX
P/N	Pandar128E3X-A01
Customer P/N	12345678-9
Software Version	1.45.119
Sensor Firmware Version	1.45.131
Controller Firmware Version	1.45.124

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

Parameter	Description
Spin Rate	Spin Rate of the motor (rpm) = frame rate (Hz) * 60
GPS	GPS (PPS) status Lock: Lidar's internal clock is in sync with GPS PPS Unlock: Not in sync
NMEA (GPRMC/GPGGA)	NMEA status Lock: After receiving a valid NMEA message Unlock: Not receiving a valid NMEA message for over 2 s
PTP	PTP status 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 (Settings). Locked: Absolute offset is within the user-specified limit. Frozen (Holdover): Attempting to recover the connection to the PTP master.

Parameter	Description
P/N	Part Number • 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 (Pandar128E3X).
Customer P/N	Customer-Specified Part Number • Can be changed. • Format: 1 to 20 characters, digits or hyphen (-) • Default: empty Users may send PTC or HTTP commands to: • enable/disable the display of Customer P/N • change Customer P/N • See Section 5 (Communication Protocol). The above settings do not change with firmware upgrades/downgrades, and are not affected by the "Reset All Settings" button (on the Settings page).

4.2 Settings

Reset All Settings

Control IP

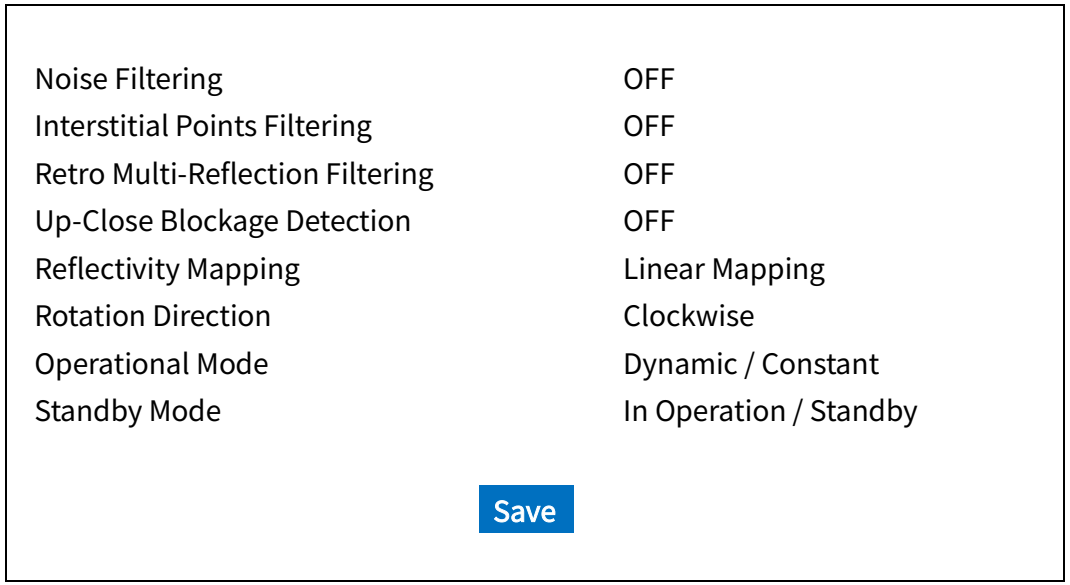
IPv4 Address		192.168.1.201
IPv4 Mask		255.255.255.0
IPv4 Gateway		192.168.1.1
VLAN	☐	0
Ethernet Communication Mode		Slave

Settings

Destination IP		255.255.255.255
Lidar Destination Port		2368
Spin Rate		600 rpm
Return Mode		Last and Strongest
Sync Angle	☐	0
Trigger Method		Angle Based
Clock Source		GPS
GPS Mode		GPRMC
GPS Destination Port		10110

(Continued on the next page)

(Continued)



Button	Description
Reset All Settings	Reset all the configurable parameters to factory defaults, including: • Section 4.2 (Settings) • Section 4.3 (Azimuth FOV) • Section 4.4 (High Resolution)
Save	Save and execute all the settings on this page. • Exception: Standby Mode takes effect immediately without having to click "Save".

4.2.1 Network Settings

Parameter	Options	Description
VLAN	Default: OFF VLAN ID: 1 to 4094	To enable VLAN tagging: • 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). **Warnings** 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 (invalid value) by default. • When checking the checkbox, users will be alerted to input a valid VLAN ID. • When unchecking the checkbox, the VLAN ID will default to zero. **Notes** • Once configured, the VLAN ID does not change during firmware upgrades. • When VLAN is enabled, PTP connection will be lost; when VLAN is disabled, PTP connection will automatically recover.

<table>
<tr><th>Parameter</th><th>Options</th><th>Description</th></tr>
<tr><td>Ethernet Comm. Mode</td><td>Slave (default)
Master</td><td>Only for automotive Ethernet (1000Base-T1).

Slave mode (default):
• The receiving host shall be in Master mode.
• Connect the lidar directly or use a connection box.

Master mode:
• Connect the lidar to a Master host, select "Master" and click "Save" at the bottom of the Settings page.
• Connection to web control will be lost. Then connect the lidar directly to a Slave host.
• Connection box is not supported.

⚠ 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 the default settings.</td></tr>
<tr><td>Destination IP</td><td>Any address except for 0.0.0.0, 127.0.0.1, and the lidar's IP.

Default: 255.255.255.255</td><td><table><tr><th>Mode</th><th>Destination IP</th></tr><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 IP address</td></tr></table></td></tr>
</table>

4.2.2 Function Settings

Parameter	Options	Description
Spin Rate	600 RPM (default) 1200 RPM	The set spin rate is also shown on web control (see Section 4.1 Web Control – Home).
Return Mode	Single Return • Last / Strongest / First Dual Return • 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 Point Cloud UDP Data).
Sync Angle	0° to 360°	Phase lock angle • To activate this function, check the checkbox and input an azimuth. • At every full second, the lidar will rotate to that azimuthal position (see Section 1.2 Lidar Structure). Definition of full second • When GPS is locked: the rising edge of the GPS PPS signal • When PTP is tracking or locked: retrieved from the PTP master clock • When neither GPS nor PTP is locked: the rising edge of the lidar's internal 1 Hz signal • Detailed in Appendix II (Absolute Time of Point Cloud Data) To phase-lock multiple lidars: Connect the lidars to the same clock source and set the same sync angle, and these lidars will rotate to that same azimuthal position at every full second.

<table>
<tr><th>Parameter</th><th>Options</th><th>Description</th></tr>
<tr><td>Trigger Method</td><td>Angle-Based (default)
Time-Based</td><td>The way laser firings are triggered.<table><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 us.</td></tr></table></td></tr>
<tr><td>Noise Filtering</td><td>OFF (default)
ON</td><td>To mitigate the scattered false positives (i.e. noise points) in point cloud data.</td></tr>
<tr><td>Interstitial Points Filtering</td><td>OFF (default)
ON</td><td>To mitigate the interstitial points.
Definition of interstitial points: when a beam partially hits on a front target's edge and further hits on a rear target, the return signal can result in a false point located between both targets.</td></tr>
<tr><td>Retro Multi-Reflection Filtering</td><td>OFF (default)
ON</td><td>To mitigate the false positives at twice the distance of a retroflector.</td></tr>
<tr><td>Up-Close Blockage Detection</td><td>OFF (default)
ON</td><td>When OFF, the Distance field in Point Cloud Data Packets only outputs distance measurements that are over 0.3 m.
When ON, see Section 3.1.2 (Point Cloud UDP Data).</td></tr>
<tr><td>Reflectivity Mapping</td><td>Linear (default)
Nonlinear Mapping 1#/2#</td><td><table><tr><td>Linear</td><td>The Reflectivity field in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%).</td></tr><tr><td>Nonlinear 1# and 2#</td><td>Increases the contrast in low-reflectivity regions (see Appendix III Nonlinear Reflectivity Mapping).</td></tr></table></td></tr>
<tr><td>Rotation Direction</td><td>Clockwise (default)
Counterclockwise</td><td>Direction of motor rotation</td></tr>
</table>

<table>
<tr><th>Parameter</th><th>Options</th><th>Description</th></tr>
<tr><td>Operational Mode</td><td>Dynamic (default)
Constant</td><td>Under each Operational Mode, the lidar automatically shifts between a selection of Operational States according to:
• ambient temperature
• High Resolution settings (see Section 4.4 Web Control – High Resolution)

<table>
<tr><th>Operational Mode</th><th>Horizontal Resolution Mode</th><th>Operational States (in order of priority)</th></tr>
<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>
</table>

Definition of Operational States:
<table>
<tr><th>Operational States</th><th>Horizontal Resolution Mode</th><th>Laser Power</th></tr>
<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 range capability)</td></tr>
<tr><td>Shutdown</td><td colspan="2">Motor not running and lasers not firing</td></tr>
</table>
</td></tr>
<tr><td>Standby Mode</td><td>In Operation (default)
Standby</td><td>In Standby mode, the motor stops running and lasers stop firing.</td></tr>
</table>

4.2.3 Time Settings

Clock Source	**GPS**
GPS Mode	GPRMC
GPS Destination Port	10110

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

■ **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

■ **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 µs (integer) Default: 1	Specify the 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 UDP/IP: Available only for 1588v2 profile L2: Available for all profiles
Domain Number	0 to 127 (integer) Default: 0	Domain attribute of the local clock
PTP logAnnounceInterval	-2 to 3 Default: 1	Time interval between Announce messages Default: 1 log second (2 seconds) Available only when Profile == 1588v2

Parameter	Options	Description
PTP logSyncInterval	-7 to 3 Default: 1	Time interval between Sync messages Default: 1 log second (2 seconds) Available only when Profile == 1588v2
PTP logMinDelayReqInterval	-7 to 3 Default: 0	Minimum permitted mean time between Delay_Req messages Default: 0 log second (1 second) Available only when Profile == 1588v2

When using the 1588v2 profile:

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

Button	Description
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.

Note

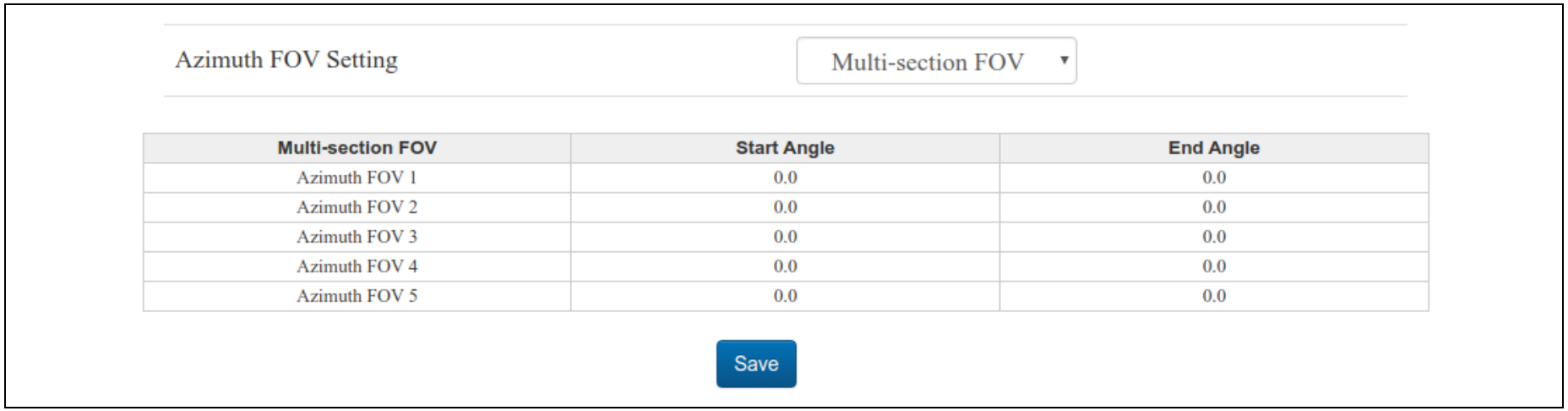
- The angles in degrees are accurate to the first decimal place.
- If the Start Angle is larger than the End Angle, then the actual range is the union of [Start Angle, 360°) and [0°, End Angle).
  - For instance, when the angle range is set to be [270°, 90°), the actual azimuth FOV is [270°, 360°)∪[0°,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

4.3.1 For all channels

Input a Start Angle and an End Angle to form a continuous angle range.
This range applies to all channels.

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.



4.4 High Resolution

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

Button	Description
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 # counts from 1.

Notes

- The horizontal resolution of near field measurement is always 0.4° at 10 Hz and 0.8° at 20 Hz.
- See Appendix I (Channel Distribution) for the definition of near/far field measurement.

4.5 Operation Statistics

These operating parameters are shown in real time:

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
...	...
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 connector) are shown in real time:

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

4.7 Upgrade

Preparation

- Please contact Hesai technical support to receive encrypted and signed upgrade files.
- During the upgrade, it is recommended to place a protective cover (supplied with the lidar) or other opaque material over the lidar's cover lens.

Upgrade

- Click the "Upload" button, select an upgrade file, and confirm your choice in the pop-up window.
- When the upgrade is complete, the lidar will automatically reboot, and the past versions will be logged in the Upgrade Log.

Button	Description
Restart	Software reboot Afterwards, the Start-Up Counts in the Operation Statistics page increments by 1.

Parameter	Current Value
Software Version	1.45.119
Firmware of Sensor Version	1.45.131
Firmware of Controller Version	1.45.124
Upgrade Log	-

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

4.8 Log

The process logs in this page can be used for software troubleshooting.

Parameter	Description
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

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

Login Control

Authentication	ON
Current Password	Current Password Forgot Password?
New Password	New Password
Confirm 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 (see Section 4.10 Login).
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.

Notes

- 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	Description
Authentication	Login control. Forced to be ON.
Current Password	When turning on/off the Cyber Security Master Switch or when changing the password, input here. • 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	Format • 8 to 30 characters • Containing at least one digit and one letter (case sensitive) • Special characters are allowed
Confirm New Password	-

In case the password is forgotten:

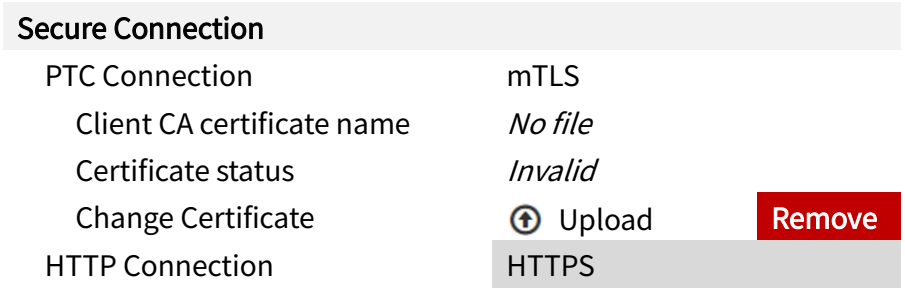
If **TLS** is selected for PTC Connection	Users can only **reset the password**: • Click on "Forgot password?" and it redirects to the Reset Password page; obtain a reset code. • Contact Hesai technical support, provide the reset code to obtain a verification code. • Input the verification code in Reset Password page and click on "Submit".
If **mTLS** is selected for PTC Connection	Users are allowed to **change the password** (without providing the current password) by sending a PTCS command. See Section 5 (Communication Protocol).

4.9.2 Secure Connection

When the Cyber Security Master Switch is ON:

TLS:

mTLS:



Parameter	Options	Description
PTC Connection	TLS (default) mTLS	PTC connection mode TLS (one-way auth): Only the user authenticates the lidar. mTLS (two-way auth): The user and the lidar authenticate each other. Recommended for enhanced security. • Click the "Upload" button to upload a user CA certificate chain. • Before returning a trial/loaner lidar or an RMA lidar to Hesai, click "Remove" to remove the uploaded certificate.
HTTP Connection	Forced to be HTTPS	HTTP connection mode After configuring the HTTPS environment (see Section 4.9.4): • 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	8 to 32 digits or letters (case sensitive)	Used for negotiating a session key. • Default key: **12345678** • To avoid data breach risks, please change the default key and keep your new key securely.

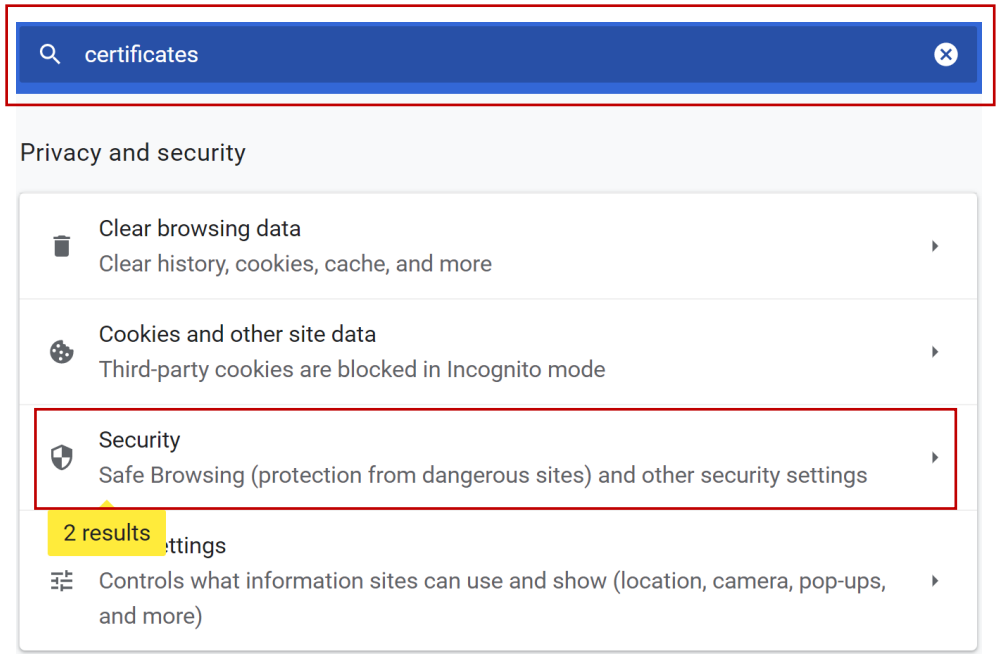
4.9.4 Configure HTTPS Environment

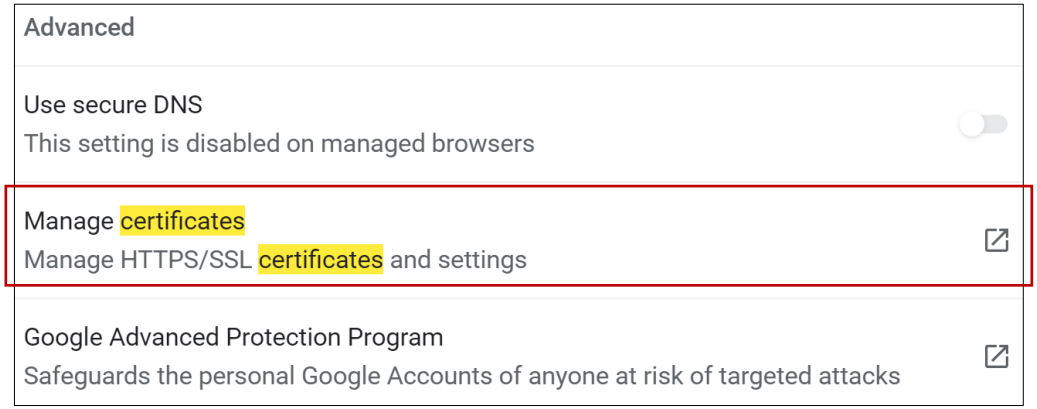
Before using HTTPS, import the lidar CA certificate chain into your browser.

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

Chrome and Firefox in Windows 10 are used as an example.

1) Go to the Settings/Options/Preference page of your browser → Input "Certificate" in the search bar → Select "Manage/View Certificates"

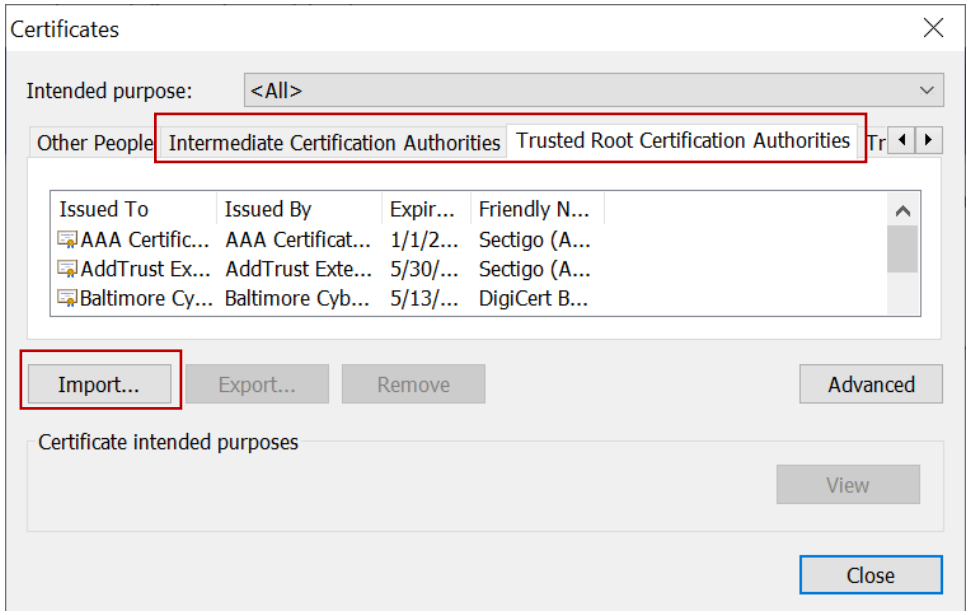


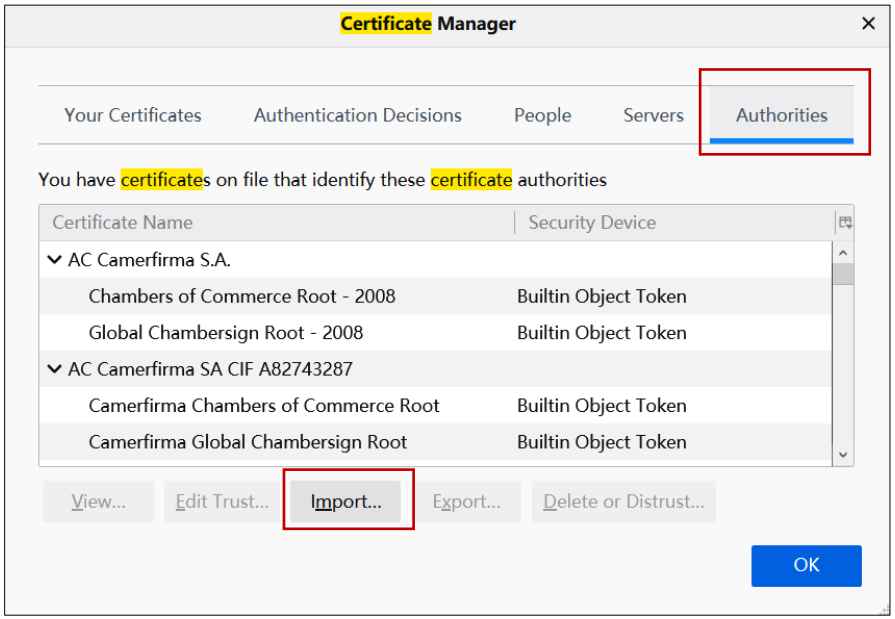


2) In the pop-up dialog box

• If "Intermediate Certification Authorities" and "Trusted Root Certification Authorities" are two separate tabs (see left-hand screenshot), click "Import" to upload the intermediate certificate under the former tab, and upload the root certificate under the latter tab

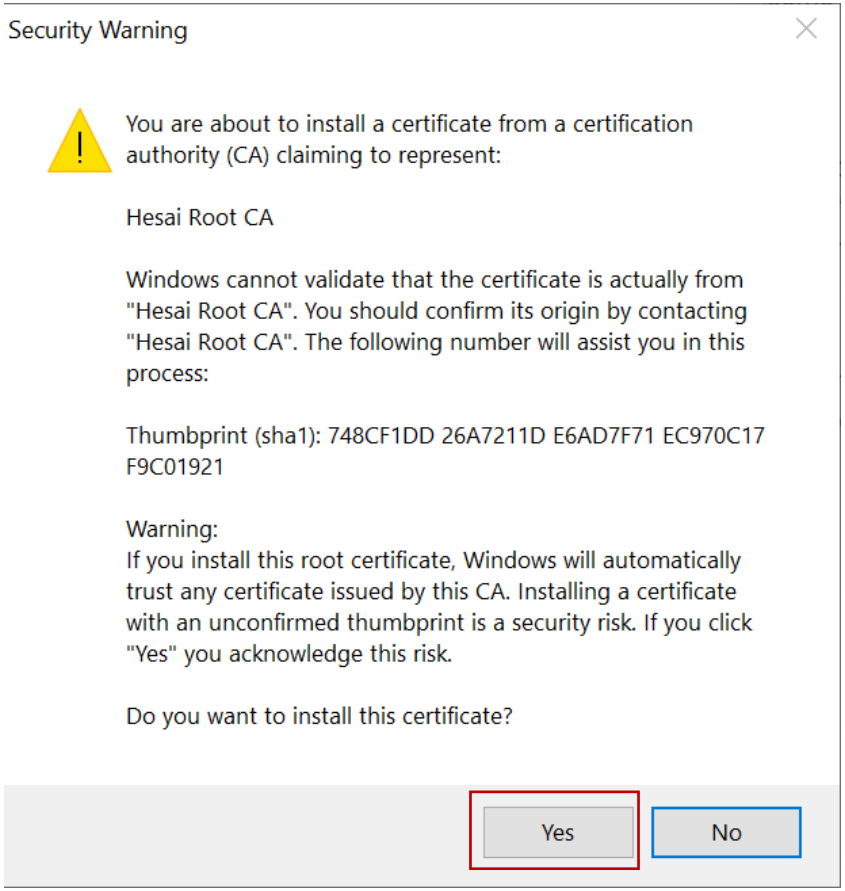
• If only one tab is named "Authorities" (see right-hand screenshot), click "Import" to upload the intermediate and root certificates under this tab, or upload only the certificate chain file under this tab.

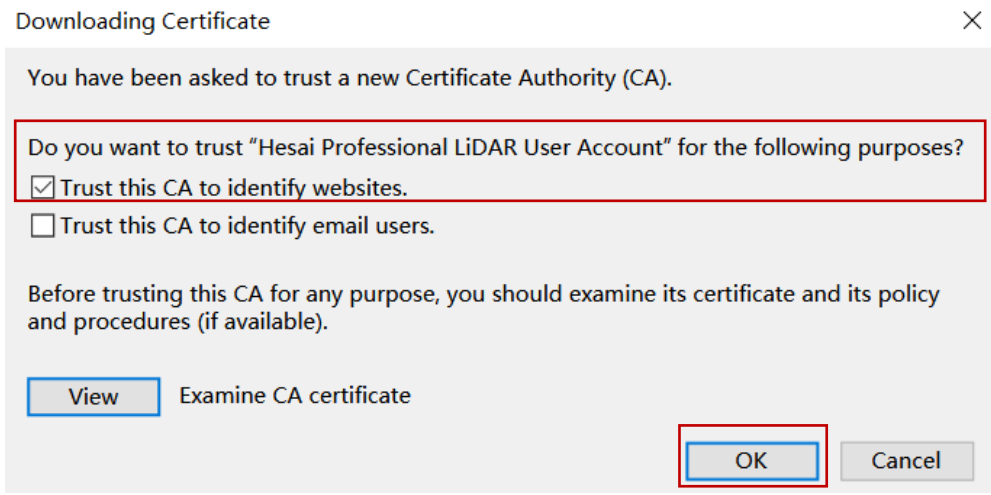




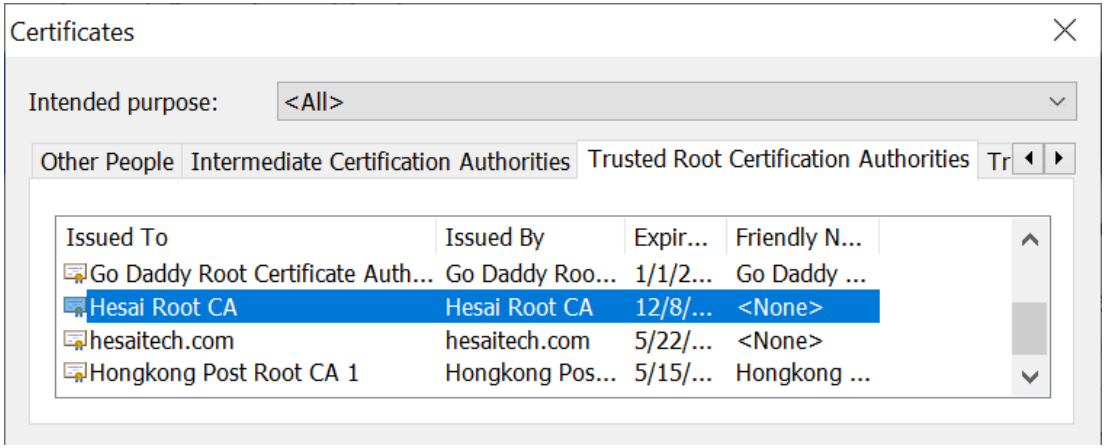
Follow the default settings in the Import Certificate wizard and click "Next" if applicable.

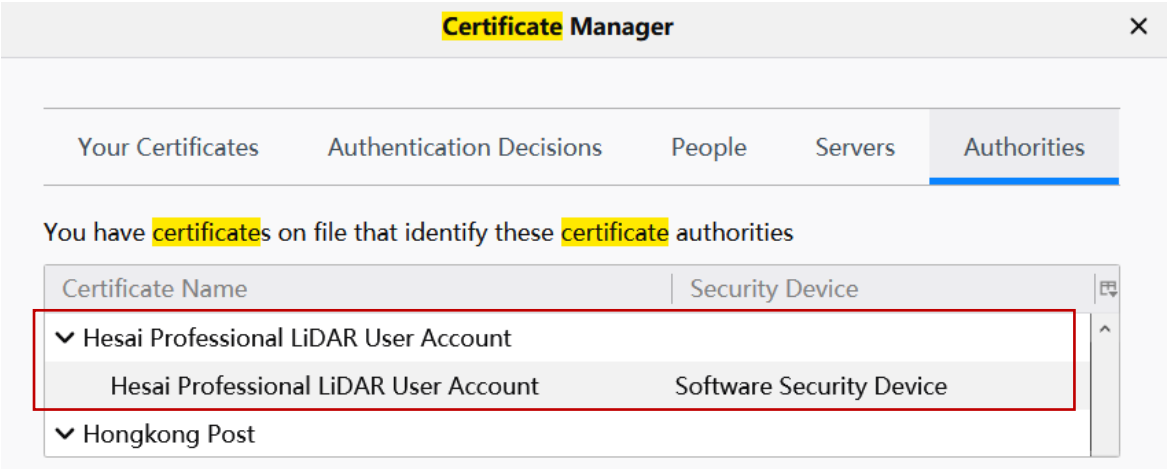
In case the following warnings appear, select "Trust this CA to identify websites".





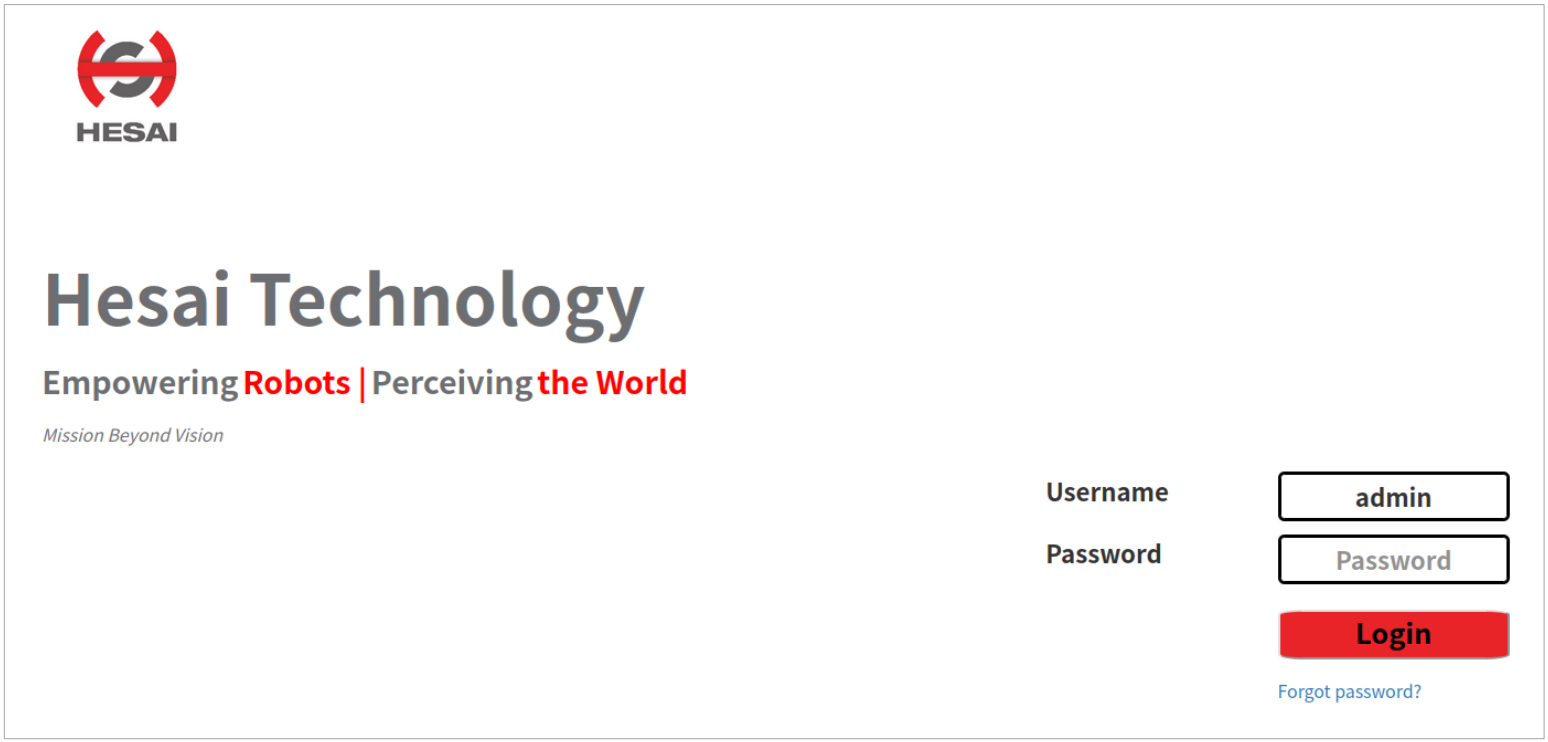
3) When the import is complete, the CA certificate appears in the dialog box. Double-click to see detailed information.





4.10 Login

When the Cyber Security Master Switch on the Security page is ON (see Section 4.9 Security), login control will be activated and the current URL will redirect to the Login page.



Username	admin
Password	Default: **123456** To effectively implement login control, please change the default password (see Section 4.9 - Security) and keep your new password securely.

5 Communication Protocol

To acquire Hesai lidar's PTC (Pandar TCP Commands) and HTTP API Reference Manual, please contact Hesai technical support.

Lidar models that support cybersecurity can communicate using the encrypted PTCS (PTC over TLS) and HTTPS (HTTP over TLS) API.

- Data format is the same with the cleartext PTC/HTTP API.
- To use PTCS, make sure your TLS version is 1.3 or above, with OpenSSL 1.1.1 or above.

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

6 Sensor Maintenance

■ Cleaning

Stains on the product's cover lens, such as dirt, fingerprints, and oil, can negatively affect point cloud data quality.
Please perform the following steps to remove the stains.

⚠ Warnings

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

Notes

- Only clean the stained area of the cover lens.
- Check before using a lint-free wipe. If the wipe is stained, use another.

1) Thoroughly wash your hands or wear a pair of powder-free PVC gloves.
2) To remove dust, blow dry air onto the cover lens, or use a piece of lint-free wipe to lightly brush across the dusty area.

To remove persistent stains, move on to the next step.

3) Spray the cover lens with warm, neutral solvent using a spray bottle.

Solvent type	Soft sponge with a mild soap solution Mild soap solution: maximum two tablespoons of neutral soap in 1 quart (1 liter) of water.
Solvent temperature	20 to 25°C

(Continued on the next page)

(Continued)

4) When the stains have loosened, dip a piece of lint-free wipe 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.

7 Troubleshooting

In case the following procedures cannot solve the problem, please contact Hesai technical support.

Symptoms	Points to Check
Indicator light is off on the connection box	Verify that: • power adapter is properly connected and in good condition; • connection box is intact; • input voltage and current satisfy the requirements in Section 2.3 (Connection Box). Power on again to check if the symptom persists.
Motor is not running	Verify that: • power adapter is properly connected and in good condition; • if a connection box is used, the connection box is intact; • input voltage and current satisfy the requirements in Section 1.4 (Specifications) and 2.3 (Connection Box); • web control can be accessed (see "cannot open web control" on the next page); • the lidar is not in standby mode (see Section 4.2 Web Control – Settings). Power on again to check if the symptom persists.

Symptoms	Points to Check
Motor is running but no output data is received, neither on Wireshark nor on PandarView	Verify that: • Ethernet cable is properly connected (by unplugging and plugging again); • Lidar's Destination IP is correctly set on the Settings page of web control; • horizontal FOV is properly set on the Azimuth FOV page of web control; • firmware version of the sensor is correctly shown on the Upgrade page of web control; • Lidar is emitting laser light. This can be checked by using an infrared camera, an infrared sensor card, or a phone camera without 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. Power on again to check if the symptom persists.
Can receive data on Wireshark but not on PandarView	Verify that: • the Lidar Destination Port is set correctly on the Settings page of web control • PC's firewall is disabled, or that PandarView 2 is added to the firewall exceptions • if VLAN is enabled, the PC's VLAN ID is the same with the lidar's • the latest PandarView 2 version (see the Download page of Hesai's official website or contact Hesai technical support) is installed on the PC Power on again to check if the symptom persists.

Symptoms	Points to Check
Cannot open web control	Verify that • Ethernet cable is properly connected (by unplugging and plugging again) • Lidar's IP is in the same subnet with the PC's. Users may use WireShark to check the lidar's IP that broadcasts data packets • if VLAN is enabled, the PC's VLAN ID is the same with the lidar's Afterwards, • restart PC, or connect the lidar to another PC • power on again to check if the symptom persists
Abnormal packet size (missing packets)	Verify that: • horizontal FOV is properly set on the Azimuth FOV page of web control; • motor's spin rate is steady on the Home page of web control; • Lidar's internal temperature is between -40°C and 110°C on the Operation Statistics page of web control • Ethernet is not overloaded; • no switch is connected into the network. The data transmitted from other devices may cause network congestion and packet loss. Afterwards: • connect the PC only to the lidar and check for packet loss; • power on again to check if the symptom persists.

Symptoms	Points to Check
Abnormal point cloud (obviously misaligned points, flashing points, or incomplete FOV)	Verify that: • Lidar's cover lens is clean. If not, refer to Section 6 (Sensor Maintenance) for the cleaning method; • Lidar's calibration file is imported; see *PandarView 2 User Manual* (Use); • horizontal FOV is properly set on the Azimuth FOV page of web control; • motor's spin rate is steady on the Home page of web control; • Lidar's internal temperature is between -40°C and 110°C on the Operation Statistics page of web control. Afterwards, check for packet loss: • If no packet is missing and yet the point cloud flashes, please update PandarView 2 to the latest version (see the Download page of Hesai's official website or contact Hesai technical support) and restart the PC. If the point cloud is still abnormal: • try connecting the lidar to another PC; • power on again to check if the symptom persists.
GPS cannot be locked	Verify that: • GPS receiver is properly connected; • PPS signal is connected to the lidar; • Destination GPS Port is correct on the Settings page of web control; • input GPS signals satisfy the electrical requirements in Section 2.2 (Interface) and Section 2.3.1 (Connection Box). Power on again to check if the symptom persists;

Appendix I Channel Distribution

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

①	Channel # counts from 1, from the top to bottom
②③	Design values of each channel's horizontal (azimuth) angle offset and vertical (elevation) angle. • The accurate values are recorded in this lidar's unit's calibration file • Refer to Section 3.1.3 (Point Cloud Data Analysis) for the data parsing scheme
④⑤	Actual measurement range, confined by the allocated Time of Flight (ToF) for each channel
⑥	The 32 channels with ④ = 0.3 m are **NF-enabled channels** • All channels fire laser pulses that measure the far field (>2.85 m) • Additionally, the NF-enabled channels also fire laser pulses that measure only the near field (0.3 to 2.85 m), at a time other than these channels' far field firings • The horizontal resolution of NF measurement is always 0.4° at 10 Hz and 0.8° at 20 Hz
⑦	Probability of Detection (PoD) = 70% The values in brackets only indicate detection capability, while the actual measurement range is cut off to ⑤. Channels 98 to 128 have enhanced near- and mid-field detection, since these channels typically point to the ground in the far field.
⑧	Channels 34 to 65 are **FF-enhanced channels**, able to detect 200 m@10% (see data in ⑦)
⑨	Probability of Detection (PoD) = 70%
⑩	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 Web Control - High Resolution) • ⑤ = 200 m

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
01	3.257°	14.436°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
02	3.263°	13.535°	2.85 m	100 m	-	100 m	-	100 m @ 10%	-
03	1.091°	13.082°	0.3 m	100 m	YES	100 m	-	100 m @ 10%	-
04	3.268°	12.624°	2.85 m	100 m	-	100 m	-	100 m @ 10%	-
05	1.093°	12.165°	2.85 m	100 m	-	100 m	-	100 m @ 10%	-
06	3.273°	11.702°	0.3 m	100 m	YES	(120 m)	-	100 m @ 6%	-
07	1.094°	11.239°	2.85 m	100 m	-	(120 m)	-	100 m @ 6%	-
08	3.278°	10.771°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
09	1.095°	10.305°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
10	3.283°	9.830°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
11	1.096°	9.356°	2.85 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°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
14	3.291°	7.921°	2.85 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°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
17	1.100°	6.467°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
18	-1.104°	5.978°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
19	-3.306°	5.487°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
20	-1.106°	4.996°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
21	-3.311°	4.501°	0.3 m	100 m	YES	(140 m)	-	100 m @ 3%	-
22	-1.109°	4.007°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
23	-3.318°	3.509°	2.85 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°	2.85 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°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
28	5.535°	1.761°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
29	3.325°	1.637°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
30	-3.33°	1.511°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
31	1.107°	1.386°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
32	-5.538°	1.258°	2.85 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°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
35	7.731°	0.88°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
36	5.543°	0.756°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
37	3.329°	0.63°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
38	-3.336°	0.505°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
39	1.108°	0.379°	2.85 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

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
41	-7.738°	0.124°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
42	-1.117°	0.000°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
43	7.743°	-0.129°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
44	5.551°	-0.254°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
45	3.335°	-0.380°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
46	-3.342°	-0.506°	2.85 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°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
49	-7.750°	-0.887°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
50	-1.119°	-1.012°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
51	7.757°	-1.141°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
52	5.560°	-1.266°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
53	3.340°	-1.393°	2.85 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
55	1.111°	-1.646°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
56	-5.564°	-1.773°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
57	-7.762°	-1.901°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
58	-1.121°	-2.027°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
59	7.768°	-2.155°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
60	5.569°	-2.282°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
61	3.345°	-2.409°	0.3 m	200 m	YES	200 m	YES	200 m @ 10%	YES
62	-3.353°	-2.535°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
63	1.113°	-2.663°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
64	-5.573°	-2.789°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
65	-7.775°	-2.916°	2.85 m	200 m	-	200 m	YES	200 m @ 10%	YES
66	-1.123°	-3.044°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
67	7.780°	-3.172°	2.85 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°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
70	-3.358°	-3.552°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
71	1.115°	-3.680°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
72	-5.582°	-3.806°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
73	-7.787°	-3.933°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
74	-1.125°	-4.062°	2.85 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°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
77	3.356°	-4.444°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
78	-3.363°	-4.571°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
79	1.116°	-4.699°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
80	-5.591°	-4.824°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
81	-7.799°	-4.951°	2.85 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°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
84	5.595°	-5.336°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
85	3.360°	-5.463°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
86	-3.369°	-5.589°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
87	1.118°	-5.718°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
88	-5.599°	-5.843°	2.85 m	200 m	-	140 m	-	200 m @ 37%	YES
89	-7.811°	-5.968°	2.85 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%	-
91	-3.374°	-6.607°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
92	-1.130°	-7.117°	2.85 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°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
95	-3.383°	-8.640°	2.85 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°	2.85 m	100 m	-	(140 m)	-	100 m @ 3%	-
98	3.386°	-10.160°	2.85 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°	2.85 m	100 m	-	100 m	-	100 m @ 10%	-

Channel Distribution (To Be Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
101	1.129°	-11.672°	2.85 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°	2.85 m	100 m	-	100 m	-	100 m @ 10%	-
104	3.401°	-13.173°	2.85 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°	2.85 m	100 m	-	50 m	-	100 m @ 120%	-
107	1.135°	-14.66°	2.85 m	100 m	-	50 m	-	100 m @ 120%	-
108	3.410°	-15.154°	0.3 m	100 m	YES	50 m	-	100 m @ 120%	-
109	1.137°	-15.645°	2.85 m	100 m	-	50 m	-	100 m @ 120%	-
110	3.416°	-16.135°	2.85 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°	2.85 m	100 m	-	50 m	-	100 m @ 120%	-
113	1.142°	-17.592°	2.85 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°	2.85 m	100 m	-	50 m	-	100 m @ 120%	-
116	-1.143°	-19.030°	2.85 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°	2.85 m	100 m	-	25 m	-	100 m @ 1600%	-
119	-3.433°	-20.445°	2.85 m	100 m	-	25 m	-	100 m @ 1600%	-
120	-1.145°	-20.918°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-

Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity	Far Field Enhanced?	Min. Reflectivity @ Max. Instrument Range	High-Res?
	Horiz. Offset	Vertical	Min	Max					
121	-3.436°	-21.379°	2.85 m	100 m	-	25 m	-	100 m @ 1600%	-
122	-1.146°	-21.848°	2.85 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°	2.85 m	100 m	-	25 m	-	100 m @ 1600%	-
125	-3.443°	-23.219°	2.85 m	100 m	-	25 m	-	100 m @ 1600%	-
126	-1.146°	-23.678°	0.3 m	100 m	YES	25 m	-	100 m @ 1600%	-
127	-3.446°	-24.123°	2.85 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 II Absolute Time of Point Cloud Data

■ Source of Absolute Time

The lidar retrieves the current absolute time by connecting to an external clock source (GPS/PTP).
Users can select the clock source, see Section 4.2 (Web Control - Settings).

1) GPS as the Clock Source

- The lidar connects to a third-party GPS module to obtain the PPS (pulse-per-second) signal and the NMEA sentence ($GPRMC or $GPGGA).
- Users may select either $GPRMC or $GPGGA sentences (see Section 4.2 Web Control – Settings).
- Users may check the signal status of GPS PPS and NMEA (see Section 4.1 Web Control - Home).
- 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 & Time (accurate to the second)	Lidar behavior
Unlocked	Virtual	Starts counting from a virtual UTC time (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, obtain the actual date and time by • extracting the date and time from the previous NMEA message, and • automatically adding 1 full second.
Lost	Drifting	Starts counting from the last synchronized time, using the lidar's internal 1 Hz signal. Will gradually drift from the actual GPS time.

PPS status	µs time	Description
Unlocked	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).
Lost	Drifting	Counts using the internal 1 Hz signal. Will gradually drift from the actual GPS second.

2) PTP as the Clock Source

- The lidar connects to a third-party PTP master to obtain the absolute time.
- Users may configure the PTP settings (see Section 4.2 Web Control – Settings).
- Users may check the PTP signal status (see Section 4.1 Web Control - Home).
- The lidar does not output GPS Data Packets.

The absolute time is updated as follows.

PTP Status	Date & Time (accurate to μs)	Description
Free Run	Virtual	Starts counting from a virtual UTC time (such as 2000-01-01 00:00:00), using the lidar's internal 1 Hz signal.
Tracking or Locked	Synchronized	Extract the actual date and time from the PTP Master's messages.
Frozen	Drifting	Starts counting from the last synchronized time, using the lidar's internal 1 Hz signal. Will gradually drift from the actual PTP time.

Notes

- 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.

■ Absolute Time of Point Cloud Data Packets

The absolute time of a Point Cloud Data Packet (denoted as t0) is calculated as follows:

$$t0 = t\_s + t\_ms$$

where

- t_s is the whole second part (see the Date & Time field).
- t_ms is the microsecond part (see the Timestamp field).
- For definition of the above fields (see Section 3.1.2 Point Cloud UDP Data – Tail).

■ Start Time of Each Block

Given the absolute time of a Point Cloud Data Packet (t0), the start time of each block (i.e., the time when the first firing starts) can be calculated.

Single Return Mode

The start time of each block depends on the horizontal resolution - whether the lidar is operating in High Resolution mode or Standard mode (defined in Section 4: Web Control - High Resolution).

Block	Start Time (μs) in High Resolution Mode	Start Time (μs) in Standard Mode
Block 1	t0 + 3.148 - 27.778	t0 + 3.148 - 27.778 * 2
Block 2	t0 + 3.148	t0 + 3.148

Dual Return Mode

The start time of each block is independent of the horizontal resolution.

Block	Start Time (μs)
Block 1 & Block 2	t0 + 3.148

■ Firing Time Offset of Each Channel

Assume that the start time of Block m is T(m), $m \in \{1, 2\}$, then
the laser firing time of Channel n in Block m is $t(m, n) = T(m) + \Delta t(n)$, $n \in \{1, 2, \ldots, 128\}$.

$\Delta t(n)$ is determined below:

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: 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 of Channel n in Block m, in the Body the Point Cloud Data Packet
- If Distance > 2.85 m, the data point is generated from a far-field firing
- If Distance≤2.85 m, the data point is generated from a near-field firing

4) Look up $\Delta t(n)$ in the tables below

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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	-	-	-	6-91	-	-	-	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	-
	17	-	-	4786	-	-	-	4086	-	32564	-	31864	-
	18	6441	7206	-	-	6091	-	-	-	6441	7206	6091	-
	19	-	-	4786	-	-	-	4086	-	32564	-	31864	-
	20	776	-	-	-	776	-	-	-	776	-	776	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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
	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	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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	-
	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	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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	-
	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	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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	-
	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	-	-	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	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	101	-	-	4786	-	-	-	4086	-	32564	-	31864	-
	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	-
	119	776	-	-	-	776	-	-	-	776	-	776	-
	120	-	-	776	1541	-	-	776	-	28554	29319	28554	-

Δt(n) – Firing Time Offset (Unit: ns), in the Ascending Order of Channel No.

(continued on the next page)

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 #	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

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
3	776	1	0	2	776	1	0	3	776	1	0	2	776	1	0
10	776	1	0	13	776	1	0	10	776	1	0	13	776	1	0
20	776	1	0	16	776	1	0	20	776	1	0	16	776	1	0
91	776	1	0	97	776	1	0	91	776	1	0	97	776	1	0
96	776	1	0	102	776	1	0	96	776	1	0	102	776	1	0
113	776	1	0	107	776	1	0	113	776	1	0	107	776	1	0
119	776	1	0	120	776	1	0	119	776	1	0	120	776	1	0
126	776	1	0	128	776	1	0	126	776	1	0	128	776	1	0
3	1541	2	1	120	1541	2	1	126	1541	2	1	128	1541	2	1
4	2431	3	0	102	2021	3	1	96	2021	3	1	6	2431	3	0
11	2431	3	0	6	2781	4	0	4	2781	4	0	15	2431	3	0
21	2431	3	0	15	2781	4	0	11	2781	4	0	22	2431	3	0
90	2431	3	0	22	2781	4	0	21	2781	4	0	95	2431	3	0
98	2431	3	0	95	2781	4	0	90	2781	4	0	103	2431	3	0
99	2431	3	0	103	2781	4	0	98	2781	4	0	106	2431	3	0
116	2431	3	0	106	2781	4	0	99	2781	4	0	117	2431	3	0
125	2431	3	0	117	2781	4	0	116	2781	4	0	124	2431	3	0
21	3196	4	1	124	2781	4	0	125	2781	4	0	117	3196	4	1

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
90	3676	5	1	15	3546	5	1	99	3546	5	1	8	4086	5	0
1	4436	6	0	6	4026	6	1	1	4436	6	0	17	4086	5	0
5	4436	6	0	8	4786	7	0	5	4436	6	0	19	4086	5	0
25	4436	6	0	17	4786	7	0	25	4436	6	0	24	4086	5	0
92	4436	6	0	19	4786	7	0	92	4436	6	0	101	4086	5	0
100	4436	6	0	24	4786	7	0	100	4436	6	0	108	4086	5	0
105	4436	6	0	101	4786	7	0	105	4436	6	0	112	4086	5	0
114	4436	6	0	108	4786	7	0	114	4436	6	0	115	4086	5	0
121	4436	6	0	112	4786	7	0	121	4436	6	0	24	4851	6	1
1	5201	7	1	115	4786	7	0	114	5201	7	1	108	5331	7	1
105	5681	8	1	9	6441	8	0	7	6091	8	0	9	6091	8	0
7	6441	9	0	14	6441	8	0	12	6091	8	0	14	6091	8	0
12	6441	9	0	23	6441	8	0	18	6091	8	0	23	6091	8	0
18	6441	9	0	94	6441	8	0	93	6091	8	0	94	6091	8	0
93	6441	9	0	110	6441	8	0	104	6091	8	0	110	6091	8	0
104	6441	9	0	111	6441	8	0	109	6091	8	0	111	6091	8	0
109	6441	9	0	118	6441	8	0	122	6091	8	0	118	6091	8	0
122	6441	9	0	123	6441	8	0	127	6091	8	0	123	6091	8	0

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
127	6441	9	0	9	7206	9	1	93	6856	9	1	123	6856	9	1
18	7206	10	1	111	7686	10	1	12	7336	10	1	32	7746	10	0
32	8096	11	0	32	8446	11	0	32	8096	11	0	45	7746	10	0
45	8096	11	0	45	8446	11	0	45	8096	11	0	50	7746	10	0
50	8096	11	0	50	8446	11	0	50	8096	11	0	51	7746	10	0
51	8096	11	0	51	8446	11	0	51	8096	11	0	65	7746	10	0
65	8096	11	0	65	8446	11	0	65	8096	11	0	76	7746	10	0
76	8096	11	0	76	8446	11	0	76	8096	11	0	79	7746	10	0
79	8096	11	0	79	8446	11	0	79	8096	11	0	86	7746	10	0
86	8096	11	0	86	8446	11	0	86	8096	11	0	26	10031	11	0
26	10381	12	0	26	10731	12	0	26	10381	12	0	35	10031	11	0
35	10381	12	0	35	10731	12	0	35	10381	12	0	47	10031	11	0
47	10381	12	0	47	10731	12	0	47	10381	12	0	48	10031	11	0
48	10381	12	0	48	10731	12	0	48	10381	12	0	61	10031	11	0
61	10381	12	0	61	10731	12	0	61	10381	12	0	68	10031	11	0
68	10381	12	0	68	10731	12	0	68	10381	12	0	70	10031	11	0
70	10381	12	0	70	10731	12	0	70	10381	12	0	73	10031	11	0
73	10381	12	0	73	10731	12	0	73	10381	12	0	68	11426	12	1

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
28	12666	13	0	26	12126	13	1	28	12666	13	0	28	12316	13	0
33	12666	13	0	28	13016	14	0	33	12666	13	0	33	12316	13	0
34	12666	13	0	33	13016	14	0	34	12666	13	0	34	12316	13	0
43	12666	13	0	34	13016	14	0	43	12666	13	0	43	12316	13	0
53	12666	13	0	43	13016	14	0	53	12666	13	0	53	12316	13	0
54	12666	13	0	53	13016	14	0	54	12666	13	0	54	12316	13	0
72	12666	13	0	54	13016	14	0	72	12666	13	0	72	12316	13	0
87	12666	13	0	72	13016	14	0	87	12666	13	0	87	12316	13	0
27	14951	14	0	87	13016	14	0	33	14061	14	1	27	14601	14	0
29	14951	14	0	27	15301	15	0	27	14951	15	0	29	14601	14	0
39	14951	14	0	29	15301	15	0	29	14951	15	0	39	14601	14	0
40	14951	14	0	39	15301	15	0	39	14951	15	0	40	14601	14	0
60	14951	14	0	40	15301	15	0	40	14951	15	0	60	14601	14	0
62	14951	14	0	60	15301	15	0	60	14951	15	0	62	14601	14	0
74	14951	14	0	62	15301	15	0	62	14951	15	0	74	14601	14	0
89	14951	14	0	74	15301	15	0	74	14951	15	0	89	14601	14	0
37	17236	15	0	89	15301	15	0	89	14951	15	0	37	16886	15	0
42	17236	15	0	37	17586	16	0	37	17236	16	0	42	16886	15	0

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
57	17236	15	0	42	17586	16	0	42	17236	16	0	57	16886	15	0
59	17236	15	0	57	17586	16	0	57	17236	16	0	59	16886	15	0
63	17236	15	0	59	17586	16	0	59	17236	16	0	63	16886	15	0
64	17236	15	0	63	17586	16	0	63	17236	16	0	64	16886	15	0
78	17236	15	0	64	17586	16	0	64	17236	16	0	78	16886	15	0
84	17236	15	0	78	17586	16	0	78	17236	16	0	84	16886	15	0
30	19521	16	0	84	17586	16	0	84	17236	16	0	30	19171	16	0
31	19521	16	0	30	19871	17	0	30	19521	17	0	31	19171	16	0
41	19521	16	0	31	19871	17	0	31	19521	17	0	41	19171	16	0
52	19521	16	0	41	19871	17	0	41	19521	17	0	52	19171	16	0
66	19521	16	0	52	19871	17	0	52	19521	17	0	66	19171	16	0
67	19521	16	0	66	19871	17	0	66	19521	17	0	67	19171	16	0
77	19521	16	0	67	19871	17	0	67	19521	17	0	77	19171	16	0
80	19521	16	0	77	19871	17	0	77	19521	17	0	80	19171	16	0
44	21806	17	0	80	19871	17	0	80	19521	17	0	44	21456	17	0
46	21806	17	0	44	22156	18	0	44	21806	18	0	46	21456	17	0
49	21806	17	0	46	22156	18	0	46	21806	18	0	49	21456	17	0
58	21806	17	0	49	22156	18	0	49	21806	18	0	58	21456	17	0

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

High Performace State

(continued)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	1			Azi_S	2			Azi_S	3		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
71	21806	17	0	58	22156	18	0	58	21806	18	0	71	21456	17	0
75	21806	17	0	71	22156	18	0	71	21806	18	0	75	21456	17	0
85	21806	17	0	75	22156	18	0	75	21806	18	0	85	21456	17	0
88	21806	17	0	85	22156	18	0	85	21806	18	0	88	21456	17	0
75	23201	18	1	88	22156	18	0	88	21806	18	0	36	23741	18	0
36	24091	19	0	36	24441	19	0	36	24091	19	0	38	23741	18	0
38	24091	19	0	38	24441	19	0	38	24091	19	0	55	23741	18	0
55	24091	19	0	55	24441	19	0	55	24091	19	0	56	23741	18	0
56	24091	19	0	56	24441	19	0	56	24091	19	0	69	23741	18	0
69	24091	19	0	69	24441	19	0	69	24091	19	0	81	23741	18	0
81	24091	19	0	81	24441	19	0	81	24091	19	0	82	23741	18	0
82	24091	19	0	82	24441	19	0	82	24091	19	0	83	23741	18	0
83	24091	19	0	83	24441	19	0	83	24091	19	0	82	25136	19	1
40	27056	20	1	47	27406	20	1	54	27056	20	1	61	26706	20	1
Total	104	-	8	Total	104	-	8	Total	104	-	8	Total	104	-	8

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

Standard or Energy Saving State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	0			Azi_S	1			Azi_S	1		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
119	776	1	0	90	3676	5	1	119	776	1	0	99	3546	5	1
126	776	1	0	121	4436	6	0	126	776	1	0	121	4436	6	0
91	776	1	0	114	4436	6	0	91	776	1	0	114	4436	6	0
20	776	1	0	25	4436	6	0	20	776	1	0	25	4436	6	0
3	776	1	0	92	4436	6	0	3	776	1	0	92	4436	6	0
10	776	1	0	5	4436	6	0	10	776	1	0	5	4436	6	0
113	776	1	0	1	4436	6	0	113	776	1	0	1	4436	6	0
96	776	1	0	105	4436	6	0	96	776	1	0	105	4436	6	0
3	1541	2	1	100	4436	6	0	126	1541	2	1	100	4436	6	0
125	2431	3	0	1	5201	7	1	96	2021	3	1	114	5201	7	1
116	2431	3	0	105	5681	8	1	125	2781	4	0	127	6091	8	0
21	2431	3	0	127	6441	9	0	116	2781	4	0	122	6091	8	0
90	2431	3	0	122	6441	9	0	21	2781	4	0	93	6091	8	0
11	2431	3	0	93	6441	9	0	90	2781	4	0	18	6091	8	0
4	2431	3	0	18	6441	9	0	11	2781	4	0	7	6091	8	0
99	2431	3	0	7	6441	9	0	4	2781	4	0	12	6091	8	0
98	2431	3	0	12	6441	9	0	99	2781	4	0	109	6091	8	0
21	3196	4	1	109	6441	9	0	98	2781	4	0	104	6091	8	0

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

Standard or Energy Saving State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	0			Azi_S	1			Azi_S	1		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
104	6441	9	0	41	19521	13	0	93	6856	9	1	59	17236	13	0
18	7206	10	1	80	19521	13	0	12	7336	10	1	41	19521	14	0
33	12666	11	0	30	19521	13	0	33	12666	11	0	80	19521	14	0
72	12666	11	0	66	19521	13	0	72	12666	11	0	30	19521	14	0
54	12666	11	0	31	19521	13	0	54	12666	11	0	66	19521	14	0
34	12666	11	0	77	19521	13	0	34	12666	11	0	31	19521	14	0
87	12666	11	0	52	19521	13	0	87	12666	11	0	77	19521	14	0
53	12666	11	0	67	19521	13	0	53	12666	11	0	52	19521	14	0
28	12666	11	0	49	21806	14	0	28	12666	11	0	67	19521	14	0
43	12666	11	0	88	21806	14	0	43	12666	11	0	49	21806	15	0
57	17236	12	0	46	21806	14	0	33	14061	12	1	88	21806	15	0
64	17236	12	0	58	21806	14	0	57	17236	13	0	46	21806	15	0
78	17236	12	0	71	21806	14	0	64	17236	13	0	58	21806	15	0
42	17236	12	0	85	21806	14	0	78	17236	13	0	71	21806	15	0
63	17236	12	0	44	21806	14	0	42	17236	13	0	85	21806	15	0
37	17236	12	0	75	21806	14	0	63	17236	13	0	44	21806	15	0
84	17236	12	0	75	23201	15	1	37	17236	13	0	75	21806	15	0
59	17236	12	0	40	27056	16	1	84	17236	13	0	54	27056	16	1

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

Standard or Energy Saving State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	0			Azi_S	1			Azi_S	1		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
128	28554	17	0	15	31324	21	1	128	28554	17	0	115	31864	21	0
120	28554	17	0	6	31804	22	1	120	28554	17	0	112	31864	21	0
97	28554	17	0	115	32564	23	0	97	28554	17	0	19	31864	21	0
16	28554	17	0	112	32564	23	0	16	28554	17	0	24	31864	21	0
13	28554	17	0	19	32564	23	0	13	28554	17	0	17	31864	21	0
2	28554	17	0	24	32564	23	0	2	28554	17	0	8	31864	21	0
107	28554	17	0	17	32564	23	0	107	28554	17	0	101	31864	21	0
102	28554	17	0	8	32564	23	0	102	28554	17	0	108	31864	21	0
120	29319	18	1	101	32564	23	0	128	29319	18	1	24	32629	22	1
102	29799	19	1	108	32564	23	0	117	30209	19	0	108	33109	23	1
117	30559	20	0	123	34219	24	0	124	30209	19	0	123	33869	24	0
124	30559	20	0	118	34219	24	0	95	30209	19	0	118	33869	24	0
95	30559	20	0	23	34219	24	0	22	30209	19	0	23	33869	24	0
22	30559	20	0	94	34219	24	0	15	30209	19	0	94	33869	24	0
15	30559	20	0	9	34219	24	0	6	30209	19	0	9	33869	24	0
6	30559	20	0	14	34219	24	0	103	30209	19	0	14	33869	24	0
103	30559	20	0	111	34219	24	0	106	30209	19	0	111	33869	24	0
106	30559	20	0	110	34219	24	0	117	30974	20	1	110	33869	24	0

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence

Standard or Energy Saving State

(continued on the next page)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	0			Azi_S	1			Azi_S	1		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
9	34984	25	1	26	39904	29	1	123	34634	25	1	89	42379	29	0
111	35464	26	1	89	43079	30	0	65	35524	26	0	40	42379	29	0
65	36224	27	0	40	43079	30	0	32	35524	26	0	62	42379	29	0
32	36224	27	0	62	43079	30	0	86	35524	26	0	74	42379	29	0
86	36224	27	0	74	43079	30	0	50	35524	26	0	39	42379	29	0
50	36224	27	0	39	43079	30	0	79	35524	26	0	29	42379	29	0
79	36224	27	0	29	43079	30	0	45	35524	26	0	60	42379	29	0
45	36224	27	0	60	43079	30	0	76	35524	26	0	27	42379	29	0
76	36224	27	0	27	43079	30	0	51	35524	26	0	81	51519	30	0
51	36224	27	0	81	52219	31	0	73	37809	27	0	56	51519	30	0
73	38509	28	0	56	52219	31	0	48	37809	27	0	38	51519	30	0
48	38509	28	0	38	52219	31	0	70	37809	27	0	82	51519	30	0
70	38509	28	0	82	52219	31	0	26	37809	27	0	55	51519	30	0
26	38509	28	0	55	52219	31	0	47	37809	27	0	69	51519	30	0
47	38509	28	0	69	52219	31	0	61	37809	27	0	36	51519	30	0
61	38509	28	0	36	52219	31	0	68	37809	27	0	83	51519	30	0
68	38509	28	0	83	52219	31	0	35	37809	27	0	82	52914	31	1

Δt(n) – Firing Time Offset, in the Ascending Order of Firing Sequence
Standard or Energy Saving State
(continued)

Azi_S: Azimuth State Ch #: Channel No. Time: Firing time (ns) Seq: Firing Sequence NF: Near Field (1 for YES, 0 for NO)

Azi_S	0			Azi_S	0			Azi_S	1			Azi_S	1		
Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF	Ch #	Time	Seq	NF
35	38509	28	0	47	55184	32	1	68	39204	28	1	61	54484	32	1
Total	144	-	16	Total	144	-	16	Total	144	-	16	Total	144	-	16

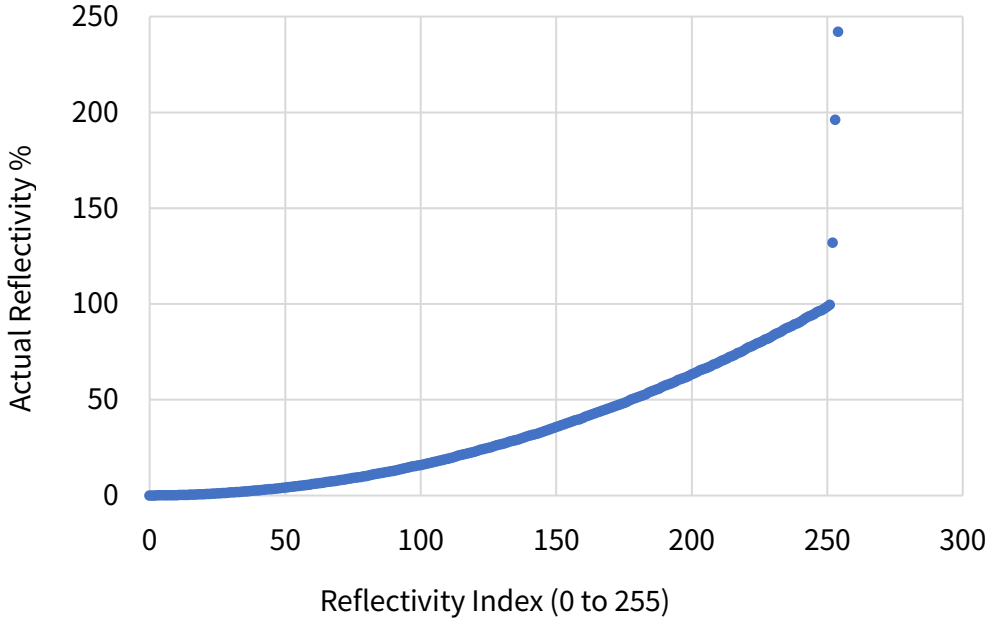
Appendix III Nonlinear Reflectivity Mapping

By default, the 1-byte reflectivity data in Point Cloud Data Packets linearly represents target reflectivity from 0 to 255%.

Alternatively, users may choose the Nonlinear Mapping mode (see Section 4.2 Web Control - Settings).

■ **Nonlinear Mapping 1#**

This mapping increases the contrast in low-reflectivity region. The nonlinear relationship is detailed below.



Nonlinear Reflectivity Mapping 1# (Continued on the Next Page)

Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
0	0	20	0.67	40	2.69	60	5.9
1	0.01	21	0.75	41	2.81	61	6.1
2	0.02	22	0.81	42	2.94	62	6.3
3	0.03	23	0.87	43	3.07	63	6.5
4	0.04	24	0.95	44	3.21	64	6.7
5	0.05	25	1.05	45	3.36	65	6.9
6	0.08	26	1.15	46	3.5	66	7.1
7	0.11	27	1.25	47	3.64	67	7.3
8	0.13	28	1.35	48	3.79	68	7.5
9	0.15	29	1.45	49	3.93	69	7.7
10	0.19	30	1.55	50	4.08	70	7.9
11	0.23	31	1.65	51	4.25	71	8.12
12	0.26	32	1.75	52	4.42	72	8.37
13	0.29	33	1.85	53	4.58	73	8.62
14	0.34	34	1.95	54	4.75	74	8.87
15	0.39	35	2.06	55	4.92	75	9.1
16	0.44	36	2.19	56	5.1	76	9.3
17	0.5	37	2.31	57	5.3	77	9.5
18	0.56	38	2.44	58	5.5	78	9.7
19	0.61	39	2.56	59	5.7	79	9.9

Nonlinear Reflectivity Mapping 1# (Continued on the Next Page)

Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
80	10.17	100	15.87	120	22.83	140	31.17
81	10.5	101	16.17	121	23.25	141	31.5
82	10.83	102	16.5	122	23.75	142	31.83
83	11.12	103	16.83	123	24.17	143	32.25
84	11.37	104	17.17	124	24.5	144	32.75
85	11.62	105	17.5	125	24.83	145	33.25
86	11.87	106	17.83	126	25.25	146	33.75
87	12.12	107	18.17	127	25.75	147	34.25
88	12.37	108	18.5	128	26.17	148	34.75
89	12.62	109	18.83	129	26.5	149	35.25
90	12.87	110	19.17	130	26.83	150	35.75
91	13.17	111	19.5	131	27.25	151	36.25
92	13.5	112	19.83	132	27.75	152	36.75
93	13.83	113	20.25	133	28.17	153	37.25
94	14.17	114	20.75	134	28.5	154	37.75
95	14.5	115	21.17	135	28.83	155	38.25
96	14.83	116	21.5	136	29.25	156	38.75
97	15.12	117	21.83	137	29.75	157	39.17
98	15.37	118	22.17	138	30.25	158	39.5
99	15.62	119	22.5	139	30.75	159	39.83

Nonlinear Reflectivity Mapping 1# (Continued on the Next Page)

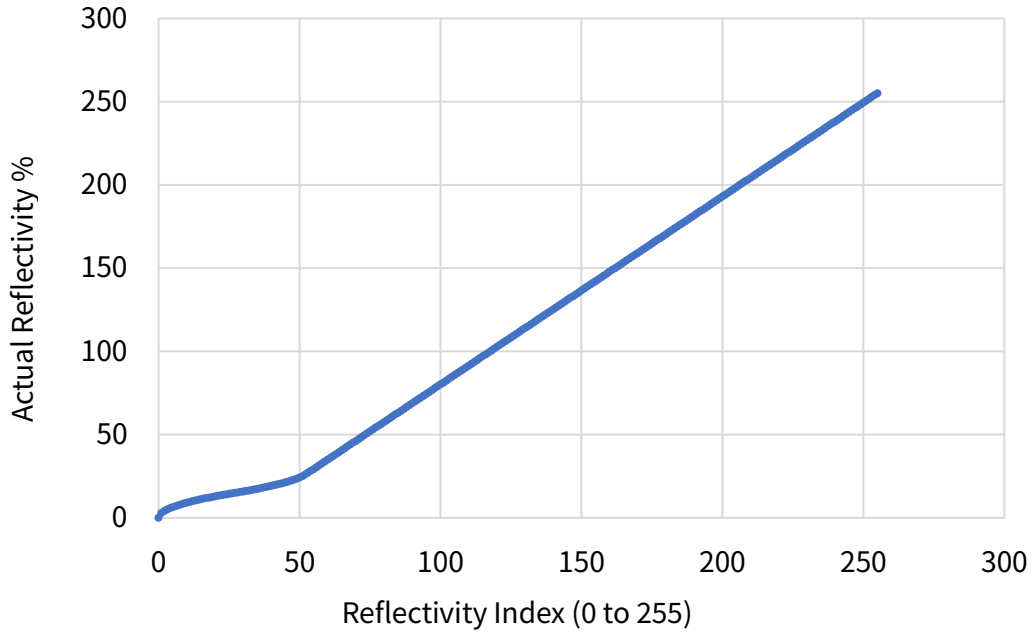
Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
160	40.5	180	51.25	200	63.25	220	76.5
161	41.25	181	51.75	201	63.75	221	77.25
162	41.75	182	52.25	202	64.5	222	77.75
163	42.25	183	52.75	203	65.25	223	78.5
164	42.75	184	53.5	204	65.75	224	79.25
165	43.25	185	54.25	205	66.25	225	79.75
166	43.75	186	54.75	206	66.75	226	80.5
167	44.25	187	55.25	207	67.5	227	81.25
168	44.75	188	55.75	208	68.25	228	81.75
169	45.25	189	56.5	209	68.75	229	82.5
170	45.75	190	57.25	210	69.5	230	83.5
171	46.25	191	57.75	211	70.25	231	84.25
172	46.75	192	58.25	212	70.75	232	84.75
173	47.25	193	58.75	213	71.5	233	85.5
174	47.75	194	59.5	214	72.25	234	86.5
175	48.25	195	60.25	215	72.75	235	87.25
176	48.75	196	60.75	216	73.5	236	87.75
177	49.5	197	61.25	217	74.25	237	88.5
178	50.25	198	61.75	218	74.75	238	89.25
179	50.75	199	62.5	219	75.5	239	89.75

Nonlinear Reflectivity Mapping 1# (Continued)

Reflectivity Index (0 to 255)	Reflectivity (%)
240	90.5
241	91.5
242	92.5
243	93.25
244	93.75
245	94.5
246	95.5
247	96.25
248	96.75
249	97.5
250	98.5
251	99.5
252	132
253	196
254	242

■ **Nonlinear Mapping 2#**

This mapping increases the resolution of low-reflectivity objects, especially lane markings. The nonlinear relationship is detailed below.



Nonlinear Reflectivity Mapping 2# (Continued on the Next Page)

Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
0	0	20	12.91	40	19.2	60	34.99
1	2.89	21	13.23	41	19.59	61	36.12
2	4.08	22	13.54	42	20	62	37.25
3	5	23	13.84	43	20.43	63	38.37
4	5.77	24	14.14	44	20.87	64	39.5
5	6.45	25	14.43	45	21.34	65	40.63
6	7.07	26	14.72	46	21.84	66	41.76
7	7.64	27	15	47	22.36	67	42.89
8	8.16	28	15.28	48	22.93	68	44.02
9	8.66	29	15.57	49	23.55	69	45.15
10	9.13	30	15.86	50	24.23	70	46.28
11	9.57	31	16.16	51	25	71	47.4
12	10	32	16.46	52	25.92	72	48.53
13	10.41	33	16.77	53	27.09	73	49.66
14	10.8	34	17.09	54	28.22	74	50.79
15	11.18	35	17.42	55	29.35	75	51.92
16	11.55	36	17.75	56	30.47	76	53.05
17	11.9	37	18.1	57	31.6	77	54.18
18	12.25	38	18.45	58	32.73	78	55.3
19	12.58	39	18.82	59	33.86	79	56.43

Nonlinear Reflectivity Mapping 2# (Continued on the Next Page)

Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
80	57.56	100	80.14	120	102.71	140	125.28
81	58.69	101	81.26	121	103.84	141	126.41
82	59.82	102	82.39	122	104.97	142	127.54
83	60.95	103	83.52	123	106.09	143	128.67
84	62.08	104	84.65	124	107.22	144	129.8
85	63.21	105	85.78	125	108.35	145	130.93
86	64.33	106	86.91	126	109.48	146	132.05
87	65.46	107	88.04	127	110.61	147	133.18
88	66.59	108	89.16	128	111.74	148	134.31
89	67.72	109	90.29	129	112.87	149	135.44
90	68.85	110	91.42	130	114	150	136.57
91	69.98	111	92.55	131	115.12	151	137.7
92	71.11	112	93.68	132	116.25	152	138.83
93	72.23	113	94.81	133	117.38	153	139.95
94	73.36	114	95.94	134	118.51	154	141.08
95	74.49	115	97.07	135	119.64	155	142.21
96	75.62	116	98.19	136	120.77	156	143.34
97	76.75	117	99.32	137	121.9	157	144.47
98	77.88	118	100.45	138	123.02	158	145.6
99	79.01	119	101.58	139	124.15	159	146.73

Nonlinear Reflectivity Mapping 2# (Continued on the Next Page)

Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)	Reflectivity Index (0 to 255)	Reflectivity (%)
160	147.86	180	170.43	200	193	220	215.58
161	148.98	181	171.56	201	194.13	221	216.7
162	150.11	182	172.69	202	195.26	222	217.83
163	151.24	183	173.81	203	196.39	223	218.96
164	152.37	184	174.94	204	197.52	224	220.09
165	153.5	185	176.07	205	198.65	225	221.22
166	154.63	186	177.2	206	199.77	226	222.35
167	155.76	187	178.33	207	200.9	227	223.48
168	156.88	188	179.46	208	202.03	228	224.6
169	158.01	189	180.59	209	203.16	229	225.73
170	159.14	190	181.72	210	204.29	230	226.86
171	160.27	191	182.84	211	205.42	231	227.99
172	161.4	192	183.97	212	206.55	232	229.12
173	162.53	193	185.1	213	207.67	233	230.25
174	163.66	194	186.23	214	208.8	234	231.38
175	164.79	195	187.36	215	209.93	235	232.51
176	165.91	196	188.49	216	211.06	236	233.63
177	167.04	197	189.62	217	212.19	237	234.76
178	168.17	198	190.74	218	213.32	238	235.89
179	169.3	199	191.87	219	214.45	239	237.02

Nonlinear Reflectivity Mapping 2# (Continued)

Reflectivity Index (0 to 255)	Reflectivity (%)
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 IV Legal Notice

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Hesai Product Warranty Service Manual is on the Warranty Policy page of Hesai's official website: https://www.hesaitech.com/warranty-policy/

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