Dual Channel Waveform Processing Airborne LiDAR Scanning System for High-Point Density and Ultra-Wide Area Mapping

RIEGL VQ-1560i

- *high laser pulse repetition rate up to 2 MHz*
- *up to 1.33 million measurements per second on the ground*
- *offers data acquisition at a wide range of point densities*
- *two waveform processing LiDAR channels offering excellent multiple target detection capability*
- *enables Multiple-Time-Around (MTA) processing of up to 25 pulses simultaneously in the air*
- *excellent suppression of atmospheric clutter*
- *offers online waveform processing as well as smart and full waveform recording*
- *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*
- *detachable handgrips for facilitated handling*

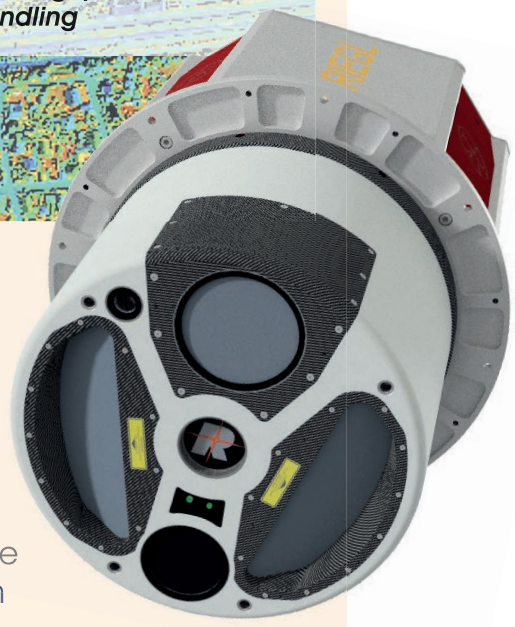
The ultra-high performance, fully integrated and calibrated Dual Channel Airborne Mapping System *RIEGL* VQ-1560i makes use of *RIEGL*'s sophisticated Waveform-LiDAR technology enabling an excellent multiple-target detection capability and Multiple-Time-Around (MTA) processing. The system is capable of online waveform processing as well as full or smart waveform recording, resulting in unsurpassed information content on each single target.

The VQ-1560i provides a laser pulse repetition rate of up to 2 MHz resulting in more than 1.3 million measurements per second on the ground and operates at an altitude of up to 18,300 ft. That allows operation at varying flight altitudes resulting in a wide range of point densities. Thus, the system is ideally suited for aerial survey of ultra-wide areas as well as of complex urban environments. By the way, faster and more efficient flight planning and safer flights are enabled.

The *RIEGL* VQ-1560i comes with a unique forward/nadir/backward scan angle. This enables capturing data from multiple angles more effectively and more accurately at a high point density. With its large field of view of 58 degrees and its widely variable scan parameters the system enables highly efficient scan data acquisition.

The system is equipped with a seamlessly integrated high performance IMU/GNSS unit and an optional 150 megapixel RGB camera as well as another camera, e.g. a thermal camera or a 100 megapixels near-infrared camera. All individual components are integrated into a compact housing, featuring a mounting flange for interfacing typical hatches or gyro-stabilized leveling mounts.

Applications:
- *Ultra Wide Area / High Altitude Mapping*
- *High Point Density Mapping*
- *Mapping of Complex Urban Environments*
- *Glacier & Snowfield Mapping*
- *City Modeling*
- *Mapping of Lakesides & River Banks*
- *Agriculture & Forestry*
- *Corridor Mapping*



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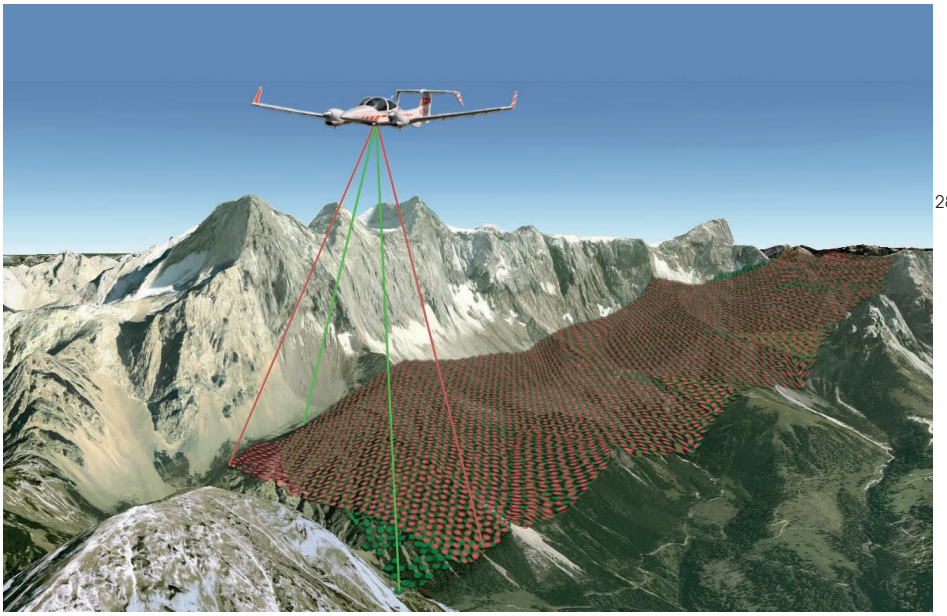
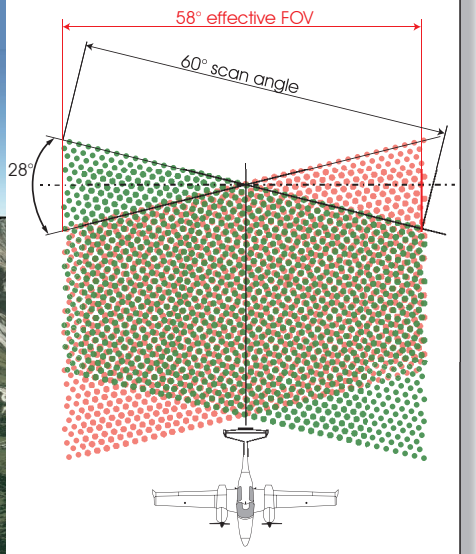
LASER MEASUREMENT SYSTEMS

RIEGL VQ-1560i Scan Pattern

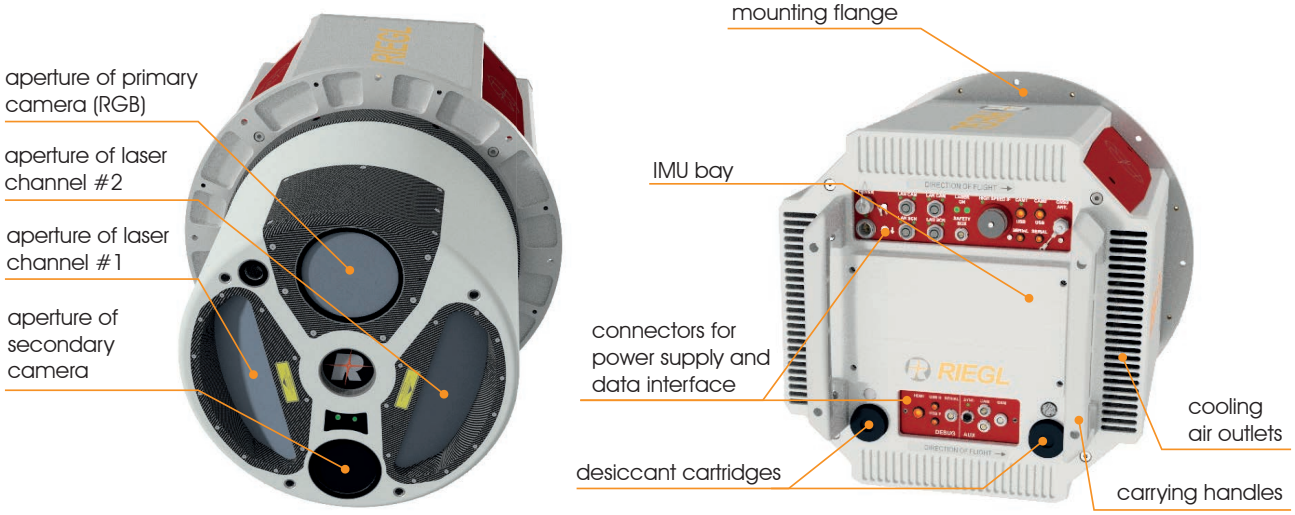




Each channel delivers straight parallel scan lines. The scan lines of the two channels are tilted against each other by 28 degrees providing an optimum distribution of the measurements on the ground invariant to changes in terrain height.

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

RIEGL VQ-1560i Elements of Function and Operation



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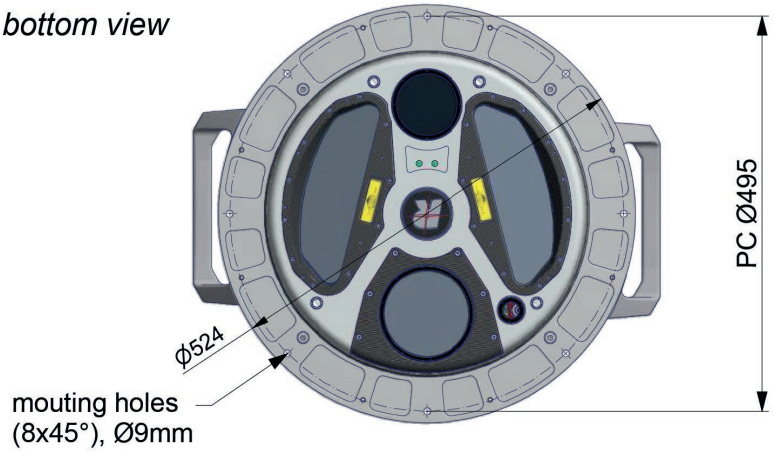
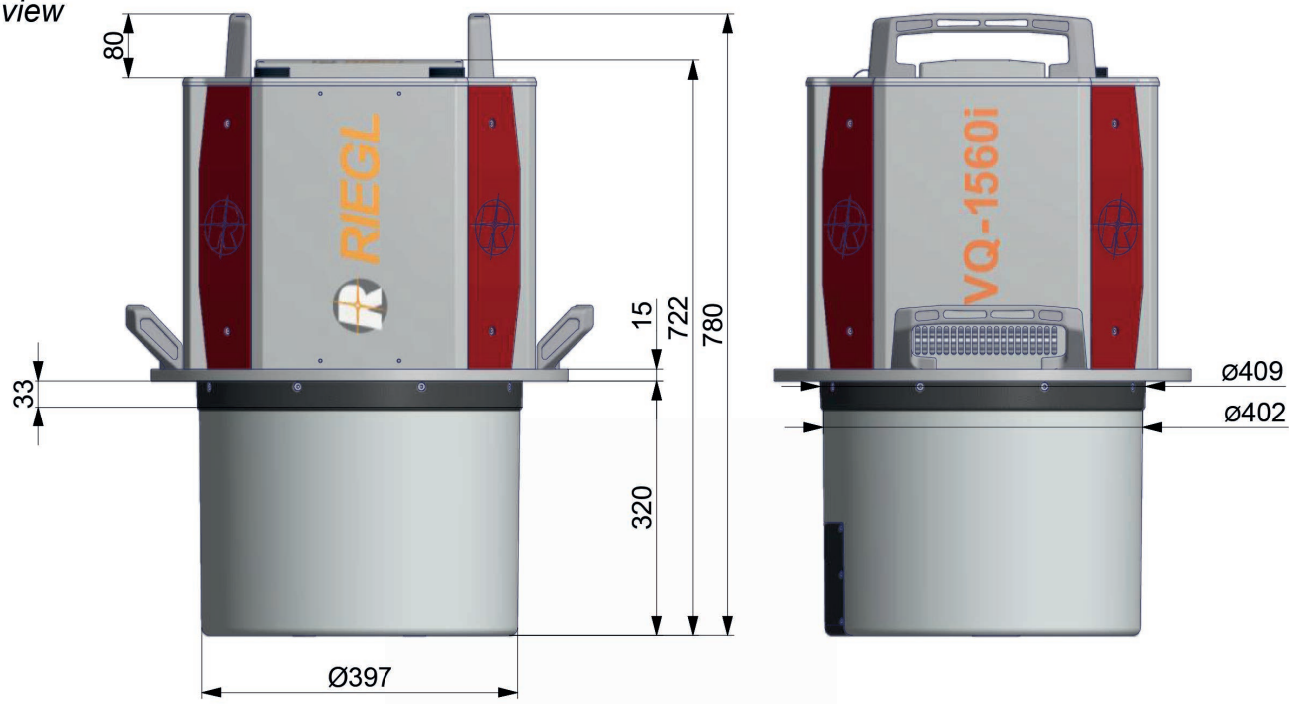
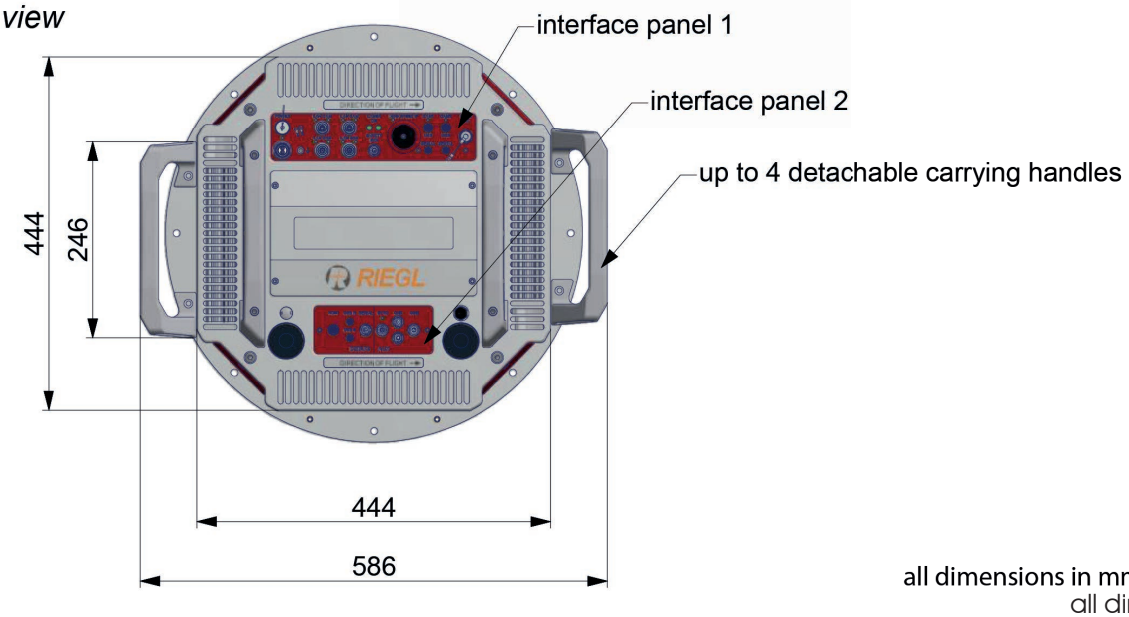
bottom view



side view



top view



all dimensions in mm

all dimensions in mm

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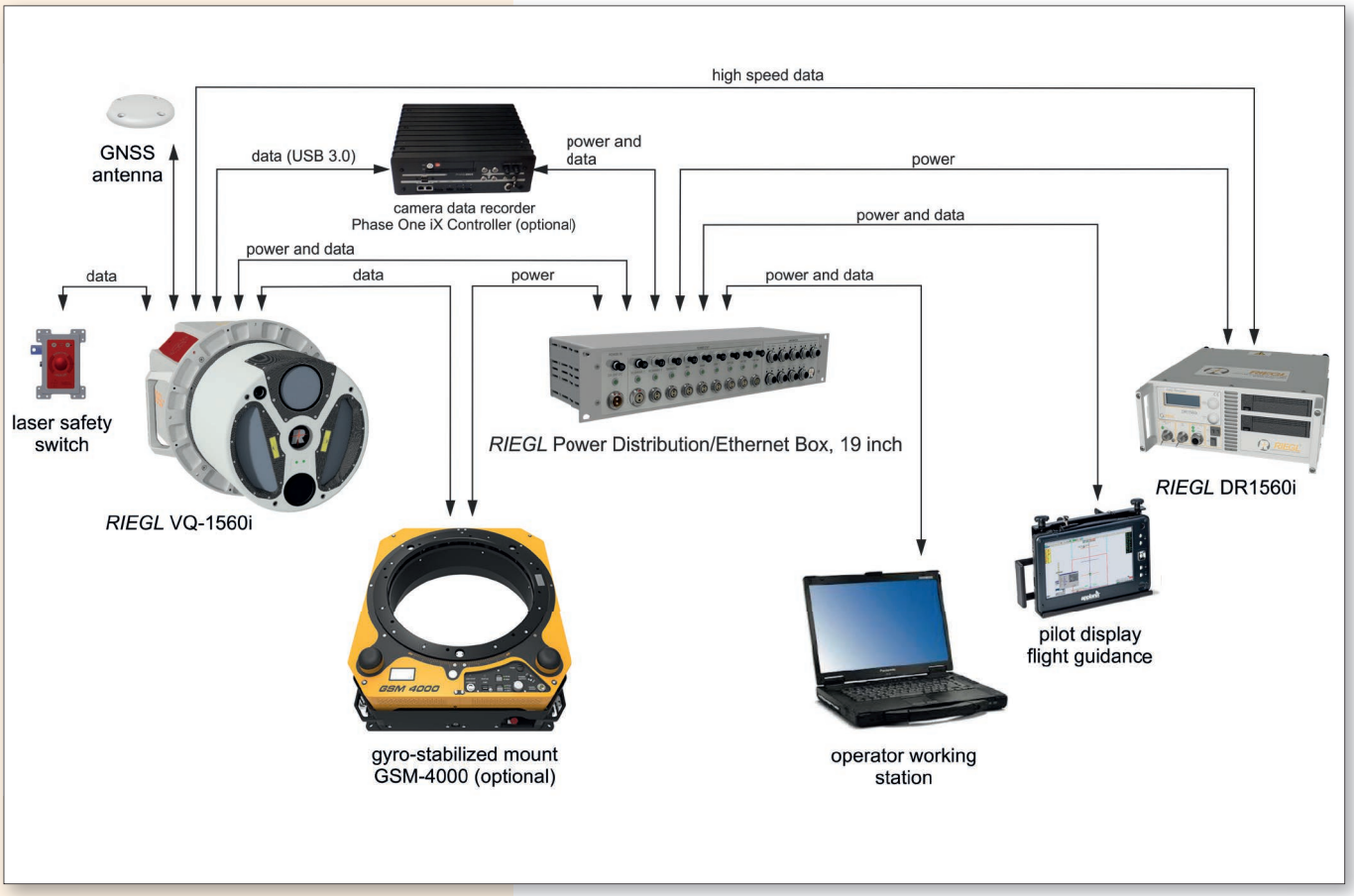
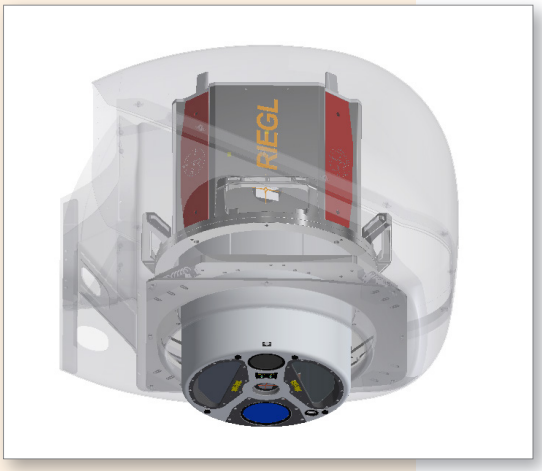
RIEGL VQ-1560i System Components



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

RIEGL VQ-1560i Installation Examples



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

RIEGL VQ-1560i installed on GSM-4000 gyro-stabilized platform to be used in a helicopter or fixed-wing aircraft

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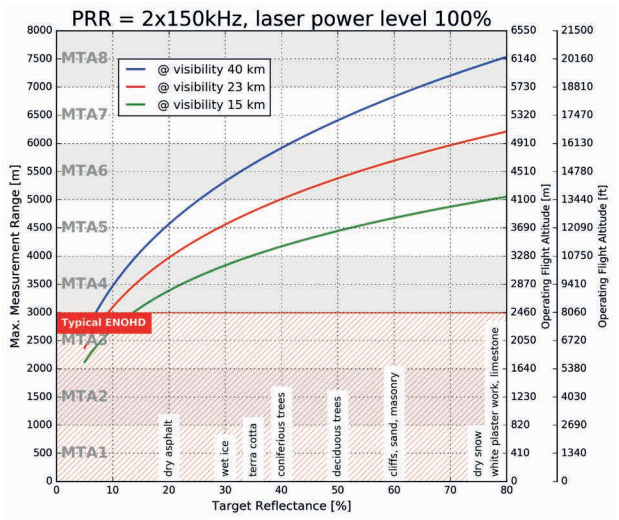
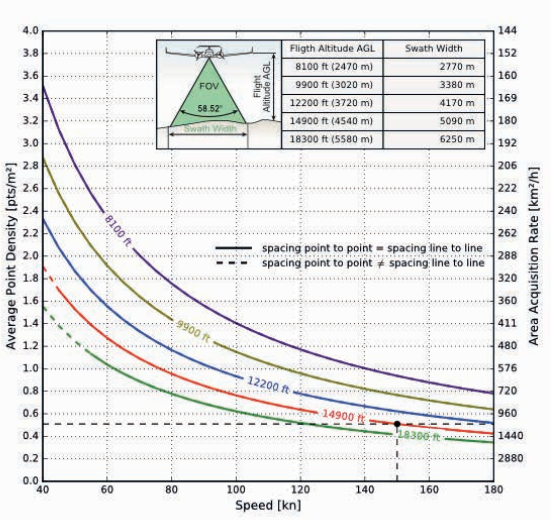
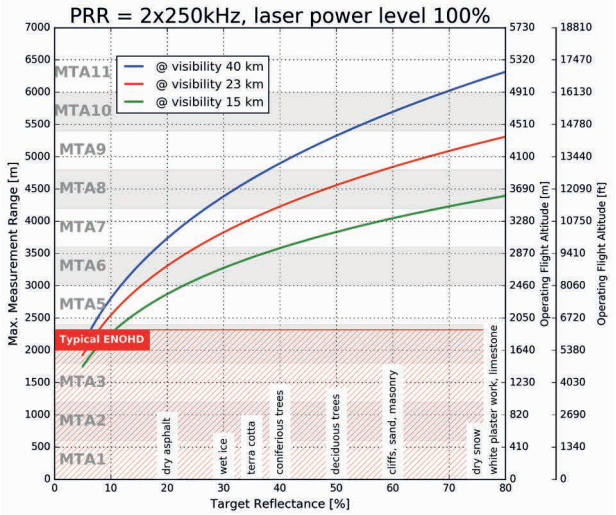
Measurement Range & Point Density *RIEGL* VQ-1560i

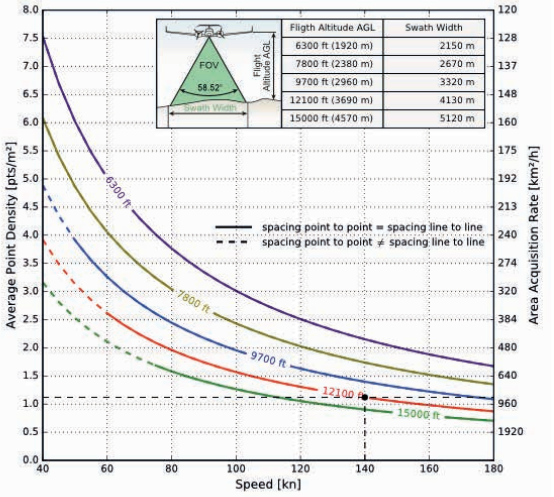




Example: VQ-1560i at 150,000 pulses/sec, laser power level 100%
Altitude = 14,900 ft AGL, Speed 150 kn

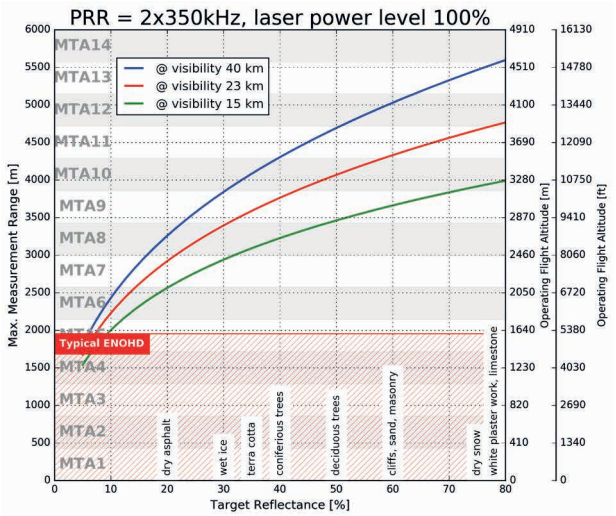
Results: Point Density ~ 0.51 pts/m²
Area Acquisition Rate ~ 1130 km²/h

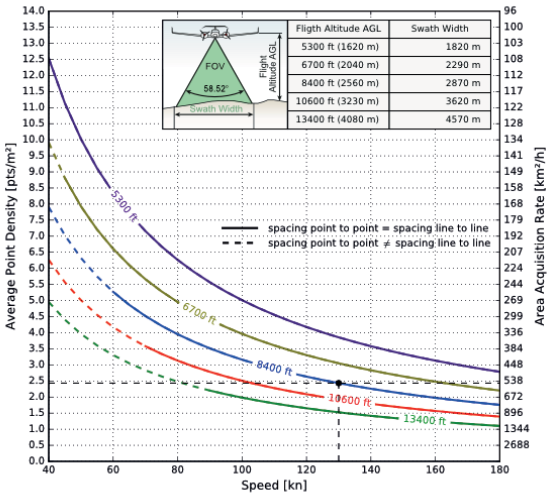




Example: VQ-1560i at 250,000 pulses/sec, laser power level 100%
Altitude = 12,100 ft AGL, Speed 140 kn

Results: Point Density ~ 1.12 pts/m²
Area Acquisition Rate ~ 857 km²/h





Example: VQ-1560i at 350,000 pulses/sec, laser power level 100%
Altitude = 8,400 ft AGL, Speed 130 kn

Results: Point Density ~ 2.43 pts/m²
Area Acquisition Rate ~ 552 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.

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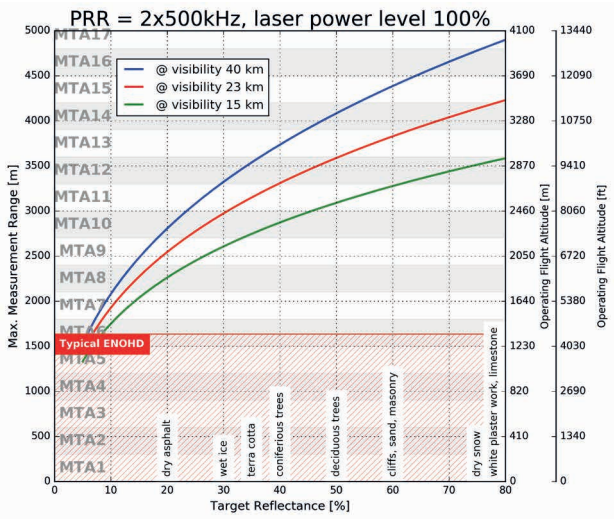
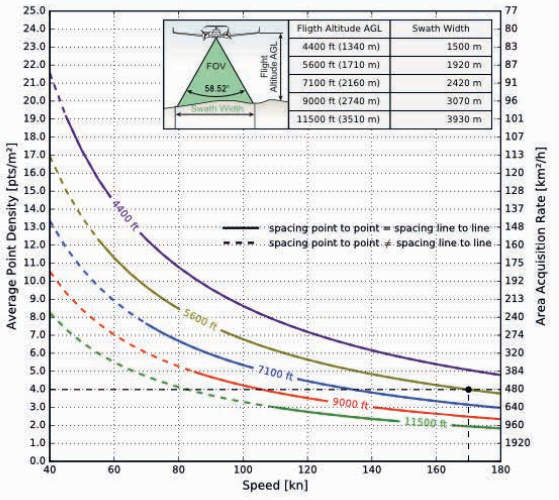
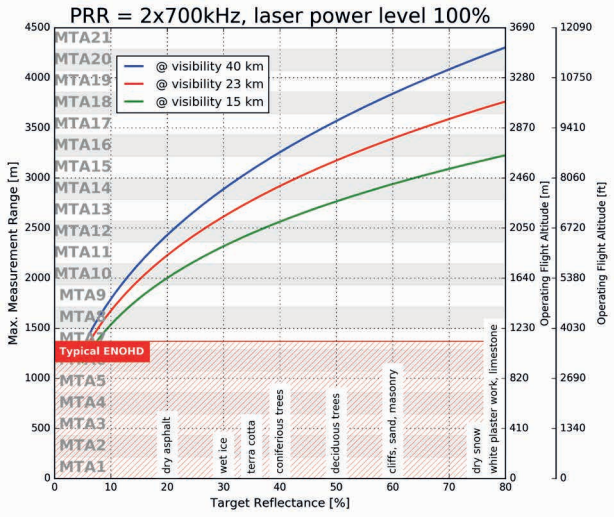
Measurement Range & Point Density *RIEGL* VQ-1560i

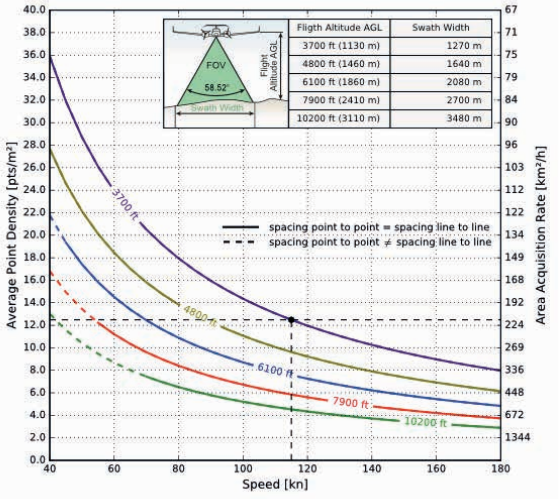




Example: VQ-1560i at 500,000 pulses/sec, laser power level 100%
Altitude = 5,600 ft AGL, Speed 170 kn

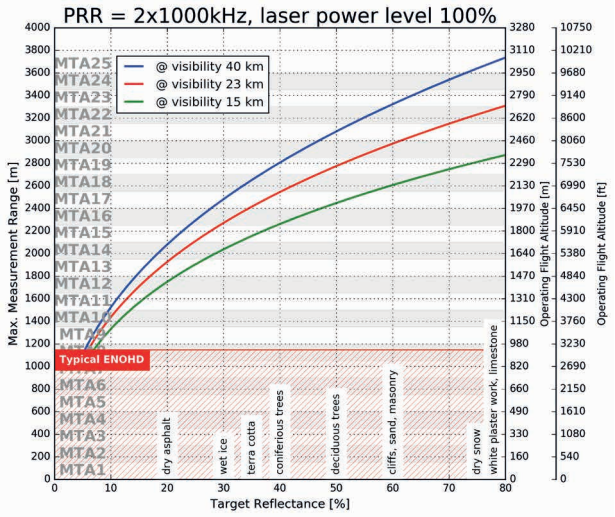
Results: Point Density ~ 3.97 pts/m²
Area Acquisition Rate ~ 481 km²/h

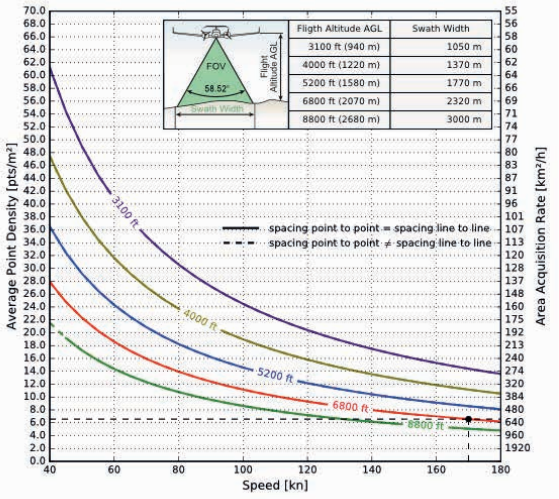




Example: VQ-1560i at 700,000 pulses/sec, laser power level 100%
Altitude = 3,700 ft AGL, Speed 115 kn

Results: Point Density ~ 12.49 pts/m²
Area Acquisition Rate ~ 215 km²/h





Example: VQ-1560i at 1,000,000 pulses/sec, laser power level 100%
Altitude = 6,800 ft AGL, Speed 170 kn

Results: Point Density ~ 6.57 pts/m²
Area Acquisition Rate ~ 584 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.

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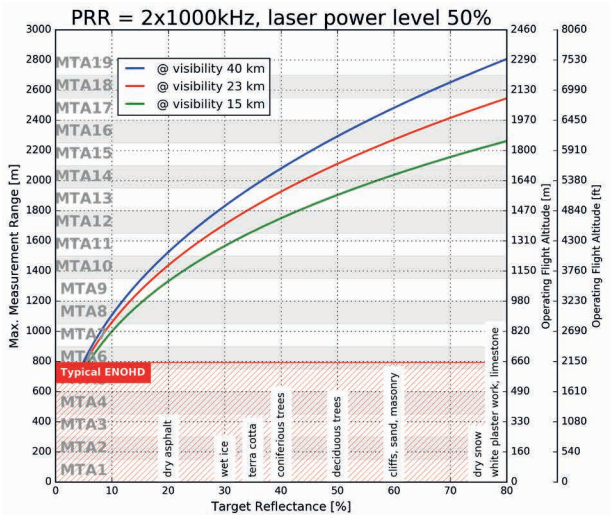
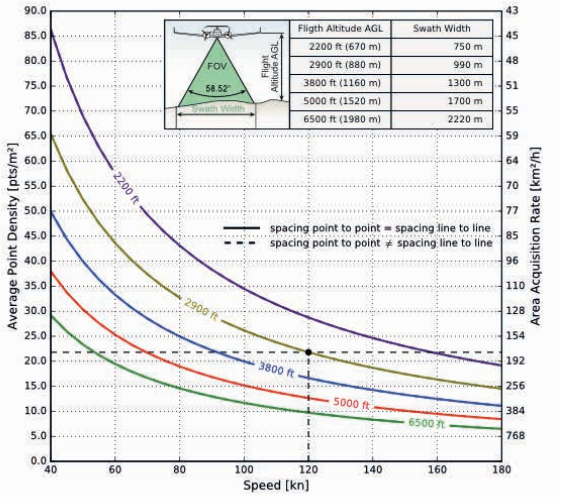
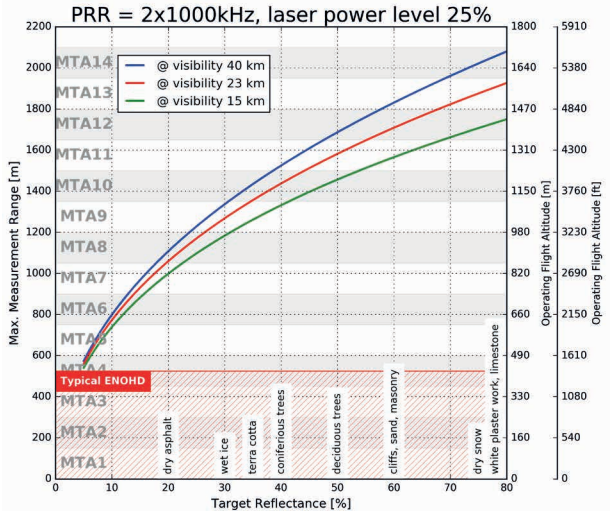
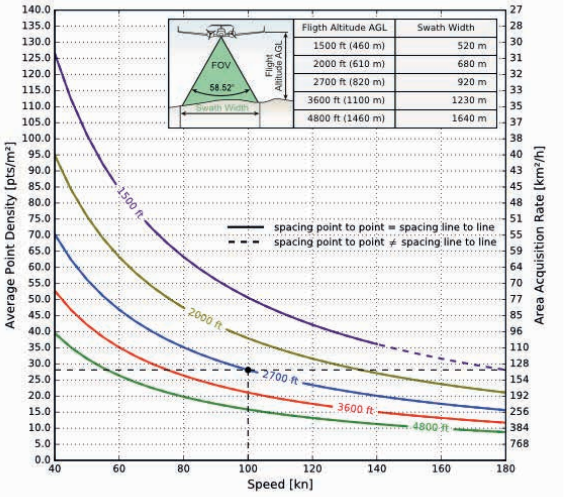




Example: VQ-1560i at 1,00,000 pulses/sec, laser power level 50%
Altitude = 2,900 ft AGL, Speed 120 kn

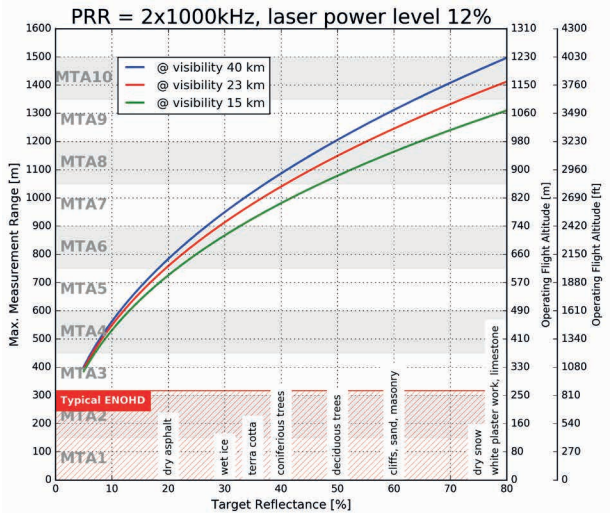
Results: Point Density ~ 21.81 pts/m²
Area Acquisition Rate ~ 176 km²/h

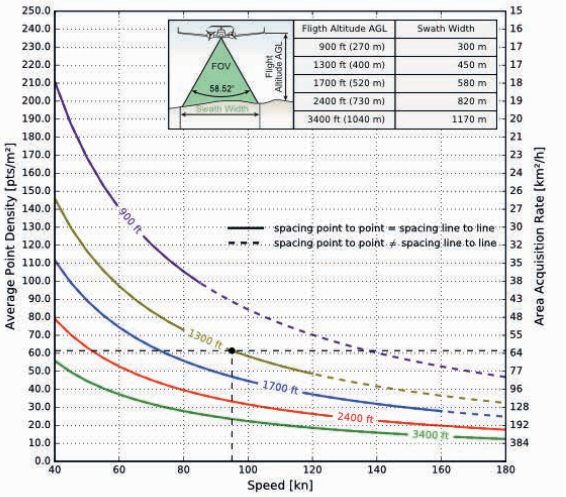




Example: VQ-1560i at 1,000,000 pulses/sec, laser power level 25%
Altitude = 2,700 ft AGL, Speed 100 kn

Results: Point Density ~ 28.11 pts/m²
Area Acquisition Rate ~ 136 km²/h





Example: VQ-1560i at 1,000,000 pulses/sec, laser power level 12%
Altitude = 1,300 ft AGL, Speed 95 kn

Results: Point Density ~ 61.45 pts/m²
Area Acquisition Rate ~ 62 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.

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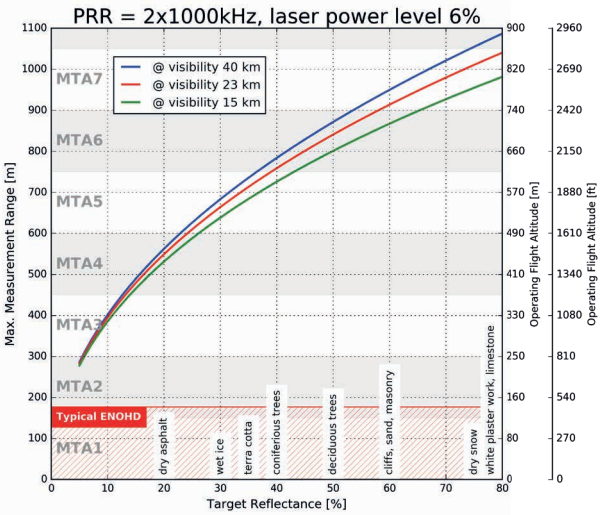
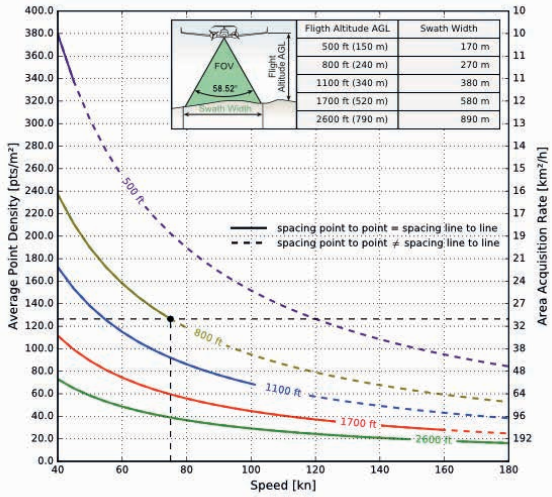
Measurement Range & Point Density *RIEGL* VQ-1560i





Example: VQ-1560i at 1,000,000 pulses/sec, laser power level 6%
Altitude = 800 ft AGL, Speed 75 kn

Results: Point Density ~ 126.49 pts/m²
Area Acquisition Rate ~ 30 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

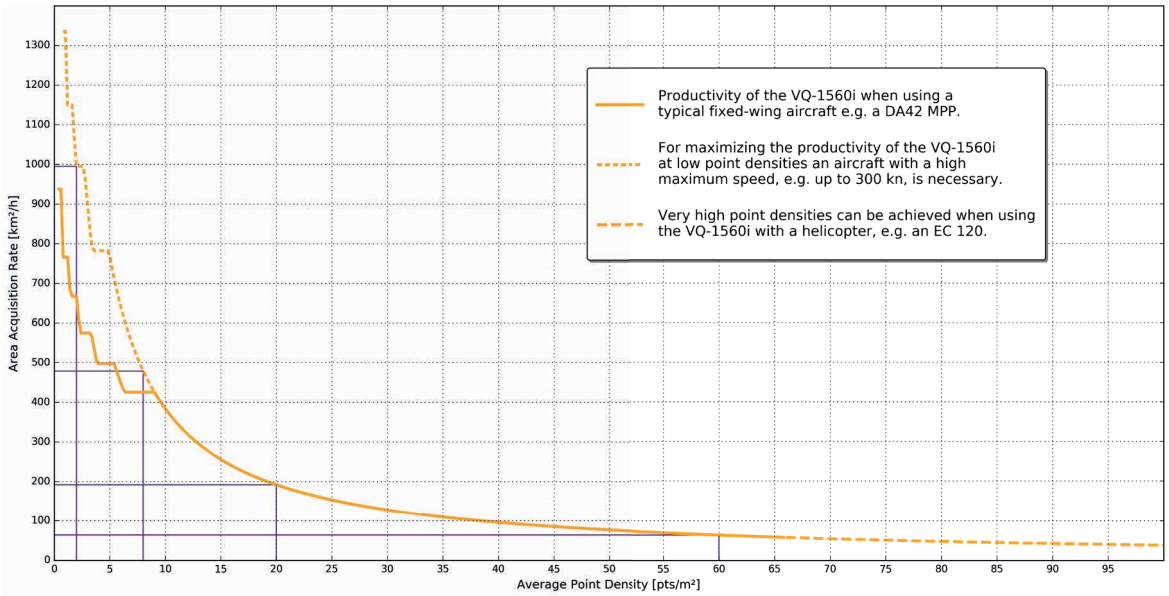
- 20% overlap of neighboring flight strips. This overlap covers a roll angle of ±5° or a reduction of flight altitude AGL of 20%.

Typical ENOHD

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

RIEGL VQ-1560i Productivity

The *RIEGL* VQ-1560i Dual Channel Airborne Mapping System offers highest productivity.



Examples [1]				
Average Point Density	2 pts/m²	8 pts/m²	20 pts/m²	60 pts/m²
Flight Altitude	6560 ft 2000 m	4500 ft 1370 m	3300 ft 1000 m	1150 ft 351 m
Ground Speed	300 kn	210 kn	115 kn	110 kn
Swath Width	2240 m	1540 m	1130 m	400 m
Productivity	996 km²/h	480 km²/h	192 km²/h	64 km²/h
Measurement Rate [2]	933 000 meas./sec	1.33 mill meas./sec	1.33 mill meas./sec	1.33 mill meas./sec
Camera GSD [3] [4]	184 mm	126 mm	92 mm	32 mm
Camera Trigger Intervall [4]	4.15 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 100 MPixel CMOS camera with a FOV of 56.2° x 43.7° and 60% image overlap in flight direction (endlap).

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Laser Product Classification

Class 3B Laser Product according to IEC60825-1:2014
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.

Range Measurement Performance

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

Laser Power Level	100%				
Laser Pulse Repetition Rate (PRR) [1]	2 x 150 kHz	2 x 250 kHz	2 x 350 kHz	2 x 500 kHz	2 x 700 kHz
Max. Measuring Range [2] [3]					
natural targets ρ ≥ 20 %	4500 m	3700 m	3200 m	2800 m	2400 m
natural targets ρ ≥ 60 %	6800 m	5600 m	5000 m	4300 m	3800 m
Max. Operating Flight Altitude Above Ground Level (AGL) [2] [4]	5600 m 18300 ft	4600 m 15000 ft	4100 m 13400 ft	3500 m 11500 ft	3100 m 10200 ft
NOHD [5] [7]	370 m	290 m	240 m	200 m	170 m
ENOHD [6] [7]	2450 m	1900 m	1600 m	1340 m	1120 m

Laser Power Level	100%	50%	25%	12%	6%
Laser Pulse Repetition Rate (PRR) [1]	2 x 1000 kHz	2 x 1000 kHz	2 x 1000 kHz	2 x 1000 kHz	2 x 1000 kHz
Max. Measuring Range [2] [3]					
natural targets ρ ≥ 20 %	2050 m	1500 m	1100 m	780 m	560 m
natural targets ρ ≥ 60 %	3300 m	2450 m	1800 m	1300 m	940 m
Max. Operating Flight Altitude Above Ground Level (AGL) [2] [4]	2700 m 8800 ft	2000 m 6500 ft	1450 m 4800 ft	1050 m 3400 ft	770 m 2500 ft
NOHD [5] [7]	140 m	95 m	61 m	36 m	21 m
ENOHD [6] [7]	940 m	650 m	430 m	260 m	145 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 amiguities have to be resolved by multiple-time-around processing.
4) Typical values for reflectivity ρ ≥ 60 %, 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 10 kn. 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 MHz
Effective Measurement Rate	up to 1.33 MHz @ 60° scan angle
Echo Signal Intensity	provided for each echo signal
Laser Wavelength	near infrared
Laser Beam Divergence	≤ 0.18 mrad @ 1/e [12], ≤ 0.25 mrad @ 1/e² [13]
Number of Targets per Pulse	with online waveform processing: practically unlimited [14] [15] monitoring data output: first pulse

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 [16] - 600 lines/sec
Angular Step Width Δϑ	0.006° ≤ Δϑ ≤ 0.180° [17] [18]
Angle Measurement Resolution	0.001°

8) Limitation for range measurement capability, does not consider laser safety issues! The minimum range for valid reflectivity 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) Measured at the 1/e points. 0.18 mrad correspond to an increase of 18 cm of beam diameter per 1000 m distance.
13) Measured at the 1/e² points. 0.25 mrad correspond to an increase of 25 cm of beam diameter per 1000 m distance.
14) Depending on laser pulse repetition rate, up to a max. of 15 targets per laser pulse.
15) If the laser beam hits, in part, more than one target, the laser's pulse power is split accordingly. Thus, the achievable range is reduced.
16) The minimum scan rate depends on the selected laser PRR.
17) The minimum angular step width depends on the selected laser PRR.
18) The maximum angular step width is limited by the maximum scan rate.

Technical Data to be continued at page 10

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

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 / Current 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. 55 kg without any camera but including a typical IMU/GNSS unit approx. 60 kg with optional components
Protection Class	IP54
Max. Flight Altitude operating / not operating	18500 ft (5600 m) above MSL[1] / 18500 ft (5600 m) above MSL
Temperature Range operation / storage	0°C up to +40°C / -10°C up to +50°C

1) Mean Sea Level

Recommended IMU/GNSS System [2] [3]

IMU Accuracy [4]	
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

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.

2) 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.
3) The *RIEGL* VQ-1560i Laser Scanning system supports different IMU/GNSS Systems, details on request.
4) One sigma values, no GNSS outages, post-processed with base station data

RIEGL LASER MEASUREMENT SYSTEMS

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