Echo Digitization and Waveform Analysis in Airborne and Terrestrial Laser Scanning

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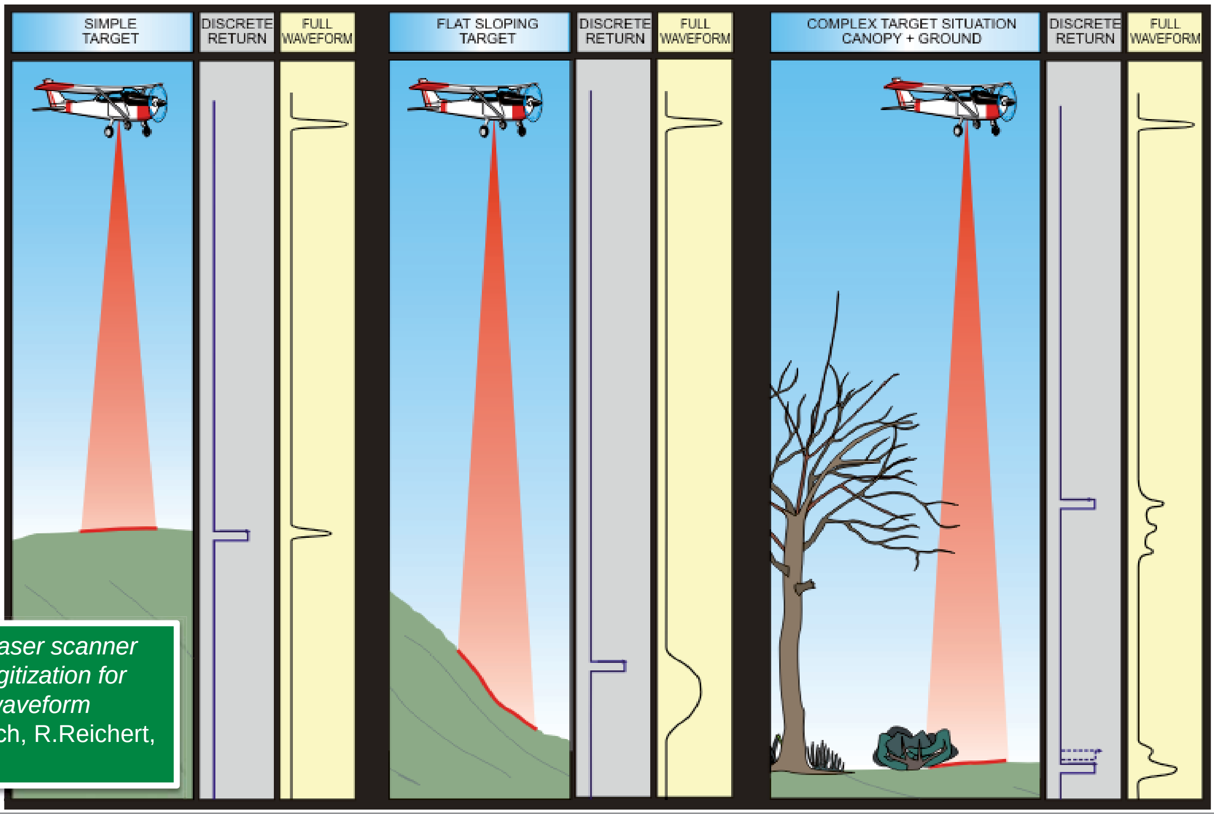
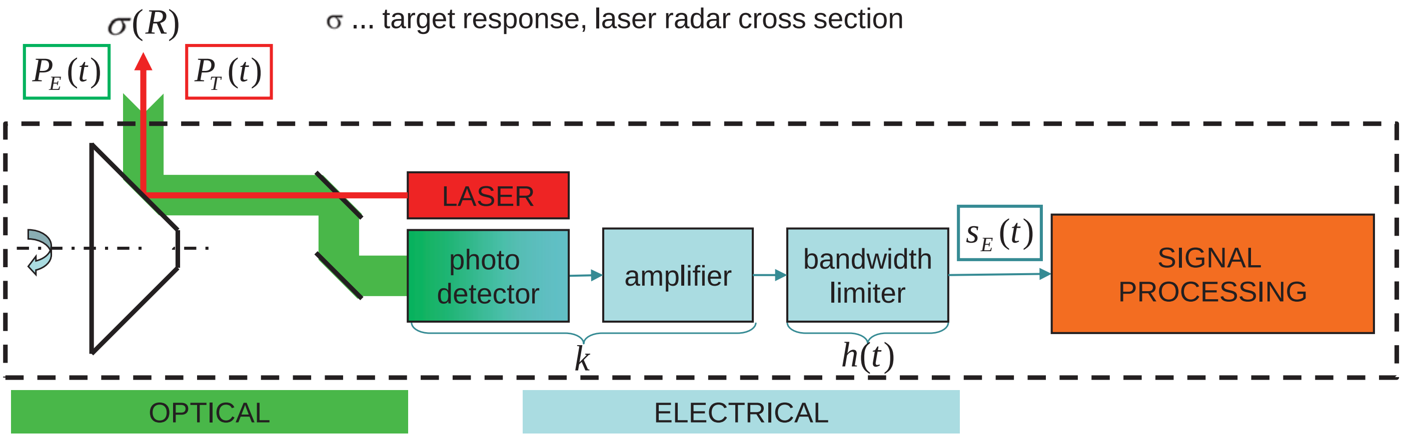


"*High resolution laser scanner with waveform digitization for subsequent full waveform analysis*", A. Ullrich, R.Reichert, SPIE Proc, 2005.

σ ... target response, laser radar cross section



$P_T(t)$

$$P_E(R) = P_T(R) * \sigma(R)$$

$$s_E(t) = k.P_E(t) * h(t)$$

$$s_E(t) = k.P_T(t) * \sigma(t) * h(t)$$

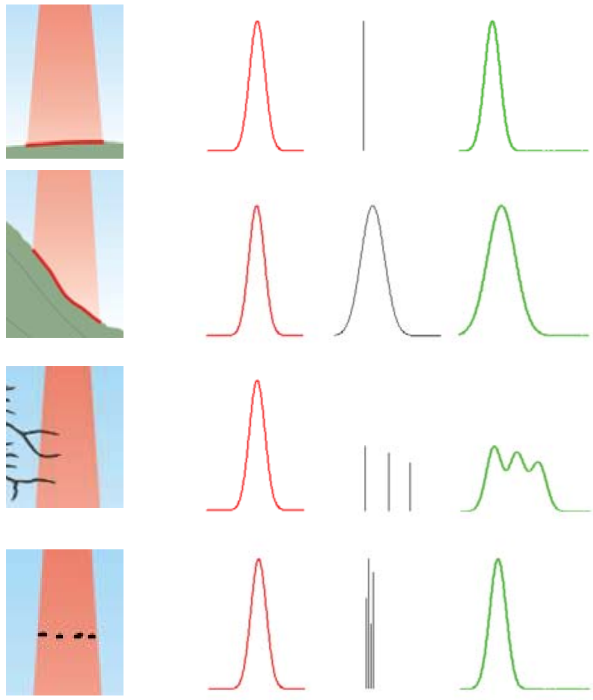
$$s_E(t) = \underbrace{k.P_T(t) * h(t)}_{\text{system response}} * \sigma(t)$$

$$s_E(t) = s_R(t) * \sigma(t)$$

$$R = \frac{v_g}{2} t$$

- analog (discrete return)
- digitization and offline analysis
- digitization and online processing
- digitization, online processing and offline analysis

$$s_R(t) * \sigma(R) = s_E(t)$$



flat target, normal incidence
Dirac delta function (approximation)

sloping target
Gaussian response (approximation)

small targets at different ranges
sum of Dirac delta function

small targets at nearly the same range
sum of Dirac delta function

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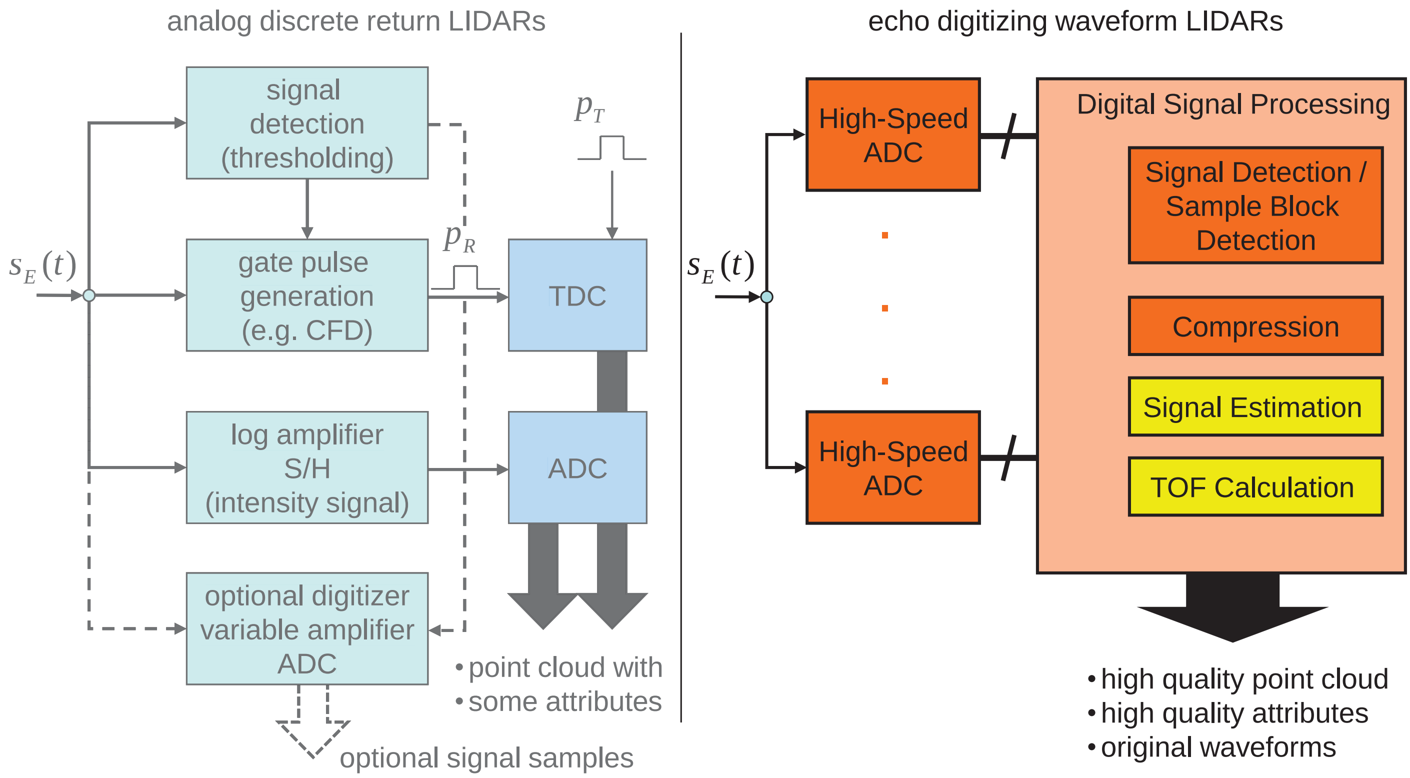
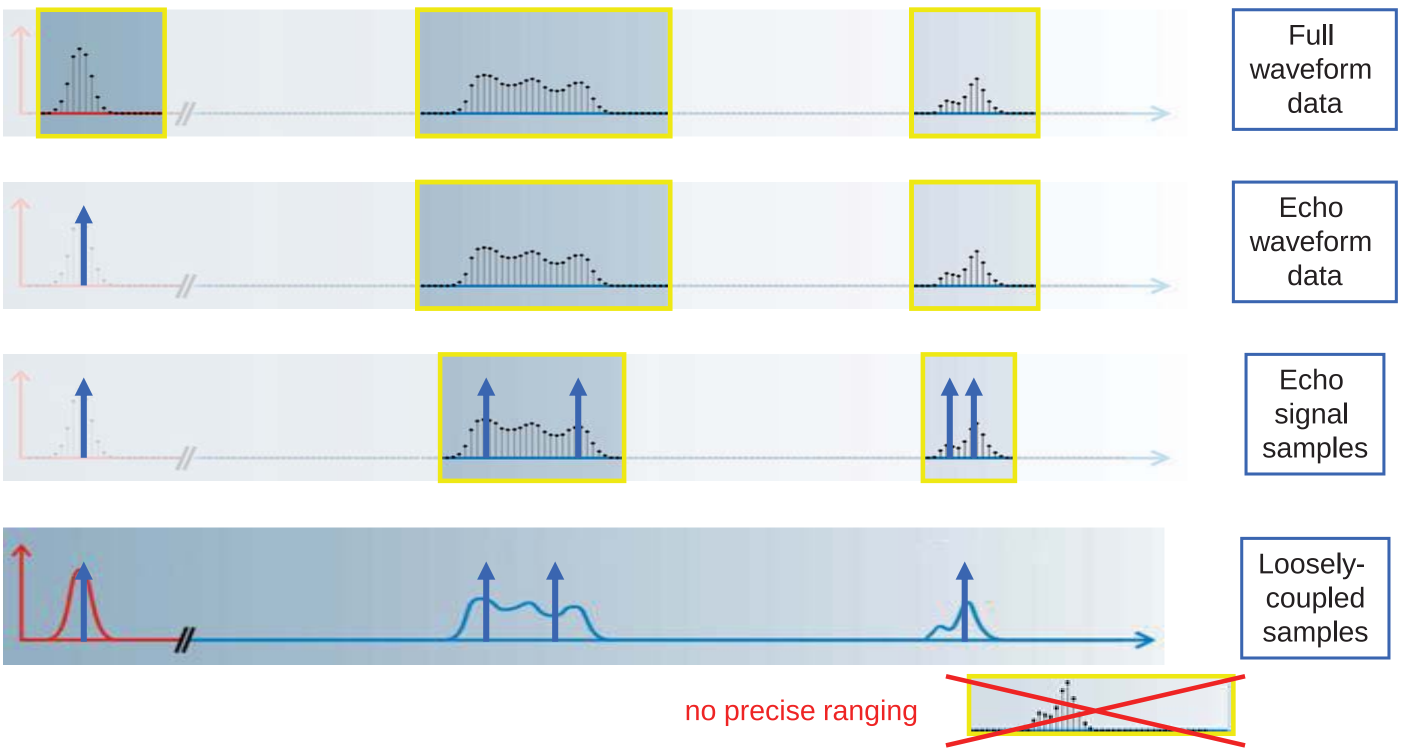
LASER MEASUREMENT SYSTEMS

- signal detection
  - discrimination against noise
  - threshold detection (fixed, range dependent, dynamic threshold)
- signal estimation
  - temporal position → time of flight → range to target
  - signal strength → amplitude → laser radar cross-section / reflectance
  - signal-to-noise ratio → range noise
  - signal shape →
    - pulse width (Gaussian decomposition)
    - pulse shape deviation (V-Line)

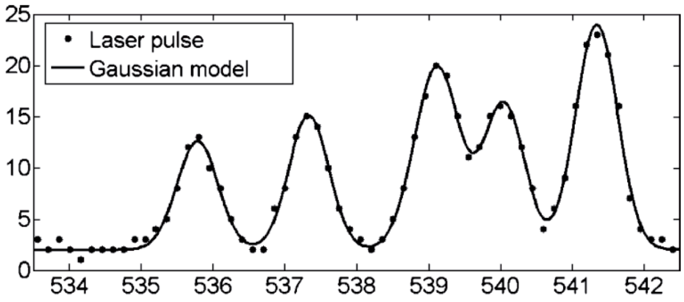
- point in 3D
- point attributes (radiometric)
- point precision
- additional information for filtering / classification

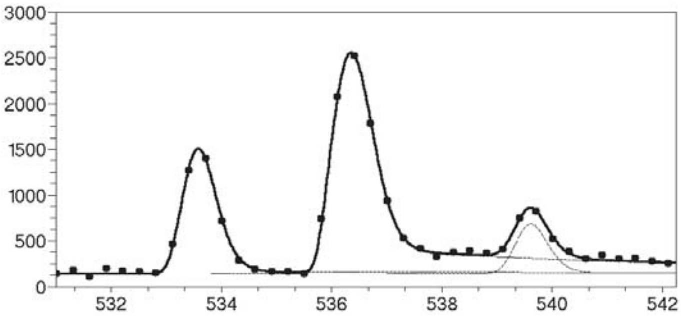


Signal Processing Electronics



Categories of Waveform Data





Gaussian decomposition

- assumes Gaussian system response
- estimates pulse width
- estimates target‘s depth (width)
- robust and fast
- *RIEGL* RiANALYZE

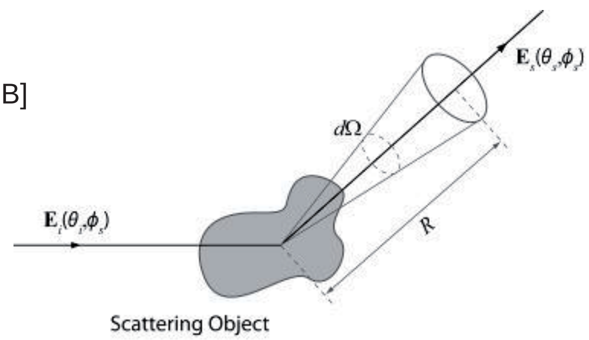
System response fitting

- relies on knowledge of system response
- copes with non-linear distortion of receiver
- estimates pulse shape deviation
- real-time computation (3 MTargets/sec)
- *RIEGL* V-Line Online Waveform Processing

- Deconvolution
- B-Spline Deconvolution
- CFD, zero crossing, 2nd derivate detection, ...

Laser Radar Cross Section (LRCS)

- cross section σ in [m²]
- area-normalized cross section values in [m²m⁻²] or [dB]
  - by laser footprint area: γ
  - by illuminated object area: σ^0



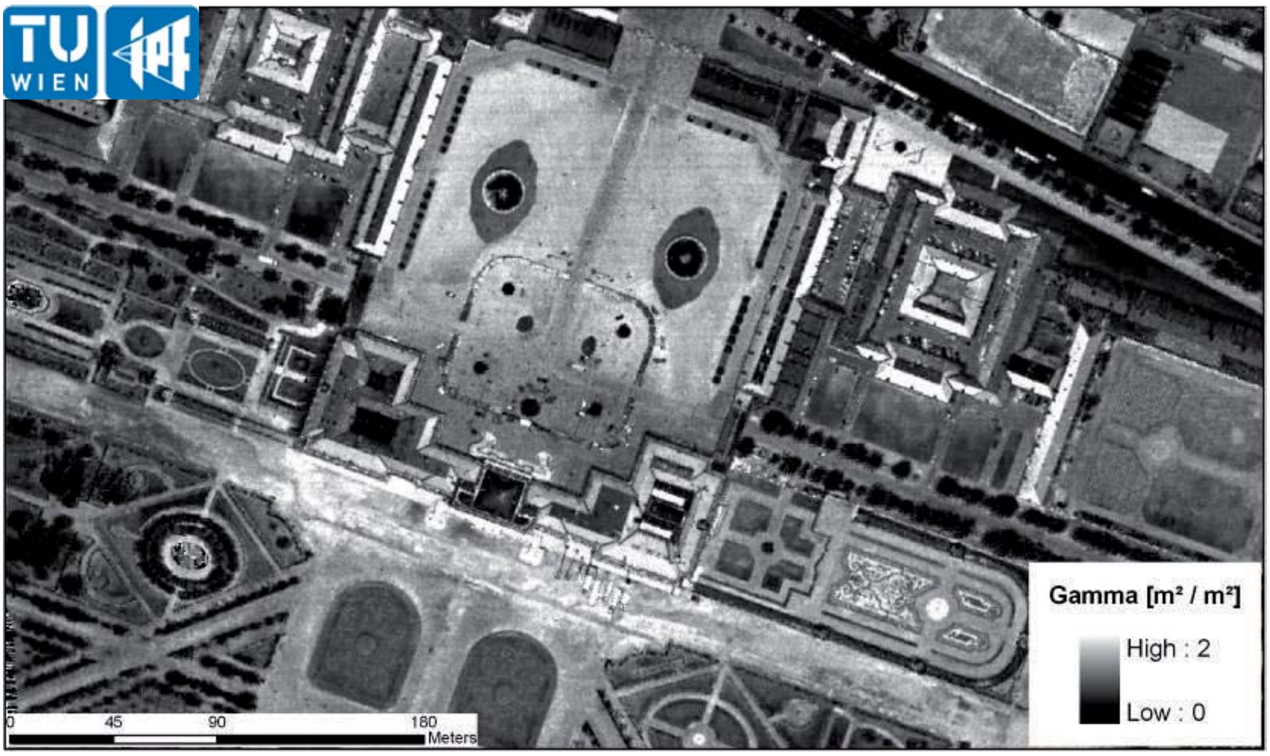
$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{\langle \mathbf{E}_s \cdot \mathbf{E}_s^* \rangle}{|\mathbf{E}_i|^2} = A_i \ \rho \ d$$

actual geometric cross-section of target interacting with laser beam

reflectance

directivity of backscattered reflection

Radiometric calibration of small-footprint airborne laser scanner measurements: Basic physical concepts, Wagner, W., ISPRS Journal of Photogrammetry and Remote Sensing, **65**, 2010.

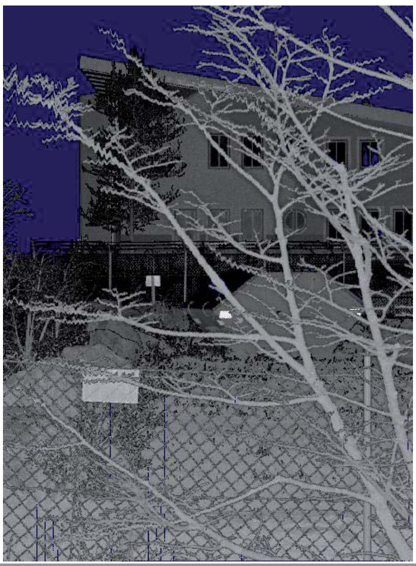


Radiometric Calibration

Encoding by **calibrated amplitude**
(0 dB to 50 dB above detection threshold)
Brightness decreases from near objects to far objects.

$$A_{dB} = 10 \cdot \log\left(\frac{P_{echo}}{P_{DL}}\right)$$

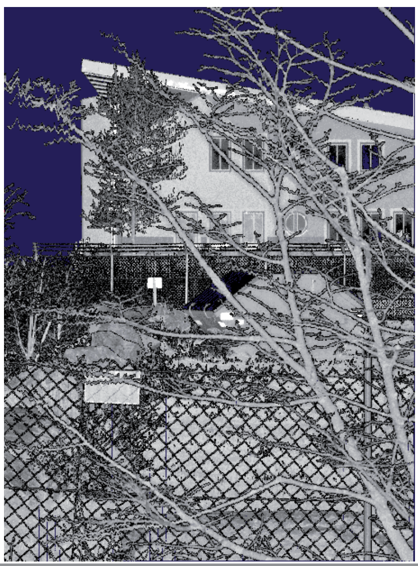
A_{dB} … calibrated amplitude [dB]
P_{echo} ..echo signal power [W]
P_{DL} … detection limit [W]



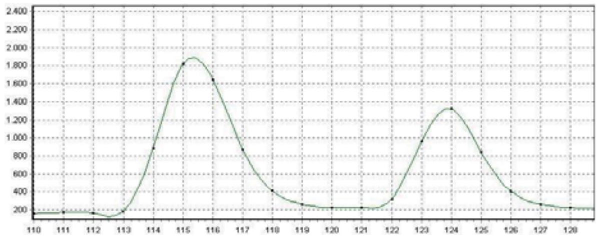
Encoding by **reflectance** (-20 dB to 3 dB, with respect to diffuse white target)
Brightness independent of object distance.

$$\rho_{rel,T} = A_{dB,T} - A_{dB,White}(R_T)$$

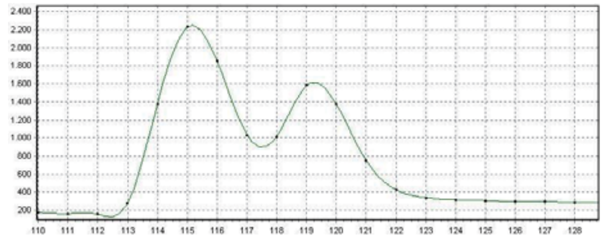
R_T … target range



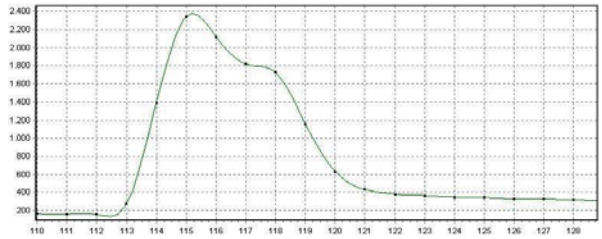
Calibrated Amplitude and Reflectance



clear separation of target returns
FWA→ perfect result
OWP→ perfect result
DRS→ accurate results



merging of target returns
FWA→ perfect result
OWP→ satisfying result
DRS→ range error on second target



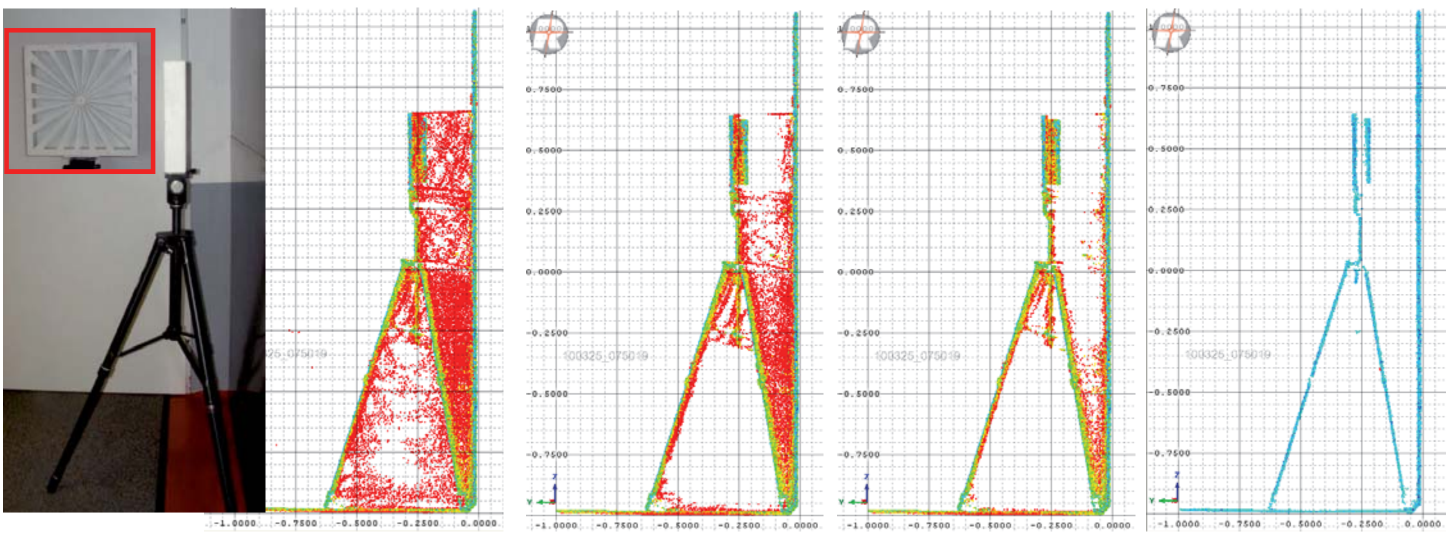
severe merging of target returns
FWA→ nearly perfect result
OWP→ just one target, but detection of pulse shape deviation
DRS→ just one target, no hint to second target

FWA .. Full Waveform Analysis **OWP** .. Online Waveform Processing **DRS** .. Discrete Return System

Close-up on Merging Targets

- Deviation δ of echo pulse shape from emitted pulse shape
- Similarity of echo pulse to instrument-specific system response
- Measure for “reliability of range result”

δ unlimited | $\delta_{max} = 50$ | $\delta_{max} = 25$ | $\delta_{max} = 6$



Deviation of Echo Pulse Shape

- ~~LIDAR with full waveform analysis is a research topic, but not practical for real surveying~~
- **in every day use at numerous service providers, mass data production, high-rel applications, but also the basis for numerous scientific papers**
- ~~discrete return delivers same multi-pulse resolution (it's all about resolution)~~
- **echo digitization delivers best resolution, AND a lot of additional valuable attributes**
- ~~you can generate / synthesize waveform data from discrete return signals~~
- **no, you can't recover information that has been lost in the detection process**
- ~~if you really have to have FW data, make use of the optional digitizer~~
- **the optional digitizer is loosely coupled and provides just some data with questionable usability**

- *RIEGL* echo digitizing LIDAR systems are widely used in surveying (TLS, MLS, ALS, ILS)
- Full waveform analysis, online waveform processing, or combination of both
- Echo digitizing LIDAR systems provide data with
  - high accuracy and high precision
  - multi-target capability
  - calibrated amplitude data
  - calibrated reflectance data
  - data to „clean-up“ point clouds
  - data to improve classification