HDL™-64E S2

USER'S MANUAL

High Definition Lidar™ Sensor

IMPORTANT SAFETY INSTRUCTIONS

CAUTION
RISK OF ELECTRIC SHOCK
DO NOT OPEN

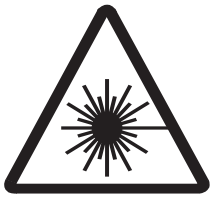
Caution

To reduce the risk of electric shock, do not remove cover (or back). No user-serviceable parts inside. 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. **Heat —** The product should be situated away from heat sources such as radiators, heat registers, stoves, or other products that produce heat.
6. **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.



MAX Power: 1 mW
Wave Length: 905nm

Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated 7/2001

INVISIBLE LASER RADIATION
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 1M LASER PRODUCT

AVOID EXPOSURE-LASER RADIATION IS EMITTED FROM THESE APERTURES

Model No:

Serial No:

Mfg Date:

VELODYNE Lidar, Inc.
MORGAN HILL, CA (USA)

Table of Contents

Introduction

Congratulations on your purchase of a Velodyne HDL-64E S2 High Definition Lidar Sensor. This product represents a breakthrough in sensing technology by providing more information about the surrounding environment than previously possible.

This guide first covers installation and wiring, then addresses output packet construction and interpretation, and finally discusses the serial interface to the unit and software updates.

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

Each shipment contains:

- HDL-64E S2 sensor
- Wiring harness
- CD with user manual, calibration file (db.XML) and DSR viewer

NOTE: The HDL-64E S2 is shipped in a wooden crate, however it can be transported in a wheeled case, such as Pelican Model 1560. Model 1560 maintains the 50 lb. weight limit on many airlines for checked baggage without additional expense, if packed with the HDL-64E S2 sensor and 10 ft. cable only. Please note airline exemptions are subject to change. To order, contact Pelican directly at www.pelican.com.

Principles of Operation

The HDL-64E S2 operates on a rather simple premise: instead of a single laser firing through a rotating mirror, 64 lasers are mounted on upper and lower blocks of 32 lasers each and the entire unit spins. This design allows for 64 separate lasers to each fire thousands of times per second, providing exponentially more data points per second and a much richer point cloud than conventional designs. The unit inherently delivers a 360-degree horizontal field of view (FOV) and a 26.8 degree vertical FOV.

Additionally, state-of-the-art digital signal processing and waveform analysis are employed to provide high accuracy, extended distance sensing and intensity data. The HDL-64E S2 is rated to provide usable returns up to 120 meters.

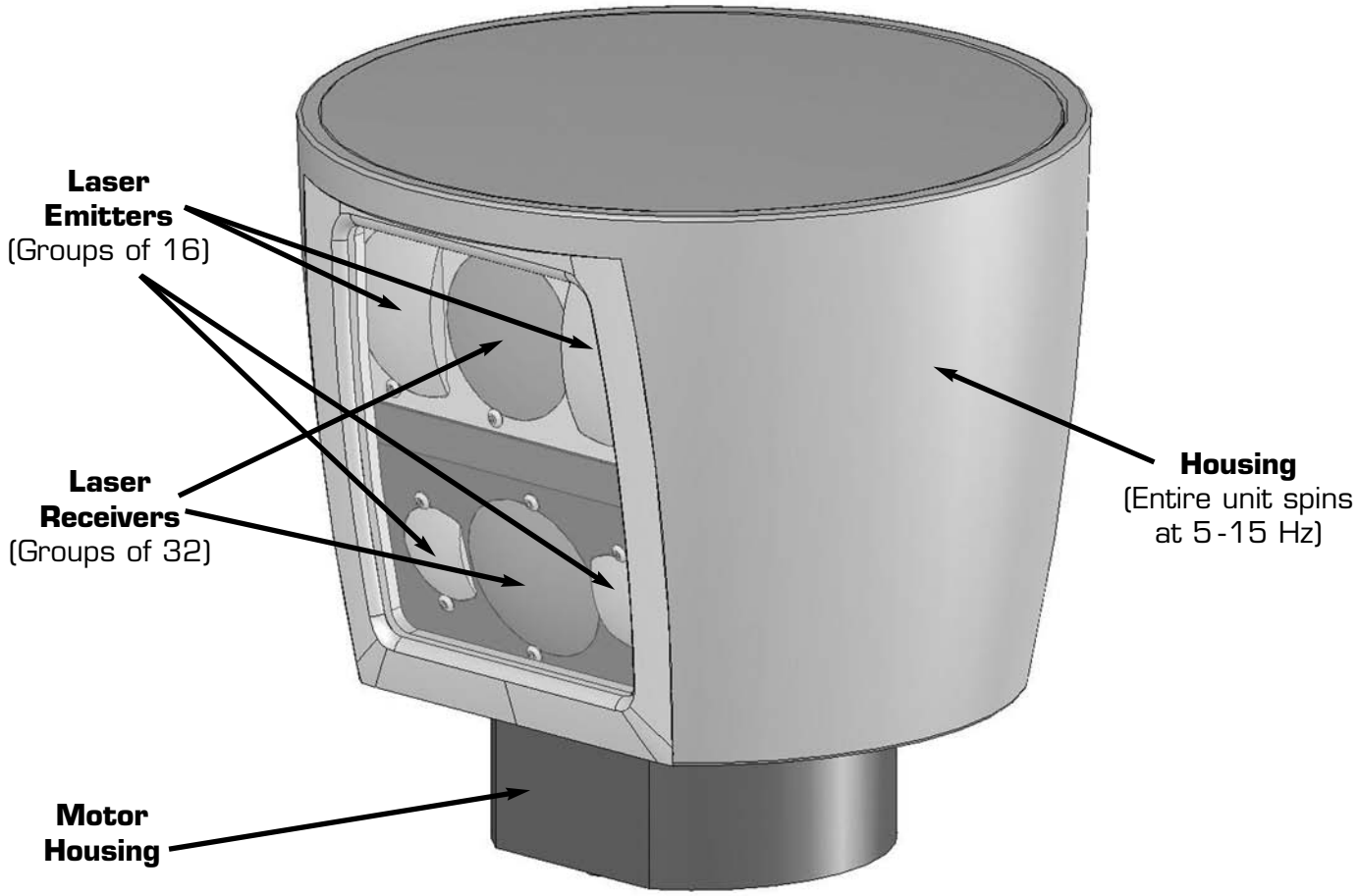


Figure 1. HDL-64E S2 design overview.

The HDL-64E S2 employs a direct drive motor system — there are no belts or chains in the drive train.

Front/Back Mounting

The HDL-64E S2 base provides two mounting options: side mount and top mount. See Figure 2 for front/back mounting options, Figure 3 for side/side mounting, and Figure 4 for top mounting instructions. The sensor can be mounted at any angle from 0 to 90 degrees with respect to the base of the sensor. Refer to Appendix E for complete dimensions.

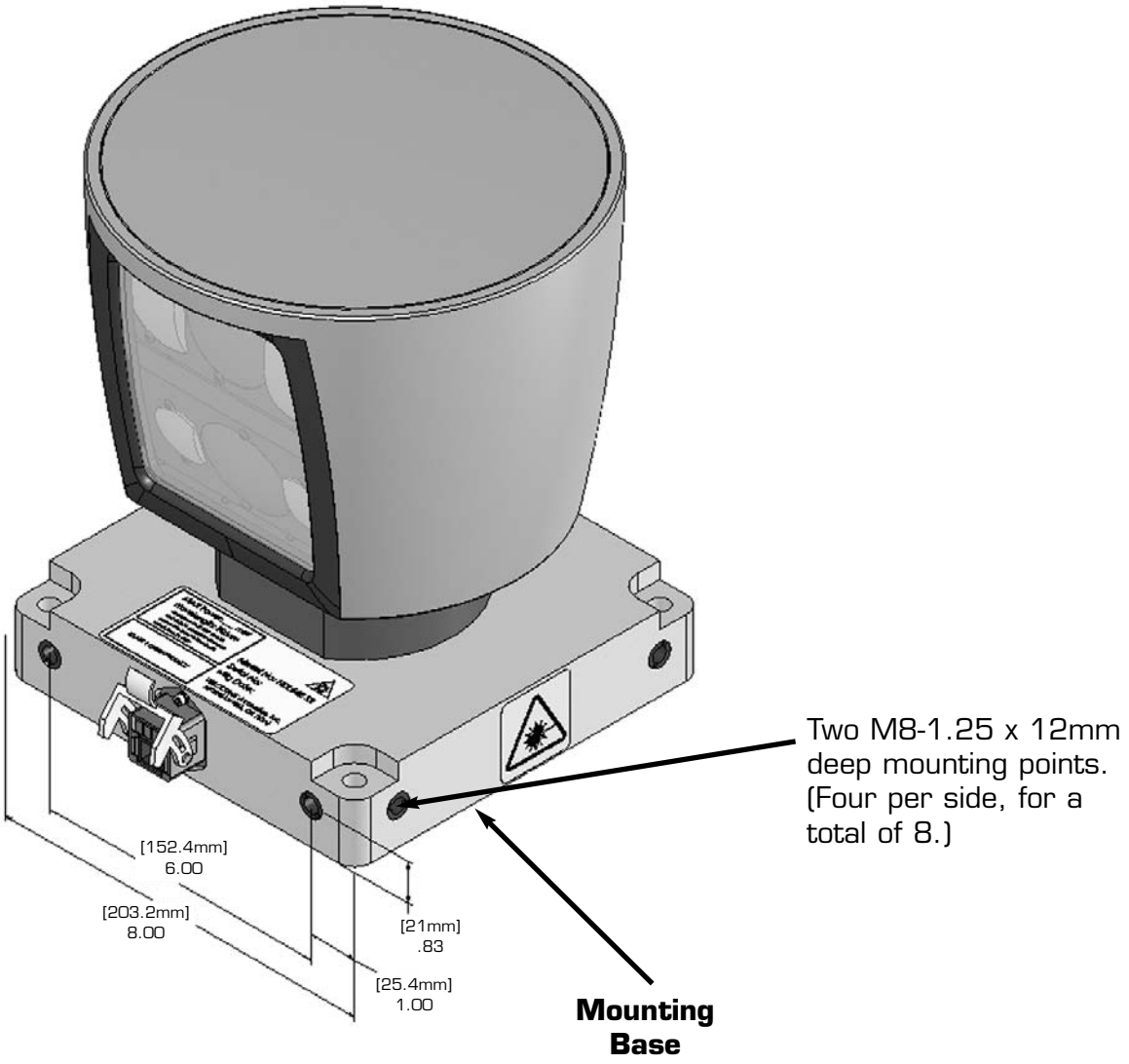


Figure 2. Front and back HDL mounting illustration.

See Figure 2. This figure shows the HDL-64E S2's base plate screw locations with threaded inserts for standard M8 hardware.

Side Mounting

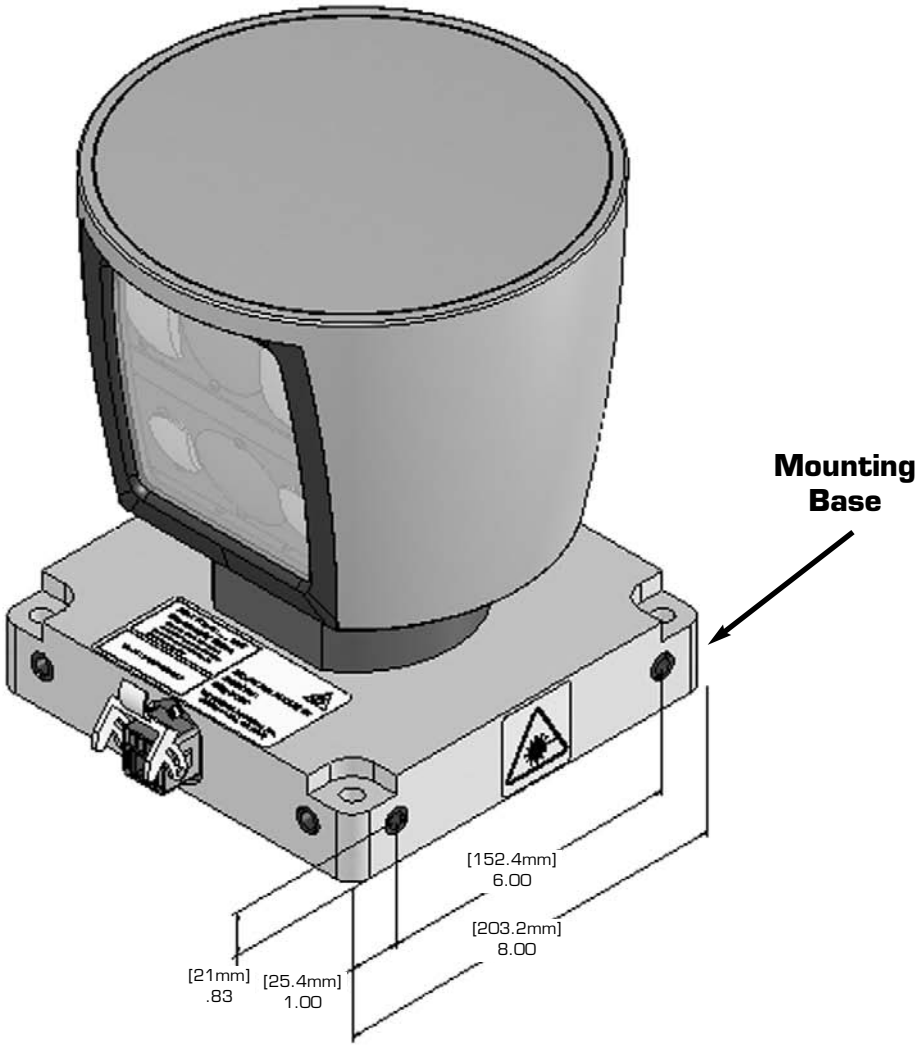


Figure 3. Side/side HDL mounting illustration.

Top Mounting

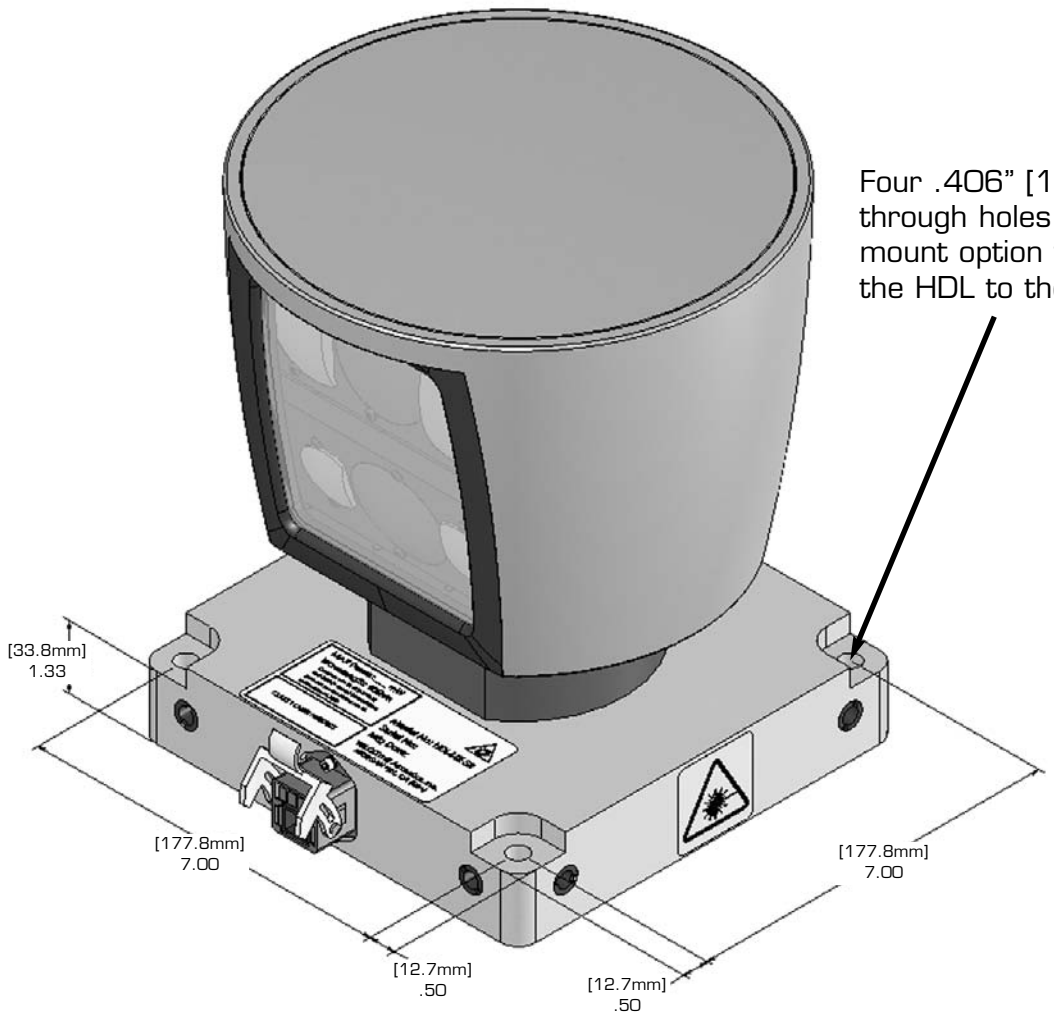


Figure 4. HDL top mounting illustration.

Figure 4 shows the location of four .406" [10.3mm] thru holes for top mounting.

For all mounting options, be sure the HDL-64E S2 is mounted securely to withstand vibration and shock without risk of detachment. The unit need not be shock proofed — it is designed to withstand standard automotive G-forces.

The HDL-64E S2 is weatherproofed to withstand wind, rain, and other adverse weather conditions. The spinning nature of the HDL-64E S2 helps the unit shed excess water from the front window that could hamper performance.

Wiring

The HDL-64E S2 comes with a pre-wired connector, wired with power, DB9 serial, and standard RJ-45 Ethernet connectors.The connector wires are approximately 10' [3 meters] in length.

Power. Connect the red and black wires to vehicle power. Be sure red is positive polarity. THE HDL-64E S2 IS RATED ONLY FOR 12 VOLTS. Any voltage applied over 16 volts could damage the unit. Expect the unit to draw 4-6 amps during normal usage.

NOTE: The HDL-64E S2 does not have a power switch. It spins whenever power is applied. The HDL-64E S2 has a lockout circuit that prevents its lasers from firing at low RPMs.

Ethernet. This standard Ethernet connector is designed to connect to a standard PC. See the next section on usage for UDP packet formats.

NOTE: The HDL-64E S2 is only compatible with network cards that have either MDI or AUTO MDIX capability.

Serial Interface. The connector also features an RS-232 DB9 serial connector. This connector allows for a firmware update to be applied to the HDL-64E S2 (Velodyne may release firmware updates from time to time). It also accepts commands to change the RPM of the unit.

Cable Diagram. If you wish to wire your own connector, refer to Appendix A for a layout of the wiring pins.

USAGE

Data Packet Construction

The HDL-64E S2 outputs UDP Ethernet packets. Each packet contains a data payload of 1206 bytes that consists of 12 blocks of 100-byte firing data followed by six bytes at the end of each packet that contains a spin counter and firmware version information. Each packet can be for either the upper or lower laser banks (called "laser blocks") - each bank contains 32 lasers.

The packet format is as follows:

2 bytes of header info. This header indicates whether the packet is for the upper block or the lower block. The upper block will have a header of OxEEFF and the lower block will have a header of OxDDFF.

2 bytes of rotational info. This is an integer between 0 and 35999. Divide this number by 100 to get degrees from 0.

32 laser returns broken into 3 bytes each. Each return contains two bytes of distance information in .2 centimeter [2mm] increments, and one byte of intensity information (0 – 255, with 255 being the most intense return). A zero distance value within the data packet indicates there are no returns up to 120 meters, the maximum range of the device.

Six status bytes at the end of the packet:

2 bytes spin count (binary). This field is incremented for each revolution. After 65,535 revolutions, the counter resets to 0.

4 bytes alternating between:

- (A) A reading showing the internal temperature of the unit. You will see a "DegC" ASCII string as the last four bytes of the packet. The two bytes before this string are the thermistor's reading in C in hex 8.8 format. This is in "big endian format" - i.e. the byte immediately preceding the DegC text is the whole degrees, and the byte preceding that is the fraction of a degree in 1/256 increments. So if you see c0 1a, the temperature of the thermistor is 26.75 degrees C.

- (B) Or, the version number of the firmware in ASCII character format "Vxxx" where “xxx” is the version number, e.g. "25b” which represents version 2.5b (the most current software version as of this writing).

The minimum return distance for the HDL-64E S2 is approximately 3 feet [.9 meters]. **Returns closer than this should be ignored.**

The HDL-64E S2 data is presented as distances and intensities only. Velodyne includes a packet viewer called DSR, whose installer files are on the CD that came with the unit. DSR reads in the packets from the HDL-64E S2 unit, performs the necessary calculations to plot the points presented in 3-D space, and plots the points on the viewer screen.

Correction Angles

Each HDL-64E S2 laser is fixed with respect to vertical angle and offset to the rotational index data provided in each packet. For each data point issued by the HDL-64E S2, rotational and horizontal correction factors must be applied to determine the point’s location in 3-D space referred to by the return. Each HDL-64E S2 unit comes with its own unique .XML file, called db.XML, that was generated as a result of the calibration performed at Velodyne’s factory. DSR uses this XML file to display points accurately. The .XML file also holds the key to interpreting the packet data for users that wish to create their own software applications.

db.XML contains 64 instances of the following five values used to interpret the packet data:

rotCorrection: This parameter is the rotational correction angle, in degrees, for each laser, as viewed from the back of the unit. Positive factors rotate to the left, and negative values rotate to the right.

vertCorrection: This parameter is the vertical correction angle, in degrees, for each laser, as viewed from the back of the unit. Positive values have the laser pointing up, and negative values have the laser pointing down.

distCorrection: Each laser has its own unique distance due to minor variations in the parts used to construct the laser. This correction factor, in centimeters, accounts for this variance. This number should be directly added to the distance value read in the packet.

vertoffsetCorrection: This value represents the height of each laser, in centimeters, as measured from the bottom of the base. It is a fixed value for all upper block lasers and a different fixed value for all lower block lasers.

horizOffsetCorrection: This value represents the horizontal offset of each laser, in centimeters, as viewed from the back of the laser. It is a constant positive or negative value for all lasers.

Use the above values from the .XML file to calculate each point's position in 3-D space. Use the first 32 points for the upper block and the second 32 points for the lower block. The rotational info found in the header is used to determine the packets position with respect to the 360 degree horizontal field of view.

Note: There is a file on the CD called "HDL Source Example" that shows the calculations using the above correction factors.

Controlling the Spin Rate

The HDL-64E S2 can spin at rates ranging from 300 RPM (5 Hz) to 900 RPM (15 Hz). The default is 600 RPM (10 Hz). Note that changing the spin rate does not change the data rate – the unit will send out the same number of packets (at a rate of 1.3 million data points per second) regardless of spin rate. The image resolution will increase or decrease depending on rotation speed. See Appendix B for angular resolution figures for various spin rates.

To control the HDL's spin rate, connect the serial cable to an available RS-232 COM port and issue a serial command of the format #HDLRPMnnn$ where nnn is an integer between 300 and 900. The characters are case sensitive and must be CAPS. The HDL-64E S2 will adopt the new spin rate. Use the following serial parameters: Baud 9600, Parity: None, Data bits: 8, Stop bits: 1. The HDL-64E S2 has no echo back feature, so no serial data will be returned from the HDL-64E S2.

Firmware Update

Velodyne may issue firmware updates from time to time. To apply the update, connect the DB9 RS-232 cable to a standard Windows-compatible PC's serial port. The HDL-64E S2 must be powered up and spinning during the update.

Execute the file supplied by Velodyne – all the software and firmware is included to update the unit. Once the file is executed, the following screen will appear:

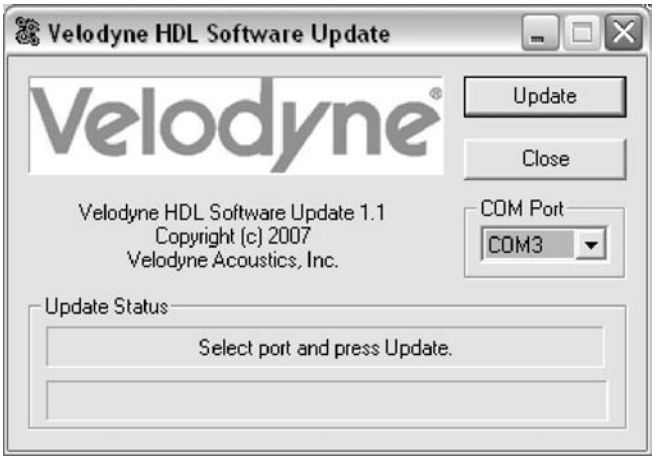


Figure 5. HDL software update screen capture.

Press update and the unit will update. If the update was successful, the unit will begin to spin down for a few seconds then power back up with the new firmware running. If the first update is not successful, it is recommended to try the update again several times before seeking assistance from Velodyne.

NOTE: The entire new firmware is uploaded and checksummed before being applied to the flash memory inside the HDL-64E S2. If the checksum is corrupted, no software update occurs. This protects the unit in the event of power or data loss during the firmware update.

Troubleshooting

Use this chart to troubleshoot common problems with the HDL-64E S2.

Problem	Resolution
Unit doesn't spin	Verify power connection and polarity. Verify proper voltage – should be 12 volts drawing about 3-4 amps. Remove bottom cover and check inline fuse. Replace if necessary.
Unit spins but no data	Verify Ethernet wiring. Verify packet output from another source (e.g. Ethereal/Wireshark).
No serial communication	Verify RS-232 cable connection. Unit must be active and spinning for RS-232 update. It may take several tries for the update to be effective.

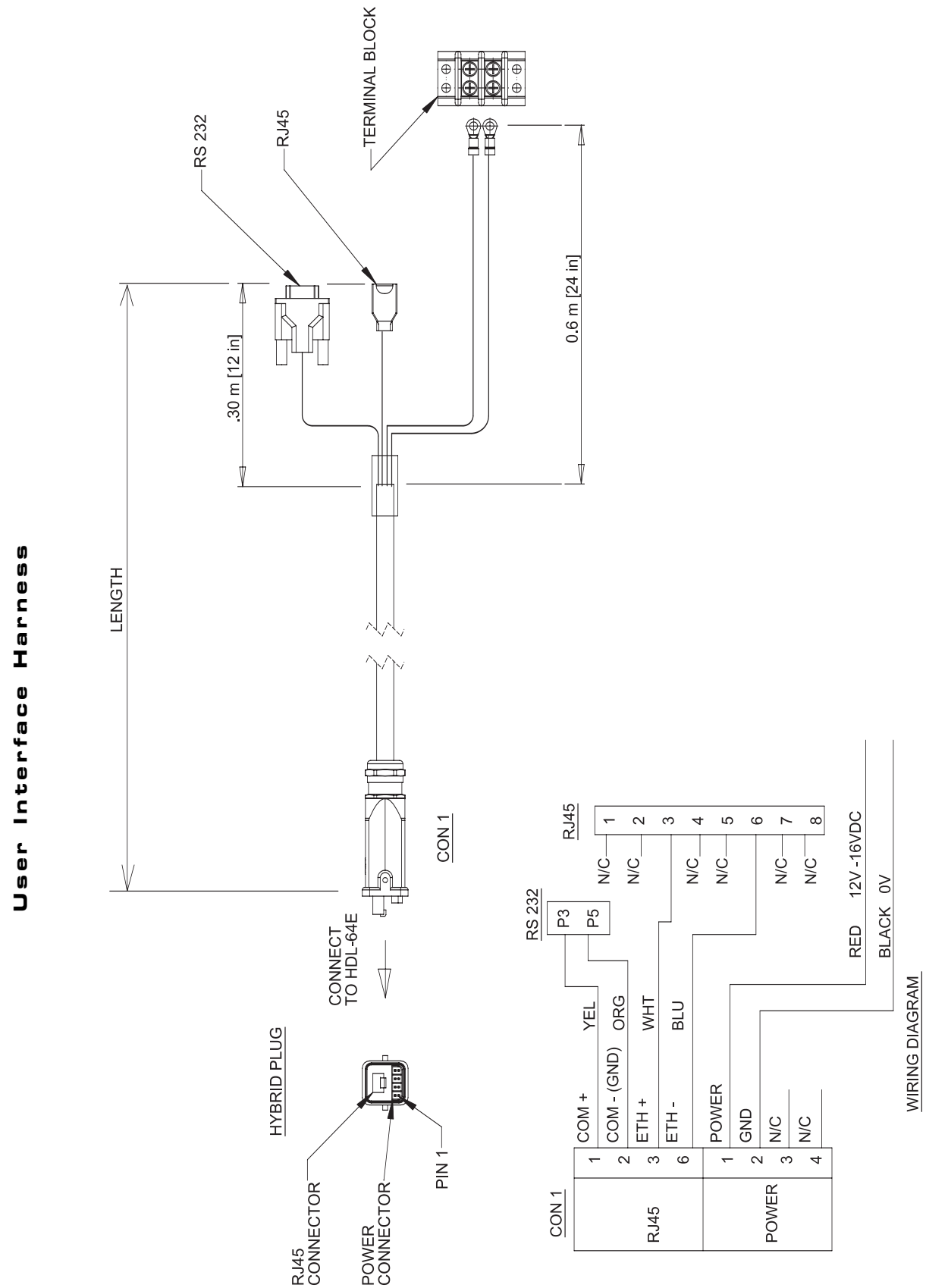
Service and Maintenance

There are no user service or maintenance requirements or procedures for the Velodyne HDL-64E S2.

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

SPECIFICATIONS

Sensor:	• 64 lasers/detectors • 360 degree field of view (azimuth) • 0.09 degree angular resolution (azimuth) • 26.8 degree vertical field of view (elevation) -+2° up to -24.8° down with 64 equally spaced angular subdivisions (approximately 0.4°) • 1.5 cm (1 SIGMA) distance accuracy • 5-15 Hz rotation rate update (user selectable) • 50 meter range for pavement (~0.10 reflectivity) • 120 meter range for cars and foliage (~0.80 reflectivity) • >1.333 M points per second • <0.05 milliseconds latency
Laser:	• Class 1 - eye safe • 4 x 16 laser block assemblies • 905 nm wavelength • 5 nanosecond pulse • Adaptive power system for minimizing saturation and blinding
Mechanical:	• 12V input (16V max) @ 4 amps • <29 lbs. [13.15 Kg] • 10" [254mm] tall cylinder of 8" [203.2mm] OD diameter • 300 RPM - 900 RPM spin rate (user selectable)
Output:	• 100 MBPS UDP Ethernet packets
Dimensions (H/W/D):	• Unit: 10.13" x 8.80" x 9.10" [257.3mm x 223.5mm x 231.1mm] • Crate: 19.5" x 18" x 18" [495.3mm x 457.2mm x 457.2mm]
Shipping Weight: (approx.)	• 68 lbs [30.8 Kg]


User Interface Harness
TERMINAL BLOCK
RS 232
RJ45
LENGTH
.30 m [12 in]
0.6 m [24 in]
CON 1
CONNECT TO HDL-64E
HYBRID PLUG
RJ45 CONNECTOR
POWER CONNECTOR
PIN 1
RS 232
P3
P5
RJ45
N/C
COM +
YEL
COM - (GND)
ORG
ETH +
WHT
ETH -
BLU
POWER
GND
RED 12V -16VDC
BLACK 0V
CON 1
RJ45
POWER
WIRING DIAGRAM

Appendix B - Angular Resolution

Upper & Lower Block				
RPM	RPS (Hz)	Points Per Revolution	Points Per Revolution Per Laser	Angular Resolution (degrees)
300	5	266624	4166	0.0864
600	10	133312	2083	0.1728
900	15	88896	1389	0.2591

Note:
20,833 points per second, per laser x 64 = 1,333,312 total points per second therefore, the HDL-64E S2 generates greater than 1.3 million points per second.

Appendix C - Digital Sensor Recorder (DSR)

Digital Sensor Recorder (DSR)

DSR is a 3-dimensional point cloud visualization software program designed for use with the HDL-64E S2. It can be located on the CD provided with each HDL-64E S2 sensor. Velodyne offers this software as an "out of the box" tool for the rendering and recording of point cloud data from the HDL-64E S2 sensor.

DSR is intended as a reference platform from which the user can develop their own adaptation and visualization software packages.

Note: A code snippet is provided on the same CD to aid in understanding the methods at which DSR parses the data points generated by the HDL-64E S2 sensor.

Installing DSR

Locate the DSR executable program on the provided CD. Double click on "DSR-1.1-2-install 3.exe" to begin the installation onto the host computer. Use of the default settings during the installation is highly recommended.

When the installation is complete, follow the "Utilizing the db.xml calibration data file in DSR" instructions in the next section to calibrate the DSR viewer to your new sensor.

Note: failure to use the calibration db.xml file supplied with your sensor will result in an inaccurate point cloud rendering in DSR.

Using DSR

DSR gives the user the ability to view point cloud data in real time or to create a recording of such data for future reference and playback. The recorded data will be stored in a standard pcap file format.

Note: These files can become quite large so the user should be mindful of recording duration when created.

Live Playback:

For live playback, first secure and power up the HDL-64E S2 sensor so that it is spinning. Connect the RJ45 Ethernet connector to your host computer's network connection. You may wish to utilize auto DNS settings for your computers network configuration.

DSR desktop icon = 

Open DSR from your desktop icon created during the installation. Pull down the "Options" menu and select the proper input device. Go to "Options" again and deselect the "Show Ground Plane" option. (Leave this feature off for the time being or until the ground plane has been properly adjusted).

You can now go to “Options/Properties” to change the individual settings for each LASER channel if so desired.

REFRESH button = 

Provided that your computer is now receiving data packets, click on the Refresh button to start live viewing of a point cloud. The initial image is of a directly overhead perspective. See page 17 for mouse and key commands used to manipulate the 3D image within the viewer.

Note: The image can be manipulated in all directions and become disorienting. If you lose perspective, simply press F1 to return to the original view.

Recording Data:

RECORD button = 

Once the input of streaming data has been confirmed through the live playback feature, click on the Record button and the program will request the name and location for the pcap file to be created. Recording will begin immediately once the file information has been entered. Click on the Record button again to discontinue the capture. One can string multiple recordings together on the same file by performing the Record function repeatedly. A new file name will not be requested until after the session has been aborted.

Note: An Ethernet capture utility such as Wireshark® can also be used as a pcap capture utility.

Playback of Recorded files:

Use the File → Open command to open a previously captured pcap file for playback. The DSR playback controls are similar to any DVD/VCR control features.

PLAY button = 

PAUSE button = 

Press the Play button to render the file. The Play button will alternate to Pause when in playback mode.

FORWARD button = 

REVERSE button = 

Use the Forward and Reverse buttons to change the direction of playback.

Note: The X, Y, Z and distance figures at the bottom of the image represent the distance of the x,y,z crosshairs with respect to the origin point indicated by the small white circle. The concentric gray circles and grid lines represent 10 meter increments from the sensor.

Utilizing the db.XML calibration data file in DSR

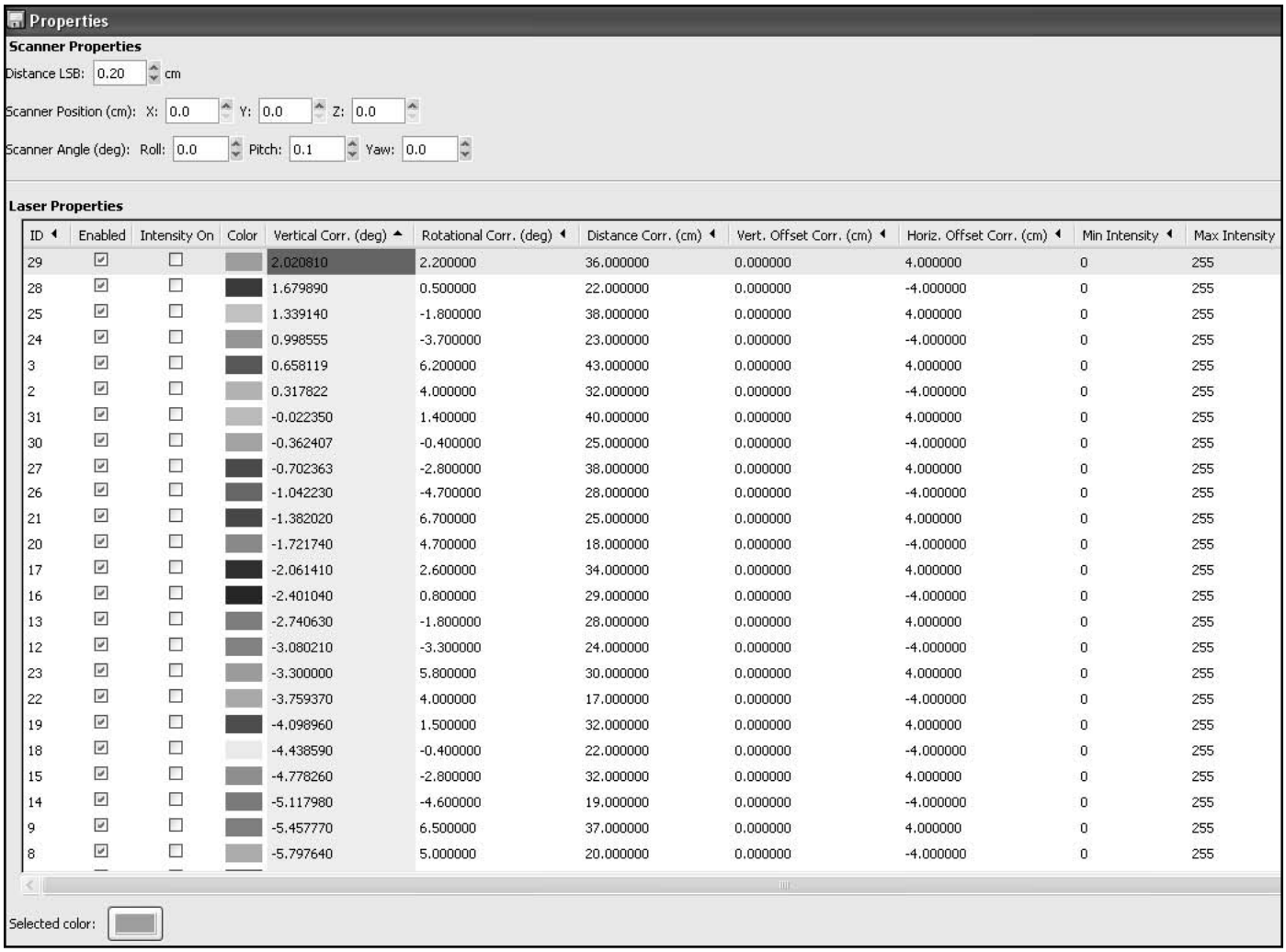
The db.XML file provided with your Velodyne HDL-64E S2 contains all of the necessary data for the proper alignment of the point cloud information gathered by the HDL sensor for each laser. {vertical correction (deg), rotational correction (deg), distance correction (cm), vertical offset (cm), horizontal offset (cm), minimum and maximum intensity (0-255)}.

When implemented properly, the image viewable from the Digital Sensor Recorder (DSR) will be properly calibrated to provide an accurate visual representation of the environment in which the sensor is being applied.

This data should also be used in any other program using the data generated by the HDL-64E S2.

To integrate the db.XML file into the DSR program, — follow these steps.

1. Provided that DSR has been installed on the host computer using the default settings, follow this path: c:\program files\Digital Sensor Recorder
2. Cut and paste the existing db.XML file to another location and rename as the default_db.XML
3. Copy and paste the db.XML file provided on the CD to the DSR program folder previously opened
4. Close out the windows and the program is ready to run
5. Open the DSR program
6. Click options\properties
7. Check that the new values are present and that they reflect the values in the example screen captures that are provided on the CD [Fig.6 sample]
8. Your DSR viewer is now calibrated to your sensor



ID	Enabled	Intensity On	Color	Vertical Corr. (deg)	Rotational Corr. (deg)	Distance Corr. (cm)	Vert. Offset Corr. (cm)	Horiz. Offset Corr. (cm)	Min Intensity	Max Intensity
29	☑	☐		2.020810	2.200000	36.000000	0.000000	4.000000	0	255
28	☑	☐		1.679890	0.500000	22.000000	0.000000	-4.000000	0	255
25	☑	☐		1.339140	-1.800000	38.000000	0.000000	4.000000	0	255
24	☑	☐		0.998555	-3.700000	23.000000	0.000000	-4.000000	0	255
3	☑	☐		0.658119	6.200000	43.000000	0.000000	4.000000	0	255
2	☑	☐		0.317822	4.000000	32.000000	0.000000	-4.000000	0	255
31	☑	☐		-0.022350	1.400000	40.000000	0.000000	4.000000	0	255
30	☑	☐		-0.362407	-0.400000	25.000000	0.000000	-4.000000	0	255
27	☑	☐		-0.702363	-2.800000	38.000000	0.000000	4.000000	0	255
26	☑	☐		-1.042230	-4.700000	28.000000	0.000000	-4.000000	0	255
21	☑	☐		-1.382020	6.700000	25.000000	0.000000	4.000000	0	255
20	☑	☐		-1.721740	4.700000	18.000000	0.000000	-4.000000	0	255
17	☑	☐		-2.061410	2.600000	34.000000	0.000000	4.000000	0	255
16	☑	☐		-2.401040	0.800000	29.000000	0.000000	-4.000000	0	255
13	☑	☐		-2.740630	-1.800000	28.000000	0.000000	4.000000	0	255
12	☑	☐		-3.080210	-3.300000	24.000000	0.000000	-4.000000	0	255
23	☑	☐		-3.300000	5.800000	30.000000	0.000000	4.000000	0	255
22	☑	☐		-3.759370	4.000000	17.000000	0.000000	-4.000000	0	255
19	☑	☐		-4.098960	1.500000	32.000000	0.000000	4.000000	0	255
18	☑	☐		-4.438590	-0.400000	22.000000	0.000000	-4.000000	0	255
15	☑	☐		-4.778260	-2.800000	32.000000	0.000000	4.000000	0	255
14	☑	☐		-5.117980	-4.600000	19.000000	0.000000	-4.000000	0	255
9	☑	☐		-5.457770	6.500000	37.000000	0.000000	4.000000	0	255
8	☑	☐		-5.797640	5.000000	20.000000	0.000000	-4.000000	0	255

Figure 6. Calibration values as seen in DSR/File/Properties

NOTE: *Example of image. Values will be different from those on your CD.*

DSR Key Controls

Zoom:
Z = Zoom in
Shift, Z = Zoom out

Z axis rotation:
Y = Rotate CW
Shift, Y = Rotate CCW

X axis rotation:
P = Rotate CW
Shift, P = Rotate CCW

Y axis rotation:
R = Rotate CW
Shift, R = Rotate CCW

Z Shift:
F = Forward
B = Back

X Shift:
L = Left
H = Right

Y Shift:
U = Up
D = Down

Aux. Functions:
Ctrl, (Z,Y,P,R,F,B,L,H,U,D) Direction = Fine Movement

Alt, (Z,Y,P,R,F,B,L,H,U,D) Direction= Very Fine Movement

DSR Mouse Controls

Rotational:
Left Button/Move

Slide:
Right Button/Move

Zoom:
Scroll forward = Zoom In
Scroll backward = Zoom Out

Appendix D - Ethernet Timing Table

HDL-64E S2 Ethernet Timing Table Overview

The HDL-64E S2 Ethernet Timing Table is designed to answer the question of how much time elapses between the actual capturing of a distance point and when that point is output from the device. By registering the event of the Ethernet data capture, HDL-64E S2 users can then trace back in time the exact point in time at which any particular distance point was captured by the HDL-64E S2.

In the HDL-64E S2, the upper block and lower block collect distance points simultaneously, with each block issuing single laser pulses at a time. That is, each upper block laser fires in sequence and in unison to a corresponding laser from the lower block. For example, laser 32 fires simultaneously with laser 0, laser 33 fires with laser 1, and so on. Unlike the HDL-64E, which issued three upper block returns for every lower block return, the HDL-64E S2 has an equal number of upper and lower block returns. This is why when interpreting the delay table each sequential pair of data blocks will represent the upper and lower block respectively, and each upper and lower block pair of data blocks in the Ethernet packet will have the same delay values.

Ethernet packets are assembled until the entire 1200 bytes have been collected, representing six upper block sequences and six lower block sequences. The packet is then transmitted via a UDP packet over Ethernet, starting from the last byte acquired. See a sample of the packet layout on page 20.

HDL-64E S2 Ethernet Transmit Timing Table

Data Block	Laser Block	Laser Numbers Lower, Upper																
		0,32	1,33	2,34	3,35	4,36	5,37	6,38	7,39	8,40	9,41	10,42	11,43	12,44	13,45	14,46	15,47	16,48
1	Upper	419.3	418.6	417.8	417.1	416.4	415.7	414.9	414.2	413.5	412.7	412.0	411.3	410.6	409.8	409.1	408.4	407.7
2	Lower	419.3	418.6	417.8	417.1	416.4	415.7	414.9	414.2	413.5	412.7	412.0	411.3	410.6	409.8	409.1	408.4	407.7
3	Upper	396.0	395.3	394.5	393.8	393.1	392.4	391.6	390.9	390.2	389.5	388.7	388.0	387.3	386.5	385.8	385.1	384.4
4	Lower	396.0	395.3	394.5	393.8	393.1	392.4	391.6	390.9	390.2	389.5	388.7	388.0	387.3	386.5	385.8	385.1	384.4
5	Upper	372.7	372.0	371.3	370.5	369.8	369.1	368.3	367.6	366.9	366.2	365.4	364.7	364.0	363.2	362.5	361.8	361.1
6	Lower	372.7	372.0	371.3	370.5	369.8	369.1	368.3	367.6	366.9	366.2	365.4	364.7	364.0	363.2	362.5	361.8	361.1
7	Upper	349.4	348.7	348.0	347.2	346.5	345.8	345.0	344.3	343.6	342.9	342.1	341.4	340.7	339.9	339.2	338.5	337.8
8	Lower	349.4	348.7	348.0	347.2	346.5	345.8	345.0	344.3	343.6	342.9	342.1	341.4	340.7	339.9	339.2	338.5	337.8
9	Upper	326.1	325.4	324.7	323.9	323.2	322.5	321.7	321.0	320.3	319.6	318.8	318.1	317.4	316.7	315.9	315.2	314.5
10	Lower	326.1	325.4	324.7	323.9	323.2	322.5	321.7	321.0	320.3	319.6	318.8	318.1	317.4	316.7	315.9	315.2	314.5
11	Upper	302.8	302.1	301.4	300.6	299.9	299.2	298.5	297.7	297.0	296.3	295.5	294.8	294.1	293.4	292.6	291.9	291.2
12	Lower	302.8	302.1	301.4	300.6	299.9	299.2	298.5	297.7	297.0	296.3	295.5	294.8	294.1	293.4	292.6	291.9	291.2

Table continued below . . .

Data Block	Laser Block	Laser Numbers Lower, Upper														
		17,49	18,50	19,51	20,52	21,53	22,54	23,55	24,56	25,57	26,58	27,59	28,60	29,61	30,62	31,63
1	Upper	406.9	406.2	405.5	404.7	404.0	403.3	402.6	401.8	401.1	400.4	399.6	398.9	398.2	397.5	396.7
2	Lower	406.9	406.2	405.5	404.7	404.0	403.3	402.6	401.8	401.1	400.4	399.6	398.9	398.2	397.5	396.7
3	Upper	383.6	382.9	382.2	381.4	380.7	380.0	379.3	378.5	377.8	377.1	376.3	375.6	374.9	374.2	373.4
4	Lower	383.6	382.9	382.2	381.4	380.7	380.0	379.3	378.5	377.8	377.1	376.3	375.6	374.9	374.2	373.4
5	Upper	360.3	359.6	358.9	358.1	357.4	356.7	356.0	355.2	354.5	353.8	353.1	352.3	351.6	350.9	350.1
6	Lower	360.3	359.6	358.9	358.1	357.4	356.7	356.0	355.2	354.5	353.8	353.1	352.3	351.6	350.9	350.1
7	Upper	337.0	336.3	335.6	334.9	334.1	333.4	332.7	331.9	331.2	330.5	329.8	329.0	328.3	327.6	326.8
8	Lower	337.0	336.3	335.6	334.9	334.1	333.4	332.7	331.9	331.2	330.5	329.8	329.0	328.3	327.6	326.8
9	Upper	313.7	313.0	312.3	311.6	310.8	310.1	309.4	308.6	307.9	307.2	306.5	305.7	305.0	304.3	303.5
10	Lower	313.7	313.0	312.3	311.6	310.8	310.1	309.4	308.6	307.9	307.2	306.5	305.7	305.0	304.3	303.5
11	Upper	290.4	289.7	289.0	288.3	287.5	286.8	286.1	285.3	284.6	283.9	283.2	282.4	281.7	281.0	280.3
12	Lower	290.4	289.7	289.0	288.3	287.5	286.8	286.1	285.3	284.6	283.9	283.2	282.4	281.7	281.0	280.3

First Trans Trigger to Ethernet Trans Enable	419.3 us
Ethernet Output Duration	100 us
Total Packet Bytes	1248
Header Bytes	42
Data Bytes	1200
Footer Bytes	6
Byte per microsecond	12.48
Microseconds per Byte	0.080128

How to use this table

The table above represents an HDL-64E S2 data packet. The laser returns will come out in the order listed above.
Simply subtract from the timestamp of the output event of the packet each data value to arrive at the actual time the distance point was captured inside the HDL-64E S2.

HDL-64E S2 Sample Data Packet

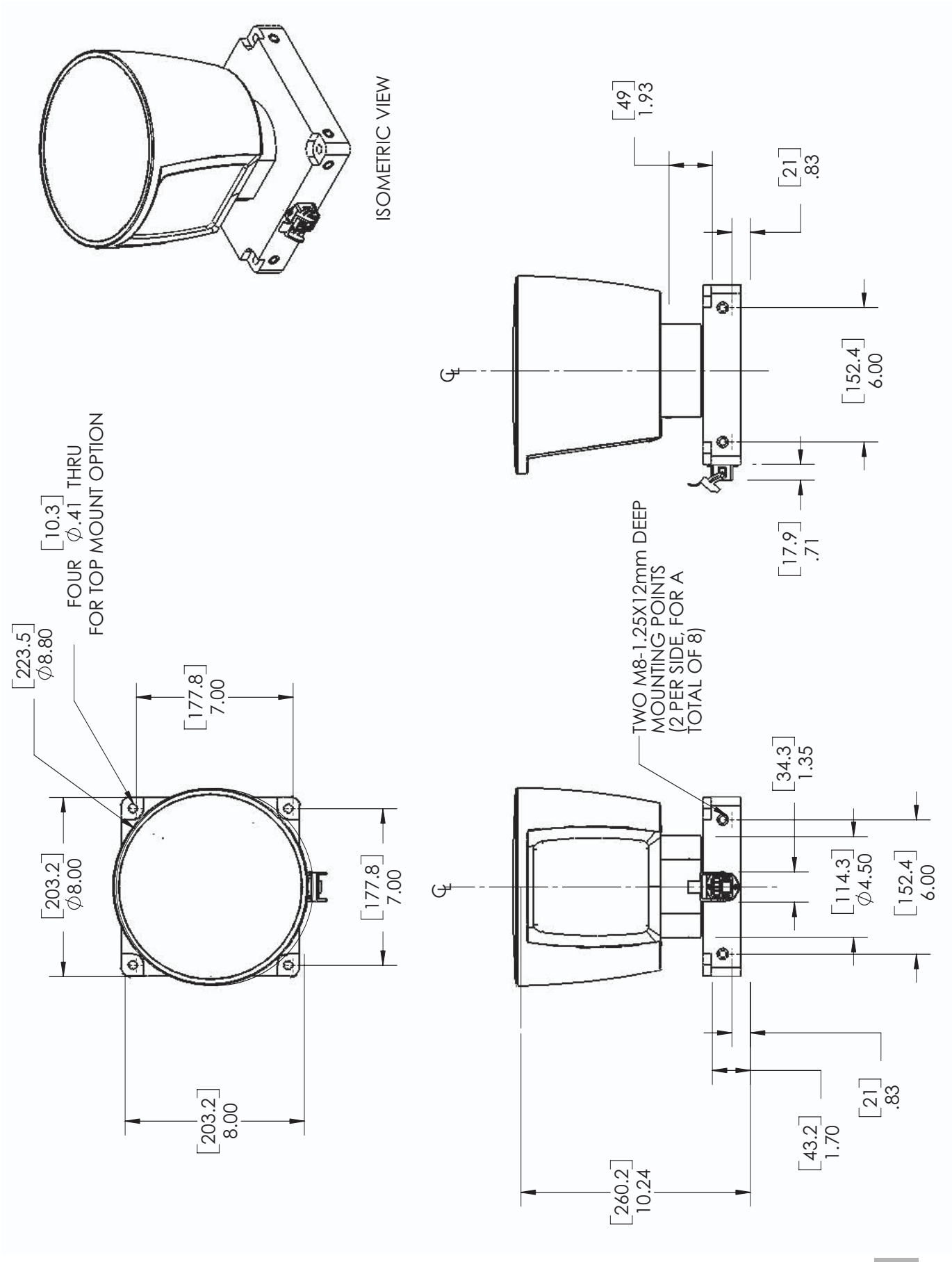
```
No.     Time        Source                Destination           Protocol Info
      5 0.001121    192.168.3.43          192.168.3.255         UDP      Source port: https  Destination port: 2368

Frame 5 (1248 bytes on wire, 1248 bytes captured)
Ethernet II, Src: 00:00:00_00:00:00 (00:00:00:00:00:00), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
Internet Protocol, Src: 192.168.3.43 (192.168.3.43), Dst: 192.168.3.255 (192.168.3.255)
User Datagram Protocol, Src Port: https (443), Dst Port: 2368 (2368)
Data (1206 bytes)

0000  ff ee c2 01 73 05 3d 51 05 36 a9 05 3f c1 05 34   ....s.=Q.6..?..4
0010  a1 05 3f c0 05 3e 6c 05 37 74 05 41 6e 05 39 72   ..?..>l.7t.An.9r
0020  05 37 75 05 3a 5b 05 3c 72 05 3e 6d 05 39 68 05   .7u.:[.<r.>m.9h.
0030  3a 7c 05 3a 79 05 40 5a 05 37 44 05 38 70 05 42   :|.:y.@Z.7D.8p.B
0040  a1 05 3c e2 05 37 61 05 37 6d 05 3a 93 05 3d c2   ..<..7a.7m.:..=.
0050  05 3e 85 05 36 b8 05 39 c0 05 37 ba 05 3d 88 05   .>..6..9..7..=..
0060  39 c0 05 39 ff dd c2 01 01 05 1e 15 05 3d 1c 06   9..9.........=..
0070  76 cf 04 3b 03 05 23 92 05 20 37 04 39 9a 04 3d   v..;..#.. 7.9..=
0080  0b 05 9d 0c 05 39 92 04 3f 0b 05 20 17 06 1f 19   .....9..?.. ....
0090  06 3e ea 04 43 d0 05 39 20 06 26 48 06 53 c4 05   .>..C..9 .&H.S..
00a0  23 00 06 29 cd 04 89 d1 04 3b 97 05 42 06 05 39   #..).....;..B..9
00b0  46 05 3e 20 05 5c 9f 04 33 20 06 96 59 05 8d 7e   F.> .\..3 ..Y..~
00c0  05 71 06 06 4e 17 06 59 ff ee c2 01 67 05 3b 55   .q..N..Y....g.;U
00d0  05 36 a6 05 40 c3 05 33 a4 05 3e b4 05 3b 69 05   .6..@..3..>..;i.
00e0  38 72 05 40 6a 05 38 70 05 37 70 05 3b 5c 05 3c   8r.@j.8p.7p.;\.<
00f0  72 05 3f 74 05 39 6b 05 3a 76 05 3a 76 05 3f 50   r.?t.9k.:v.:v.?P
0100  05 39 48 05 3a 75 05 40 9c 05 3d db 05 37 5e 05   .9H.:u.@..=..7^.
0110  37 72 05 3a 97 05 3d c5 05 3d 81 05 36 ba 05 38   7r.:..=..=..6..8
0120  bb 05 37 ba 05 3b 8b 05 3b b3 05 3c ff dd c2 01   ..7..;..;..<....
0130  06 05 1f 0f 05 3e 16 06 78 ca 04 3d 1c 05 22 91   .....>..x..=.."."
0140  05 1f 3b 04 3b 8e 04 3b 0d 05 9b 0d 05 39 8b 04   ..;.;..;.....9..
0150  3c 0c 05 20 22 06 1f 1a 06 3e ea 04 41 dd 05 39   <.. "....>..A..9
0160  3a 06 27 4b 06 51 c8 05 23 0f 06 29 ca 04 84 db   :.'K.Q..#..)....
0170  04 3b 9d 05 43 09 05 40 41 05 3d 22 05 5f a7 04   .;..C..@A.="._..
0180  34 26 06 93 5c 05 8d 7c 05 6a 07 06 4f 1b 06 5b   4&..\..|.j..O..[
0190  ff ee c2 01 72 05 3c 4c 05 35 ab 05 3e bd 05 36   ....r.<L.5..>..6
01a0  a9 05 40 b2 05 3c 6b 05 37 73 05 3f 6e 05 38 74   ..@..<k.7s.?n.8t
01b0  05 37 76 05 39 5b 05 3d 75 05 3e 6c 05 37 64 05   .7v.9[.=u.>l.7d.
01c0  3a 76 05 3a 78 05 41 5c 05 38 49 05 39 70 05 3f   :v.:x.A\.8I.9p.?
01d0  9d 05 3c e2 05 37 60 05 37 6b 05 3b 9b 05 3b c1   ..<..7`.7k.;..;.
01e0  05 3b 7e 05 37 b6 05 39 ba 05 38 b8 05 3a 8d 05   .;~.7..9..8..:..
01f0  3a b5 05 39 ff dd c2 01 04 05 1e 10 05 3e 1d 06   :..9.........>..
0200  79 cc 04 3b 1c 05 23 76 05 1f 36 04 3d 91 04 3b   y..;..#v..6.=..;
0210  0c 05 99 13 05 39 8d 04 3f 0a 05 20 0f 06 1e 1d   .....9..?.. ....
0220  06 3e df 04 41 d2 05 37 2d 06 26 4d 06 53 bd 05   .>..A..7-.&M.S..
0230  23 09 06 29 c8 04 88 d3 04 3b 98 05 40 0e 05 3d   #..).....;..@..=
0240  3a 05 3d 20 05 5e a1 04 34 21 06 8f 5e 05 8d 79   :.= .^..4!..^..y
0250  05 69 0b 06 50 1b 06 58 ff ee c2 01 6e 05 3c 4f   .i..P..X....n.<O
0260  05 38 a2 05 3f bf 05 35 9d 05 40 b6 05 3c 71 05   .8..?..5..@..<q.
0270  37 6c 05 40 65 05 38 82 05 35 71 05 3c 68 05 3f   7l.@e.8..5q.<h.?
0280  70 05 3e 6b 05 39 6a 05 3a 80 05 3b 72 05 3f 4e   p.>k.9j.:..;r.?N
0290  05 39 48 05 38 6f 05 41 a4 05 3c df 05 38 58 05   .9H.8o.A..<..8X.
02a0  37 76 05 39 9a 05 3e c5 05 3b 86 05 36 b4 05 39   7v.9..>..;..6..9
02b0  b6 05 37 ba 05 39 8b 05 3b b8 05 39 ff dd c2 01   ..7..9..;..9....
02c0  09 05 1e 0a 05 3f 1a 06 78 c6 04 3c 0d 05 22 75   .....?..x..<.."u
02d0  05 1f 3f 04 3f 8c 04 3c 0d 05 99 0e 05 39 8e 04   ..?.?..<.....9..
```

Continued . . .

```
02e0  3c 12 05 1f 11 06 1f 1b 06 3f e2 04 41 cf 05 39   <........?..A..9
02f0  33 06 25 4c 06 53 c9 05 23 05 06 29 cc 04 86 d0   3.%L.S..#..)....
0300  04 3b 95 05 3f 09 05 3f 40 05 3d 21 05 5b a4 04   .;..?..?@.=!.[..
0310  35 21 06 92 5c 05 8d 7e 05 73 07 06 4f 1b 06 5e   5!..\..~.s..O..^
0320  ff ee c2 01 6e 05 3d 51 05 38 aa 05 42 c7 05 34   ....n.=Q.8..B..4
0330  a2 05 41 bf 05 3e 6b 05 38 72 05 40 6a 05 39 75   ..A..>k.8r.@j.9u
0340  05 35 77 05 3b 5b 05 3d 77 05 3f 71 05 39 68 05   .5w.;[.=w.?q.9h.
0350  39 7f 05 3c 73 05 40 57 05 39 43 05 39 72 05 3f   9..<s.@W.9C.9r.?
0360  a5 05 3d d8 05 34 5f 05 36 77 05 3a 96 05 3e c2   ..=..4_.6w.:..>.
0370  05 3f 8b 05 35 b7 05 39 b7 05 37 c2 05 3b 88 05   .?..5..9..7..;..
0380  39 b1 05 38 ff dd c2 01 04 05 1e 0b 05 3f 1d 06   9..8.........?..
0390  79 d1 04 3e 08 05 23 7c 05 1f 31 04 3a 94 04 3b   y..>..#|..1.:..;
03a0  0d 05 9c 0c 05 39 8f 04 3e 09 05 20 11 06 1f 18   .....9..>.. ....
03b0  06 3e e7 04 42 d5 05 3a 35 06 26 49 06 52 c9 05   .>..B..:5.&I.R..
03c0  22 0c 06 2a cc 04 86 d4 04 3a 9b 05 42 0b 05 40   "..*.....:..B..@
03d0  3d 05 3d 22 05 59 a5 04 34 21 06 93 5c 05 8c 82   =.=".Y..4!..\...
03e0  05 75 08 06 50 1b 06 59 ff ee c2 01 71 05 3d 54   .u..P..Y....q.=T
03f0  05 39 aa 05 3f c3 05 33 a2 05 40 bd 05 3d 71 05   .9..?..3..@..=q.
0400  36 6b 05 3f 67 05 39 75 05 36 6f 05 3c 5c 05 3c   6k.?g.9u.6o.<\.<
0410  72 05 3f 6c 05 37 6a 05 3a 78 05 39 71 05 40 53   r.?l.7j.:x.9q.@S
0420  05 38 42 05 3a 70 05 3f 99 05 3b e1 05 39 5b 05   .8B.:p.?..;..9[.
0430  37 7a 05 39 98 05 3d c3 05 3d 8b 05 38 b6 05 37   7z.9..=..=..8..7
0440  b8 05 38 c3 05 3b 88 05 39 b6 05 3a ff dd c2 01   ..8..;..9..:....
0450  05 05 1e 0f 05 3f 1c 06 77 cd 04 3f 1e 05 22 76   .....?..w..?.."v
0460  05 1f 33 04 3e 8f 04 3d 08 05 9b 11 05 39 8d 04   ..3.>..=.....9..
0470  3c 09 05 20 13 06 1f 1b 06 3c ea 04 41 cf 05 39   <.. .....<..A..9
0480  26 06 24 42 06 52 c8 05 24 0e 06 2a ca 04 86 d4   &.$B.R..$..*....
0490  04 3c a1 05 40 0e 05 3f 3e 05 3d 25 05 5b a9 04   .<..@..?>.=%.[..
04a0  35 22 06 93 5e 05 88 7f 05 73 05 06 4f 1a 06 5a   5"..^....s..O..Z
04b0  09 00 76 32 36 62                                 ..v26b
```

NOTE: Highlighted area is upper block.

Appendix E - Dimensional Drawing



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