HDL™-64E

USER'S MANUAL

High Definition Lidar™ Sensor

IMPORTANT SAFETY INSTRUCTIONS

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. **Power Sources —** The product should be connected to a power supply only of the type described in the operating instructions or as marked on the product.
7. **Cleaning —** The product should be cleaned only as recommended by the manufacturer.
8. **Nonuse Periods —** The power connection to the product should be disconnected when left unused for a long period of time.
9. **Object and Liquid Entry —** Care should be taken so that objects do not fall and liquids are not spilled onto the enclosure.
10. **Damage Requiring Service —** The product should be serviced by qualified service personnel when:
    a. The product does not appear to operate normally or exhibits a marked change in performance.
    b. The product has been dropped or damaged.
11. **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 qualified service personnel.

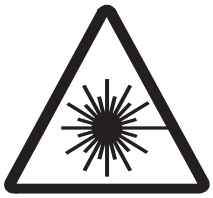


Table of Contents

Introduction

Congratulations on your purchase of a Velodyne HDL-64E High Definition Lidar Sensor. This product represents a breakthrough in sensing technology by providing exponentially 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.velodyne.com/lidar** for updates.

Principles of Operation

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

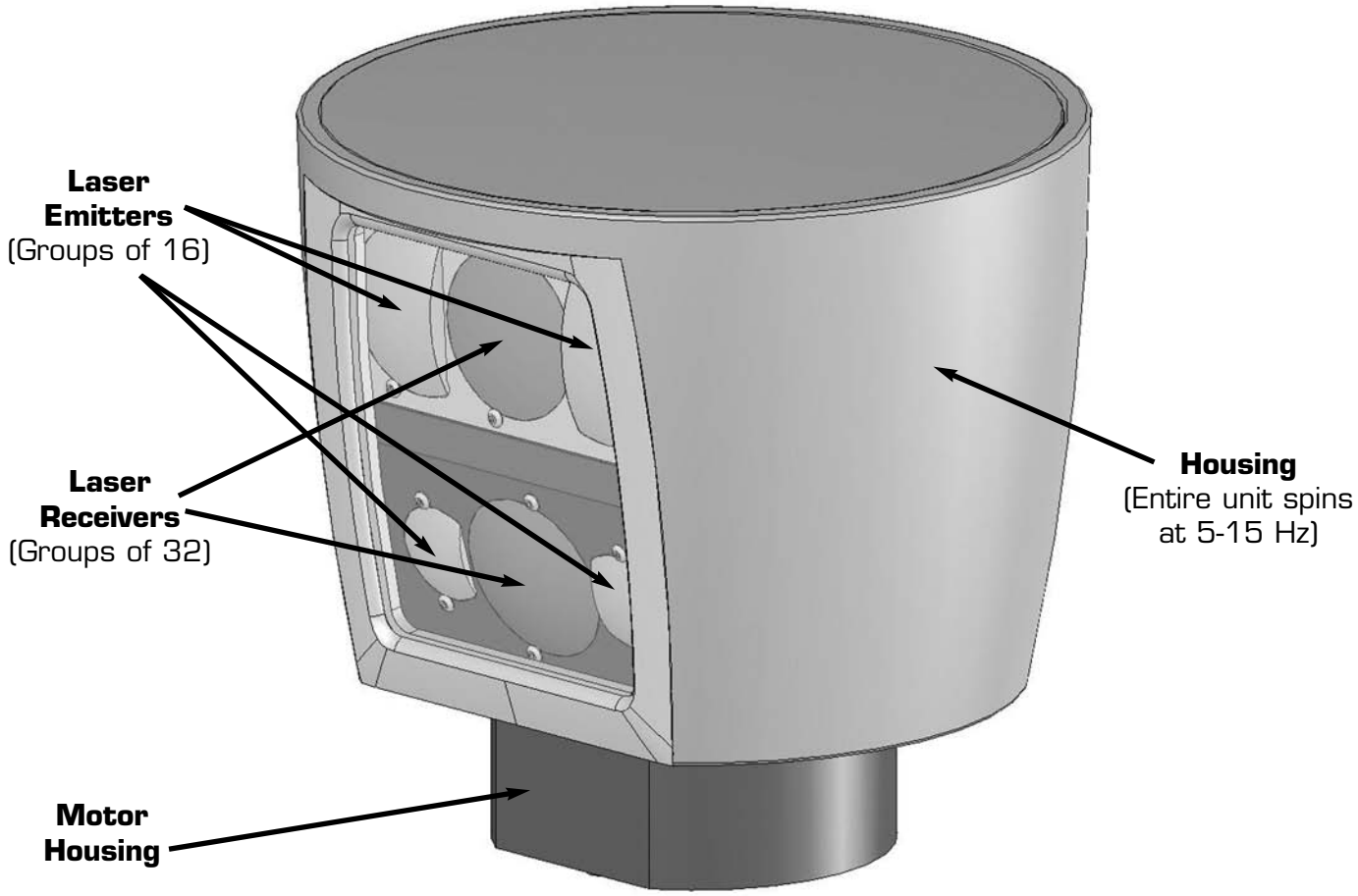


Figure 1. HDL-64E design overview.

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

Front/Back Mounting

The HDL-64E 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.

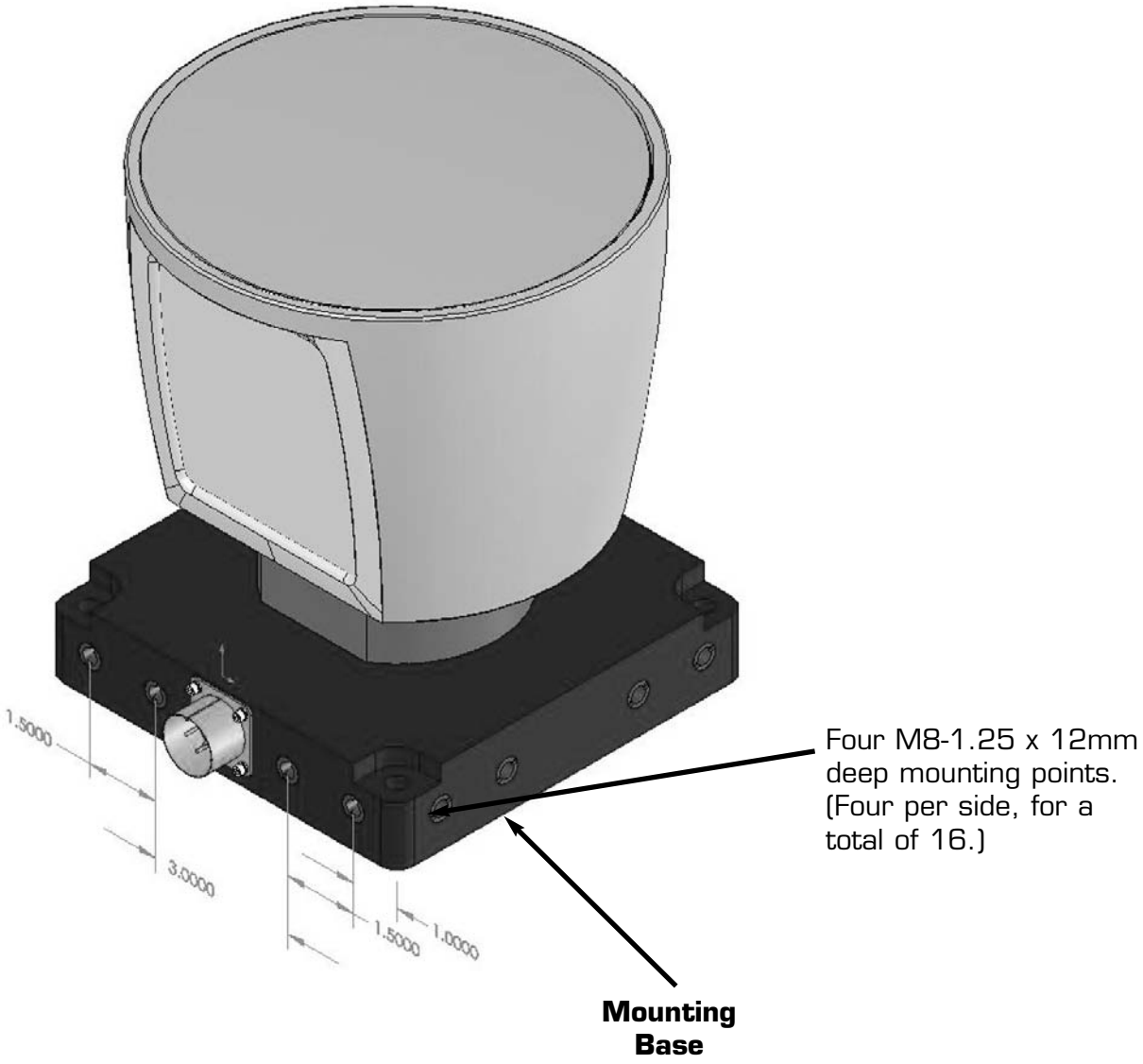


Figure 2. Front and back HDL mounting illustration.

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

Side Mounting

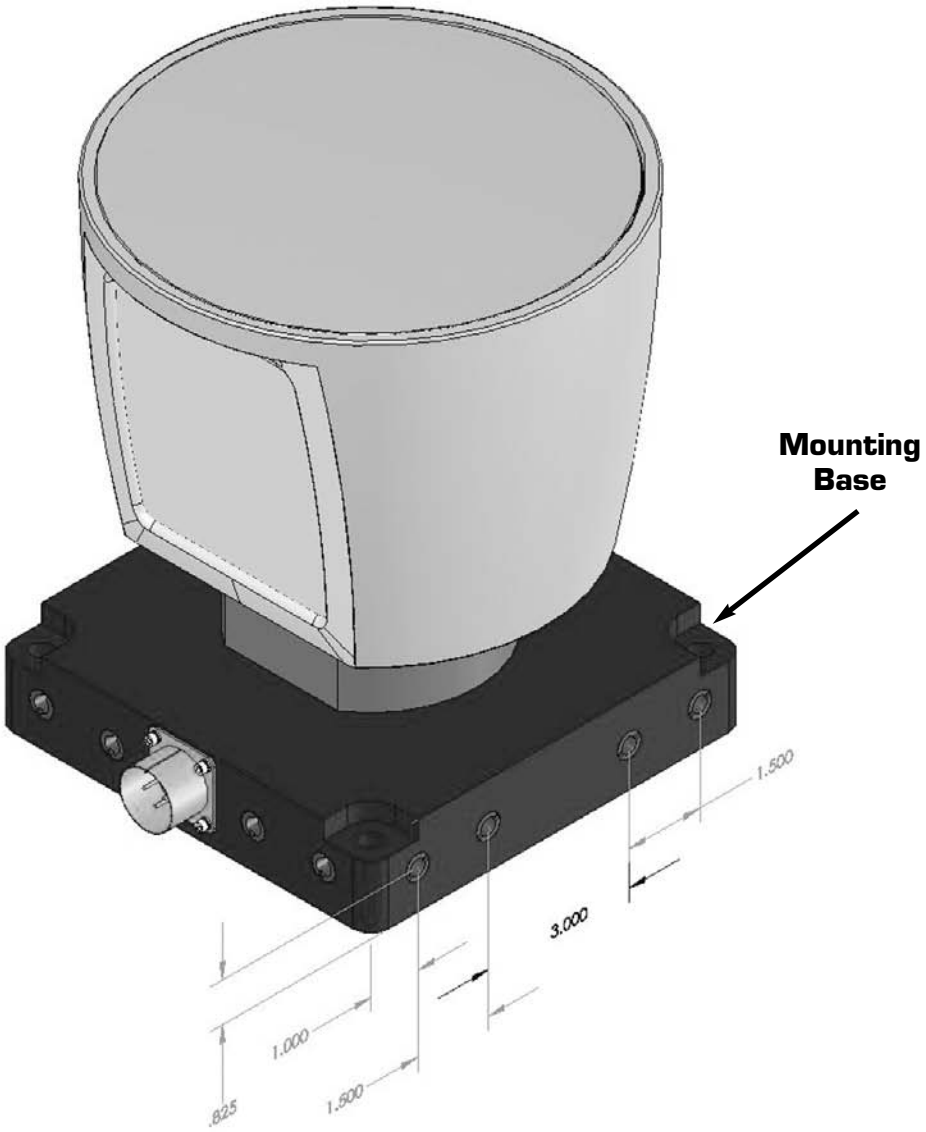


Figure 3. Side/side HDL mounting illustration.

Top Mounting

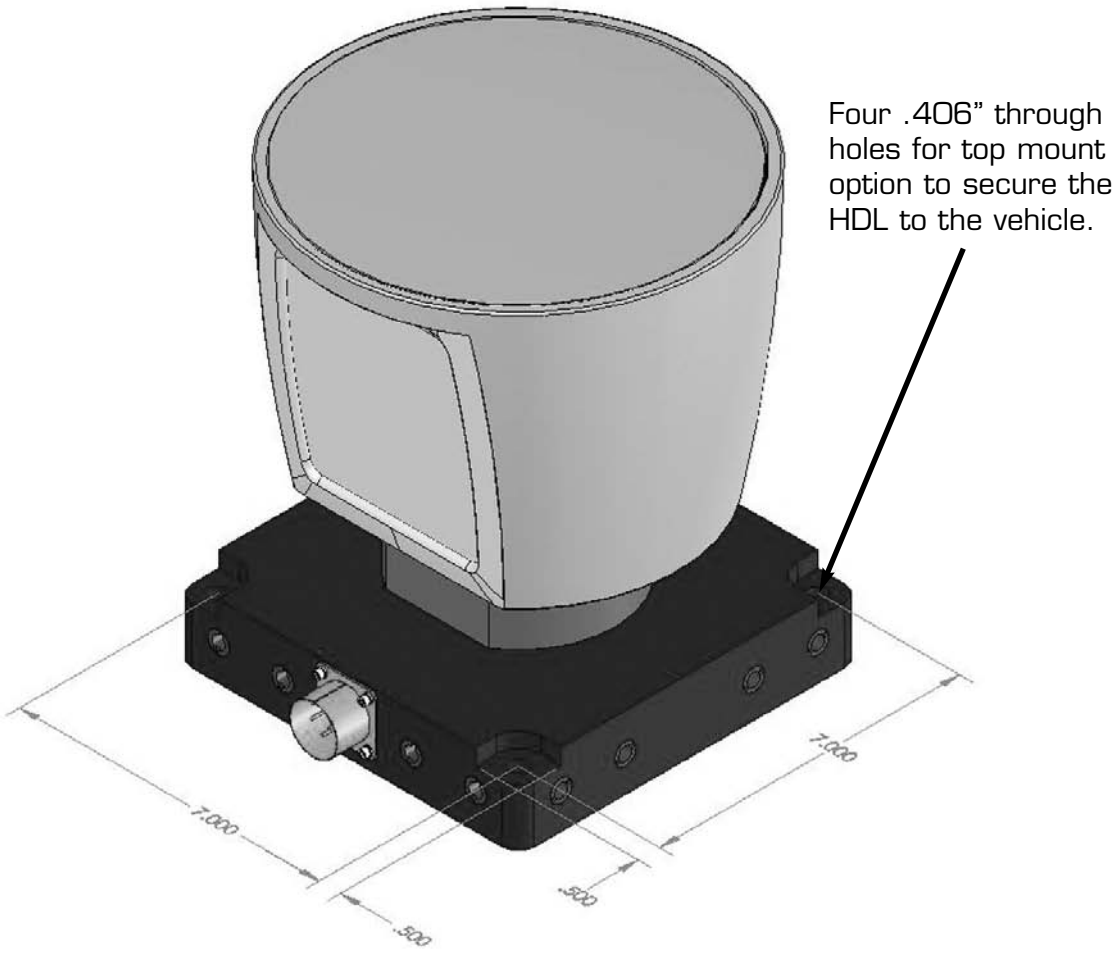


Figure 4. HDL top mounting illustration.

Figure 4 shows the location of four .406" thru holes for top mounting.

For all mounting options, be sure the HDL-64E 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 is weatherproofed to withstand wind, rain, and other adverse weather conditions. The spinning nature of the HDL-64E helps the unit shed excess water from the front window that could hamper performance. However, it is advisable to avoid exposing the HDL-64E to extreme weather conditions such as driving rain.

Wiring

The HDL-64E comes with a pre-wired connector, wired with power, DB9 serial, and standard RJ-45 Ethernet connectors.The connector wires are approximately 25' in length.

Power. Connect the red and black wires to vehicle power. Be sure red is positive polarity. THE HDL-64E 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 does not have a power switch. It spins whenever power is applied. The HDL-64E 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.

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 (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 B for a layout of the wiring pins.

USAGE

Output

The HDL-64E 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 increments, and one byte of intensity information (0 – 255, with 255 being the most intense return). A zero return indicates no return up to 65 meters.

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

Note: The HDL-64E will ouput three upper block packets for every one lower block packet. This provides more resolution when identifying objects at greater distances.

The minimum return distance for the HDL-64E is approximately three feet. **Returns closer than this should be ignored.**

Correction Angles

Each HDL-64E 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, rotational and horizontal correction factors must be applied to determine the point's location in 3-D space referred to by the return. Appendix A shows correction factors for both the upper and lower laser blocks.

Controlling the Spin Rate

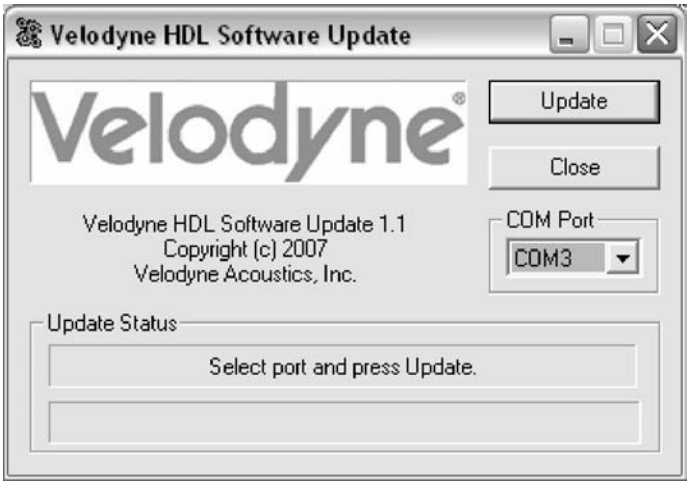
The HDL-64E can spin at rates ranging from 300 RPM (5 Hz) to 900 RPM (15 Hz). The default is 600 RPM (10 Hz). Note that changing the spin rate does not change the data rate – the unit will send out the same number of packets (at a rate of one million data points per second). The image resolution will increase or decrease depending on rotation speed. See Appendix C 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 HDL64E will adopt the new spin rate. Use the following serial parameters: Baud 9600, Parity: None, Data bits: 8, Stop bits: 1. The HDL-64E has no echo back feature, so no serial data will be returned from the HDL-64E.

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 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:



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. 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.

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. Etherreal/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.

SPECIFICATIONS

Sensor:	• 64 lasers • 360 degree horizontal field of view (azimuth) • 0.09 degree angular resolution (azimuth) • 26.8 degree vertical field of view (elevation) • <5 cm resolution (distance) • 5-15 Hz field of view update (user selectable) • 50 meter range for pavement (~0.10 reflectivity) • 120 meter range for cars and foliage (~0.80 reflectivity) • >1m points per second • <0.05 miliseconds latency
Laser:	• Class 1M - eye safe • 4 x 16 lasers assemblies • 905 nm wavelenth • 5 nanosecond pulse • Adaptive power system for minimizing saturations and blinding • Beam Shape: Lower Block @ 100 feet: 6" x .8" (w x h) Upper Block @ 100 feet: 4" x .8" (w x h)
Mechanical:	• 12-16V input @ 4 Amps (max) • 10" tall cylinder of 8" OD radius
Output:	• 100 MBPS Ethernet with UDP

Appendix A - Laser Correction Factors and Data Packet Construction/Interpretation

Firing Order - Upper 32 Lasers - Header OxEEFF				Firing Order - Lower 32 Lasers - Header OxDDFF		
Laser Number	**RCF***	**VCF****	**HCF*****	**Laser Number**	**RCF***	**VCF****
1	-4.9542347365	-7.1581190889	4.00	1	-7.443011494	-22.73788631
2	-2.8147367929	-6.8178216657	-4.00	2	-4.224232979	-22.22607199
3	2.8147367929	0.3178216657	4.00	3	4.224232979	-11.51392801
4	4.9542347365	0.6581190889	-4.00	4	7.443011494	-11.00211369
5	-0.6935618777	-6.4776502171	4.00	5	-1.033172642	-21.71468598
6	1.4410693300	-6.1375926248	-4.00	6	2.169097681	-21.20368655
7	-1.4698693300	-8.5208123798	4.00	7	-2.197897681	-24.79027242
8	0.6647618777	-8.1798890134	-4.00	8	1.004372642	-24.27632105
9	3.5633243031	-5.7976368074	4.00	9	5.36381546	-20.69303226
10	5.7049959563	-5.4577707152	-4.00	10	8.590013444	-20.18268193
11	2.7859367929	-7.8391405361	4.00	11	4.195432979	-23.76296827
12	4.9254347365	-7.4985546449	-4.00	12	7.414211494	-23.25017094
13	-4.9974347365	-3.0802132582	4.00	13	-7.486211494	-16.61531942
14	-2.8579367929	-2.7406338106	-4.00	14	-4.267432979	-16.10593813
15	-5.7769959563	-5.1179823277	4.00	15	-8.662013444	-19.6725946
16	-3.6353243031	-4.7782596485	-4.00	16	-5.43581546	-19.16272948
17	-0.7367618777	-2.4010364689	4.00	17	-1.076372642	-15.59649644
18	1.3978693300	-2.0614092976	-4.00	18	2.125897681	-15.08695403
19	-1.5130693300	-4.4385907024	4.00	19	-2.241097681	-18.65304597
20	0.6215618777	-4.0989635311	-4.00	20	0.961172642	-18.14350356
21	3.5201243031	-1.7217403515	4.00	21	5.32061546	-14.57727052
22	5.6617959563	-1.3820176723	-4.00	22	8.546813444	-14.067405
23	2.7427367929	-3.7593661894	4.00	23	4.152232979	-17.63406187
24	4.8822347365	-3.4197867418	-4.00	24	7.371011494	-17.12468058
25	-5.0406347365	0.9985546449	4.00	25	-7.529411494	-10.48982906
26	-2.9011367929	1.3391405361	-4.00	26	-4.310632979	-9.977031727
27	-5.8201959563	-1.0422292848	4.00	27	-8.705213444	-13.55731807
28	-3.6785243031	-0.7023631926	-4.00	28	-5.47901546	-13.04696774
29	-0.7799618777	1.6798890134	4.00	29	-1.119572642	-9.463678954
30	1.3546693300	2.0208123798	-4.00	30	2.082697681	-8.949727577
31	-1.5562693300	-0.3624073752	4.00	31	-2.284297681	-12.53631345
32	0.5783618777	-0.0223497829	-4.00	32	0.917972642	-12.02531402

* RCF: Rotational Correction Factor in Degrees

**VCF: Vertical Correction Factor in Degrees

***HCF: Horizontal correction factor in cm. This refers to the physical horizontal (i.e. left or right) offset of each of the laser blocks. The same value applies to both upper and lower blocks.

Horizontal correction factor for odd numbered lasers: (+)4cm.
Horizontal correction factor for even numbered lasers: (-)4cm.

Packet construction:

UDP, 100 bytes of data per firing, 12 blocks of data per packet, plus six status bytes at the end of each packet described below. There are three upper blocks returned for each lower block returned.

Data layout:

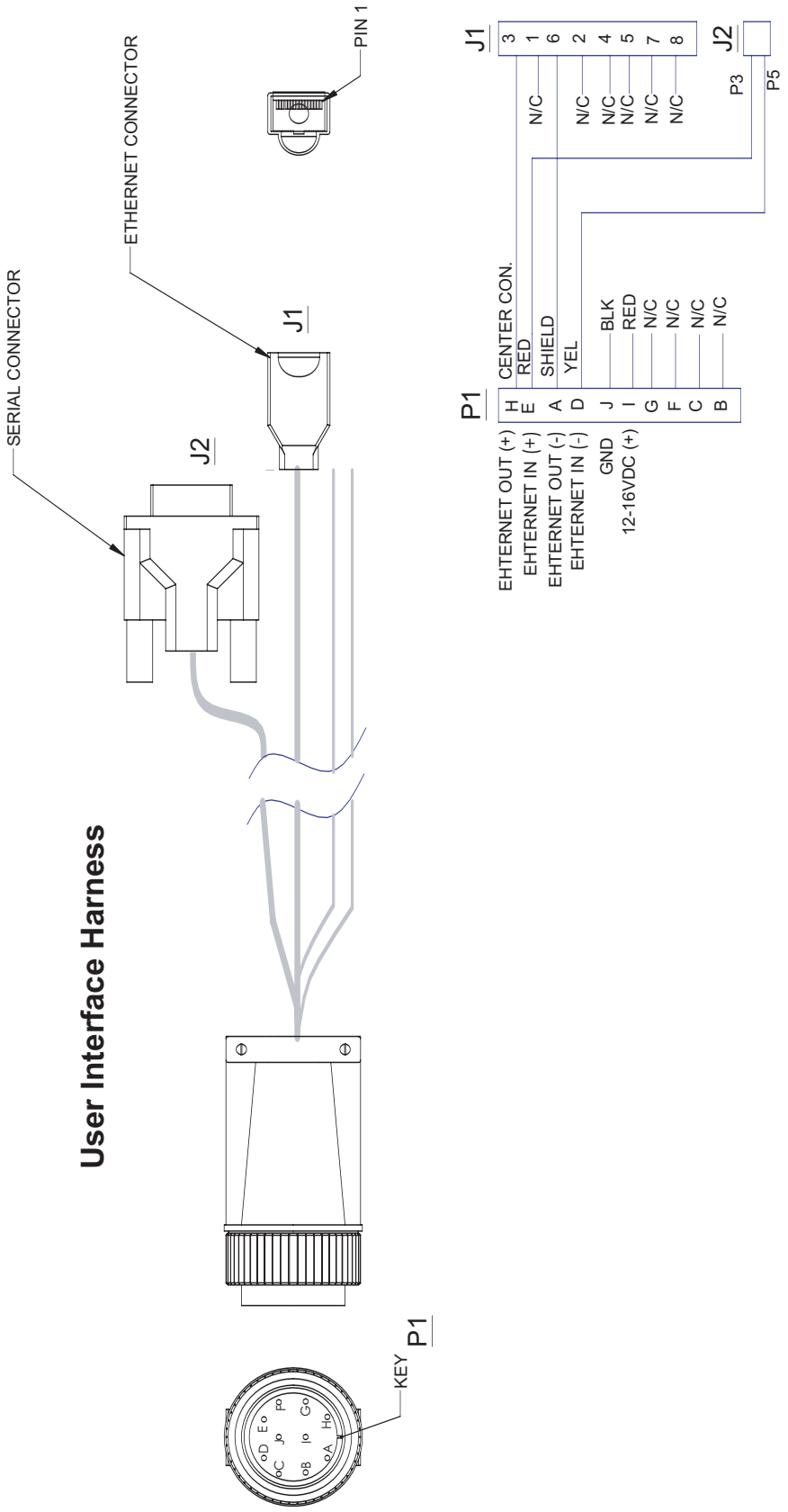
- Two bytes header info, two bytes rotational info (0-35999, divide by 100 to get degrees)

- 32 laser returns broken into three bytes each:
  - Two bytes distance information (in .2 CM increments)
  - One byte intensity information (0-255 with 255 being the most intense reflection)

- Six status bytes that alternate between packets. The end of the packet will show either:
  - 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 indian 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.

  - Or, the version number of the firmware in ASCII character format "Vn.n" where n.n is the version number, i.e. "1.5".

Appendix B - Connector Wiring Diagram



Appendix C - Angular Resolution

Lower Block				
RPM	RPS	Points Per Revolution	Points Per Revolution Per Laser	Angular Resolution (degrees)
300	5	50000	1562.5	0.2304
600	10	25000	781.25	0.4608
900	15	16667	521	0.6912

Upper Block					
RPM	RPS	Points Per Revolution	Points Per Revolution Per Laser	Angular Resolution (degrees)	Post-Lower-Block Angular Resolution (degrees)**
300	5	200000	6250	0.0576	0.1152
600	10	100000	3125	0.1152	0.2304
900	15	66667	2083	0.1728	0.3456

Notes:

The HDL-64E generates 1 million points per second
- The lower block reports 250,000 points
- The upper block reports 750,000 points

There are three upper block packets then one lower block packet reported, then the pattern repeats.

** The first upper block measurement after the lower block measurement reports has half the angular resolution.

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

408.465.2800 voice
408.779.9227 fax
408.779.9208 service fax

www.velodyne.com
Service E-mail: service@velodyne.com
Product E-mail: help@velodyne.com
Technical E-mail: techhelp@velodyne.com
Sales E-mail: lidar@velodyne.com

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