USER'S MANUAL AND
PROGRAMMING GUIDE

VLP-16

Velodyne LiDAR Puck

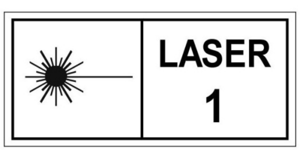
Caution

To reduce the risk of electric shock and to avoid violating the warranty, do not open sensor body. Refer servicing to qualified service personnel.

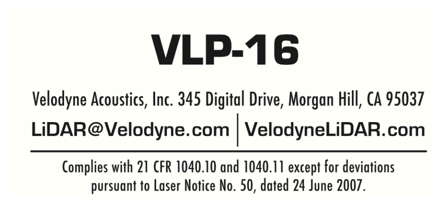
The lightning flash with arrowhead symbol is intended to alert the user to the presence of uninsulated "dangerous voltage" within the product's enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.

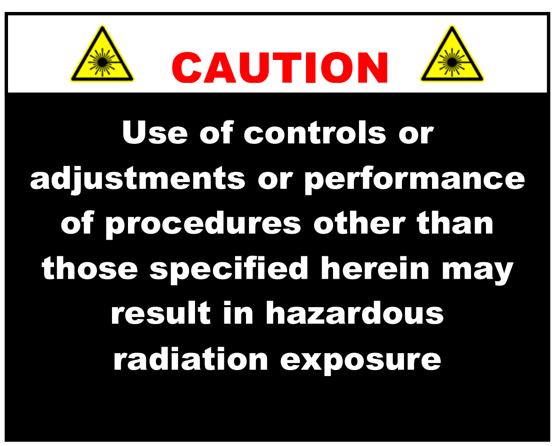
The exclamation point symbol is intended to alert the user to the presence of important operating and maintenance (servicing) instructions in the literature accompanying the product.

1. **Read Instructions** – All safety and operating instructions should be read before the product is operated.
2. **Retain Instructions** – The safety and operating instructions should be retained for future reference.
3. **Heed Warnings** – All warnings on the product and in the operating instructions should be adhered to.
4. **Follow Instructions** – All operating and use instructions should be followed.
5. **Servicing** – The user should not attempt to service the product beyond what is described in the operating instructions. All other servicing should be referred to Velodyne.



Complies with IEC 60825-1





Congratulations on your purchase of a Velodyne VLP-16 Real-Time 3D LiDAR Sensor. This sensor provides state-of-the-art 3D imaging in real time.

This manual describes how to set up and operate the VLP-16. It covers installation and wiring, output packet format and interpretation, and GPS installation notes.

This manual is undergoing constant revision and improvement – check www.velodynelidar.com for updates.

The VLP-16 creates 360º 3D images by using 16 laser/detector pairs mounted in a compact housing. The housing rapidly spins to scan the surrounding environment.

The lasers fire thousands of times per second, providing a rich, 3D point cloud in real time.

Advanced digital signal processing and waveform analysis provide high accuracy, extended distance sensing, and calibrated reflectivity data.

Unique features include:

- Horizontal Field of View (FOV) of 360°
- Rotational speed of 5-20 rotations per second (adjustable)
- Vertical Field of View (FOV) of 30°
- Returns of up to 100 meters (useful range depends on application)

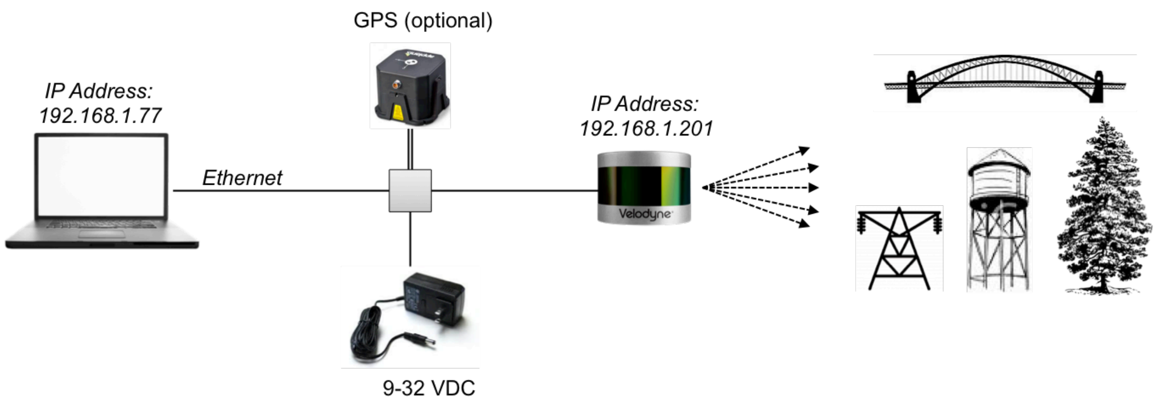


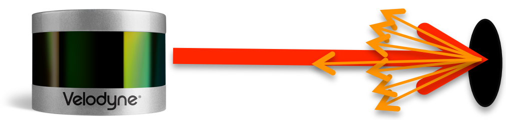
Figure 1. Overview of the LiDAR VLP-16 3D Imaging System

Calibrated Reflectivities

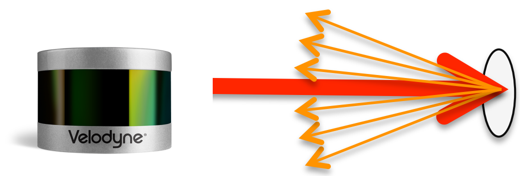
The VLP-16 measures the reflectivity of an object with 256-bit resolution independent of laser power and distance over a range from 1m to 100m. Commercially available reflectivity standards and retro-reflectors are used for the absolute calibration of the reflectivity, which is stored in a calibration table within the FPGA of the VLP-16.

- Diffuse reflectors report values from 0-100 for reflectivities from 0% to 100%.
- Retro-reflectors report values from 101 to 255 with 255 being the reported reflectivity for an ideal retro-reflector and 101-254 being the reported reflectivity for partially obstructed or imperfect retro-reflectors.

Diffuse Reflector

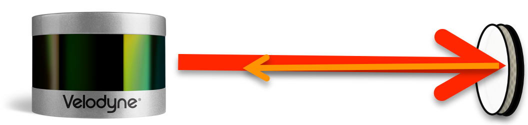


Black, absorbent diffuse reflector
(value 0)

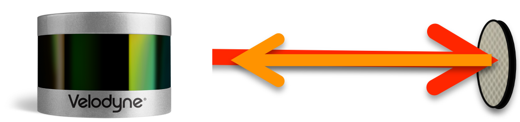


White, reflective diffuse reflector
(value 100)

Retro-Reflector:



Retro-reflector covered with semi-transparent white surface (value 101)



Retro-reflector without any coverage
(value 255)

Figure 2. Reflector Types

Return Modes

Due to the laser's beam divergence, a single laser firing often hits multiple objects producing multiple returns. The VLP-16 analyzes multiple returns and reports either the strongest return, the last return, or both returns.

In the illustration below, the majority of the beam hits the near wall while the remainder of the beam hits the far wall. The VLP-16 will record both returns only if the distance between the two objects is greater than 1m.

In the event that the strongest return is the last return, the second-strongest return is reported.

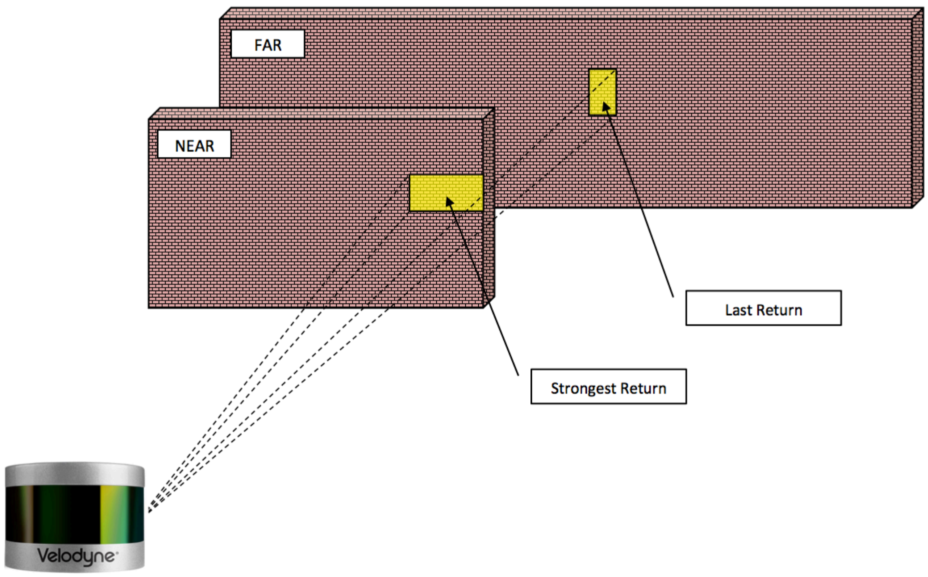


Figure 3. Return Modes

The dual return function is often used in forestry applications where the user needs to determine the height of the trees. The figure below illustrates what happens when the laser spot hits the outer canopy, penetrates the leaves and branches, and eventually hits the ground.

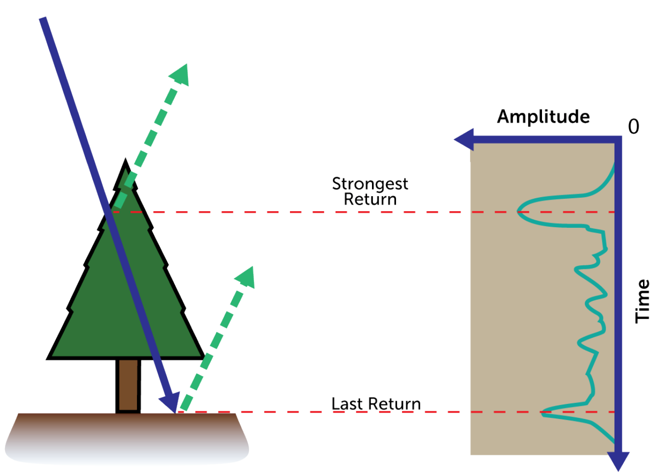


Figure 4a. Dual Returns Example 1

VeloView is able to display dual return data. *Figure 4b* below has two good examples of dual return data.

In this test area, the VLP-16 gets returns from the vinyl weather curtain (see inserted image) as well as from objects inside the building.

Additionally, you can see where the beam is split on the edge of the loading dock. The blue lines indicate the portion of the beam that hit the loading dock while the red lines indicate the portion of the beam that hit the ground beyond the loading dock.

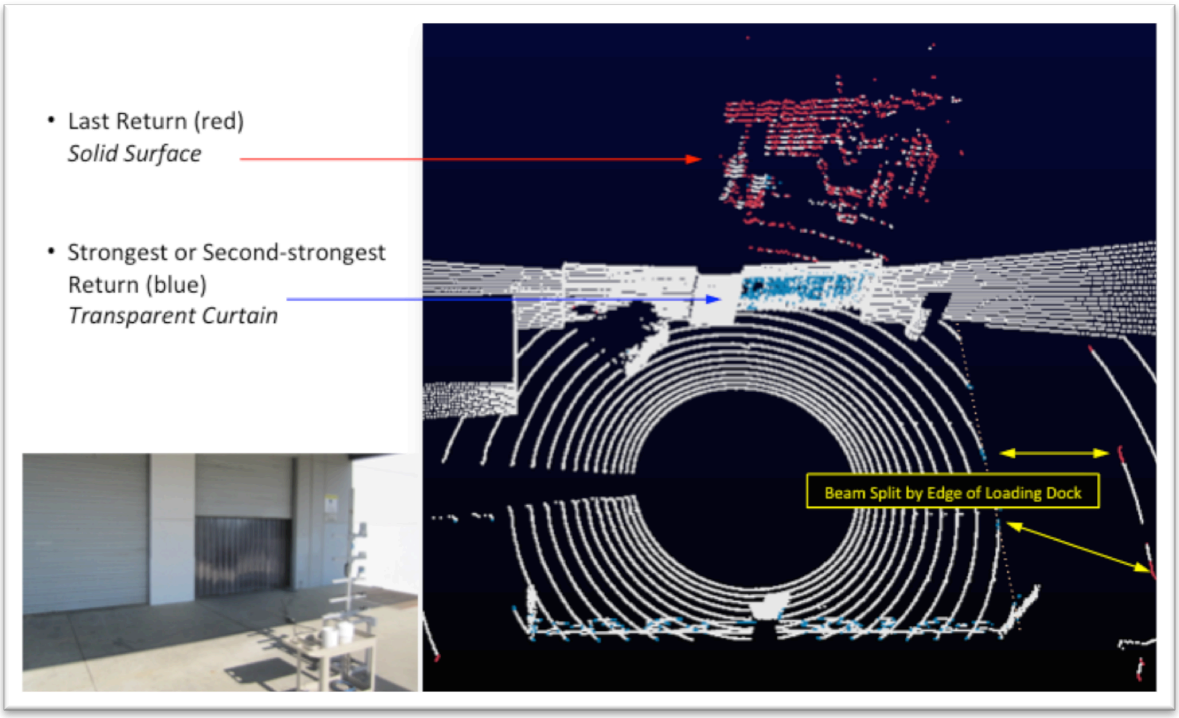


Figure 4b. Dual Returns Example 2

In dual return mode, the data rate of the sensor doubles. Data rates for the two modes are given below:

Mode	Packets/Second	Megabits/Second
Strongest	754	~ 8
Last	754	~ 8
Dual	1508	~ 16

Table 1. Dual Return Data Rates

The return mode is selected in the webserver user interface (Appendix C). In the screenshot below the **Strongest** return is selected. The other options are **Last** and **Dual**.

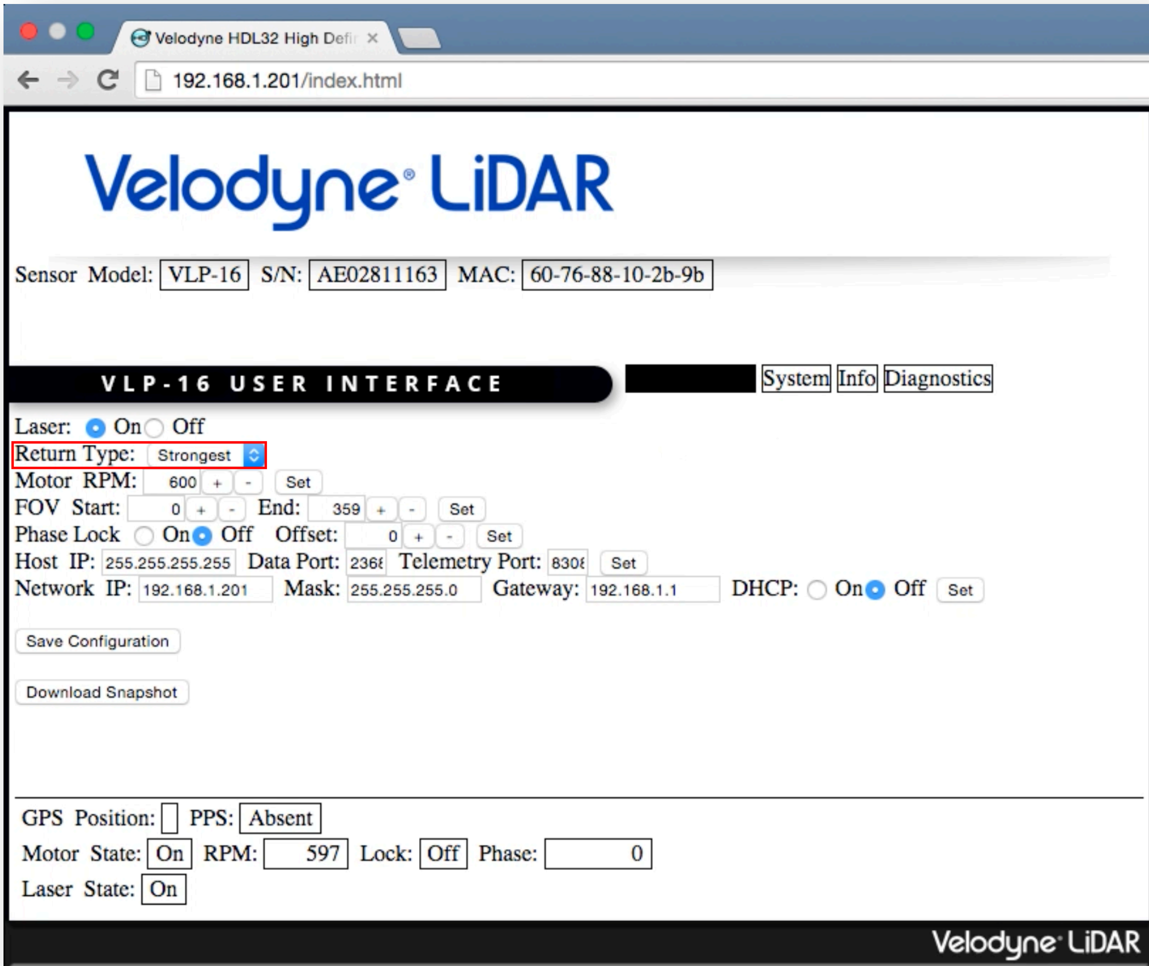


Figure 5. Selecting Return Type

This section describes the usual standard set up of the sensor assuming you are connecting the sensor to a standard computer or laptop and mounting the sensor on a vehicle. For other connections and mounting locations, please contact Velodyne for technical assistance.

A video showing the set-up of the VLP-16 in an office environment is available at:
https://www.youtube.com/watch?v=wUfHadExvs8

The standard setup involves:

1. Unpacking the shipping case contents.
2. Securely mounting the sensor to a vehicle or other scanning platform.
3. Connecting power to the sensor.
4. Connecting the sensor's data output to the computer.

Case Contents

The shipping case contains:

- VLP-16 sensor unit with ~3 meter cable terminated at an interface box
- Desktop AC/DC power adapter (North American plug)
- 6' AC cord
- Ethernet cable (1 meter)
- USB memory stick with:
    - User manual (check www.velodynelidar.com for updates)
    - Sample data sets and miscellaneous documents
    - VeloView (free, open source viewing and recording software)

Mounting

The sensor base provides one ¼-20 threaded, 9/32" deep mounting hole and two precision locating holes for dowel pins. The sensor can be mounted at any angle/orientation.

- The unit is weatherproofed to withstand wind, rain and other adverse weather conditions. Refer to the specifications page for operational and storage temperature ranges.
- Be sure the unit is mounted securely to withstand vibration and shock without risk of detachment. The unit does not need shock proofing. The unit is designed to withstand automotive G-forces; (500 m/sec^2 amplitude, 11 msec duration shock and 3G rms 5 Hz to 2000 Hz vibration).

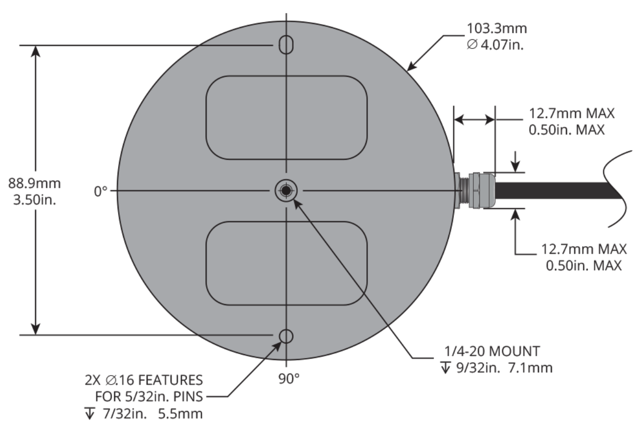


Figure 6. VLP-16 Base

Connections

The VLP-16 comes with an integral cable that is terminated at an interface box. The cable is approximately 3 meters (10') in length and is permanently attached at the sensor, but it may be removed from the interface box for ease of cable routing, direct wiring, and/or inserting in-line connector(s). The interface box provides connections for power, Ethernet, and GPS inputs. For more information on the interface box, see Appendix B.

Power

The 2.1 mm barrel plug jack fits in the included AC/DC power adapter. The center pin is positive polarity.

> ***Note:*** The VLP-16 does not have a power switch. It spins and operates approximately 5s after power has been applied.

The VLP-16 requires 8 watts of power and is commonly used in vehicle applications where standard 12 volt, 2 amp power is readily available.

1. Connect the interface box.
2. Connect to the Ethernet port of any standard computer.

> ***Note*:** Before operating the sensor, make sure that:
> - The sensor is securely mounted
> - Power is applied in the correct polarity

Ethernet

The standard RJ45 Ethernet connector connects to any standard computer.

IP Address: The IP address for each VLP-16 is set at the factory to 192.168.1.201, but can be changed by the user via the WebServer GUI. For details on how to connect to the webserver GUI, see Appendix C.

MAC address: Each VLP-16 has a unique MAC address that is defined by Velodyne and cannot be changed.

Serial Number: Each VLP-16 has a unique serial number that is defined by Velodyne and cannot be changed.

> ***Note:*** The VLP-16 is only compatible with network cards that have either MDI or AUTO MDIX capability.

GPS

The VLP-16 can synchronize its data with precision, GPS-supplied time pulses enabling users to determine the exact firing time of each laser.

External synchronization requires a user supplied GPS receiver generating a synchronization Pulse Per Second (PPS) signal and a NMEA $GPRMC message (Appendix B). The $GPRMC message provides minutes and seconds in Coordinated Universal Time. Upon synchronization, the sensor will read the minutes and seconds from the $GPRMC message and use that to set the sensor's time stamp to the number of microseconds past the hour per UTC time. Synchronizing the VLP-16's timestamps to UTC allows third party software to easily geo-reference the LiDAR data into a point cloud.

GPS Receiver Option 1: User Supplied GPS Receiver

The user must configure their GPS device to issue a once-a-second synchronization pulse (PPS, 0-5V, rising edge), typically output over a dedicated wire, and issue a once-a-second NMEA standard $GPRMC sentence. No other output message from the GPS will be accepted by the VLP-16.

Note: The $GPRMC sentence can be configured for either hhmmss format or hhmmss.s format.

The GPS signals can be wired directly to the screw-terminal inside the interface box. If you wish to wire your own GPS receiver, unscrew the top of the interface box and refer to the labeled screw terminal connector on the circuit card (Appendix B).

GPS Receiver Option 2: Velodyne Supplied GPS Receiver

A consumer grade Garmin GPS receiver that is pre-programmed by Velodyne is available for purchase by VLP-16 users. This receiver is pre-wired with a connector that plugs into the VLP-16 interface box, and it is pre-programmed to output the correct $GPRMC sentence and PPS synchronization pulse. Contact Velodyne for current pricing and order part number "92-GPS18LVC."

Figure 7. Interface Box

Using the Sensor

The VLP-16 sensor needs no configuration, calibration, or other setup to begin producing usable data. Once the unit is mounted and wired, supplying power initiates scanning and the delivery of data. The quickest way to watch the VLP-16 in action is to use VeloView, the open-source viewer software (https://github.com/Kitware/VeloView) included with the unit. VeloView reads the packets from the VLP-16 via the Ethernet connection, performs the necessary calculations to determine point locations, then plots the points in 3D on the viewer's computer. This is the recommended starting point for new users. You can observe both distance and intensity data through VeloView. For more information on VeloView, see Appendix E.

Most users will elect to create their own application-specific point cloud tracking and plotting and/or storage scheme. There are several fundamental steps to this process:

1. Establish communication with the VLP-16
2. Parse the data packets for rotational angle, measured distance, and reported calibrated reflectivities
3. Calculate X, Y, Z coordinates from reported rotational angle, measured distance, and vertical angle dependent on laser ID
4. Plot or store the data as needed

Each of these steps is described in detail below:

1. **Establish communication with the VLP-16.**
   The VLP-16 outputs two separate broadcast UDP packets. By using a network monitoring tool such as Wireshark (https://www.wireshark.org/download.html) you can capture and observe the packets as they are generated by the unit.

2. **Parse the data packets for rotational angle, measured distance, and reported calibrated reflectivities.**
   Your software needs to read the data packet from the Ethernet port, and extract the azimuth, elevation angle, distance to the object, and time stamp. Once the data is identified, proceed to the next step. See Data Packet Format in Appendix A.

3. **Calculate X, Y, Z coordinates from reported data.**
   The VLP-16 reports coordinates in spherical coordinates (r, ω, α). Consequently, a transformation is necessary to convert to XYZ coordinates. The vertical/elevation angle (ω) is fixed and is given by the Laser ID (Appendix A). The position of the return in the data packet indicates the Laser ID. The horizontal angle/azimuth (α) is reported at the beginning of every other firing sequence, and the distance is reported in the two distance bytes. With this information X, Y, Z coordinates can be calculated for each measured point. Points with distances less than one meter should be ignored. The conversion is shown in *Figure 8* on the following page.

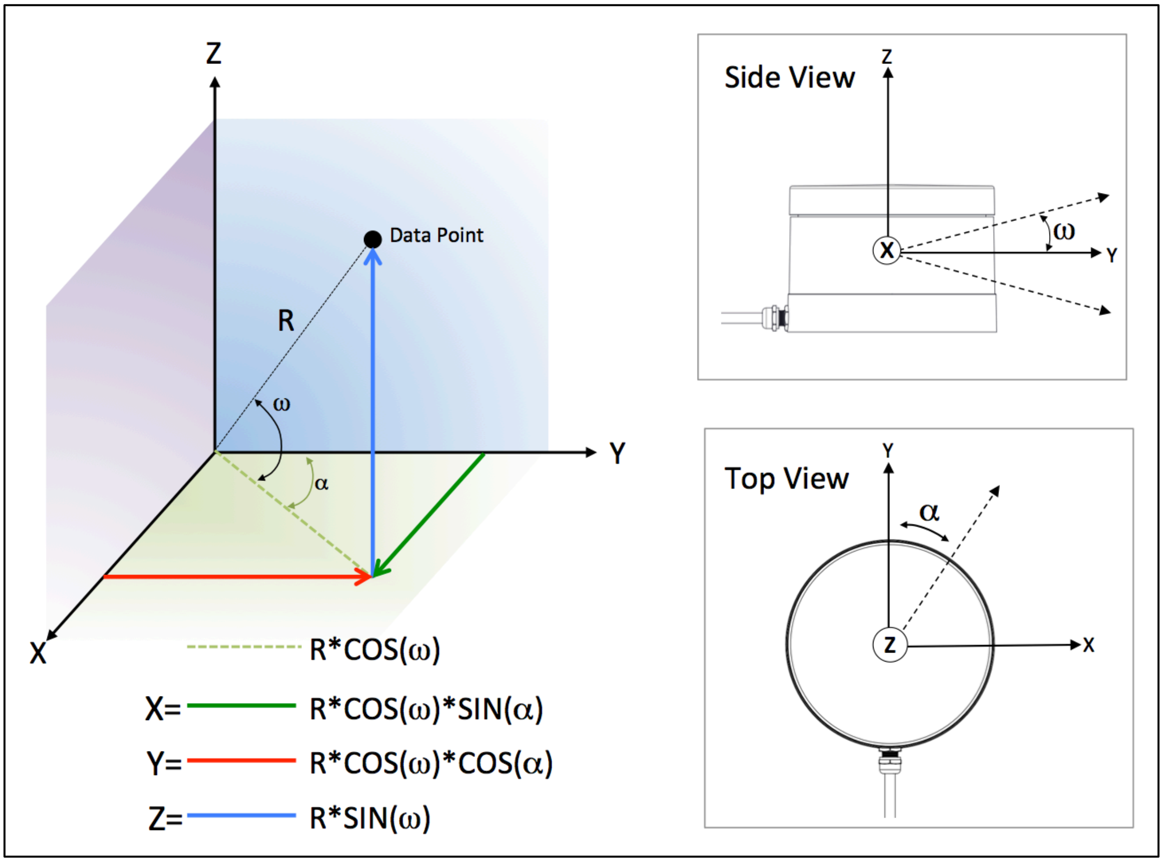


Figure 8. Spherical to XYZ Conversion

4. **Plot or store the data as needed**
   The calculated X, Y, Z data is typically stored for later processing and/or it is displayed on a computer as a series of point clouds.

   Note: The VLP-16 has the capability to synchronize its data with GPS precision time via a Pulse Per Second (PPS) signal from a GPS receiver. A synchronized timestamp from the VLP-16 sensor may be used to match the data stream from the sensor with the data stream from the attached external GPS receiver and/or Inertial Measurement Unit (IMU).

Data Packet Format

The VLP-16 outputs two types of UDP Ethernet packets: Data Packets and Position Packets.

The Data Packet is comprised of the laser return values, calibrated reflectivity values, azimuth values, a time stamp, and two factory bytes indicating the sensor model and the return mode (Strongest, Last, and Dual). The data packet is 1248 bytes long and is sent on port 2368.

Each VLP-16 data packet consists of a 42 byte header and a 1206 byte payload containing twelve blocks of 100-byte data records. The data is followed by a four-byte time stamp data and two factory bytes. The data packet is then combined with status and header data in a UDP packet and transmitted over the Ethernet.

The firing data is assembled into the packets in the firing order, with **multi-byte values - azimuth, distance, timestamp - transmitted least significant byte first**.

The basic form of the data packet is shown below.

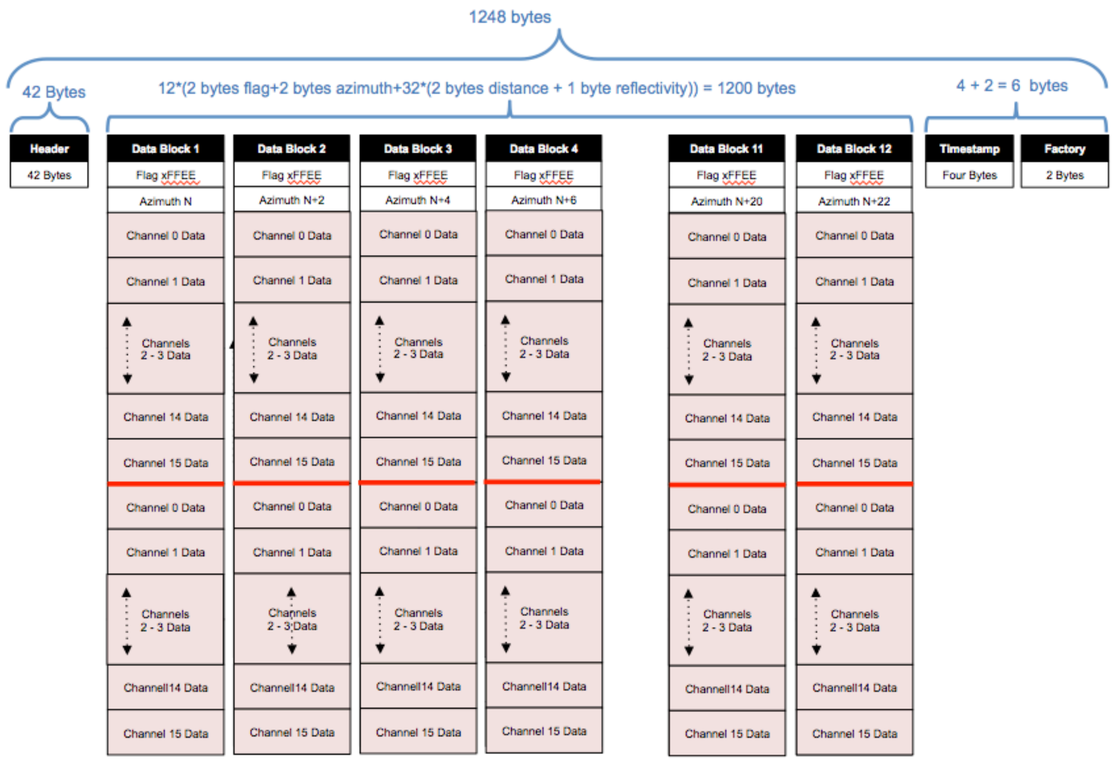


Figure 9a. Data Packet

Each data block begins with a two-byte start identifier "FF EE", then a two-byte azimuth value (rotational angle), followed by 32x 3-byte data records.

Azimuth Value

The reported azimuth is associated with the first laser shot in each collection of 16 laser shots. However, only every other encoder angle is reported for alternate firing sequences. The user can choose to interpolate that missing encoder stamp (see Appendix A).

Valid values for the azimuth range from 0° to 359.99°

For example, in *Figure 10a* on page the following page, the second azimuth calculation for the second data block would be:

1) Get Azimuth Values: 0x33 & 0x71
2) Reverse the bytes: 0x71 & 0x33
3) Combine the bytes into a two-byte, unsigned integer: 0x7133
4) Convert to decimal: 28,979
5) Divide by 100
6) Result: 289.79°

Hence value of the azimuth for the first laser firing the second data block is 289.79°

> ***Note***: The zero degree position on the sensor is directly opposite the cable connection (Appendix F).

Data Record

Each three-byte data record consists of two distance bytes and a calibrated reflectivity byte.

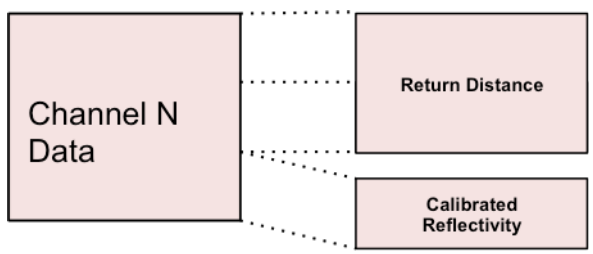


Figure 9b. Data Record

The distance and reflectivity data are collected in the same staggered order in which the lasers are fired. (see Appendix A). Distance to an object is reported in the first two of the three bytes in a data record. The Calibrated Reflectivity value is reported in the third of the three bytes. The distance is reported to the nearest 2.0mm, meaning that the unsigned integer value given by the two distance bytes needs to be multiplied by 2.0mm to calculate the absolute distance to the object.

The Calibrated Reflectivity value is defined on a scale from 0-255. Refer to the Calibrated Reflectivities section on page 3 for further details.

Below is the first part of a sample packet as displayed in Wireshark.

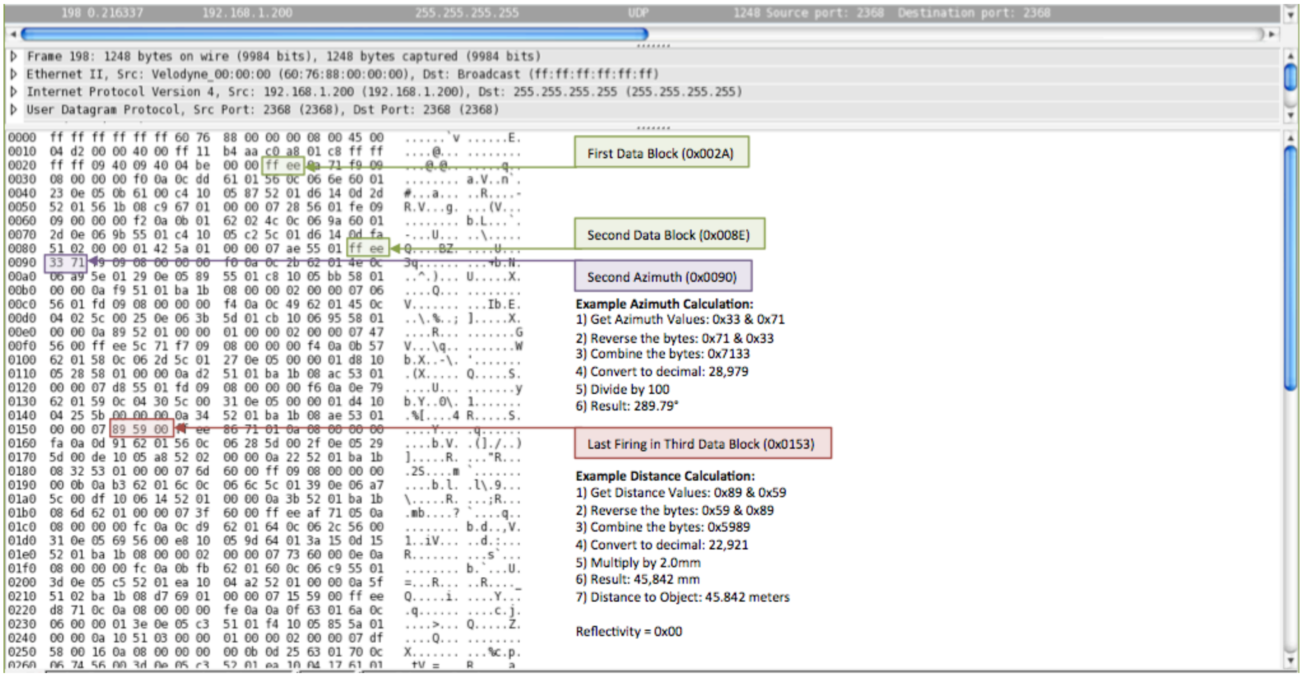


Figure 10a. Sample Packet 1

Below is the last part of a sample packet as displayed in Wireshark. Calculation of the timestamp and interpretation of the Factory Bytes are shown.

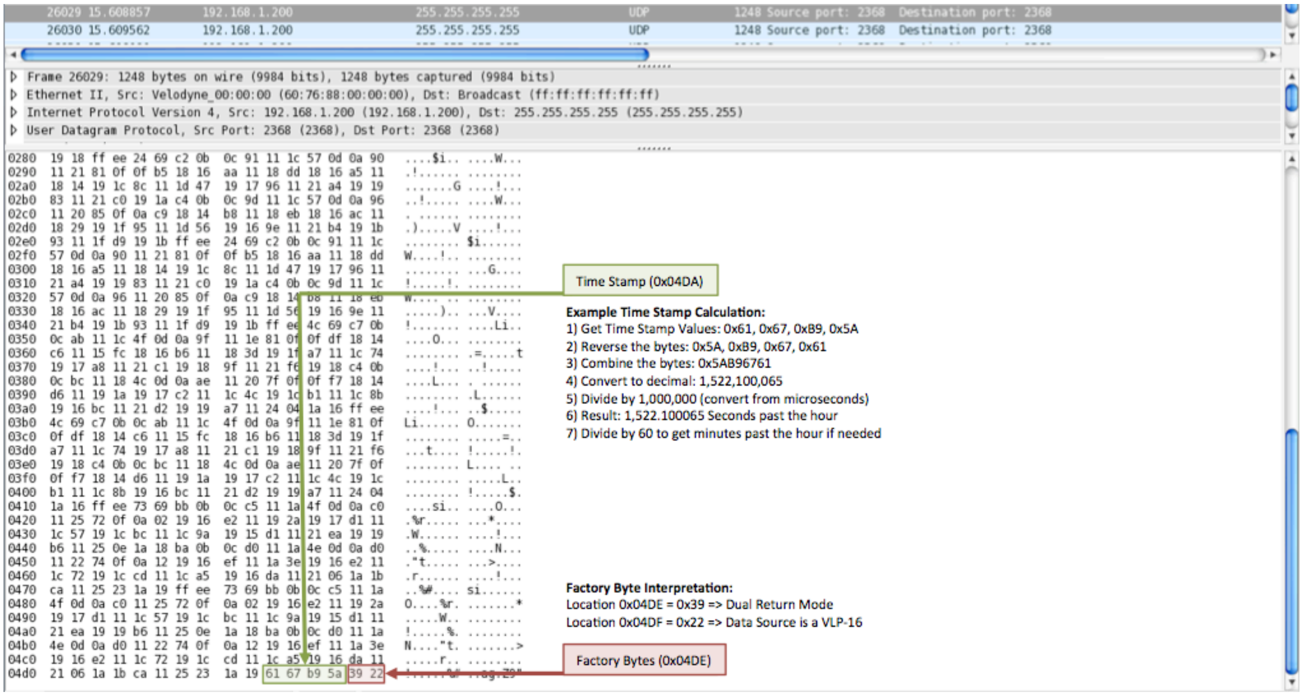


Figure 10b. Sample Packet 2

For further information regarding the packet structure see Appendix A.

Time Stamp

The four-byte time stamp is a 32-bit unsigned integer. This value represents microseconds from the top of the hour to the first laser firing in the packet. The number ranges from 0 to 3600×10^6 μs (the number of microseconds in one hour). The time stamp represents the time of the first shot of the first firing sequence. **The time stamp, like the reported distance, are transmitted least significant byte first.**

All sixteen lasers are fired and recharged every 55.296μs. The cycle time between firings is 2.304μs. There are 16 firings (16 x 2.304μs) followed by a recharge period of 18.43μs. Therefore, the timing cycle to fire and recharge 16 lasers is given by ((16 x 2.304μs) + (1 x 18.43μs)) = 55.296μs

There are 24 of these 16-laser firing groups per packet, hence, it takes 1.33ms to accumulate one data packet. This implies a data rate of 754 data packets/second (1/1.33ms).

The GPS timestamp feature is used to determine the exact firing time for each laser. This allows users to properly time-align the VLP-16 data points with the pitch, roll, yaw, latitude, longitude, and altitude data from a GPS/Inertial measurement system.

Time Stamping Accuracy

The following rules and subsequent accuracy apply for GPS time stamping.

1. When the VLP-16 powers up it runs on its own internal clock, and it begins issuing timestamps in microseconds beginning from zero. Expect a drift of about 5 seconds per day under this method.
2. When a GPS is connected and synchronized, the NMEA $GPRMC sentence is reported in the position packet as described in Appendix B. GPS time synching runs in one of two modes:

    a. When the GPS achieves lock. The VLP-16 clock will then be within +/-50ps of the correct time at all times. The timestamp reported will be in microseconds past the hour based on the current UTC provided by the GPS.
    b. Some GPS receivers have a battery back up and will continue to supply a time code for some period (hours, days, or weeks). In this instance the accuracy is as good as the back up clock in the GPS.

If the GPS is disconnected after synchronization the VLP-16 will continue to run its own clock and be subject to a drift of approximately 5 seconds per day.

Factory Bytes

Every VLP-16 data packet, beginning with firmware version 3.0.23, identifies the type of sensor from which the packet came and the return mode (Strongest, Last, Dual). The return mode determines how the packet should be interpreted. See *Figure 10b* on the previous page.

Field 4DEh		Field 4DFh	
Value	Meaning	Value	Meaning
37h	Strongest Return	21h	HDL-32E
38h	Last Return	22h	VLP-16
39h	Dual Return		

Table 2. Factory Byte

The Position Packet

The position packet is provided so the user can verify that the VLP-16 is receiving valid time updates from a GPS receiver.

The position packet is a 554 byte long UDP packet broadcasted on port 8308. It consists of:

42 byte	Ethernet header
198 bytes	Unused
4 bytes	Timestamp
4 bytes	Unused
72 byte	NMEA $GPRMC sentence
234 bytes	Unused

Table 3. Position Packet

An example $GPRMC message is shown below:

```
$GPRMC,220516,A,5133.82,N,00042.24,W,173.8,231.8,130694,004.2,W*70
         1     2    3     4     5      6     7     8       9      10   11  12

      1   220516     Time Stamp
      2   A          validity - A-ok, V-invalid
      3   5133.82    current Latitude
      4   N          North/South
      5   00042.24   current Longitude
      6   W          East/West
      7   173.8      Speed in knots
      8   231.8      True course
      9   130694     Date Stamp
      10  004.2      Variation
      11  W          East/West
      12  *70        checksum
```

The position packet returns the exact same $GPRMC message that was received from the GPS via the serial connection.

> ***Note:*** The *Validity* field in the $GPRMC message ('A' or 'V') should be checked by the user to ensure the GPS system and the VLP-16 are receiving valid Coordinated Universal Time (UTC) updates from the user's GPS receiver.

Providing timestamps in UTC allows third party software to geo-reference the LiDAR data into a point cloud. Upon synchronization, the sensor will read the minutes and seconds from the $GPRMC message and use that to set the sensor's time stamp to the number of microseconds past the hour per UTC time.

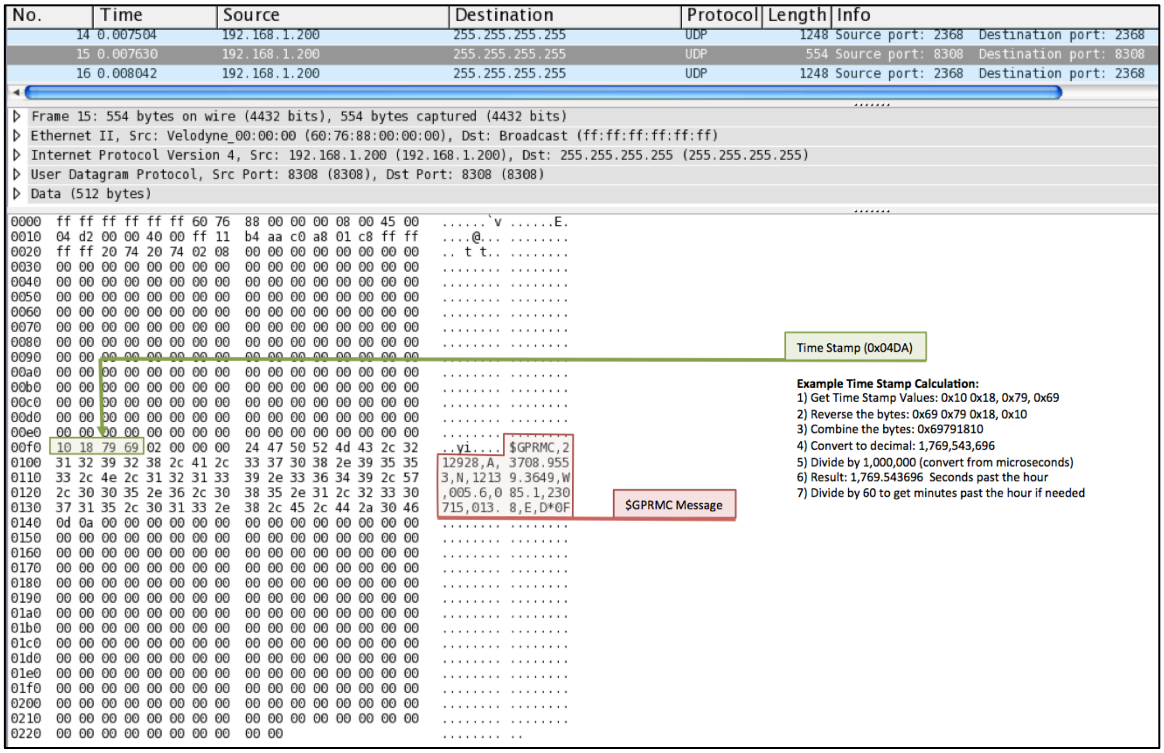


Figure 11. Position Packet

Use this chart to troubleshoot common problems with the VLP-16.

Problem	Resolution
Unit doesn't spin	Verify power connection and polarity. Verify proper voltage – should be between 9 and 32 volts drawing a minimum of one amp. Inspect the fuse in the interface module. Replace if necessary (3 Amp automotive fuse).
Unit spins but no data	Verify Ethernet wiring. Verify packet output using another application (e.g. Ethereall/Wireshark). Verify receiving computer's network settings. Set a static IP address in your computer's network settings. 192.168.1.77 Verify that no security software has been installed which may block Ethernet broadcasts.

Table 4. Troubleshooting

Service and Maintenance

There are no user serviceable nor maintenance requirements or procedures for the Velodyne VLP-16. Opening the sensor will void the warranty.

For service or maintenance, please contact Velodyne at +1 (408) 465-2800, or log on to our website at www.velodynelidar.com

Sensor:	• Time of flight distance measurement with calibrated reflectivities • 16 channels • Measurement range up to 100 meters • Accuracy +/- 3 cm (typical) • Dual returns • Field of view (vertical): 30° (+15° to -15°) • Angular resolution (vertical): 2° • Field of view (horizontal/azimuth): 360° • Angular resolution (horizontal/azimuth): 0.1º - 0.4º • Rotation rates: 5 - 20 Hz • Integrated web server for easy monitoring and configuration • Max altitude of operation 200 meters
Laser:	• Class 1 - eye safe • 903 nm wavelength
Mechanical/ Electrical/ Operational:	• Power consumption: 8 W (typical) • Operating voltage: 9 - 32 VDC (with interface box and regulated power supply) • Weight: 830 grams (without cabling) • Dimensions: 103 mm diameter x 72 mm height • Shock: 500 m/sec^2 amplitude, 11 msec duration • Vibration: 5 Hz to 2000 Hz, 3G rms • Environmental Protection: IP67 • Operating temperature -10° to + 60° C • Storage temperature -40° to +105° C
Output:	• Up to 0.3 million points/second • 100 Mbps Ethernet Connection • UDP packets containing - Distances - Calibrated relectivities - Rotation angles - Synchronized time stamps (µs resolution) • $GPRMC NMEA sentence from GPS receiver (GPS not included)
Wave Length	• 903 nm (min/max range is 896/910 nm)
Pulse Duration/ Repetition Rate	• 6 ns (duration) • 1.44µs * 16 lasers per pattern for a period of 46.1 µs = 21.7KHz (repetition)
Maximum Power/ Energy Output	•31 Watt (0.19 uJ)

Table 5. Specifications

Definitions

Firing Sequence

The time and/or process of cycle-firing all the lasers in a VLP-16. It takes 55.296 uSec to fire all 16 Lasers.

Laser Channel

A single 905nm Laser emitter and detector pair. Each laser channel is fixed at a particular elevation angle relative to the horizontal plane of the sensor. Each laser channel is given its own Laser ID number as shown in *Table 6*. The elevation angle of a particular laser channel is given by its location in the data packet.

Data Point

A data point is represented in the packet by three bytes - two bytes of distance and one byte of Calibrated Reflectivity.

Data Block

A data block is 100 bytes of data and consists of: A two-byte flag (xFFEE), a two-byte azimuth, and 32 Data Points. [100 = 2 + 2 + 32*3]. There are 12 data blocks in a packet, but for calculating time offsets it's recommended they be numbered 0-11.

Data Packet (1248 Bytes)

A data packet is 1248 bytes and consists of 42 bytes of header, twelve Data Blocks, a four-byte timestamp, and a two-byte factory field.

Return Modes (three choices)

The VLP-16 can be set to report either the strongest (by light energy) return, the last (temporally) default or both the strongest and last. If the strongest return is also the last return, then the second-strongest return is reported.

The information from two **Firing Sequences of 16 lasers** is contained in one **Data Block.** Each packet contains the data from 24 **firing sequences**. Only one Azimuth is returned per **Data Block**. See *Figure 12* on the following page.

Laser ID	Vertical Angle
0	-15°
1	1°
2	-13°
3	-3°
4	-11°
5	5°
6	-9°
7	7°
8	-7°
9	9°
10	-5°
11	11°
12	-3°
13	13°
14	-1°
15	15°

Table 6. Laser ID

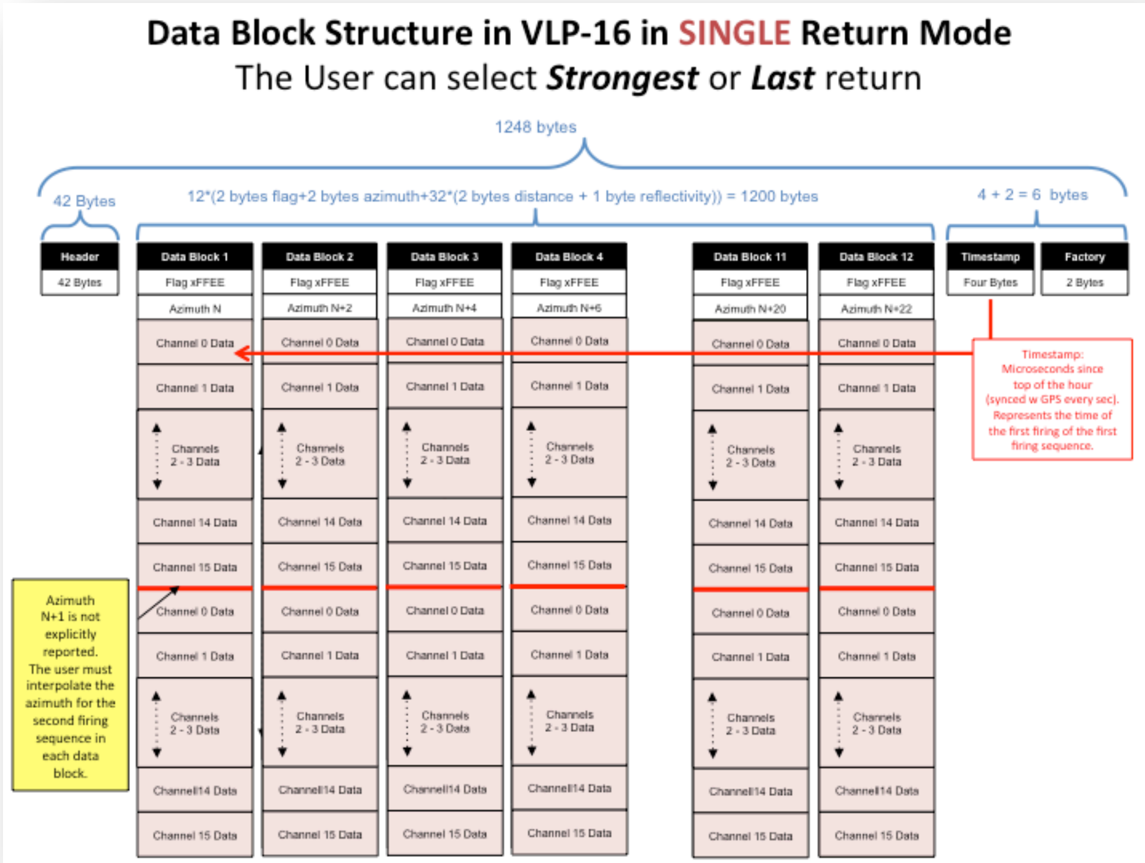


Figure 12. Data Block Structure (Single Return Mode)

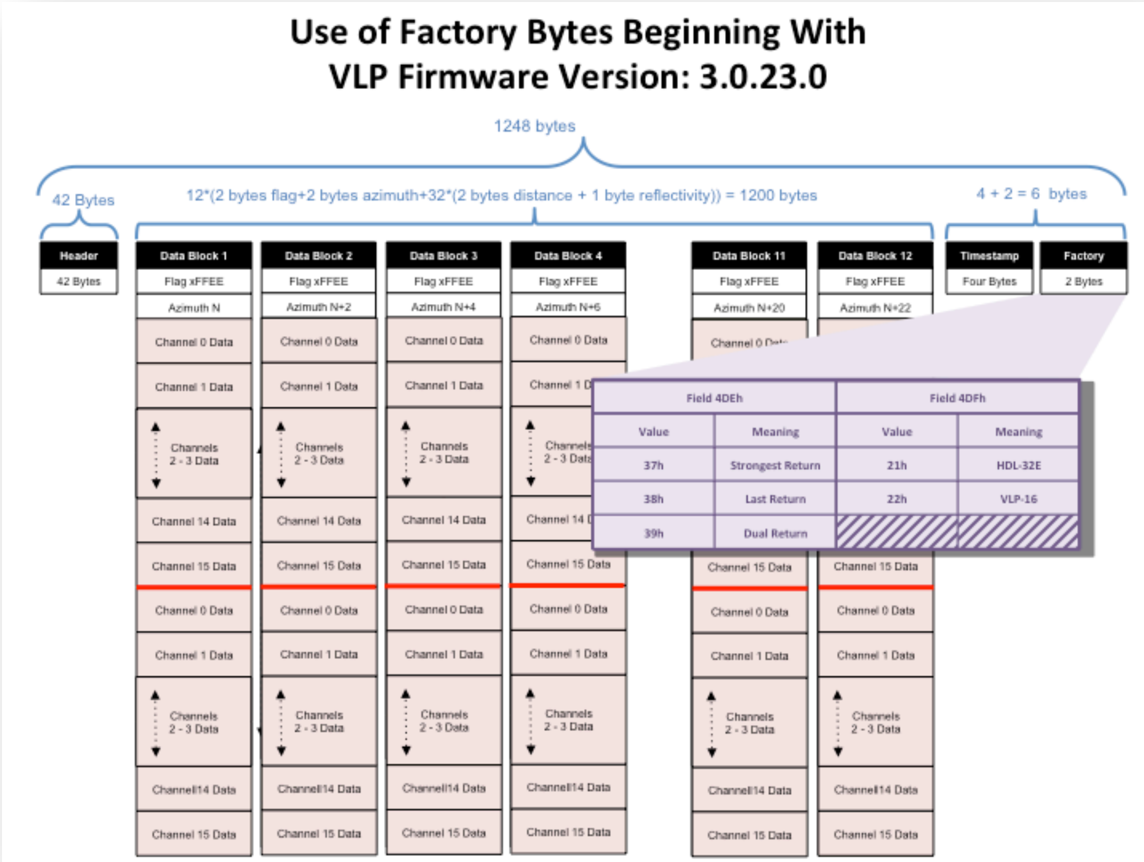


Figure 13. Factory Bytes

Beginning with firmware version 3.0.23, the factory bytes are used to indicate the current return mode and the sensor model that delivered the packet.

The addition of these fields allows the processing software to automatically determine the sensor type and return mode.

Field 4DEh		Field 4DFh	
Value	Meaning	Value	Meaning
37h	Strongest Return	21h	HDL-32E
38h	Last Return	22h	VLP-16
39h	Dual Return		

Table 2. Factory Byte

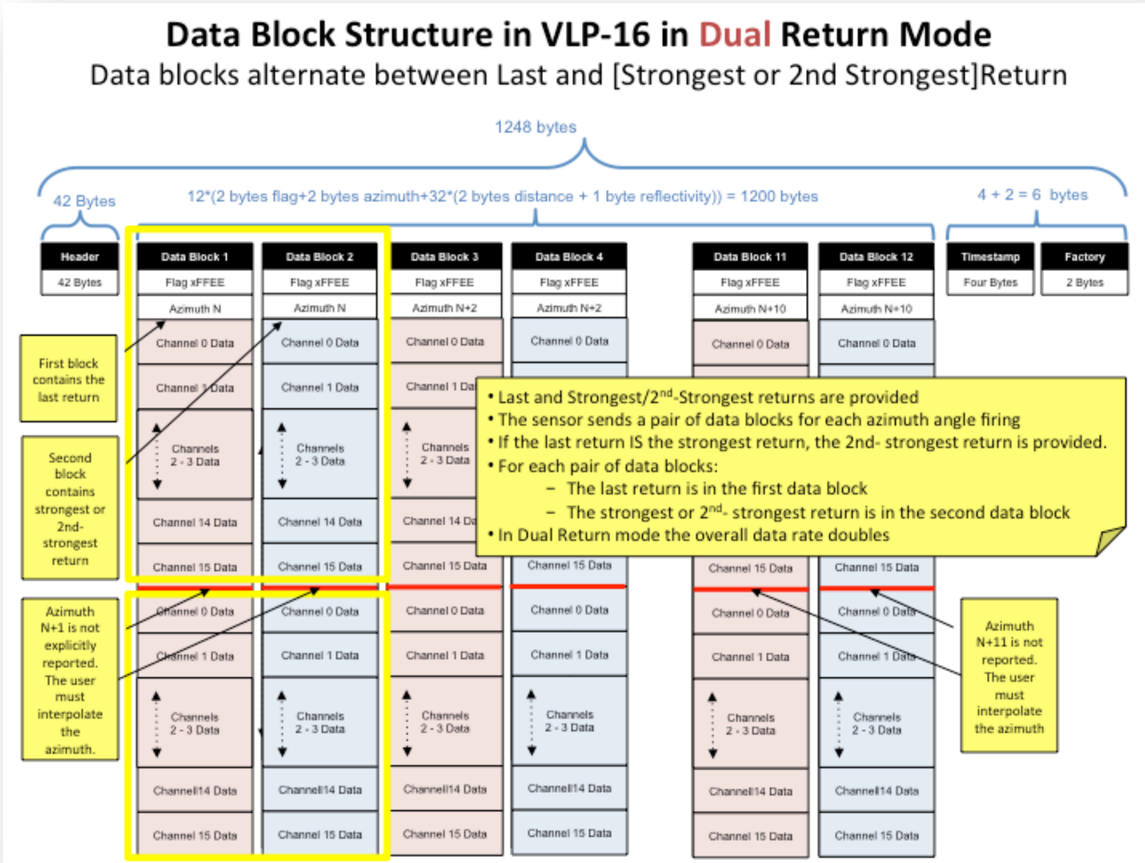


Figure 14. Data Block Structure (Dual Return Mode)

Azimuth Interpolation

Because the VLP-16 reports the azimuth value for every-other firing sequence it's helpful to interpolate the un-reported azimuth. There are several ways to interpolate the un-reported azimuth, but the one given below is simple and straight forward.

Consider a single data packet. The time between the first firing of the first set of sixteen firings (Data Block 1) and the first firing of the third set of sixteen laser firings (Data Block 2) is ~110.6μs. If you assume the rotation speed over that short interval is constant, you can assume the azimuth of the (N+1) set of sixteen laser firings is halfway between the azimuth reported with the N[th] set of 16 laser firings and the azimuth reported with the (N+2) set of laser firings.

Below is pseudo-code that performs the interpolation. The code checks to see if the azimuth rolled over from 359.99° to 0° between firing sets N and N+2.

In the example below, N=1.

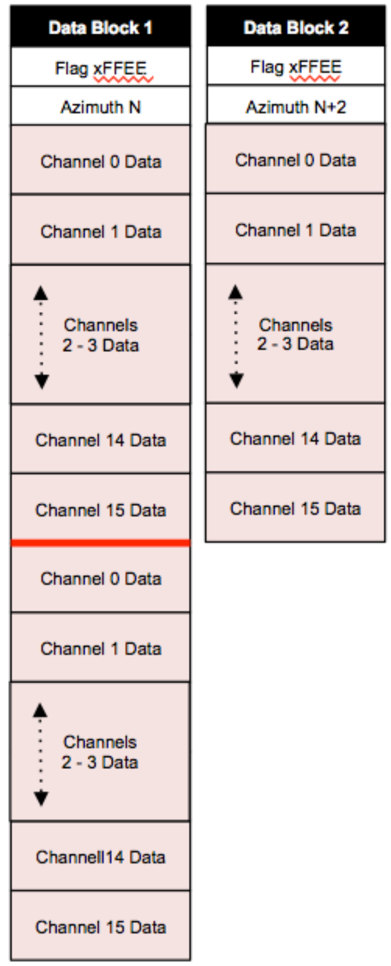


Figure 15. Azimuth Interpolation

```
//  First, adjust for a rollover from
359.99° to 0°

If (Azimuth[3] < Azimuth[1])

   Then Azimuth[3]:= Azimuth[3]+360;

Endif;

// Perform the interpolation

Azimuth[2]:=Azimuth[1]+((Azimuth[3]-Azimuth[1])/2);

// Correct for any rollover over from 359.99° to 0°

If (Azimuth[2]>360)

   Then Azimuth[2]:= Azimuth[2]-360;

Endif
```

Precise Data Point Timings

All sixteen lasers are fired and recharged every 55.296µs. The cycle time between firings is 2.304µs. There are 16 firings (16 x 2.304µs) followed by a recharge period of 18.43µs. Therefore, the timing cycle to fire and recharge all 16 lasers is given by ((16 x 2.304µs) + (1 x 18.43µs)) = 55.296µs.

To calculate the exact time in microseconds of each data point, first number the points in the firing sequence as 0-15. This becomes the data point index for your calculations. Next, number the firing sequences 0-23. This becomes your sequence index.

Because the timestamp is the time of the first data point in the packet, you need to calculate a time offset for each data point and then add that offset to the timestamp.

The offset equation is given by:

```
TimeOffset=(55.296µs * Sequence Index)+(2.304µs * Data Point Index)
```

To calculate the exact point time, add the `TimeOffset` to the timestamp.

```
ExactPointTime = Timestamp + TimeOffset
```

Example: Calculate the exact firing time of the last firing in a packet if the timestamp value is 45,231,878µs

Sequence Index = 23
Data Point Index = 15
Time Stamp = 45,231,878µs

```
ExactPointTime = Timestamp + TimeOffset

ExactPointTime = 45,231,878 + (55.296µs * 23) + (2.304µs * 15)

ExactPointTime = 45,231,878 + 1,306.368µs

ExactPointTime = 45,233,184.368µs
```

Additional examples are show in *Figure 16*, and a complete table of the offsets is given in *Table 7.*

Time offset calculation in VLP-16

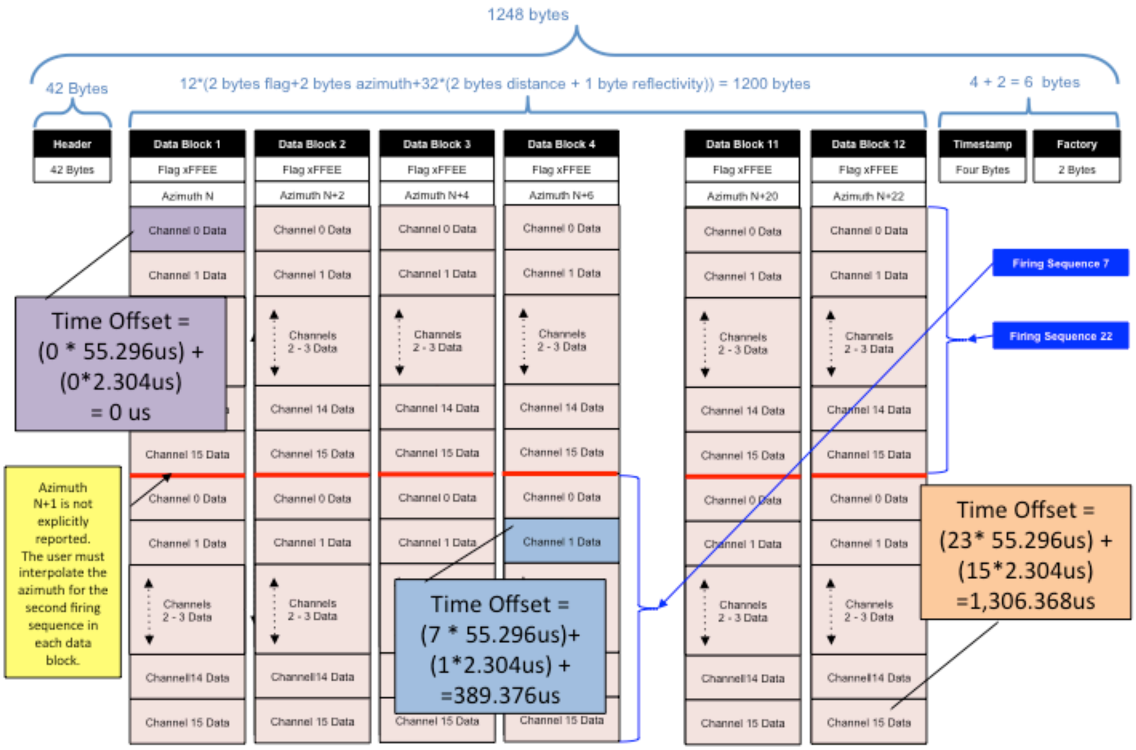


Figure 16. Time Offset Calculation

	Laser ID	Data Block											
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
First Firing	**0**	0.00	110.59	221.18	331.78	442.37	552.96	663.55	774.14	884.74	995.33	1105.92	1216.51
	1	2.30	112.90	223.49	334.08	444.67	555.26	665.86	776.45	887.04	997.63	1108.22	1218.82
	2	4.61	115.20	225.79	336.38	446.98	557.57	668.16	778.75	889.34	999.94	1110.53	1221.12
	3	6.91	117.50	228.10	338.69	449.28	559.87	670.46	781.06	891.65	1002.24	1112.83	1223.42
	4	9.22	119.81	230.40	340.99	451.58	562.18	672.77	783.36	893.95	1004.54	1115.14	1225.73
	5	11.52	122.11	232.70	343.30	453.89	564.48	675.07	785.66	896.26	1006.85	1117.44	1228.03
	6	13.82	124.42	235.01	345.60	456.19	566.78	677.38	787.97	898.56	1009.15	1119.74	1230.34
	7	16.13	126.72	237.31	347.90	458.50	569.09	679.68	790.27	900.86	1011.46	1122.05	1232.64
	8	18.43	129.02	239.62	350.21	460.80	571.39	681.98	792.58	903.17	1013.76	1124.35	1234.94
	9	20.74	131.33	241.92	352.51	463.10	573.70	684.29	794.88	905.47	1016.06	1126.66	1237.25
	10	23.04	133.63	244.22	354.82	465.41	576.00	686.59	797.18	907.78	1018.37	1128.96	1239.55
	11	25.34	135.94	246.53	357.12	467.71	578.30	688.90	799.49	910.08	1020.67	1131.26	1241.86
	12	27.65	138.24	248.83	359.42	470.02	580.61	691.20	801.79	912.38	1022.98	1133.57	1244.16
	13	29.95	140.54	251.14	361.73	472.32	582.91	693.50	804.10	914.69	1025.28	1135.87	1246.46
	14	32.26	142.85	253.44	364.03	474.62	585.22	695.81	806.40	916.99	1027.58	1138.18	1248.77
	15	34.56	145.15	255.74	366.34	476.93	587.52	698.11	808.70	919.30	1029.89	1140.48	1251.07
Second Firing	**0**	55.30	165.89	276.48	387.07	497.66	608.26	718.85	829.44	940.03	1050.62	1161.22	1271.81
	1	57.60	168.19	278.78	389.38	499.97	610.56	721.15	831.74	942.34	1052.93	1163.52	1274.11
	2	59.90	170.50	281.09	391.68	502.27	612.86	723.46	834.05	944.64	1055.23	1165.82	1276.42
	3	62.21	172.80	283.39	393.98	504.58	615.17	725.76	836.35	946.94	1057.54	1168.13	1278.72
	4	64.51	175.10	285.70	396.29	506.88	617.47	728.06	838.66	949.25	1059.84	1170.43	1281.02
	5	66.82	177.41	288.00	398.59	509.18	619.78	730.37	840.96	951.55	1062.14	1172.74	1283.33
	6	69.12	179.71	290.30	400.90	511.49	622.08	732.67	843.26	953.86	1064.45	1175.04	1285.63
	7	71.42	182.02	292.61	403.20	513.79	624.38	734.98	845.57	956.16	1066.75	1177.34	1287.94
	8	73.73	184.32	294.91	405.50	516.10	626.69	737.28	847.87	958.46	1069.06	1179.65	1290.24
	9	76.03	186.62	297.22	407.81	518.40	628.99	739.58	850.18	960.77	1071.36	1181.95	1292.54
	10	78.34	188.93	299.52	410.11	520.70	631.30	741.89	852.48	963.07	1073.66	1184.26	1294.85
	11	80.64	191.23	301.82	412.42	523.01	633.60	744.19	854.78	965.38	1075.97	1186.56	1297.15
	12	82.94	193.54	304.13	414.72	525.31	635.90	746.50	857.09	967.68	1078.27	1188.86	1299.46
	13	85.25	195.84	306.43	417.02	527.62	638.21	748.80	859.39	969.98	1080.58	1191.17	1301.76
	14	87.55	198.14	308.74	419.33	529.92	640.51	751.10	861.70	972.29	1082.88	1193.47	1304.06
	15	89.86	200.45	311.04	421.63	532.22	642.82	753.41	864.00	974.59	1085.18	1195.78	1306.37

Table 7. Timing Offset Values

Note: All times in microseconds. Combine the value shown from the packet to arrive at actual laser firing time.

Using the Interface Box

Caution!
There is no internal polarity nor over voltage production in the sensors; therefore it is imperative that the Interface Box and/or protective circuitry is incorporated in every installation.

The interface box contains circuitry to protect against:

1. Over Voltage:
   The Interface Box accepts 9-32VDC input voltage. The over voltage protection will kick in at 34V until the 3A fuse blows.

2. Reverse Voltage:
   The reverse voltage protection kicks in at 0.6V until the 3A fuse blows or the TVS diode burns out.

Using the Sensors in Hardwired Applications

The sensors may be integrated into a custom system by removing the Interface Box and cutting the interface cable to the desired length. When integrated into a custom system, adequate circuit protection – similar to that provided by the interface box - must be included to safeguard against damaging the sensors.

Failing to provide adequate circuit protection may result in severe damage to the sensors.

Important!
When shortening the interface cable, take care to ensure the terminal block is correctly wired. Reversing the power and ground at the terminal block may result in severe damage to the sensors.

Time Synchronization with an External GPS/INS System

The sensors can synchronize their data with precise GPS-supplied time. Synchronizing to the GPS pulse-per-second (PPS) signal provides the ability to compute the exact firing time of each data point which aids in geo-referencing and other applications.

To utilize these features the user must configure their GPS/INS device to issue a once-per-second synchronization pulse in conjunction with a once-per-second NMEA $GPRMC sentence. No other NMEA message will be accepted by the sensors. Other NMEA sentences might be misinterpreted by the sensors.

For additional information, please refer to the tables and diagrams in the following section "Interface Cable Signal Description."

- The serial data output from the GPS receiver should be connected to the sensor Interface Box via the screw terminal labeled: "GPS RECEIVE."
- The PPS output from the GPS/INS should be connected to the sensor Interface Box via the screw terminal labeled: "GPS PULSE."
- The ground signal(s) from the GPS/INS should be connected to the sensor Interface Box via the screw terminal labeled: "GROUND."
- Serial configuration for the NMEA Message should be 9600 baud, 8N1.

The PPS synchronization pulse and $GPRMC message may be issued concurrently or sequentially. The PPS synchronization pulse length is not critical (typical lengths are between 20ms and 200ms), but reception of the $GPRMC sentence must conclude less than 500ms after the rising edge of the synchronization pulse.

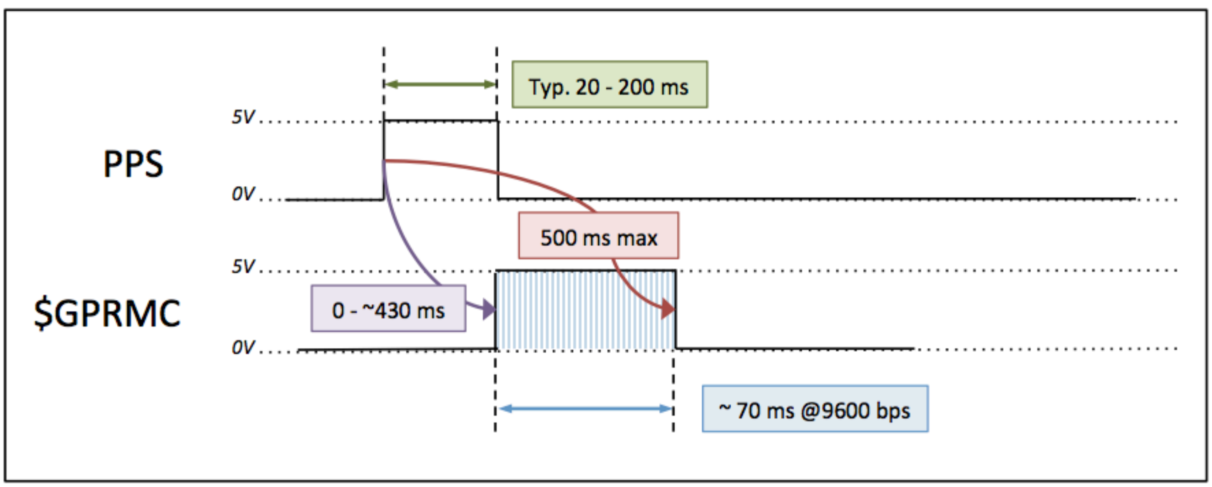


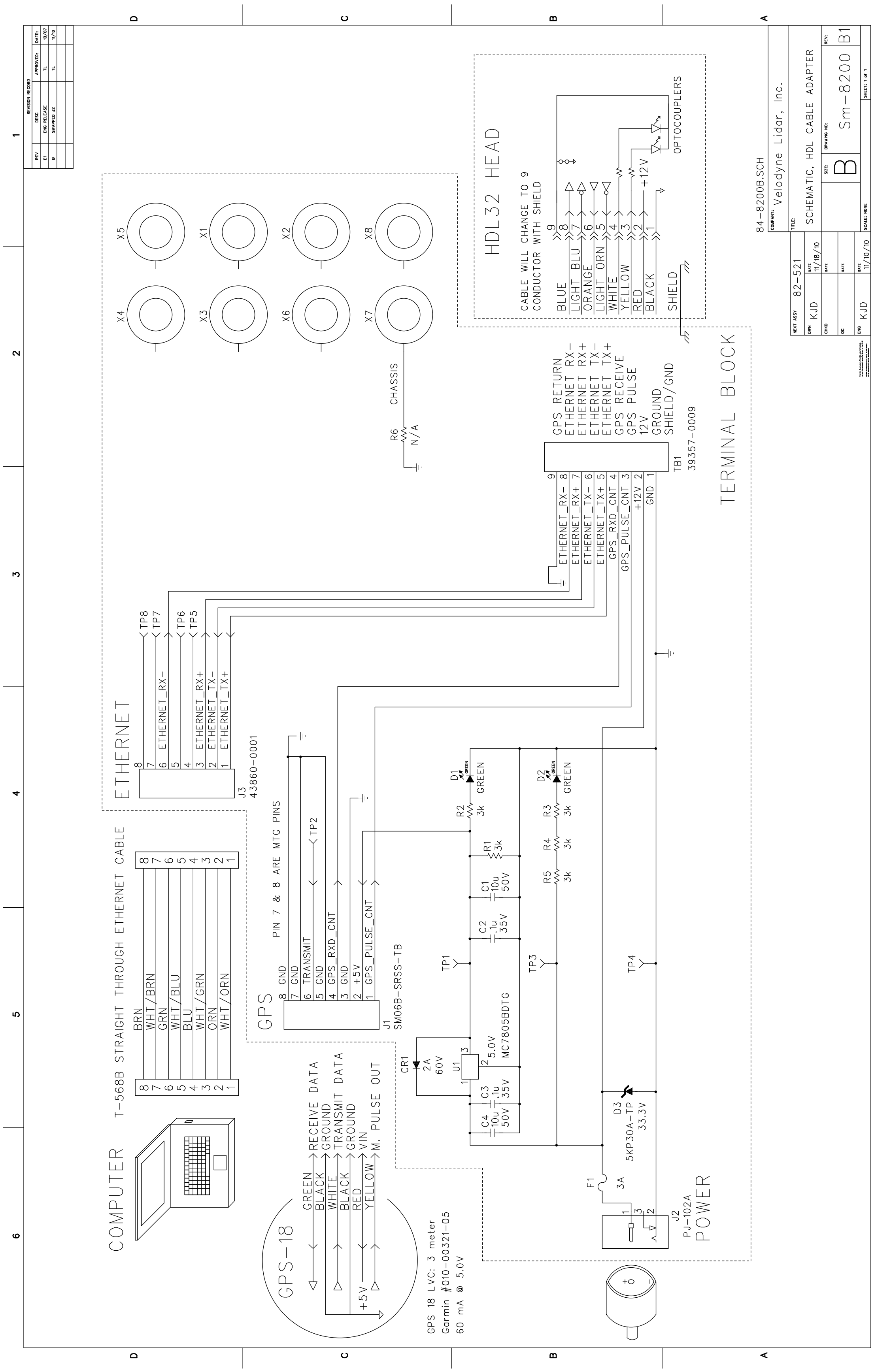
Figure 17. PPS Synchronization and $GPRMC Message

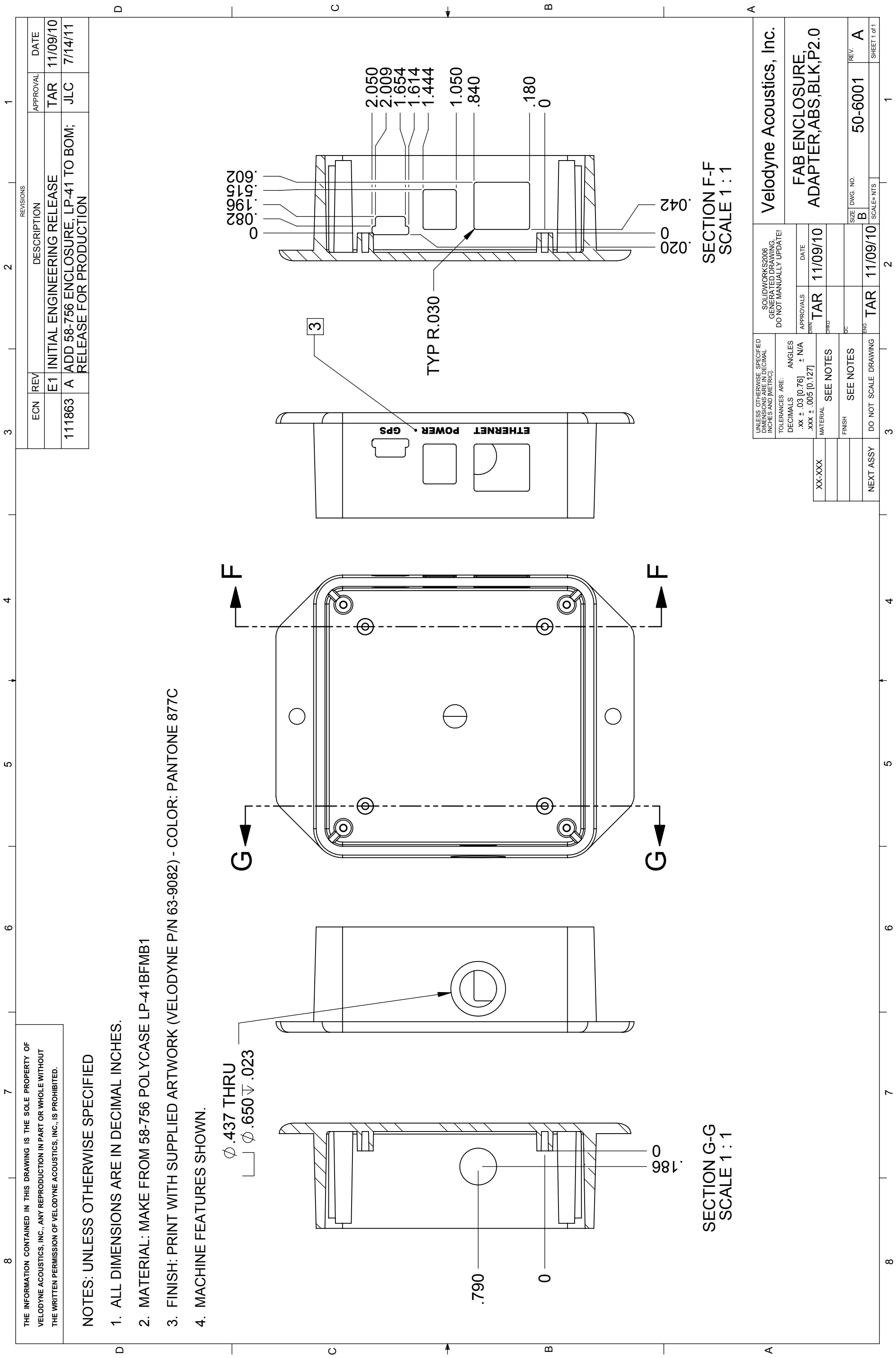
Interface Cable Signal Description

Wire	Signal	Input/Output	Specifications
Black	Ground	Input	System Ground
Red	Power	Input	9-15V DC / 12W
Yellow	GPS Sync Pulse	Input	TTL
White	GPS Serial Receive	Input	TTL
Light Orange	Ethernet TX+	Output	Differential
Orange	Ethernet TX-	Output	Differential
Light Blue	Ethernet RX+	Input	Differential
Blue	Ethernet RX-	Input	Differential

Table 8. Interface Cable Signal Description

Figure 18. Interface Box Connections


HDL32 HEAD
CABLE WILL CHANGE TO 9 CONDUCTOR WITH SHIELD
OPTOCOUPLERS
TERMINAL BLOCK
TB1 39357-0009
GPS RETURN
ETHERNET RX-
ETHERNET RX+
ETHERNET TX-
ETHERNET TX+
GPS RECEIVE
GPS PULSE
12V
GROUND
SHIELD/GND
CHASSIS
ETHERNET
J3 43860-0001
GPS
J1 SM06B-SRSS-TB
PIN 7 & 8 ARE MTG PINS
COMPUTER
T-568B STRAIGHT THROUGH ETHERNET CABLE
GPS-18
GPS 18 LVC: 3 meter
Garmin #010-00321-05
60 mA @ 5.0V
POWER
J2 PJ-102A
MC7805BDTG
5KP30A-TP 33.3V
84-8200B.SCH
Velodyne Lidar, Inc.
SCHEMATIC, HDL CABLE ADAPTER
Sm-8200
B1


THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF VELODYNE ACOUSTICS, INC., ANY REPRODUCTION IN PART OR WHOLE WITHOUT THE WRITTEN PERMISSION OF VELODYNE ACOUSTICS, INC., IS PROHIBITED.
NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN DECIMAL INCHES.
2. MATERIAL: MAKE FROM 58-756 POLYCASE LP-41BFMB1
3. FINISH: PRINT WITH SUPPLIED ARTWORK (VELODYNE P/N 63-9082) - COLOR: PANTONE 877C
4. MACHINE FEATURES SHOWN.
REVISIONS
ECN REV DESCRIPTION APPROVAL DATE
E1 INITIAL ENGINEERING RELEASE TAR 11/09/10
111863 A ADD 58-756 ENCLOSURE, LP-41 TO BOM; RELEASE FOR PRODUCTION JLC 7/14/11
ETHERNET
POWER
GPS
TYP R.030
SECTION F-F
SCALE 1 : 1
SECTION G-G
SCALE 1 : 1
⌀.437 THRU
⌀.650 ↧ .023
2.050
2.009
1.654
1.614
1.444
1.050
.840
.180
0
.020
.042
.790
.186
Velodyne Acoustics, Inc.
FAB ENCLOSURE, ADAPTER,ABS,BLK,P2.0
50-6001
SOLIDWORKS2006 GENERATED DRAWING, DO NOT MANUALLY UPDATE!
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN DECIMAL INCHES AND [METRIC]
MATERIAL SEE NOTES
FINISH SEE NOTES
DO NOT SCALE DRAWING
NEXT ASSY
XX-XXX
TAR 11/09/10
SIZE B
REV. A

Setting up your computer to communicate with the sensor

- Connect the computer to the interface box with an Ethernet Cable.
- Apply power to the sensor.
- For now, disable the WiFI connection on your computer.
- Configure your computer's IP address on its Ethernet port to manual mode.
- Set your computer's IP address to 192.168.1.77 ("77" can be any number except 0, 255, or 201)
- Set the subnet mask to 255.255.255.0
- Pull up the sensor's webserver interface by typing the sensor's network address, 192.168.201, into the address bar in your web browser.

Note: Occasionally a computer won't activate the new IP address unless the computer is rebooted. If you cannot communicate with your sensor after double checking the IP address of the sensor (with Wireshark) and the IP address of your computer, try rebooting the computer.

For detailed step-by-step instructions, follow the directions in the presentation found at this link:
http://velodyne.com/lidar/web/pdf/doc/Webserver%20Interface%20Instructions%20v1a.pdf

This procedure should only be performed if instructed by Velodyne to update a new firmware version.

- Establish communication with the webserver GUI
    - **Default IP: 192.168.1.201**
- For backup purposes, click **Download Snapshot** and save file

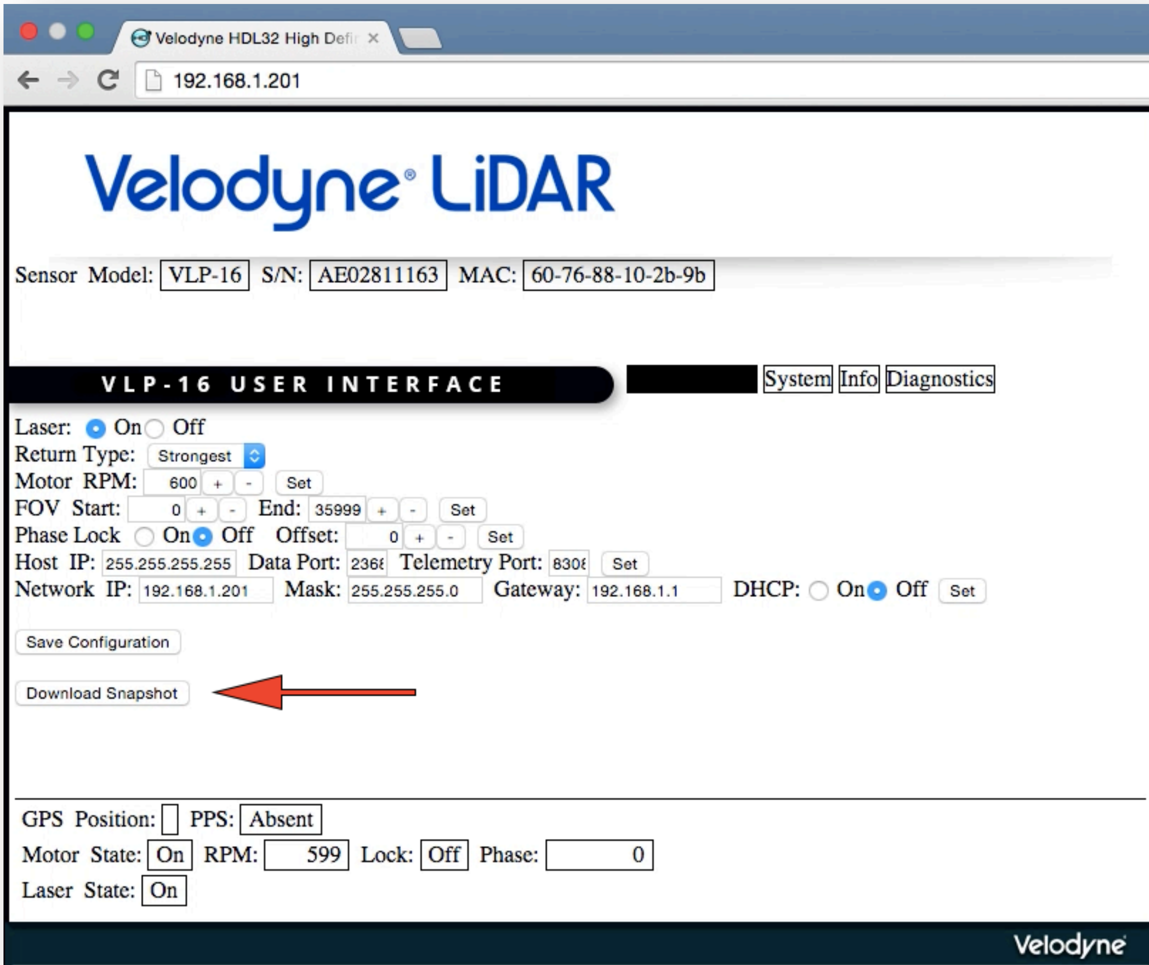


Figure 19a. Firmware Update Step 1

- Switch to **System** page

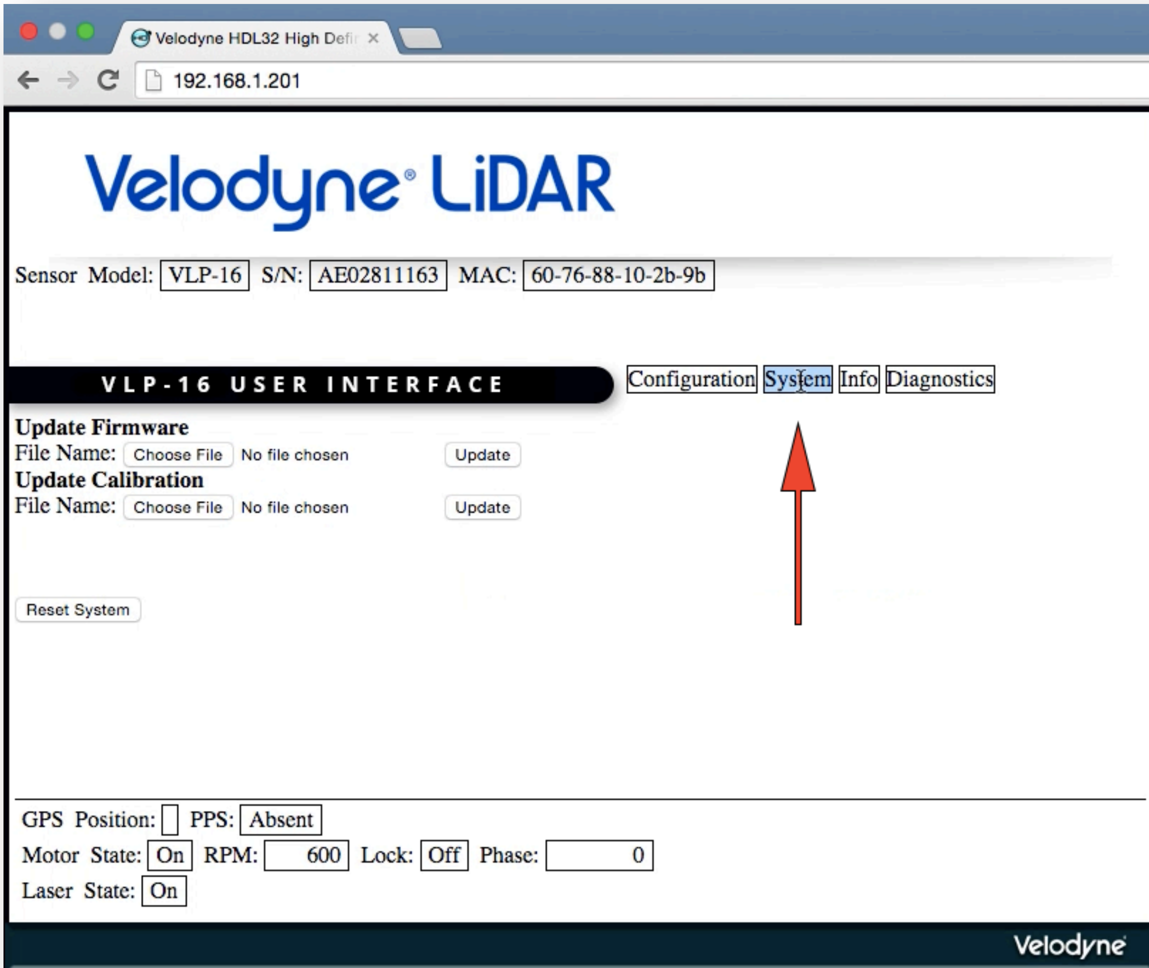


Figure 19b. Firmware Update Step 2

- Click **Choose File** and locate firmware to be uploaded
- Click **Open** and see file path in window

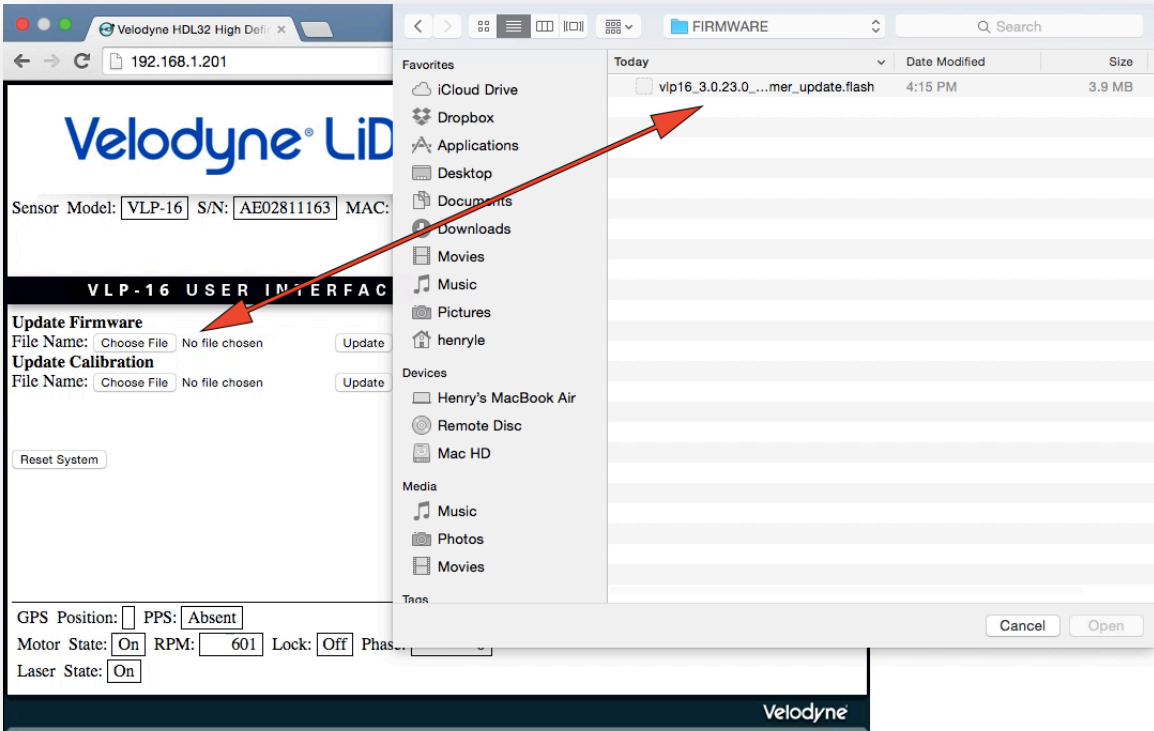


Figure 19c. Firmware Update Step 3

- Click **Update** and notice progress status

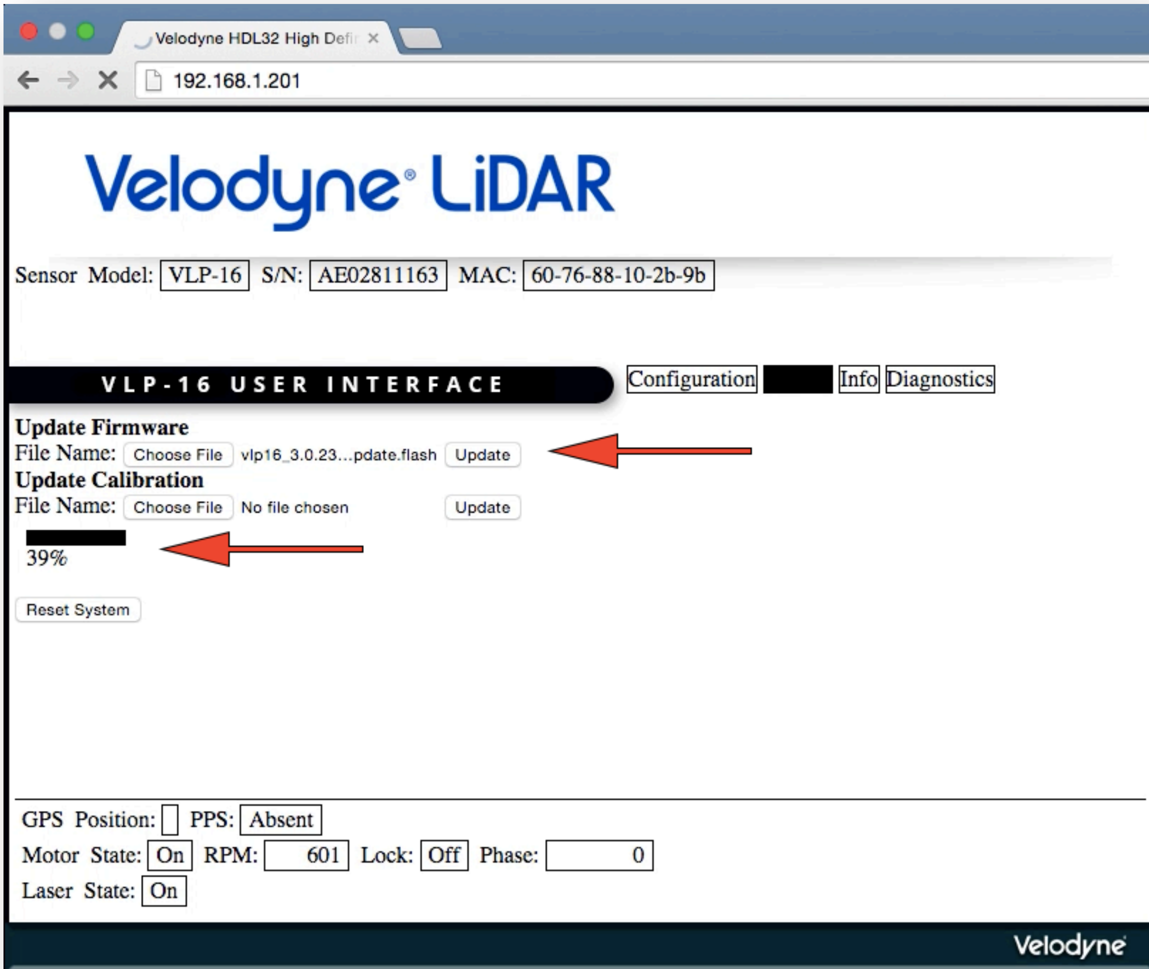


Figure 19d. Firmware Update Step 4

- Once uploaded the following window will open
- Click **Process Firmware Update**
- Monitor progress status

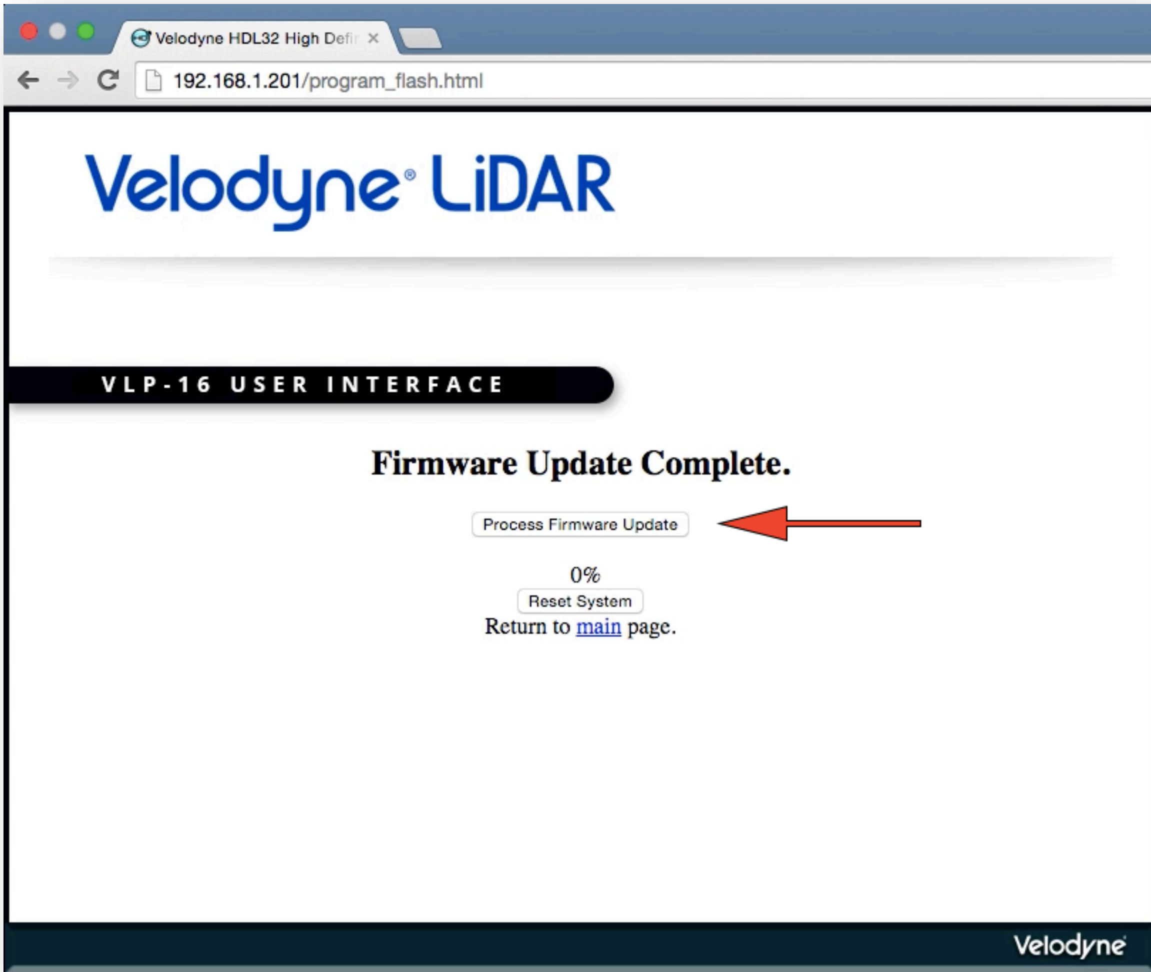


Figure 19e. Firmware Update Step 5

- Once 100% has been reached, click **Reset System**
- The main page will appear again after reset

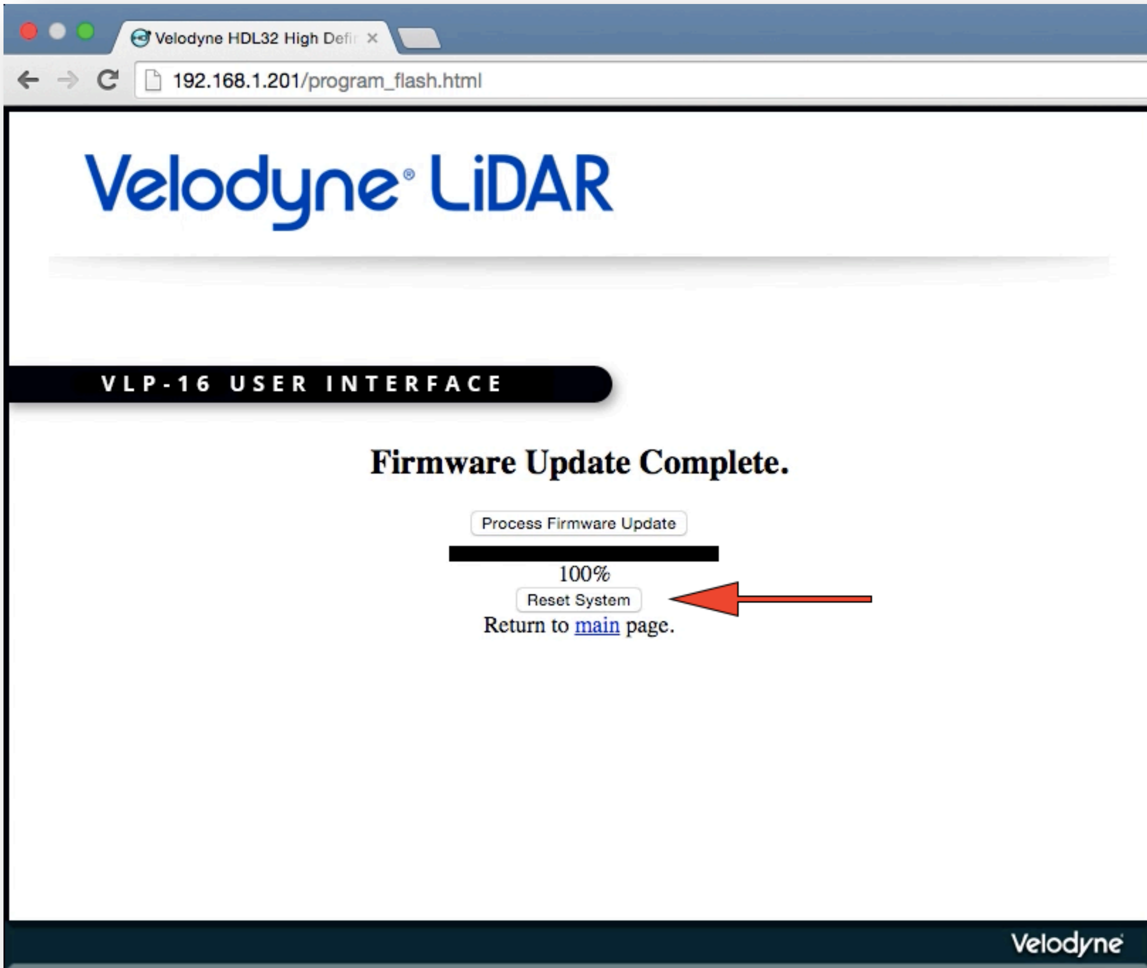


Figure 19f. Firmware Update Step 6

- Click **Download Snapshot** to save configuration after upload

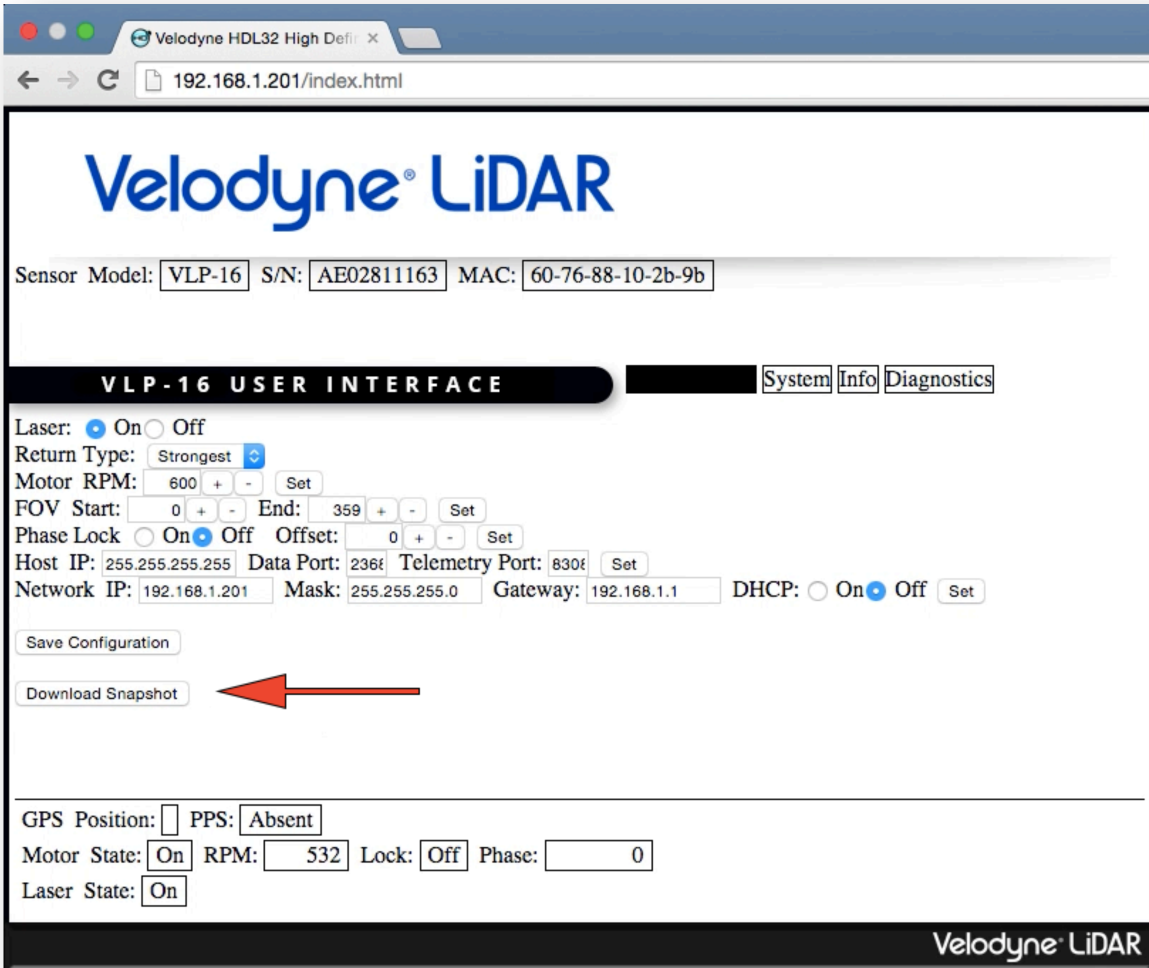


Figure 19g. Firmware Update Step 7

- Switch to **Info** screen to verify new firmware version

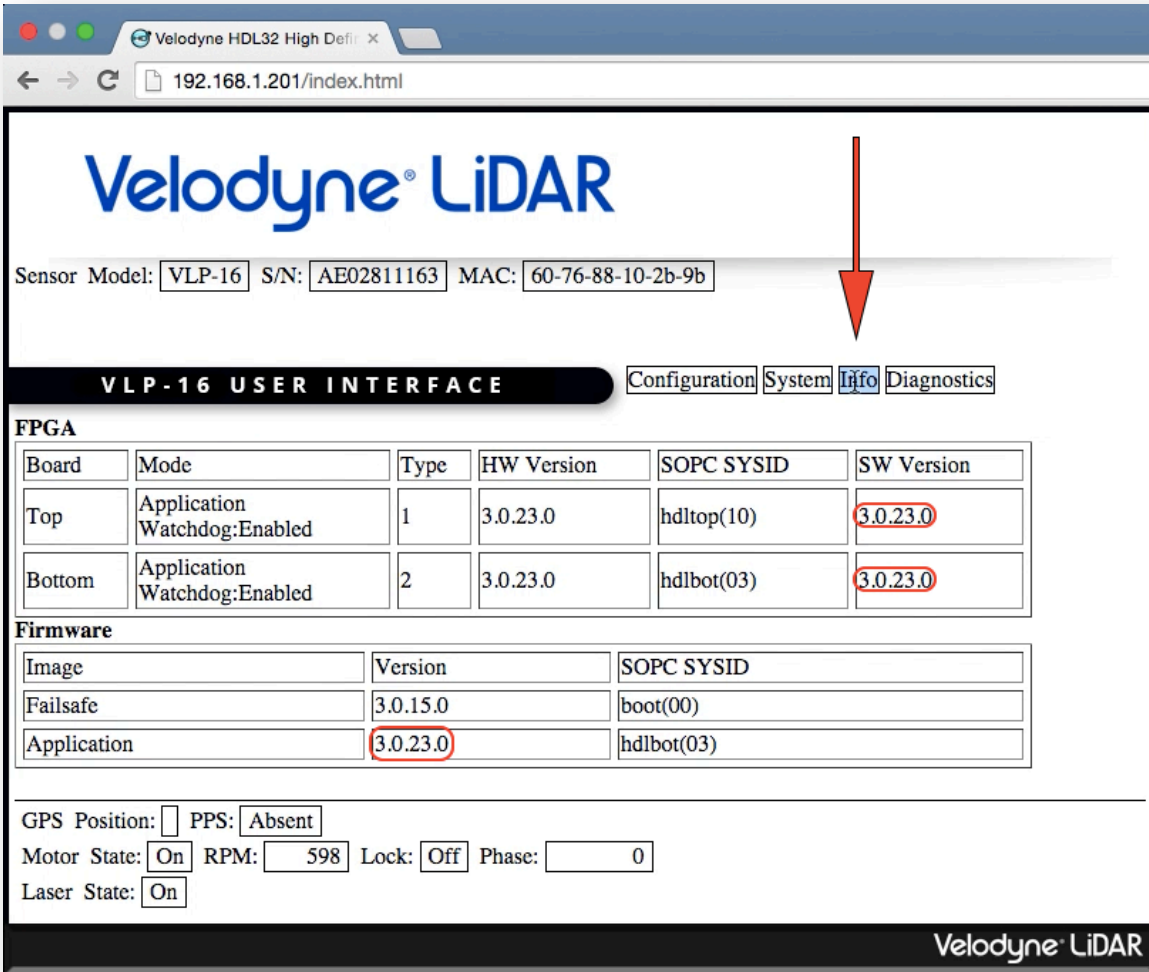


Figure 19h. Firmware Update Step 8

VeloView performs real-time visualization of 3D LiDAR data from Velodyne sensors. VeloView can also playback pre-recorded data stored in .pcap files. VeloView displays the distance measurements from the sensors as point cloud data and supports customer color maps of multiple variables such as intensity-of-return, time, distance, azimuth, and laser ID. The data can be exported as X, Y, Z data in CSV format or screenshots of the currently displayed point cloud can be exported with the touch of a button.

Features

- Input from live sensor stream or recorded .pcap file
- Visualization of LiDAR returns in 3D + time including 3D position and attribute data such as timestamp, azimuth, laser ID, etc.
- Spreadsheet inspector for LiDAR attributes
- Record to .pcap from sensor
- Export to CSV or VTK formats
- Record and export GPS and IMU data
- Ruler tool
- Visualize path of GPS data
- Show multiple frames of data simultaneously
- Show or hide subset of lasers

Installation

Download VeloView at the following link: http://www.paraview.org/Wiki/VeloView

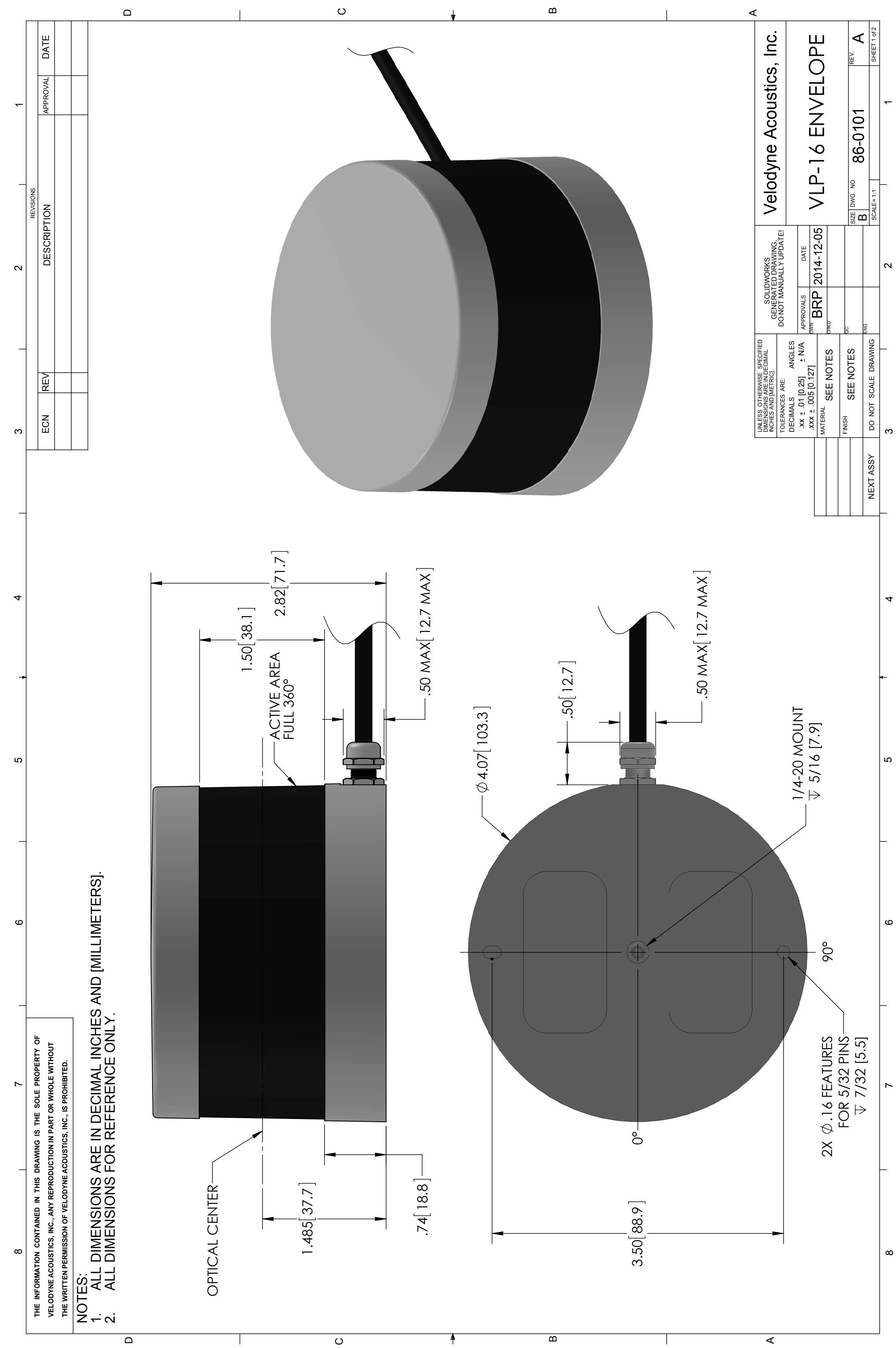
Click on the executable file and follow the on screen instructions.

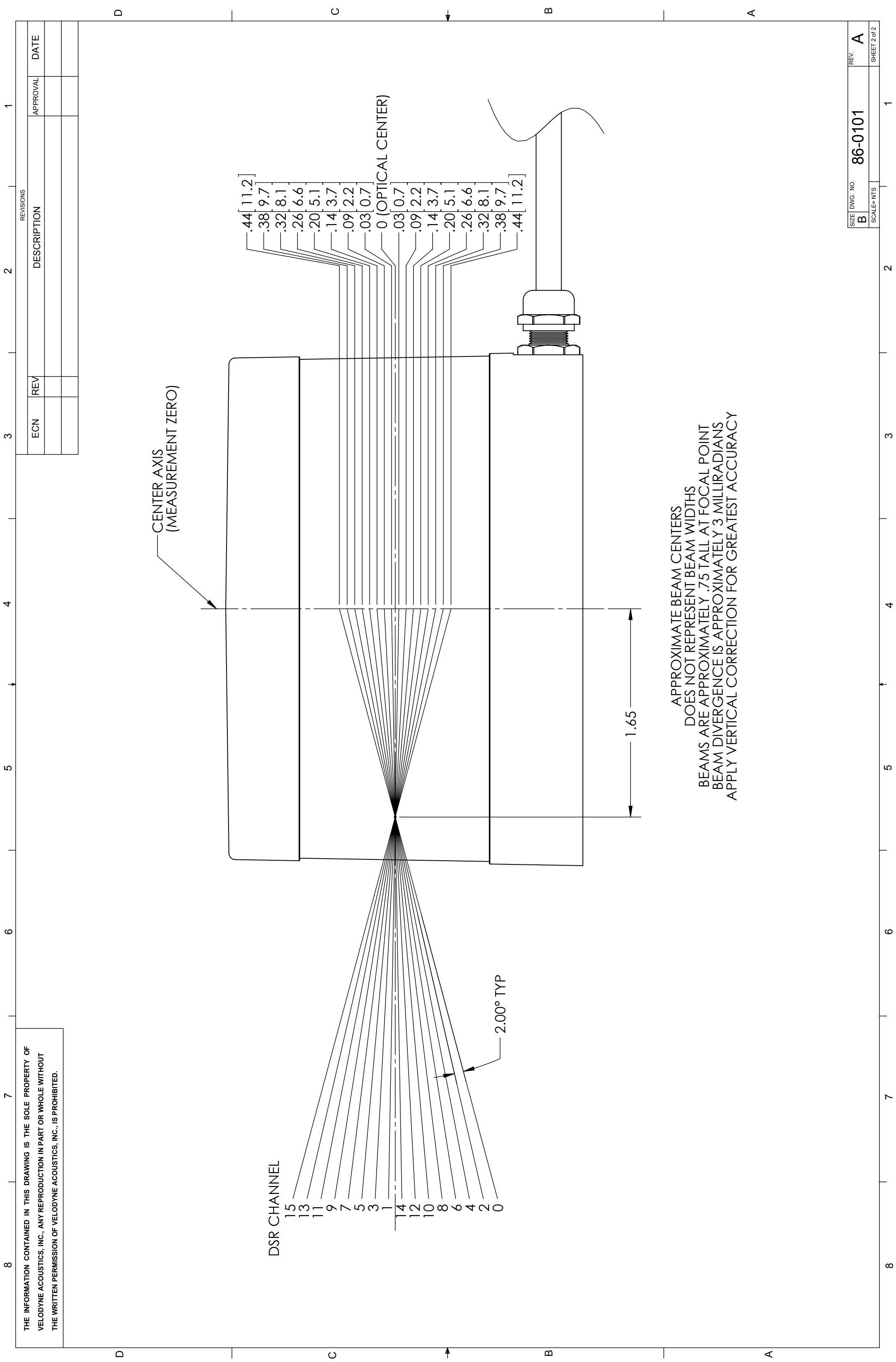
How to use

For "sensor streaming" (live display of sensor data) it is important to change the network settings of the Ethernet adapter connected to the sensor to manual IP address selection and choose:

- IP address: 192.168.1.77 (77" can be any number except 0, 255, or 201)
- Gateway: 255.255.255.0

It is important to disable firewall restrictions for the Ethernet port. Disable the firewall completely for the Ethernet device connected to the sensor or explicitly allow data from that Ethernet port (including both public and private networks).


THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF VELODYNE ACOUSTICS, INC., ANY REPRODUCTION IN PART OR WHOLE WITHOUT THE WRITTEN PERMISSION OF VELODYNE ACOUSTICS, INC., IS PROHIBITED.
NOTES:
1. ALL DIMENSIONS ARE IN DECIMAL INCHES AND [MILLIMETERS].
2. ALL DIMENSIONS FOR REFERENCE ONLY.
OPTICAL CENTER
ACTIVE AREA FULL 360°
1.50[38.1]
2.82[71.7]
.50 MAX[12.7 MAX]
1.485[37.7]
.74[18.8]
Ø4.07[103.3]
.50[12.7]
1/4-20 MOUNT ↧ 5/16 [7.9]
2X Ø.16 FEATURES FOR 5/32 PINS ↧ 7/32 [5.5]
0°
90°
3.50[88.9]
ECN
REV
REVISIONS
DESCRIPTION
APPROVAL
DATE
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN DECIMAL INCHES AND [METRIC].
TOLERANCES ARE:
DECIMALS
.xx ± .01 [0.25]
.xxx ± .005 [0.127]
ANGLES ± N/A
MATERIAL SEE NOTES
FINISH SEE NOTES
DO NOT SCALE DRAWING
NEXT ASSY
SOLIDWORKS GENERATED DRAWING, DO NOT MANUALLY UPDATE!
APPROVALS
DATE
DWN BRP 2014-12-05
Velodyne Acoustics, Inc.
VLP-16 ENVELOPE
SIZE B
DWG. NO. 86-0101
REV. A
SCALE = 1:1
SHEET 1 of 2


REVISIONS
ECN
REV
DESCRIPTION
APPROVAL
DATE
.44 [11.2]
.38 [9.7]
.32 [8.1]
.26 [6.6]
.20 [5.1]
.14 [3.7]
.09 [2.2]
.03 [0.7]
0 (OPTICAL CENTER)
.03 [0.7]
.09 [2.2]
.14 [3.7]
.20 [5.1]
.26 [6.6]
.32 [8.1]
.38 [9.7]
.44 [11.2]
CENTER AXIS
(MEASUREMENT ZERO)
1.65
APPROXIMATE BEAM CENTERS
DOES NOT REPRESENT BEAM WIDTHS
BEAMS ARE APPROXIMATELY .75 TALL AT FOCAL POINT
BEAM DIVERGENCE IS APPROXIMATELY 3 MILLIRADIANS
APPLY VERTICAL CORRECTION FOR GREATEST ACCURACY
2.00° TYP
DSR CHANNEL
15
13
11
9
7
5
3
1
14
12
10
8
6
4
2
0
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF VELODYNE ACOUSTICS, INC., ANY REPRODUCTION IN PART OR WHOLE WITHOUT THE WRITTEN PERMISSION OF VELODYNE ACOUSTICS, INC., IS PROHIBITED.
SIZE
B
DWG. NO.
86-0101
REV.
A
SCALE= NTS
SHEET 2 of 2

Velodyne Acoustics, Inc.
345 Digital Drive
Morgan Hill CA 95037

408.465.2800 Voice
408.779.9227 Fax
408.779.9208 Service Fax

www.velodynelidar.com

Service Email: lidarservice@velodyne.com
Sales Email: lidar@velodyne.com

All Velodyne LiDAR products are made in the U.S.A.

Specifications subject to change without notice.

63-9243 Rev A Aug 2015