LAS Extrabytes Implementation in *RIEGL* Software

WHITEPAPER

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1 OVERVIEW

The intention of this document is to provide some background information about the implementation of extrabytes in the LAS exports of the *RIEGL* software RiPROCESS. We believe that adding valuable additional information provided by RIEGL instruments to each point of the point cloud to the widely used LAS format provides useful benefit for further processing of Lidar data. We acknowledge the LAS format as being one of the major exchange formats in the Lidar industry and are committed to undertake the required efforts to make available the variety of information evolving from the latest developments of our instruments by means of the LAS standard.

1.1 REFERENCE

The actual implementation is based on the ASPRS documents:

LAS SPECIFICATION VERSION 1.4 – R13
Approved on November 14, 2011 and published by the American Society for Photogrammetry & Remote Sensing (www.asprs.org).

LAS SPECIFICATION VERSION 1.3 –R11
Approved in July 2009 and published by the American Society for Photogrammetry & Remote Sensing (www.asprs.org).

2 DEFINITIONS

The given overview of the definitions should provide some background information about the additional parameters provided by *RIEGL* sensors, to understand the idea behind it and how it could enhance the possibilities of postprocessing software making use of it.

2.1 INTENSITY

Up to now the intensity value is a common attribute beside the geometry information in a LAS file:
"The intensity value is the integer representation of the pulse return magnitude. This value is optional and system specific. […]Intensity, when included, is always normalized to a 16 bit, unsigned value by multiplying the value by 65,536/(intensity dynamic range of the sensor)."
This citation taken from LAS SPECIFICATION VERSION 1.4 – R13, page 10 defines pretty well how intensity values in LAS files have to be interpreted. According to the specification intensity is a unitless and scaled attribute. When reading the intensity in a LAS file, without knowing about its creation history a correct interpretation is very difficult.
To overcome this shortcoming *RIEGL* will provide the amplitude and reflectance (where available) in all further LAS exports.

2.2 AMPLITUDE

The amplitude of the echo signal reaching the laser scanner depends on a number of parameters, including system parameters like the emitted laser pulse peak power and the receiver aperture, but also including target parameters like the target's reflectance (more precise the target's laser radar cross section including also the target size and the directivity of the target's reflection) and range. By means of a careful calibration during manufacturing, *RIEGL*'s V-Line instruments provide for every detected echo signal an amplitude reading which reflects the amplitude of the optical echo signal. The amplitude is given relative to the amplitude of an echo signal at the detection threshold of the instrument. Thus, the value of the amplitude reading is a ratio, given in the units of decibel (dB). This logarithmic measure covers the wide dynamic range of *RIEGL* instrument perfectly, usually above 60 dB, i.e., a ratio of more than 1 : 1,000,000.

$$A_{dB} = 10 * log\left(\frac{P_{echo}}{P_{DL}}\right)$$ …Amplitude formula

A_{dB} …Amplitude in decibel, P_{echo} …optical input power, P_{DL} …minimum detectable input power

Therefore signal strength ratios in dB between different targets can be obtained simply by calculating the difference between the corresponding amplitude values:

$$10 * log\left(\frac{P_{echo,1}}{P_{echo,2}}\right) = A_{dB,1} - A_{dB,2}$$

2.3 REFLECTANCE

The calibrated amplitude as described above still suffers from the fundamental range dependence of the echo signal detected by the receiver, making the interpretation of scan data difficult, especially when combining data from different laser scanners and/or different scan positions. This can be resolved by providing not only the calibrated amplitude but also the relative reflectance. Reflectance is a target property and refers to the fraction of incident optical power that is reflected by that target at a certain wavelength. The reflectance is always a positive real number. *RIEGL*'s V-Line instruments provide a relative reflectance reading for each detected target as an additional attribute. The relative reflectance provided is a ratio of the actual amplitude of that target to the amplitude of a white flat target at the same range, orientated orthonormal to the beam axis, and with a size in excess of the laser footprint. The actual reflectance reading is given in decibel (dB). To be more precise, the reflectance reading of *RIEGL*'s V-Line instruments takes also the directivity of the reflection into account and can be interpreted as the normalized laser radar cross section – normalized by the laser footprint area. Negative values hint to diffusely reflecting targets, whereas positive values are usually retro-reflecting targets. A relative reflectance higher than 0 dB results from targets reflecting with a directivity different from that of a lambertian reflector. Such targets may be reflecting foils, cornercube arrays, license plates, traffic signs or mirror-like objects as, e.g. window panes or blank metal aligned perpendicular to the measurement beam.

$$\rho_{rel} = A_{dB} - A_{dB,Ref}(R)$$ …formula for relative reflectance

ρ_{rel} …relative reflectance in dB, A_{dB} …calibrated Amplitude, $A_{dB,Ref}$ (R) …Amplitude of a reference target at range R

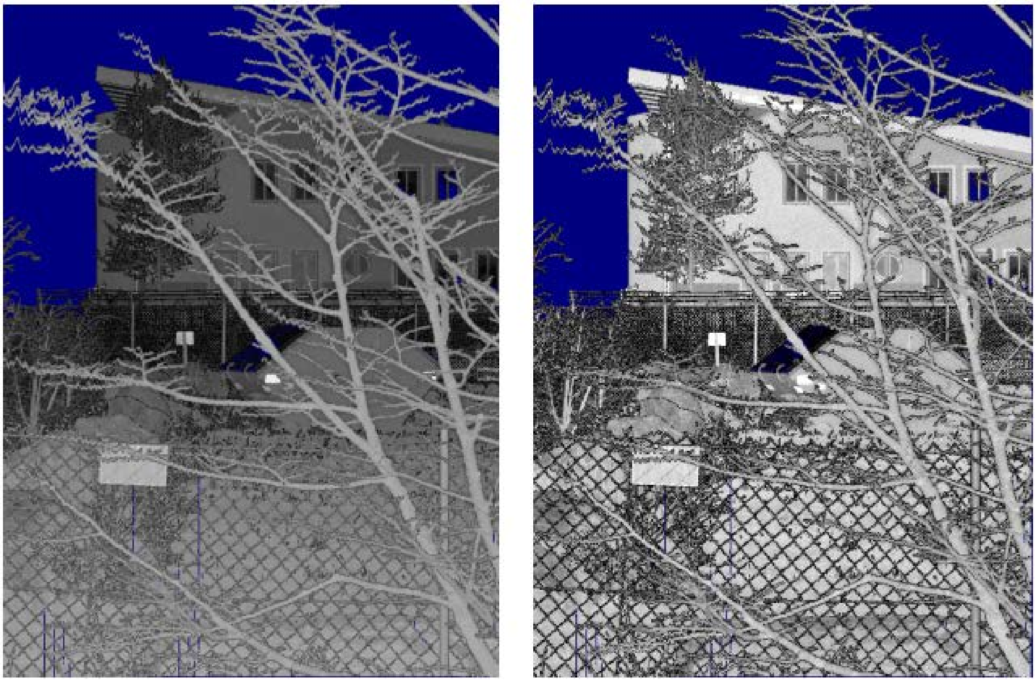
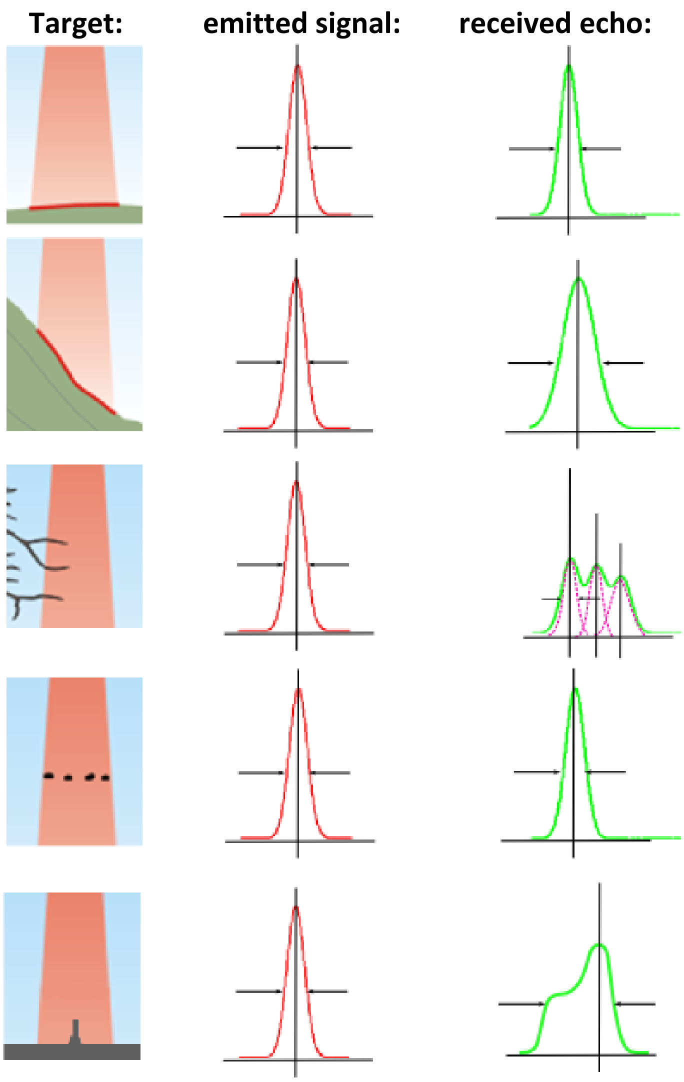


Figure 1: Left: Grey scale encoding of point cloud according to calibrated amplitude. Range of encoding 0 dB to 50 dB above detection threshold. Note that brightness decreases from near objects to far objects. Right: Grey scale encoding of point cloud according to reflectance of target. Range of encoding is -20 dB to 3 dB with respect to white diffuse target. Note that brightness is nearly independent from distance. Targets with a reflectance above 3 dB are shown in white, targets below -20 dB are black.

2.4 PULSE WIDTH

The pulse width is defined as full width at half maximum of the received echo signal and is measured in nanoseconds (ns).



Flat target: the pulse width of the received echo signal is similar to the pulse width of the emitted signal.

Slope target: the pulse width of the received echo signal is widened compared to the pulse width of the emitted signal.

Multiple targets: The received echo signals of the three targets overlap. The spatial distribution exceeds the detection threshold.

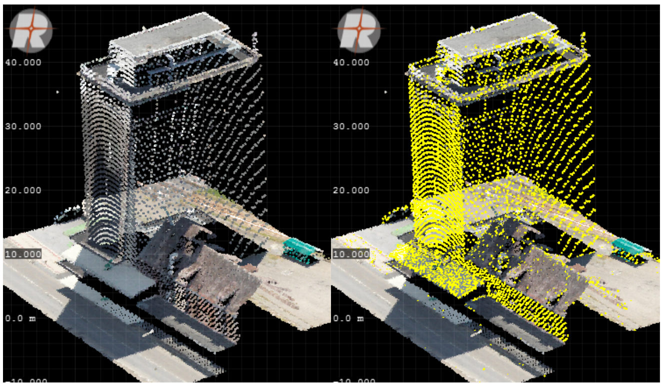
Received echo signals of objects at the same range overlap to a single echo signal. The small variation in range yield a slight widening of the echo signal.

Merged targets: the pulse width of the received echo signal is dramatically widened compare to the pulse width of the emitted signal.

Similar to the pulse shape deviation described below, the pulse width can be regarded as a quality indicator of received echo signals. As the figure above indicates the width of a received echo signals is depending on the geometry of the hit target.

2.5 PULSE SHAPE DEVIATION

RIEGL V-Line instruments make use of echo digitization and on-line waveform processing by digital signal processing. Beside target range and amplitude, the pulse shape of the echo signal is compared to the pulse shape representing the so-called system response. The pulse shape deviation can be interpreted as the comparison of the area below the shape curve and is one of the additional attributes to each point of the point cloud. Low values indicate that the echo pulse shape does not deviate significantly from the system response. High values hint to echo signals with a significantly different pulse shape, which may arise from, e.g., merging echo pulses from several targets hit by the laser beam at only slightly different ranges or extremely slanting angles of incident. This effect could be used, e.g., to detect vertical surfaces from ALS Lidar data, as indicated by the right image.



Left side: true colour representation of a pointcloud, right side: points filtered by deviation

2.6 DECIBEL

The decibel (dB) is a logarithmic unit that indicates the ratio of a physical quantity (usually power or intensity) relative to a specified or implied reference level. A ratio in decibels is ten times the logarithm to base 10 of the ratio of two physical quantities. For example a ratio of 10 corresponds to 10 dB, ratios of 0.5, 20 and 100 to -3 dB, 13 dB and 20 dB, respectively.

3 IMPLEMENTATION IN RIPROCESS

RiPROCESS is the software package for scan data adjustment, georeferencing and filtering of airborne and mobile laser scan data developed by *RIEGL*. As it is designed to process data of all *RIEGL* sensors available, the functionality regarding visualisation and export slightly changes according to the availability of attributes of different datasets. This has to be taken into account when talking about the LAS export. Due to different system architecture *RIEGL* Q-Line and V-Line instruments provide a different set of attributes.

3.1 Q-LINE INSTRUMENTS

3.1.1 Short and mid range instruments

The Q-Line instruments make use of the time-of-flight distance measurement principles of nanosecond infrared pulses. They are mostly used for topography, corridor mapping, city modelling, agriculture & forestry.

Left: LMS-Q560, right: LMS-Q680i

For the Q-Line instruments (e.g. LMS-Q560, LMS-Q680i) Amplitude and Pulse Width will be written to the extrabytes structure. For the detailed definition of the extrabyte structure refer to chapter 5.

Data_type	name	No data	min	max	scale	Description
3 (unsigned short)	Amplitude	65535	0	10000	0.01	Echo signal amplitude [dB]
3 (unsigned short)	Pulse width	-	1	10000	0.1	Full width at half maximum [ns]

For the additional attributes the Variable Length Record (VLR) header reads as follows:

Reserved	00 00 // 0
User ID	4C 41 53 46 5F 53 70 65 63 00 00 00 00 00 00 00 // „LASF_Spec“
Record ID	04 00 // 4
Record Length After Header	80 01 // 2 records (192 Bytes each) = 384 Bytes for Amplitude + Pulse width
Description	52 49 45 47 4C 20 45 78 74 72 61 20 42 79 74 65 73 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Record(s)	// „RIEGL Extra Bytes“ <Extra Bytes structure for Amplitude> <Extra Bytes structure for Pulse width>

3.1.2 Long range instruments

For the long range Q-Line instruments LMS-Q1560 and LMS-Q780 additional to the attributes mentioned above the reflectance can be provided.

Left: LMS-Q1560, right: LMS-Q780

For the Q-Line instruments LMS-Q780 and LMS-Q1560i Amplitude, Reflectance and Pulse width will be written to the extrabytes structure. For the detailed definition of the extrabyte structure refer to chapter 5.

Data_type	name	No data	min	max	scale	Description
3 (unsigned short)	Amplitude	65535	0	10000	0.01	Echo signal amplitude [dB]
4 (short)	Reflectance	-	-5000	15000	0.01	Echo signal reflectance [dB]
3 (unsigned short)	Pulse width	-	1	10000	0.1	Full width at half maximum [ns]

For the additional attributes the Variable Length Record (VLR) header reads as follows:

Reserved	00 00 // 0
User ID	4C 41 53 46 5F 53 70 65 63 00 00 00 00 00 00 00 // „LASF_Spec“
Record ID	04 00 // 4
Record Length After Header	40 02 // 3 records (192 Bytes each) = 576 Bytes for Amplitude + Reflectance + Pulse width
Description	52 49 45 47 4C 20 45 78 74 72 61 20 42 79 74 65 73 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // „RIEGL Extra Bytes“
Record(s)	<Extra Bytes structure for Amplitude> <Extra Bytes structure for Reflectance> <Extra Bytes structure for Pulse width>

3.2 V-LINE INSTRUMENTS

The V-Line instruments are available for airborne and mobile platforms and represent the next generation of state of the art echo digitization and online waveform processing. The VUX-1HA is used on mobile mapping platforms worldwide, whereas the VUX-1UAV with its 3.6kg of weight is capable of being mounted on light aircrafts and UAVs.

Left: *RIEGL* VQ-1560i, right *RIEGL* VUX-1HA

For the V-Line instruments Amplitude, Reflectance and Pulse Shape Deviation is provided. For the detailed definition of the extrabyte structure refer to chapter 5.

Data_type	name	No data	min	max	scale	description
3 (unsigned short)	Amplitude	65535	0	10000	0.01	Echo signal amplitude [dB]
4 (short)	Reflectance	-	-5000	15000	0.01	Echo signal reflectance [dB]
3 (unsigned short)	Deviation	65535	0	2^{15} - 1	-	Pulse shape deviation

For the additional attributes the Variable Length Record (VLR) header reads as follows:

Reserved	00 00 // 0
User ID	4C 41 53 46 5F 53 70 65 63 00 00 00 00 00 00 00 // „LASF_Spec“
Record ID	04 00 // 4
Record Length After Header	40 02 // 3 records (192 Bytes each) = 576 Bytes for Amplitude + Reflectance + Deviation
Description	52 49 45 47 4C 20 45 78 74 72 61 20 42 79 74 65 73 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Record(s)	// „RIEGL Extra Bytes“ <Extra Bytes structure for Amplitude> <Extra Bytes structure for Reflectance> <Extra Bytes structure for Deviation>

3.3 BACKWARD COMPATIBILITY

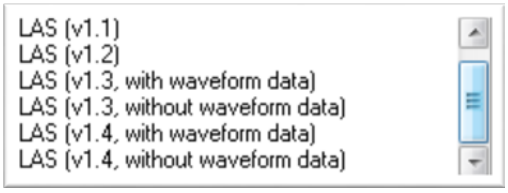
As the extrabytes structure exists since the LAS 1.1 format, the existing export functions were extended to make the additional attributes available to former versions of LAS as well. For compatibility reasons to existing LAS readers the information provided by the extrabytes will not replace existing attributes. That means that the intensity value will remain in the exports from LAS 1.1 to LAS 1.3 and LAS 1.4 with the amplitude or reflectance being added through the extrabytes. The compatibility matrix below indicates the available extrabytes for the different format versions. Please note: All versions will contain the VLR Header describing the meaning of the extrabytes. As this description mechanism is not defined expressively in the LAS specifications up to v1.3, existing readers are very likely to neglect this information.

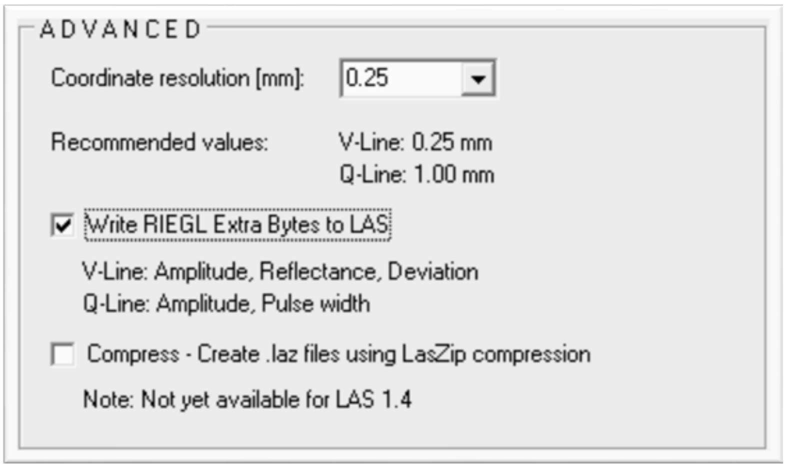
	VLR Header	Intensity	Amplitude [1) 2)]	Reflectance [3)]	Pulse width [2)]	Deviation [1)]
LAS 1.1	x	x	x	x	x	x
LAS 1.2	x	x	x	x	x	x
LAS 1.3	x	x	x	x	x	x
LAS 1.4	x	x	x	x	x	x

[1)] Available for V-Line instruments, [2)] Available for Q-Line instruments, [3)]Available for V-Line instruments and some Q-Line instruments

3.4 EXPORT DIALOG IN RIPROCESS

When exporting data from RiPROCESS the user can select from different LAS format version.
Actually the software supports the LAS 1.1, 1.2, 1.3 and 1.4 format versions.





Through the advanced settings tab the user can check the activation of the extrabytes handling. If checked the extrabytes will be exported according to the availability (sensor dependent) and the selected version automatically.

4 IMPLEMENTATION IN RISCAN PRO

RiSCAN PRO is the *RIEGL* processing package for terrestrial / static laser scan data. Static laser scanning is typically done by setting up a laser scanner on a tripod. In contrast to airborne and mobile (kinematic) laser scanning, the instrument is not moved during the data acquisition, but rotates around a frame axis. As the acquisition of static laser scan data significantly differs from the methods of kinematic laser scanning, some of the attributes defined in the LAS specification can't be written accordingly.
As a matter of fact there is no edge of flight line flag and the scan angle or scan angle rank is not representative, as static scans involve 2 scan angles (line angle and frame angle).
Despite these shortcoming LAS is recognised as the most common denominator in the terms of LiDAR data exchange and is therefore also supported in *RIEGL*'s terrestrial laser scanning software products RiSCAN PRO, RiSOLVE and RiMINING.

4.1 V-LINE INSTRUMENTS

The V-Line instruments for terrestrial laser scanning incorporate Online Waveform processing and therefore provide the same set of additional attributes as V-Line instruments for airborne and mobile laser scanning.

For the V-Line instruments Amplitude, Reflectance and Pulse Shape Deviation is provided. For the detailed definition of the extrabyte structure refer to chapter 5.

From left to right:
RIEGL VZ-400i, *RIEGL* VZ-2000, *RIEGL* VZ-4000

Data_type	name	No data	min	max	scale	description
3 (unsigned short)	Amplitude	65535	0	10000	0.01	Echo signal amplitude [dB]
4 (short)	Reflectance	-	-5000	15000	0.01	Echo signal reflectance [dB]
3 (unsigned short)	Deviation	65535	0	$2^{15} - 1$	-	Pulse shape deviation

For the additional attributes the Variable Length Record (VLR) header reads as follows:

Reserved	00 00 // 0
User ID	4C 41 53 46 5F 53 70 65 63 00 00 00 00 00 00 00 // „LASF_Spec“
Record ID	04 00 // 4
Record Length After Header	40 02 // 3 records (192 Bytes each) = 576 Bytes for Amplitude + Reflectance + Deviation
Description	52 49 45 47 4C 20 45 78 74 72 61 20 42 79 74 65 73 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // „RIEGL Extra Bytes“
Record(s)	<Extra Bytes structure for Amplitude> <Extra Bytes structure for Reflectance> <Extra Bytes structure for Deviation>

4.2 BACKWARD COMPATIBILITY

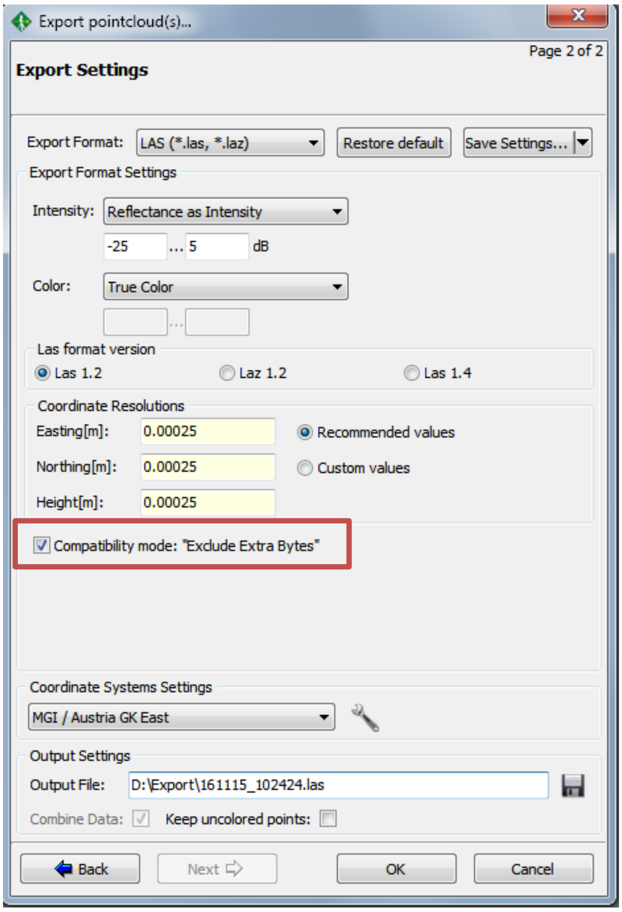
RiSCAN PRO supports the export of LAS version 1.2. and 1.4.
The compatibility matrix below indicates the available extrabytes for the different format versions. Please note: All versions will contain the VLR Header describing the meaning of the extrabytes. As this description mechanism is not defined expressively in the LAS specifications up to v1.3, existing readers are very likely to neglect this information.

	VLR Header	Intensity	Amplitude[1)]	Reflectance[1)]	Pulse width	Deviation [1)]
LAS 1.2	x	x	x	x		x
LAS 1.4	x	x	x	x		x

[1)] Available for V-Line instruments

4.3 EXPORT DIALOG IN RISCAN PRO

RiSCAN PRO supports the export of LAS versions 1.2 and 1.4 and LAZ version 1.2
LAS data will be written with extrabytes by default. In case the further processing software doesn't provide support for extrabytes, they can be disabled by checking the Compatibility mode: "exclude extrabytes" option.



5 EXTRABYTES STRUCTURE

This section describes the structure of the extrabytes as it is written to the LAS format by the export function of *RIEGL* software. A detailed description for amplitude, reflectance, pulse width and pulse shape deviation is given.

5.1.1 extrabytes structure for amplitude

reserved[2]	00 00 // 0
data_type	03 // (unsigned short)
options	0F // bit 0: no_data, bit 1: min_bit, bit 2: max_bit, bit 3: scale_bit
name[32]	41 6D 70 6C 69 74 75 64 65 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // Amplitude
unused[4]	00 00 00 00 // 0
no_data[3]	FF FF 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [65535, unused, unused]
min[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [0, unused, unused]
max[3]	10 27 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [10000, unused, unused]
scale[3]	7B 14 AE 47 E1 7A 84 3F 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [0.01, unused, unused]
offset[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
description[32]	45 63 68 6F 20 73 69 67 6E 61 6C 20 61 6D 70 6C 69 74 75 64 65 20 5B 64 42 5D 00 00 00 00 00 00 // Echo signal amplitude [dB]

5.1.2 extrabytes structure for reflectance

reserved[2]	00 00 // 0
data_type	04 // (short, signed)
options	0E // bit 1: min_bit, bit 2: max_bit, bit 3: scale_bit
name[32]	52 65 66 6C 65 63 74 61 6E 63 65 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // Reflectance
unused[4]	00 00 00 00 // 0
no_data[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
min[3]	78 EC FF FF FF FF FF FF 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [-5000, unused, unused]
max[3]	98 3A 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [15000, unused, unused]
scale[3]	7B 14 AE 47 E1 7A 84 3F 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [0.01, unused, unused]
offset[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
description[32]	45 63 68 6F 20 73 69 67 6E 61 6C 20 72 65 66 6C 65 63 74 61 6E 63 65 20 5B 64 42 5D 00 00 00 00 // Echo signal reflectance [dB]

5.1.3 extrabytes structure for pulse shape deviation

reserved[2]	00 00 // 0
data_type	03 // (unsigned short)
options	07 // bit 0: no_data_bit (data value 65535/0xFFFF is defined as no data value), bit 1: min_bit, bit 2: max_bit
name[32]	44 65 76 69 61 74 69 6F 6E 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // Deviation
unused[4]	00 00 00 00 // 0
no_data[3]	FF FF 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [65535, unused, unused]
min[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [0, unused, unused]
max[3]	FF 7F 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [32767, unused, unused]
scale[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
offset[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
description[32]	50 75 6C 73 65 20 73 68 61 70 65 20 64 65 76 69 61 74 69 6F 6E 00 00 00 00 00 00 00 00 00 00 00 // Pulse shape deviation

5.1.4 extrabytes structure for pulse width

reserved[2]	00 00 // 0
data_type	03 // (unsigned short)
options	0E // bit 1: min_bit, bit 2: max_bit, bit 3: scale_bit
name[32]	50 75 6C 73 65 20 77 69 64 74 68 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // Pulse width
unused[4]	00 00 00 00 // 0
no_data[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
min[3]	01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [1, unused, unused]
max[3]	10 27 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [10000, unused, unused]
scale[3]	9A 99 99 99 99 99 B9 3F 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [0.1, unused, unused]
offset[3]	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 // [unused, unused, unused]
description[32]	46 75 6C 6C 20 77 69 64 74 68 20 61 74 20 68 61 6C 66 20 6D 61 78 69 6D 75 6D 20 5B 6E 73 5D 00 // Full width at half maximum [ns]

6 APPENDIX

6.1 LIST OF INSTRUMENTS

The following list provides an overview of the various instruments and their assignment to the respective construction line:

	V- Line	Q-Line
Terrestrial	VZ-400 VZ-400i VZ-1000 VZ-2000 VZ-2000i VZ-4000 VZ-6000	
Mobile	VQ-180 VQ-250 VQ-450 VUX-1HA	
Airborne	VQ-380i VQ-480i VQ-580 VQ-780i VQ-820-G VQ-880-G VQ-880-GH VQ-1560i VQ-1560i-DW VUX-1LR	LMS-Q560 LMS-Q680i LMS-Q780 LMS-Q1560
UAV	VQ-480-U VUX-1UAV miniVUX-1UAV miniVUX-1DL	