Dual Wavelength Waveform Processing Airborne LiDAR Scanning System for High-Point Density Mapping Applications

RIEGL VQ-1560i-DW

- *enhanced target characterization based upon simultaneous measurements at green and infrared laser wavelengths*
- *high laser pulse repetition rate of up to 1 MHz per laser channel*
- *up to 1.33 million measurements per second on the ground*
- *data acquisition at a wide range of point densities*
- *excellent multiple target capability*
- *enables Multiple-Time-Around (MTA) processing of up to 20 pulses simultaneously in the air*
- *online waveform processing as well as smart and full waveform recording for both LiDAR channels*
- *integrated inertial measurement unit and GNSS receiver*
- *integrated, easily accessible medium format camera*
- *prepared for integration of a secondary camera*
- *high-speed fiber data interface to RIEGL data recorder*
- *housing shape and mounting flange optimized for interfacing with typical hatches and stabilized platforms*

The VQ-1560i-DW is a airborne LiDAR scanning system offering two LiDAR channels of different wavelengths, green and infrared (IR). These wavelengths are well chosen to allow the acquisition of scan data of complementary information content, thus delivering two independent reflectance distribution maps, one per laser wavelength.

Scan data acquired with the *RIEGL* VQ-1560i-DW are the input for well-established scan data processing methods but also for the development of highly sophisticated data processing and evaluation algorithms for new areas of application like vegetation mapping in agriculture and forestry. Thus the VQ-1560i-DW offers innovative technology for commercial as well as scientific and research applications.

The VQ-1560i-DW provides a laser pulse repetition rate of up to 1MHz per LiDAR channel, resulting in a total of more than 1.3 million measurements per second on the ground.

The VQ-1560i-DW works at highest productivity when both LiDAR channels are combined, typically at altitudes up to 8300 ft. However, each channel is also prepared for stand-alone operation. This channel selection capability in combination with a matched line of measurement programs as well as widely variable scan parameters enable highest possible flexibility for meeting highly specific requirements of challenging application scenarios.

The system is completed by a high performance IMU/GNSS unit and up to two optional cameras. A 150 megapixels RBG camera is intended to be used as primary camera, as secondary camera a thermal or a NIR camera can be built in. The mounting flange is optimized for simple interfacing with typical aircraft hatches and stabilized mounts by means of a specific adapter ring.

Applications:

- *Scientific and Research Applications*
- *Agriculture and Forestry*
- *Mapping of Vegetation and Normalized Difference Vegetation Index (NDVI)*
- *Glacier & Snowfield Mapping*
- *Mapping of Lake Sides & River Banks*
- *High Point Density Mapping*
- *Corridor Mapping*

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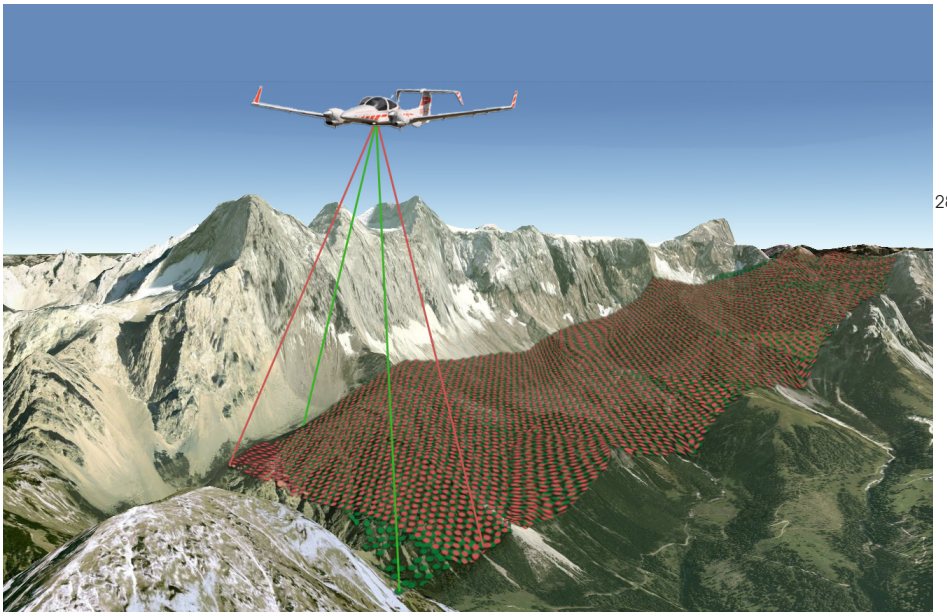
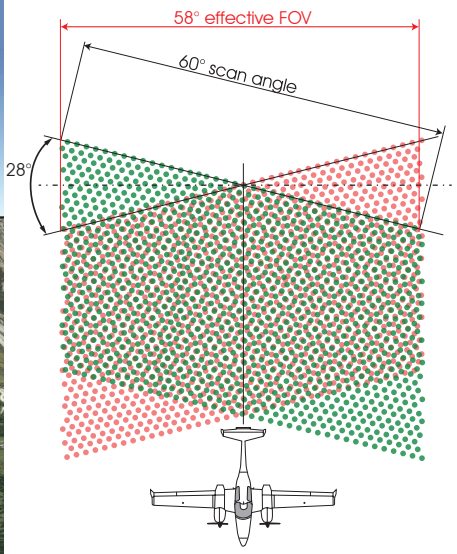
RIEGL®
LASER MEASUREMENT SYSTEMS

RIEGL VQ-1560i-DW Scan Pattern

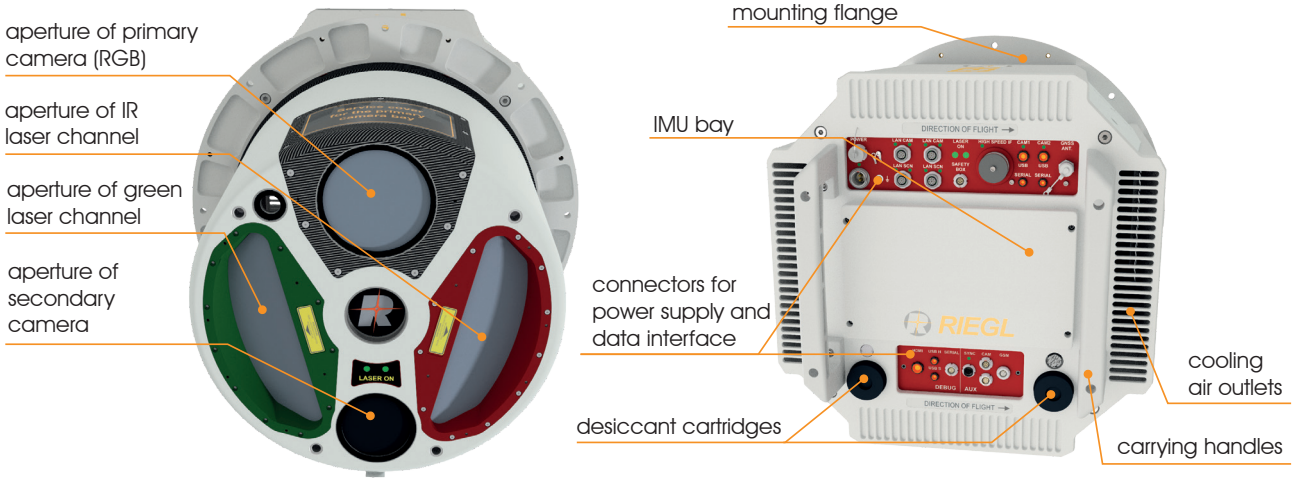




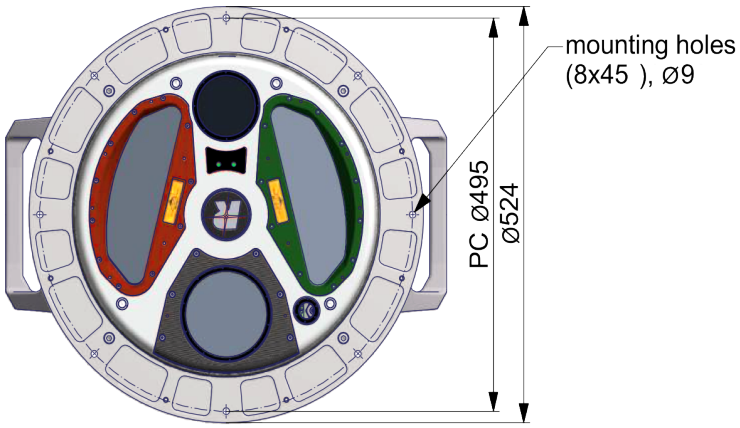
Each channel delivers straight parallel scan lines. The scan lines of the two channels are tilted against each other by 28 degrees providing an optimum distribution of the measurements on the ground invariant to changes in terrain height.

Tilt Angle of Scan Lines	± **14°**
Forward/Backward Scan Angle in Non-Nadir Direction	± **8° at the edge**

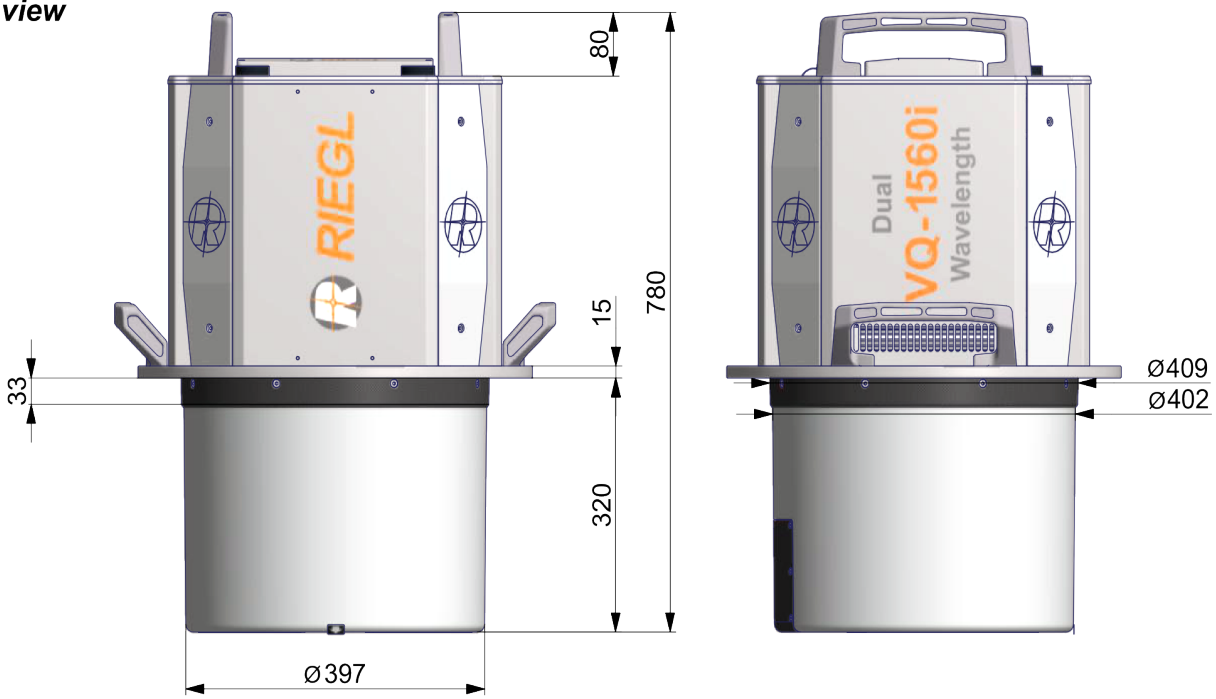
RIEGL VQ-1560i-DW Elements of Function and Operation



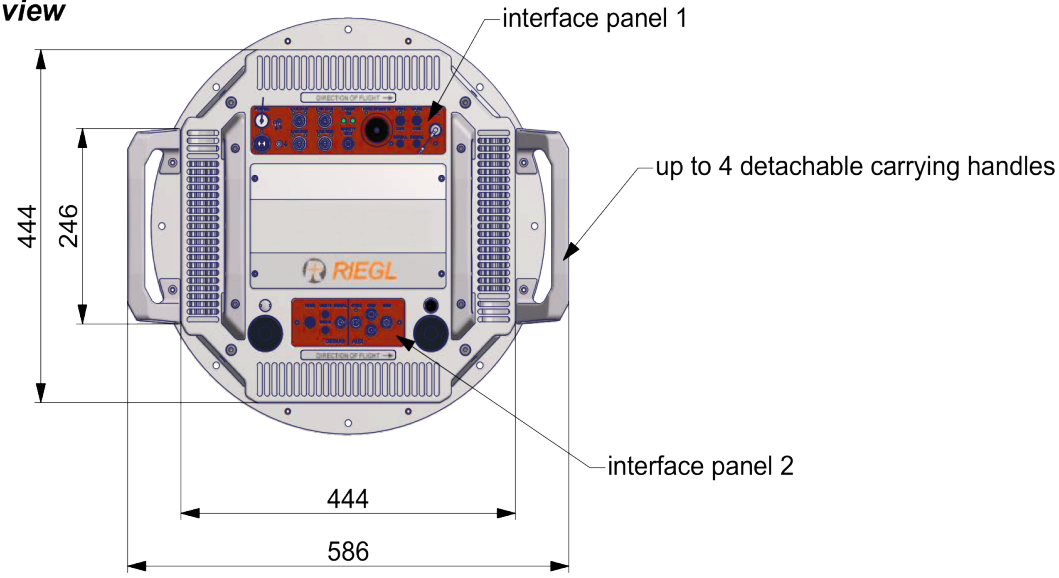
bottom view



side view

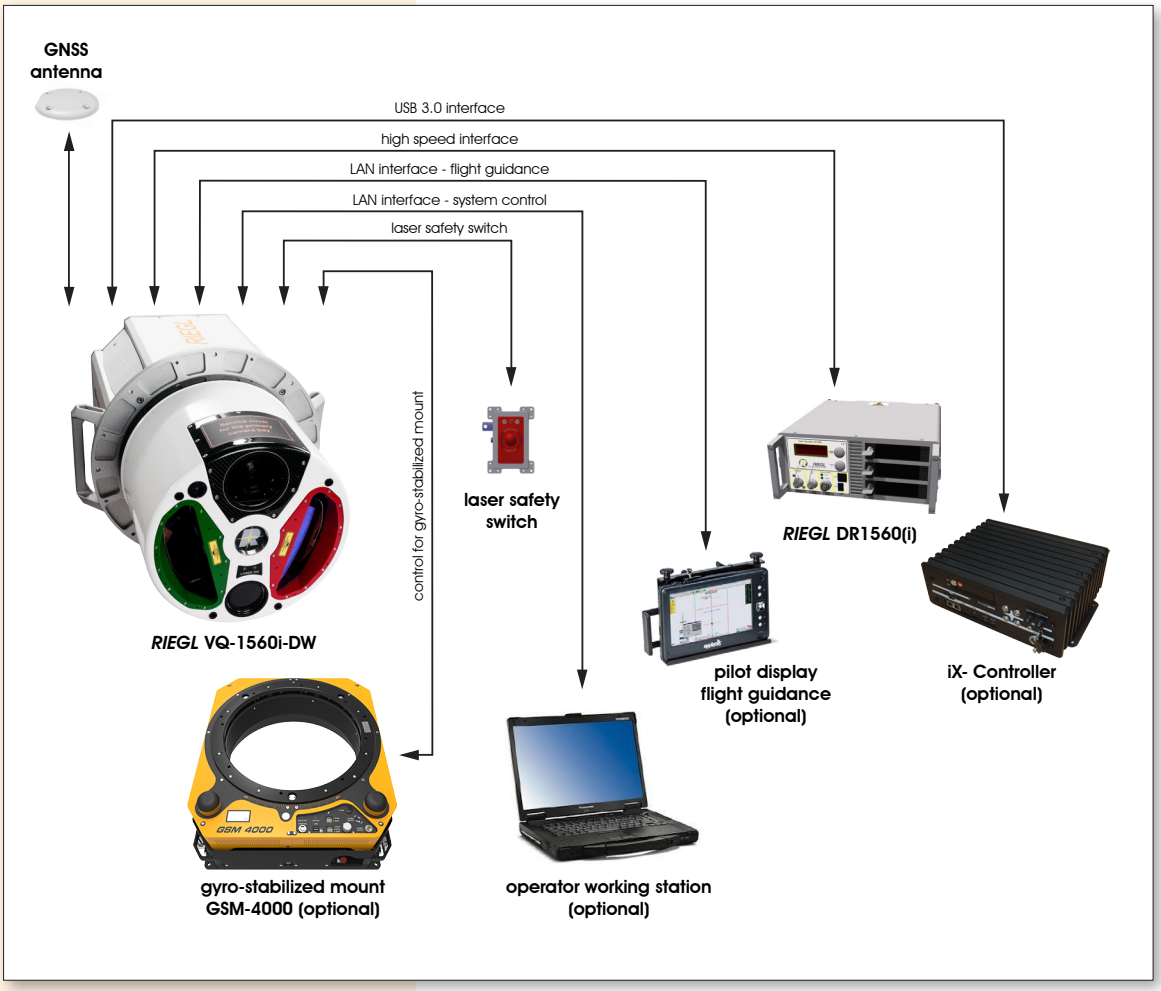


top view



all dimensions in mm

RIEGL VQ-1560i-DW System Components



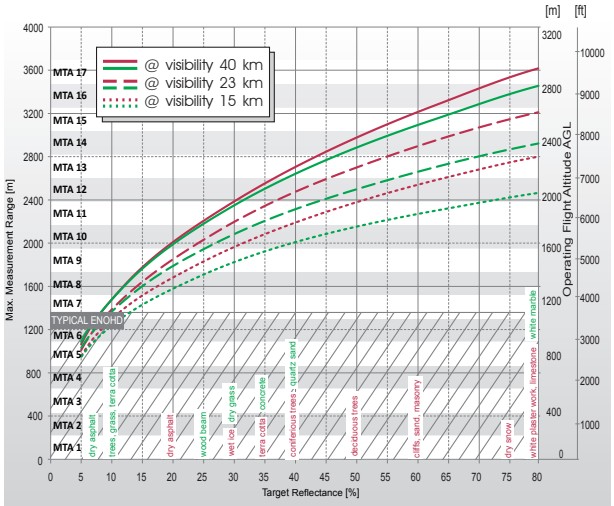
A minimum number of system components and external cabling is required for an easy and quick installation in aircrafts.

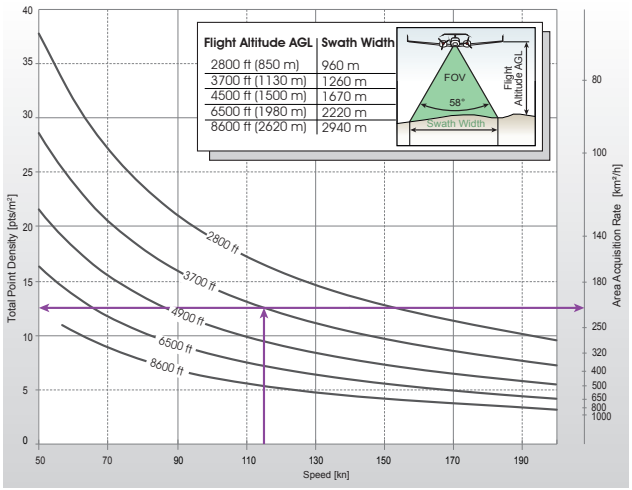
RIEGL VQ-1560i-DW Installation Examples

RIEGL VQ-1560i-DW installed in the nose pod of fixed-wing aircraft DA42 MPP

RIEGL VQ-1560i-DW installed on GSM-4000 gyro-stabilized platform preferably to be used with fixed-wing aircrafts

PRR = 2x700 kHz, laser power level 100%, green and IR laser channel

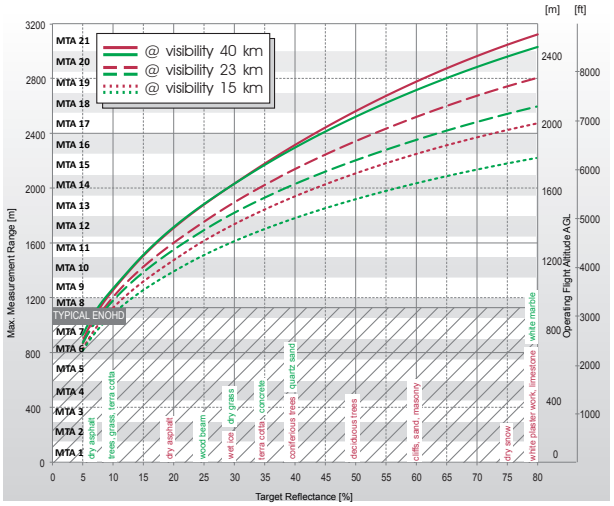


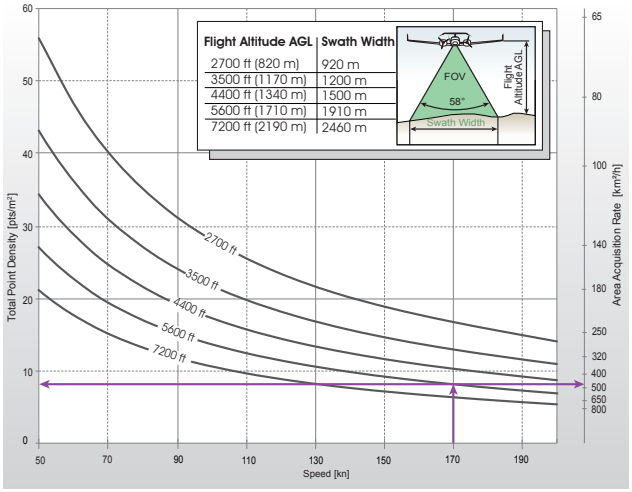


Example: VQ-1560i-DW at 2 x 700,000 pulses/sec, laser power level 100%
Altitude = 3,700 ft AGL, Speed = 115 kn

Results: Point Density ~ 12.5 pts/m²
Area Acquisition Rate ~ 215 km²/h

PRR = 2x1000 kHz, laser power level 100%, green and IR laser channel

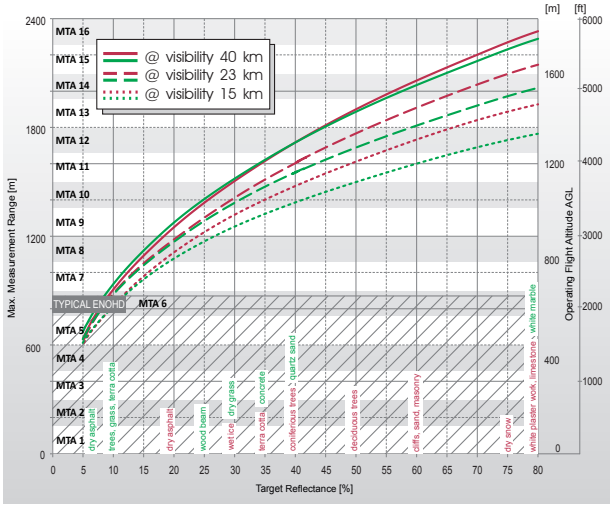


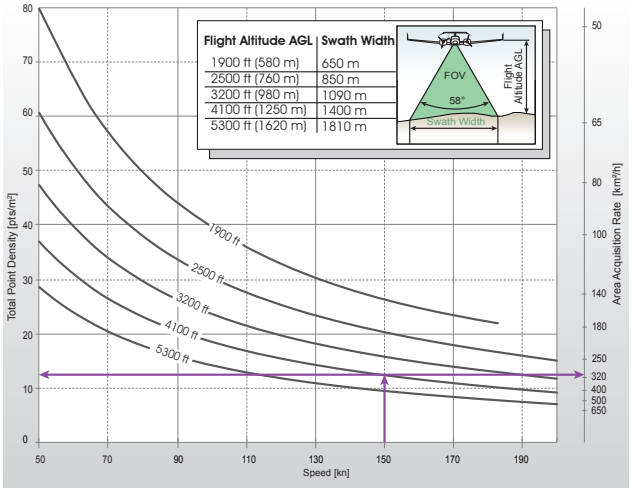


Example: VQ-1560i-DW at 2 x 1,000,000 pulses/sec, laser power level 100%
Altitude = 5,600 ft AGL, Speed = 170 kn

Results: Point Density ~ 8 pts/m²
Area Acquisition Rate ~ 480 km²/h

PRR = 2x1000 kHz, laser power level 50%, green and IR laser channel





Example: VQ-1560i-DW at 2 x 1,000,000 pulses/sec, laser power level 50%
Altitude = 4,100 ft AGL, Speed = 150 kn

Results: Point Density ~ 12.3 pts/m²
Area Acquisition Rate ~ 310 km²/h

The following conditions are assumed for the Operating Flight Altitude AGL

- ambiguity resolved by multiple-time-around (MTA) processing
- target size ≥ laser footprint
- effective FOV 58°
- average ambient brightness
- roll angle ±5°

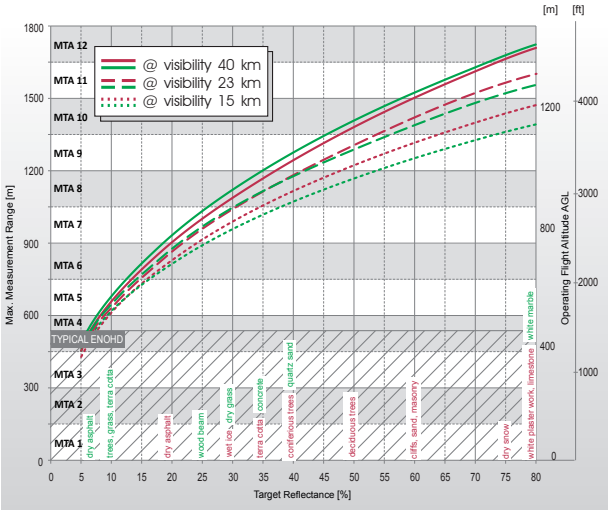
Assumptions for calculation of the Area Acquisition Rate

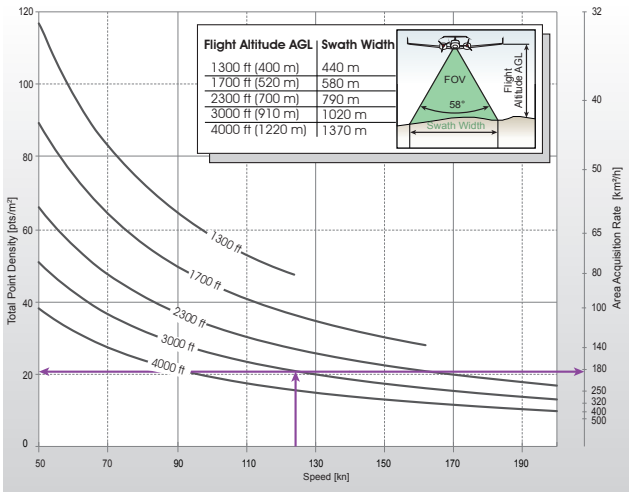
- 20% overlap of neighboring flight strips. This overlap covers a roll angle of ±5° or a reduction of flight altitude AGL of 20%.

Typical ENOHD

- Calculated under assumption of an angular step width of 0.012°, a beam divergence of 0.72mrad of the green laser and an aircraft speed higher than 10kn.

PRR = 2x1000 kHz, laser power level 25%, green and IR laser channel

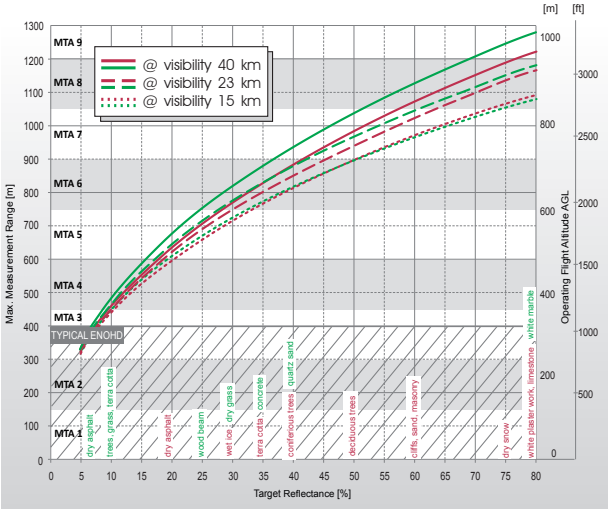


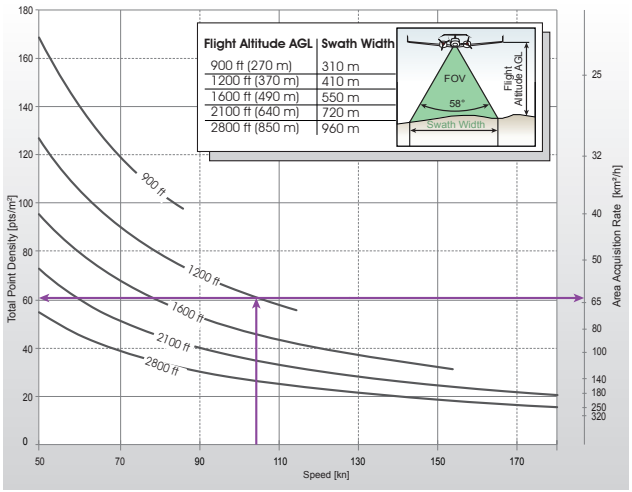


Example: VQ-1560i-DW at 2 x 1,000,000 pulses/sec, laser power level 25%
Altitude = 3,000 ft AGL, Speed = 125 kn

Results: Point Density ~ 20.2 pts/m²
Area Acquisition Rate ~ 190 km²/h

PRR = 2x1000 kHz, laser power level 12%, green and IR laser channel





Example: VQ-1560i-DW at 2 x 1,000,000 pulses/sec, laser power level 12%
Altitude = 1,200 ft AGL, Speed = 105 kn

Results: Point Density ~ 60.2 pts/m²
Area Acquisition Rate ~ 64 km²/h

The following conditions are assumed for the Operating Flight Altitude AGL

- ambiguity resolved by multiple-time-around (MTA) processing
- target size ≥ laser footprint
- effective FOV 58°
- average ambient brightness
- roll angle ±5°

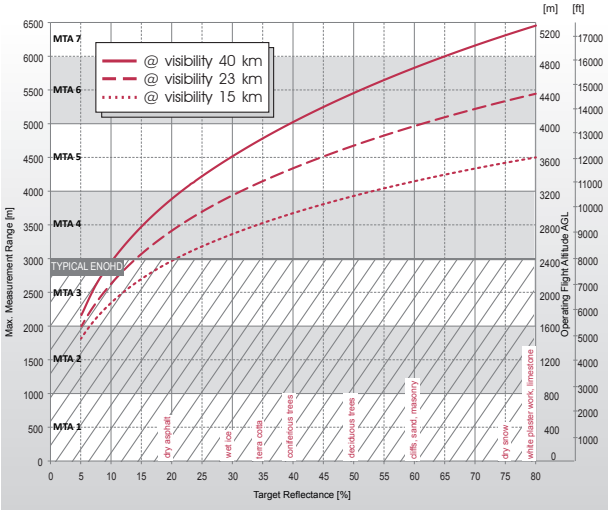
Assumptions for calculation of the Area Acquisition Rate

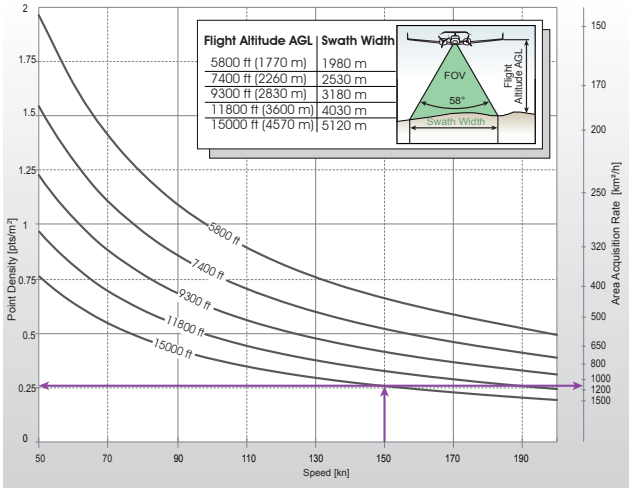
- 20% overlap of neighboring flight strips. This overlap covers a roll angle of ±5° or a reduction of flight altitude AGL of 20%.

Typical ENOHD

- Calculated under assumption of an angular step width of 0.012°, a beam divergence of 0.72mrad of the green laser and an aircraft speed higher than 10kn.

PRR = 150 kHz, laser power level 100%, IR channel only

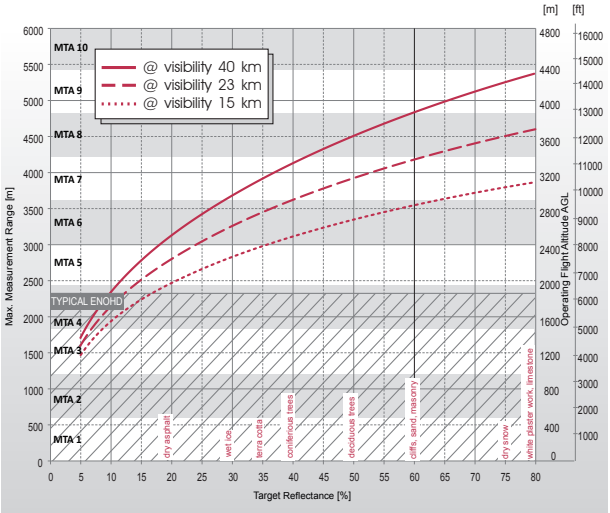


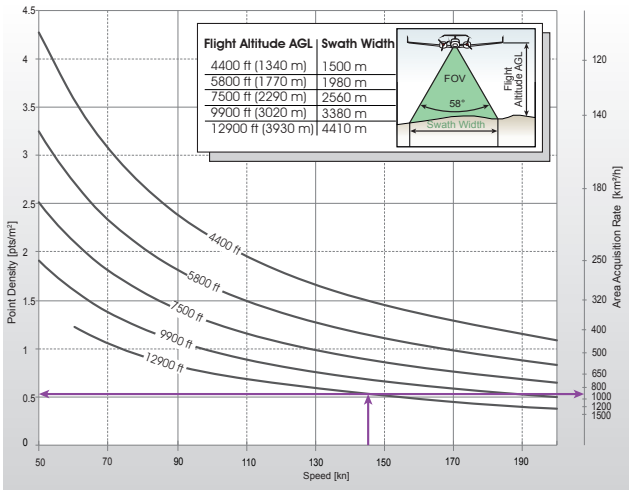


Example: VQ-1560i-DW at 150,000 pulses/sec, laser power level 100%
Altitude = 15,000 ft AGL, Speed = 150 kn

Results: Point Density ~ 0.25 pts/m²
Area Acquisition Rate ~ 1130 km²/h

PRR = 250 kHz, laser power level 100%, IR channel only

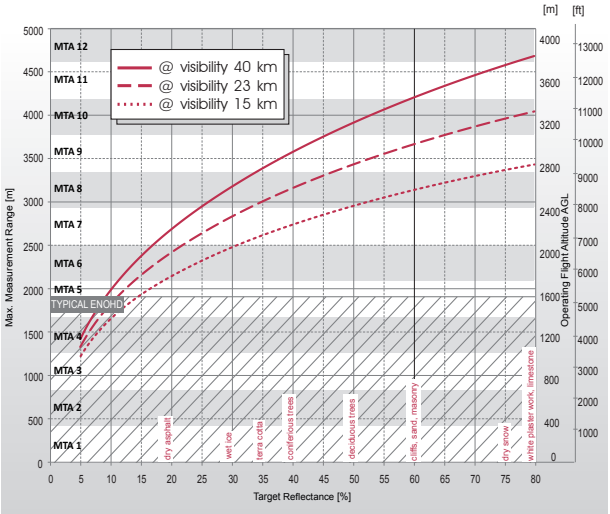


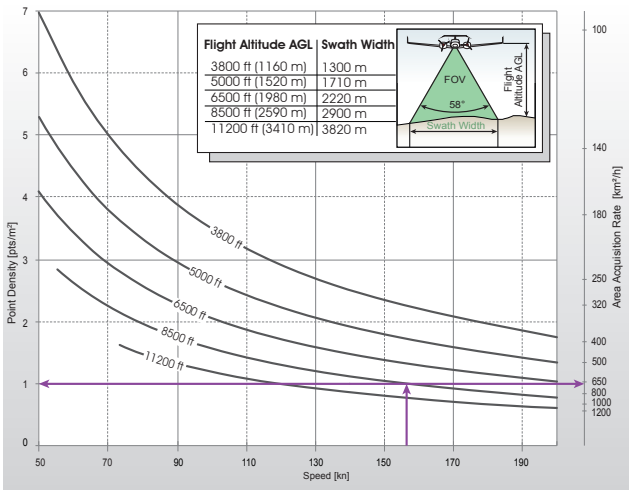


Example: VQ-1560i-DW at 250,000 pulses/sec, laser power level 100%
Altitude = 12,900 ft AGL, Speed = 145 kn

Results: Point Density ~ 0.5 pts/m²
Area Acquisition Rate ~ 950 km²/h

PRR = 350 kHz, laser power level 100%, IR channel only





Example: VQ-1560i-DW at 350,000 pulses/sec, laser power level 100%
Altitude = 8,500 ft AGL, Speed = 155 kn

Results: Point Density ~ 1 pts/m²
Area Acquisition Rate ~ 670 km²/h

The following conditions are assumed for the Operating Flight Altitude AGL

- ambiguity resolved by multiple-time-around (MTA) processing
- target size ≥ laser footprint
- effective FOV 58°
- average ambient brightness
- roll angle ±5°

Assumptions for calculation of the Area Acquisition Rate

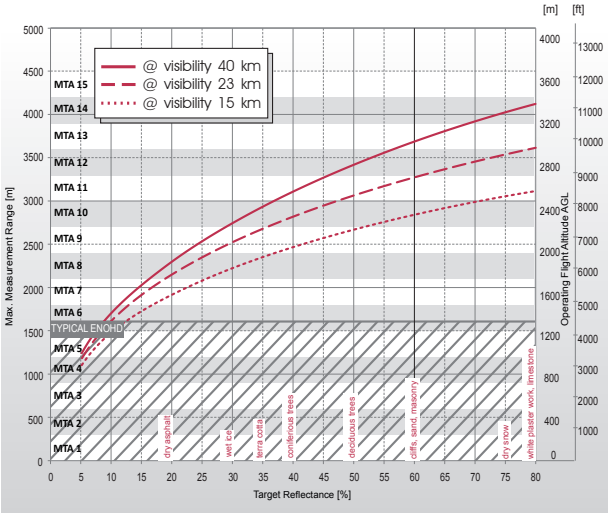
- 20% overlap of neighboring flight strips. This overlap covers a roll angle of ±5° or a reduction of flight altitude AGL of 20%.

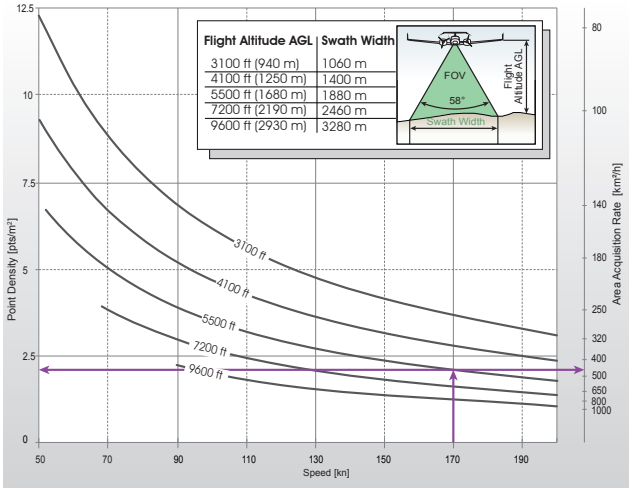
Typical ENOHD

- Calculated under assumption of an angular step width of 0.012° and an aircraft speed higher than 10kn.

Measurement Range & Point Density - IR Laser Channel Only

PRR = 500 kHz, laser power level 100%, IR channel only





Example: VQ-1560i-DW at 500,000 pulses/sec, laser power level 100%
Altitude = 5,500 ft AGL, Speed = 170 kn

Results: Point Density ~ 2 pts/m²
Area Acquisition Rate ~ 470 km²/h

The following conditions are assumed for the Operating Flight Altitude AGL

- ambiguity resolved by multiple-time-around (MTA) processing
- target size ≥ laser footprint
- effective FOV 58°
- average ambient brightness
- roll angle ±5°

Assumptions for calculation of the Area Acquisition Rate

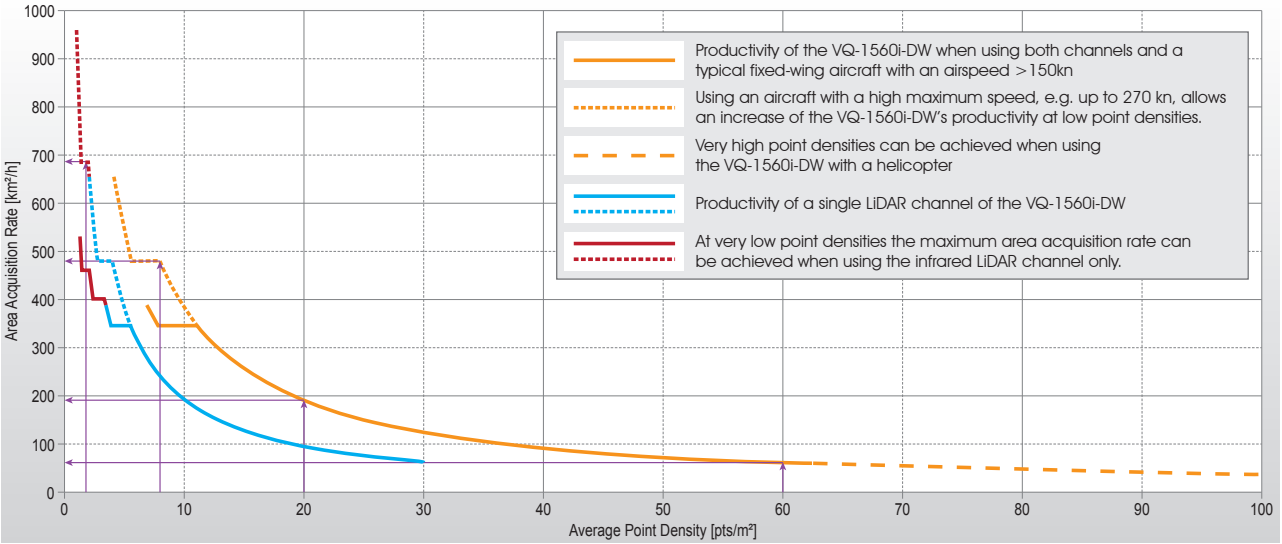
- 20% overlap of neighboring flight strips. This overlap covers a roll angle of ±5° or a reduction of flight altitude AGL of 20%.

Typical ENOHD

- Calculated under assumption of an angular step width of 0.012° and an aircraft speed higher than 10kn.

RIEGL VQ-1560i-DW Productivity

The *RIEGL* VQ-1560i-DW offers highest flexibility due to its channel selection capability.



Examples [1]				
Average Point Density	2 pts/m²	8 pts/m²	20 pts/m²	60 pts/m²
Flight Altitude	5000 ft 1520 m	4500 ft 1370 m	3300 ft 1000 m	1150 ft 351 m
Ground Speed	270 kn	210 kn	115 kn	110 kn
Swath Width	1700 m	1540 m	1130 m	400 m
Productivity	670 km²/h	480 km²/h	192 km²/h	64 km²/h
Measurement Rate [2]	466 000 meas./sec	2 x 666 000 meas./sec	2 x 666 000 meas./sec	2 x 666 000 meas./sec
Channel Selection	infrared only	green & infrared	green & infrared	green & infrared
Camera GSD [3] [4]	114 mm	103 mm	75 mm	26 mm
Camera Trigger Intervall [4]	3.5 sec	4.1 sec	5.4 sec	2.0 sec

1) calculated for 20% target reflectivity and 20% stripe overlap
2) The target detection rate is equal to the measurement rate for terrains offering only one target per laser pulse but may be much higher for vegetated areas.
3) Ground Sampling Distance
4) Calculated for a 150 MPixel CMOS camera with a FOV of 56.2° x 43.7° and 60% image overlap in flight direction (endlap).

Export Classification

Although the Dual-Wavelength LiDAR Scanning System VQ-1560i-DW has not been designed and developed for bathymetric surveys, it offers – due to integrating a green laser – to a limited extent the capability for hydrographic surveys.

The VQ-1560i-DW is subject to export restrictions as set up by the Wassenaar Arrangement. It is classified as dual-use good according to position number 6A8j3 of the official Dual-Use-List to be found on site http://www.wassenaar.org.
Within the European Union, Council Regulation (EC) No 428/2009 implements the export restrictions of the Wassenaar Arrangement. The corresponding position number is **6A008j3**.

Laser Product Classification

The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for conformance with IEC 60825-1 Ed.3., as described in Laser Notice No. 56, dated May 8, 2019.

The instrument must be used only in combination with the appropriate laser safety box.

Class 3B Laser Product according to IEC 60825-1:2014

Range Measurement Performance

as a function of laser power setting, PRR, and target reflectance

Laser Power Level: **Green and IR Laser Channel**	100%	100%	50%	25%	12%
Laser Pulse Repetition Rate (PRR) [1]	2 x 700 kHz	2 x 1000 kHz	2 x 1000 kHz	2 x 1000 kHz	2 x 1000 kHz
Max. Measuring Range [2] [3]					
natural targets, min. 20 % reflectance	2000 m	1700 m	1300 m	940 m	680 m
natural targets, min. 60 % reflectance	3100 m	2700 m	2000 m	1500 m	1120 m
Max. Operating Flight Altitude Above Ground Level (AGL) [2] [4]	2500 m 8300 ft	2200 m 7250 ft	1600 m 5300 ft	1200 m 4000 ft	910 m 3000 ft
NOHD @ 0.72 mrad of the green laser [5] [7]	280 m	240 m	165 m	115 m	80 m
ENOHD @ 0.72 mrad of the green laser [6] [7]	1120 m	940 m	650 m	450 m	320 m

1) rounded average PRR
2) Typical values for average conditions and average ambient brightness; in bright sunlight the operational range may be considerably shorter and the operational flight altitude may be considerably lower than under an overcast sky.
3) The maximum range is specified for flat targets with size in excess of the laser beam diameter, perpendicular angle of incidence, and for atmospheric visibility of 40 km. Range ambiguities have to be resolved by multiple-time-around processing.
4) Typical values for 60 % reflectance, max. effective FOV 58°, additional roll angle ± 5°
5) Nominal Ocular Hazard Distance, based upon MPE according to IEC 60825-1:2014, for single line condition
6) Extended Nominal Ocular Hazard Distance, based upon MPE according to IEC 60825-1:2014, for single line condition
7) NOHD and ENOHD have been calculated for a typical angular step width of 0.012°, an aircraft speed higher than 10kn, and beam divergences of 0.72 mrad for the green laser and 0.25 mrad for the IR laser. NOHD and ENOHD increase when reducing the angular step width or the green laser's beam divergence.

Laser Power Level: **IR Laser Channel only**	100%			
Laser Pulse Repetition Rate (PRR) [1]	150 kHz	250 kHz	350 kHz	500 kHz
Max. Measuring Range [2] [3]				
natural targets, min. 20 % reflectance	3800 m	3100 m	2700 m	2300 m
natural targets, min. 60 % reflectance	5800 m	4800 m	4200 m	3600 m
Max. Operating Flight Altitude Above Ground Level (AGL) [2] [4]	4700 m 15500 ft	3900 m 12900 ft	3400 m 11200 ft	2900 m 9600 ft
NOHD [5] [7]	370 m	290 m	240 m	200 m
ENOHD [6] [7]	2450 m	1900 m	1600 m	1350 m

1) rounded average PRR
2) Typical values for average conditions and average ambient brightness; in bright sunlight the operational range may be considerably shorter and the operational flight altitude may be considerably lower than under an overcast sky.
3) The maximum range is specified for flat targets with size in excess of the laser beam diameter, perpendicular angle of incidence, and for atmospheric visibility of 40 km. Range ambiguities have to be resolved by multiple-time-around processing.
4) Typical values for 60 % reflectance, max. effective FOV 58°, additional roll angle ± 5°
5) Nominal Ocular Hazard Distance, based upon MPE according to IEC 60825-1:2014, for single line condition
6) Extended Nominal Ocular Hazard Distance, based upon MPE according to IEC 60825-1:2014, for single line condition
7) NOHD and ENOHD have been calculated for a typical angular step width of 0.012° which means non-overlapping laser footprints and an aircraft speed higher than 10kn. NOHD and ENOHD increase when using overlapping laser footprints which may be intended e.g. for power line mapping.

Minimum Range [8]	100 m
Accuracy [9] [10]	20 mm
Precision [10] [11]	20 mm
Laser Pulse Repetition Rate	up to 2 x 1000 kHz
Effective Measurement Rate	up to 2 x 666 kHz @ 60° scan angle
Echo Signal Intensity	provided for each echo signal
Laser Wavelength	green (532 nm) and near infrared (1064 nm)
Laser Beam Divergence	user selectable for the green laser: approx. 0.7 mrad to approx. 2 mrad (1/e²) [12] fixed for the IR laser: ≤ 0.18 mrad (1/e) [13], ≤ 0.25 mrad (1/e²) [14]
Number of Targets per Pulse	with online waveform processing: practically unlimited [15] [16] monitoring data output: first pulse

8) Limitation for range measurement capability, does not consider laser safety issues! The minimum range for valid reflectance values is 250 m.
9) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
10) Standard deviation one sigma @ 250 m range under *RIEGL* test conditions.
11) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
12) A license for lower divergence settings is available on request based on a signed liability disclaimer.
13) 0.18 mrad corresponds to an increase of the 1/e beam diameter of 18 cm per 1000 m distance.
14) 0.25 mrad corresponds to an increase of the 1/e² beam diameter of 25 cm per 1000 m distance.
15) Depending on laser pulse repetition rate, up to a max. of 15 targets per laser pulse.
16) If the laser beam hits, in part, more than one target, the laser's power is split accordingly. Thus, the achievable range is reduced.

Technical Data to be continued at page 10

Technical Data *RIEGL* VQ-1560i-DW *(continued)*

Scanner Performance

Scanning Mechanism	rotating polygon mirror
Scan Pattern	parallel scan lines per channel, crossed scan lines between channels
Tilt Angle of Scan Lines	± 14° = 28°
Forward/ Backward Scan Angle in Non-Nadir Direction	± 8° at the edges
Scan Angle Range	60° total per channel, resulting in an effective FOV of 58°
Total Scan Rate	40 [1] - 600 lines/sec
Angular Step Width Δϑ	0.006° ≤ Δϑ ≤ 0.180° [2] [3]
Angle Measurement Resolution	0.001°

1) The minimum scan rate depends on the selected laser PRR.
2) The minimum angular step width depends on the selected laser PRR.
3) The maximum angular step width is limited by the maximum scan rate.

Data Interfaces

Configuration	TCP/IP Ethernet (10/100/1000 MBit/s)
Monitoring Data Output	TCP/IP Ethernet (10/100/1000 MBit/s)
Digitized Data Output	Dual glass fiber data link to *RIEGL* Data Recorder DR1560(i)
Synchronization	Serial RS232 interface, TTL input for 1 pps synchronization pulse, accepts different data formats for GNSS-time information

General Technical Data

Power Supply / Power Consumption	20 - 32 V DC / typ. 250 W max. 550 W, depending on integrated optional components
Main Dimensions (flange diameter x height)	Ø 524 mm x 780 mm (without flange mounted carrying handles)
Weight	approx. 60 kg without any camera but including a typical IMU/GNSS unit approx. 65 kg with optional components
Protection Class	IP54
Max. Flight Altitude operating / not operating	18500 ft (5600 m) above MSL[4] / 18500 ft (5600 m) above MSL
Temperature Range operation / storage	0°C up to +40°C / -10°C up to +50°C

4) Mean Sea Level

Recommended IMU/GNSS System [5] [6]

IMU Accuracy [7]	
Roll, Pitch	0.0025°
Heading	0.005°
IMU Sampling Rate	200 Hz
Position Accuracy (typ.)	0.05 m - 0.1 m

Optional Components VQ-1560i-DW

Primary Camera	RGB
Sensor Resolution	e.g. 150 MPixel CMOS
Sensor Dimensions (diagonal)	67.2 mm (medium format)
Focal Length of Camera Lens	50 mm
Field of View (FOV)	approx. 56.2° x 43.7°
Interface	USB 3.0
Data Storage	iX-Controller
Secondary Camera	Different camera types including thermal or NIR cameras can be integrated, details on request.

5) The recommended IMU is listed neither in the European Export Control List (i.e. Annex 1 of Council Regulation 428/2009) nor in the Canadian Export Control List. Detailed information on certain cases will be provided on request.
6) The *RIEGL* VQ-1560i-DW Laser Scanning system supports different IMU/GNSS Systems, details on request.
7) One sigma values, no GNSS outages, post-processed with base station data

RIEGL LASER MEASUREMENT SYSTEMS

RIEGL
Laser Measurement Systems GmbH
Riedenburgstraße 48
3580 Horn, Austria
Phone: +43 2982 4211
office@riegl.co.at | www.riegl.com

RIEGL USA Inc. | info@rieglusa.com | www.rieglusa.com
RIEGL Japan Ltd. | info@riegl-japan.co.jp | www.riegl-japan.co.jp
RIEGL China Ltd. | info@riegl.cn | www.riegl.cn
RIEGL Australia Pty Ltd. | info@riegl.com.au | www.riegl.com

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