Calibration of a Terrestrial Full Waveform Laser Scanner

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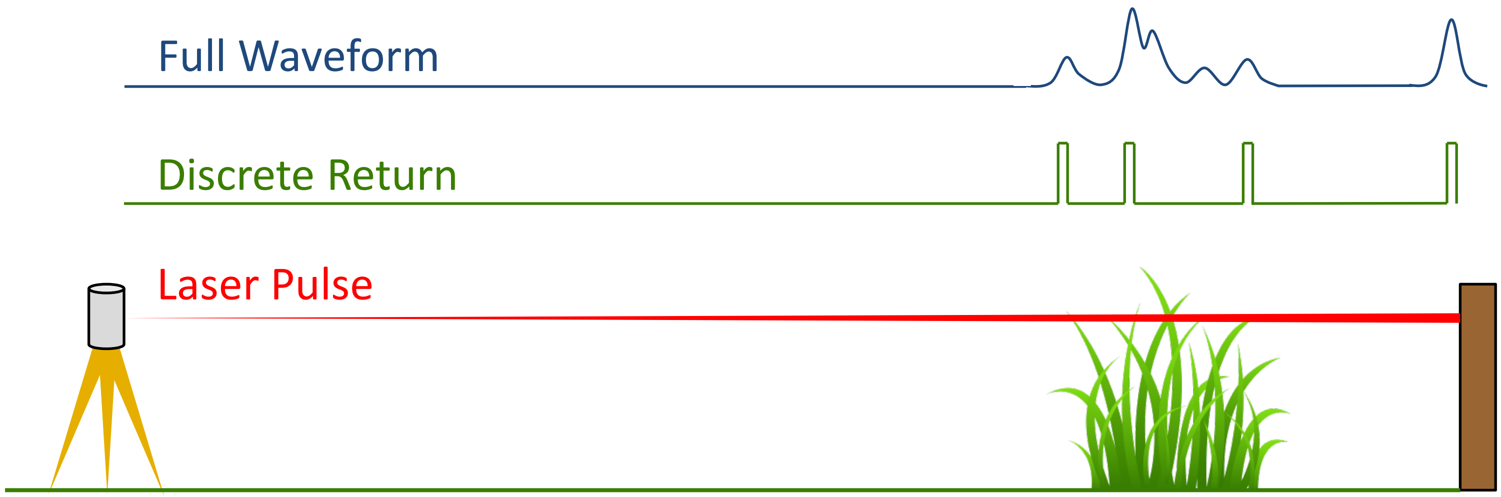
Agenda

1. Introduction & Motivation
2. Method
3. Dataset
4. Results & Analysis
    - System Response Model
    - Absolute Reflectance
    - Incidence Angle
    - Waveform Fitting
5. Future Direction

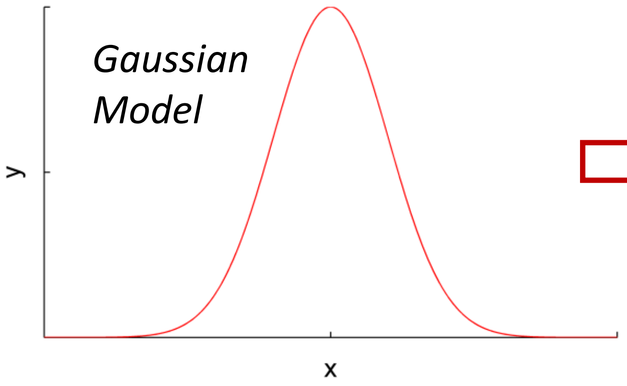
Introduction: Full Waveform LiDAR

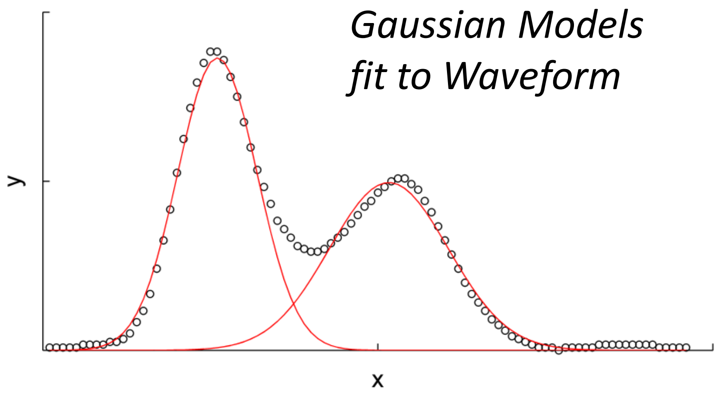
- LiDAR = **<u>Li</u>**ght **<u>D</u>**etection **<u>A</u>**nd **<u>R</u>**anging
- Discrete LiDAR
  - XYZ, Intensity
- Full Waveform LiDAR
  - Digitized record of return echo waveform
  - Derive XYZ, Peak Amplitude (Intensity)



Introduction: Full Waveform LiDAR

- Primarily used to extract additional echoes (e.g., Gaussian fitting)





- Fitting parameters also used for target property extraction
- Most research has relied upon airborne sensors

➢ *Terrestrial full waveform laser scanners* allow control of illuminated targets, enabling more more robust *calibration* methods

Motivation for Calibration

Potential: *Each digitized echo waveform contains information about the target radiometric and geometric properties*

Waveform Intensity/Amplitude

- Discrete intensity and digitized waveform amplitude scales are arbitrary
- No link between these scales and a target's physical reflectance value

Radiometric Calibration:

- Establishes a link between peak waveform amplitude and target reflectance
- Reflectance value at laser wavelength provides target spectral property information

Motivation for Calibration

Potential: *Each digitized echo waveform contains information about the target radiometric and geometric properties*

Waveform Fitting

- Parametric model fitting struggles with complex system response shapes
- Sub-optimal models produce improper parameter extraction and decreased ranging accuracy (examples on next slide)

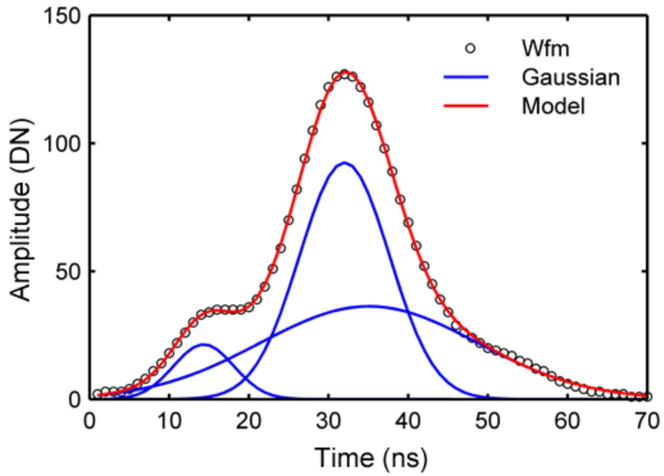
System Response Calibration:

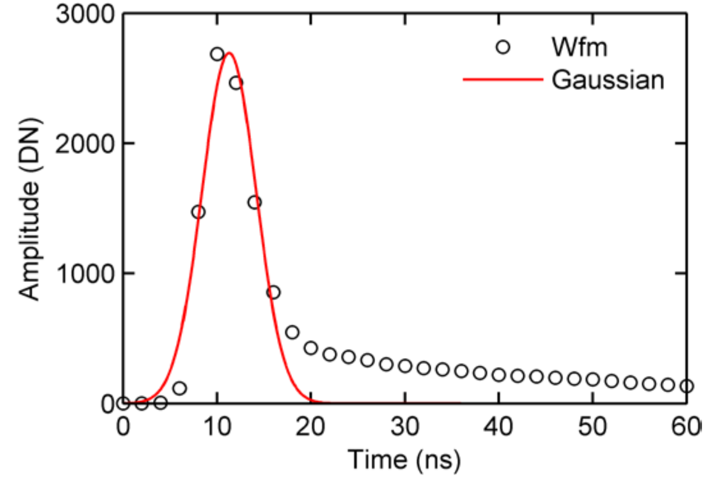
- Determines the system response shape for ideal waveform fitting
- Analysis of deviations from fitted system response models may yield information on target geometric properties

Motivation for Calibration

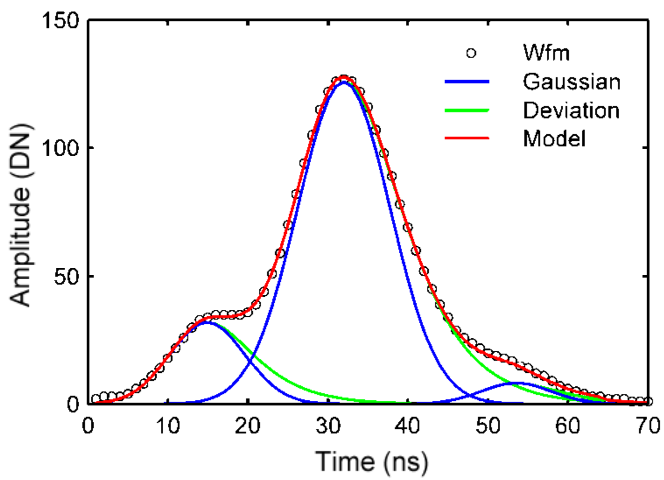
Optech Gemini *Riegl VZ-400*

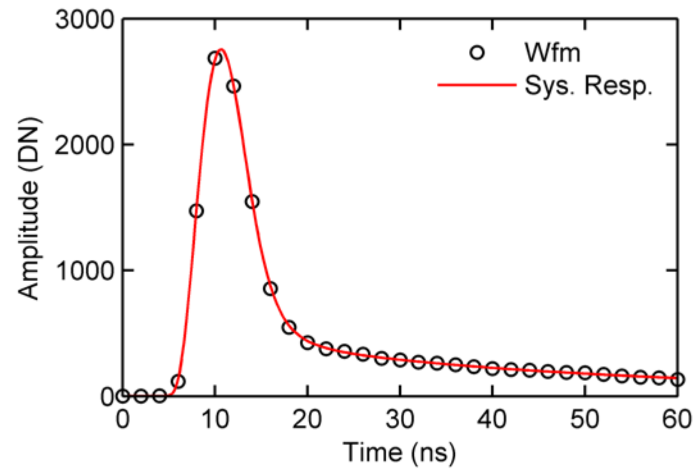
Gaussian Model Fit





~ System Response Fit





Method – Radiometric Calibration

Goal = link peak waveform amplitude to target reflectance

1. Store peak waveform amplitude from targets of known reflectance
2. Measurements at multiple ranges
   - Range attenuation
   - System nonlinearity
   - ~Atmospheric attenuation
3. Result = Table of Amplitude vs. Reflectance vs. Range
   - Empirical, system specific
   - Estimate target reflectance from any subsequent waveform

Method – System Response Calibration

Goal = System response model spanning dynamic range

1. Utilize the radiometric calibration measurements
2. Store average waveform
   - Same target, normal incidence
   - Span detector dynamic range
3. Result = Table of system response waveform shapes
   - Empirical, System Specific
   - Accommodates system non-linearity
   - Ideal fitting model for any amplitude waveform return

➢ Note
   - Ideally, the emitted laser pulse is sampled
   - Practical alternative is to measure target with known, standard properties

Dataset

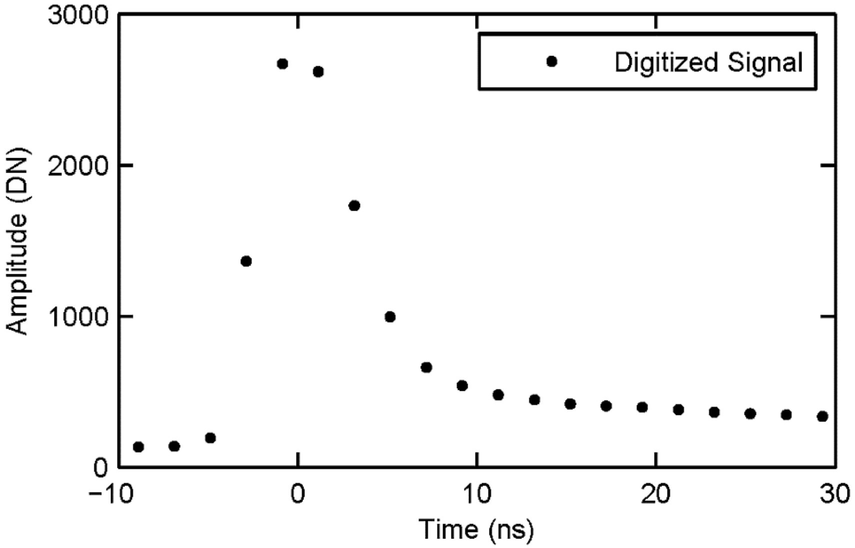
- Riegl VZ-400 with full waveform option
  - 1550 nm laser wavelength
  - ~ 5-7 ns FWHM pulse width
  - Two modes: Long Range & High Speed
  - Two detector channels: High power & Low power
- Labsphere Spectralon: 20% (32%), 50% (60%) , 99% reflectivity

Dataset

- Measurement ranges:
  - 2 - 32 m: 2 m increments
  - 35 - 70 m: 5 m increments
  - 80 - 140 m: 10 m increments
  - 160 - 260 m: 20 m increments

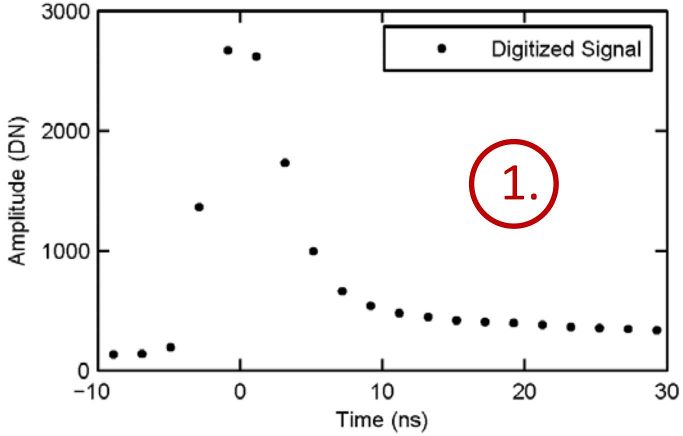
- Incidence angles
  - 0°, 20°, 40°, 60°
  - 99% Spectralon only

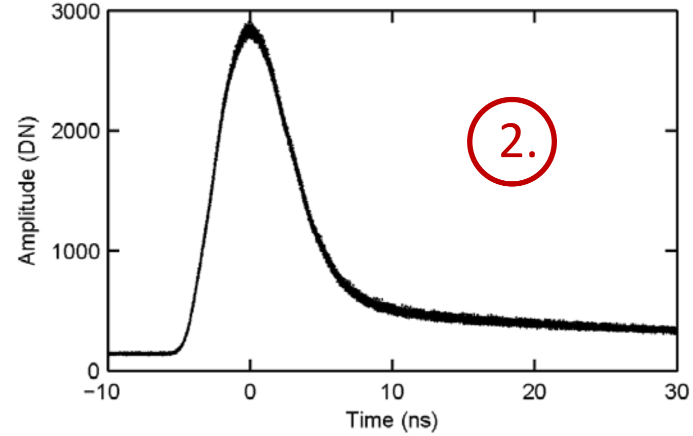
- Sparse waveforms
  - 500 MHz (2 ns) digitizer
  - 5-7 ns pulse width

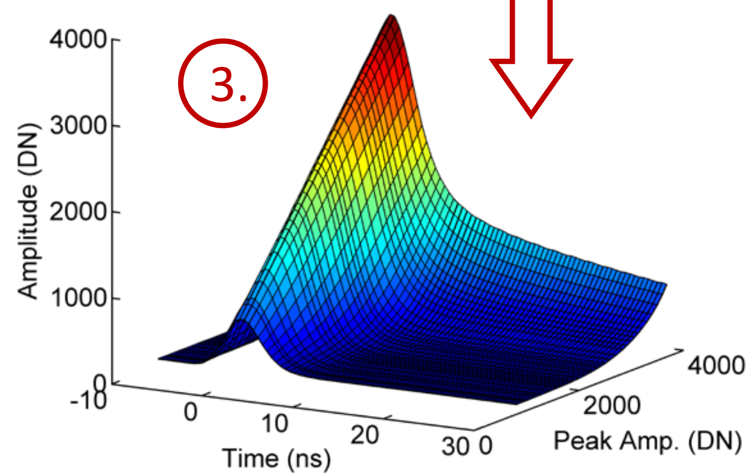


Typical VZ-400 Waveform

Results: System Response Model



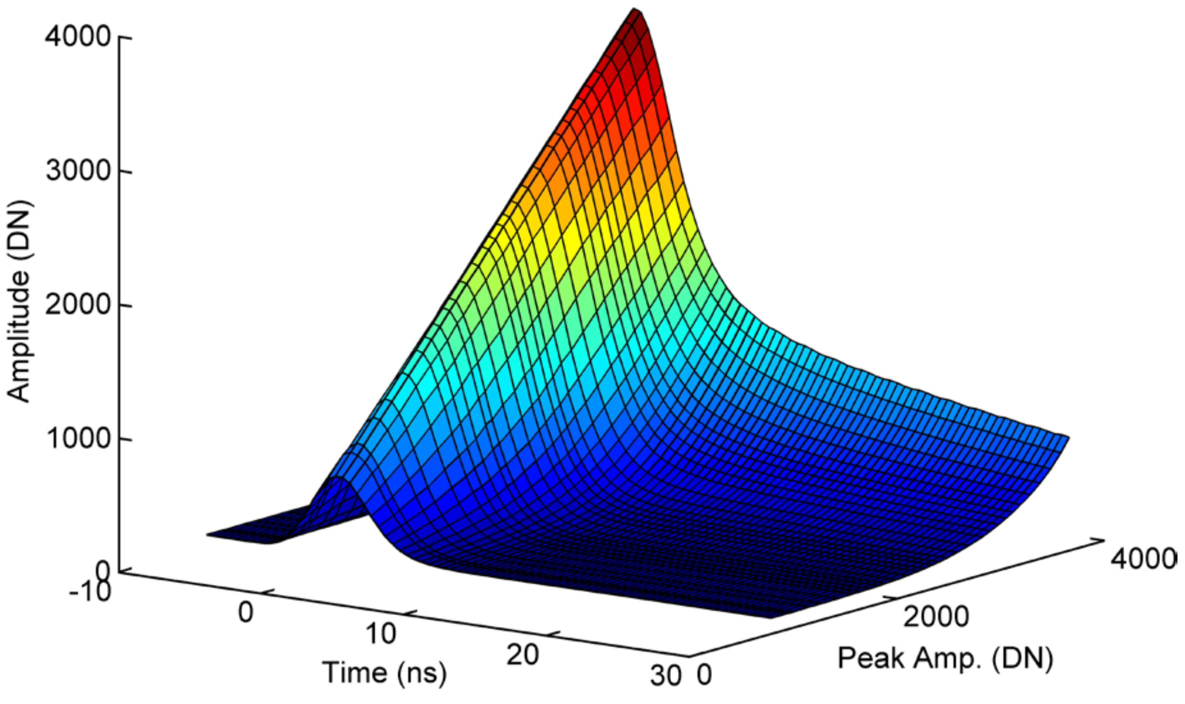




1. Sparse single waveform
2. Several thousand aligned waveforms at each range
3. Each aligned set of waveforms averaged and combined to form a system response model

Results: System Response Model

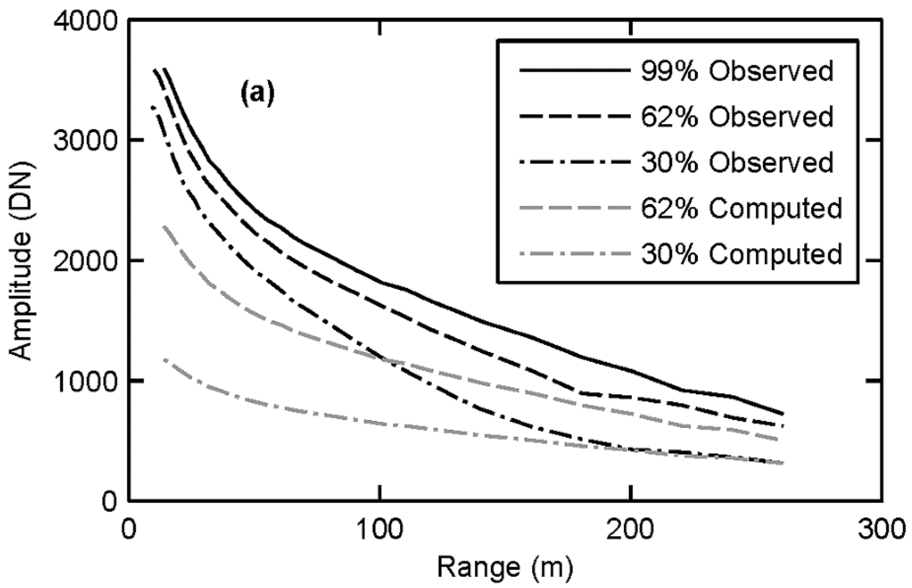
- Nonlinear response at high amplitudes



➢ Stored in table format for simple interpolation at any desired amplitude or range

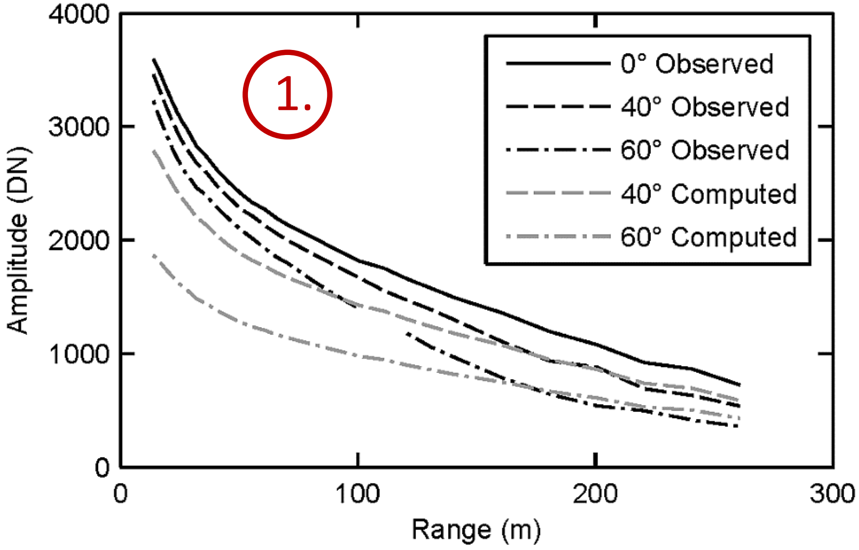
Results: Absolute Reflectance

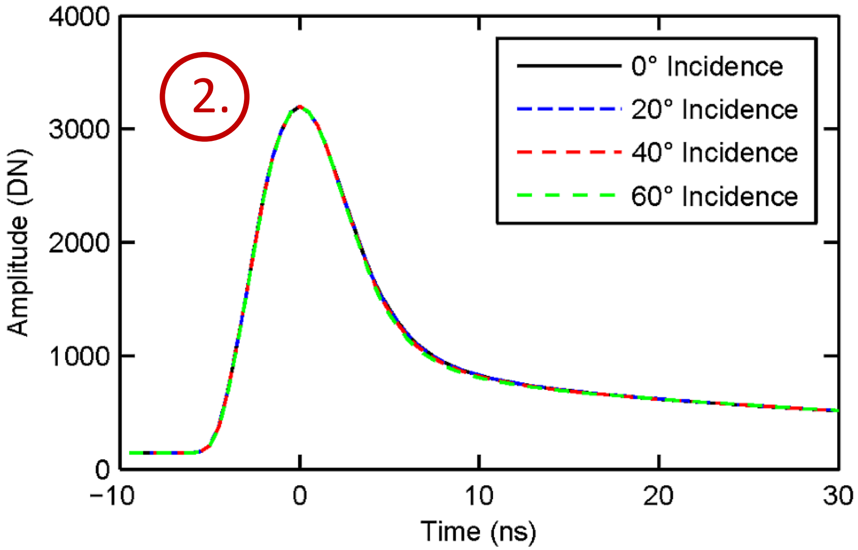
- Peak waveform amplitudes are not proportional to absolute reflectance until beyond ~175 m



➢ Estimated target reflectance for a given range and peak amplitude is easily interpolated

Results: Incidence Angle





1. Peak amplitude does not follow cosine law until range > ~150 m
2. Increased incidence angle does not increase waveform width
   - Small beam divergence/footprint
   - Width increase below digitizer resolution

➢ Target incidence angle information limited to peak amplitude

Results: Least Squares Waveform Fit

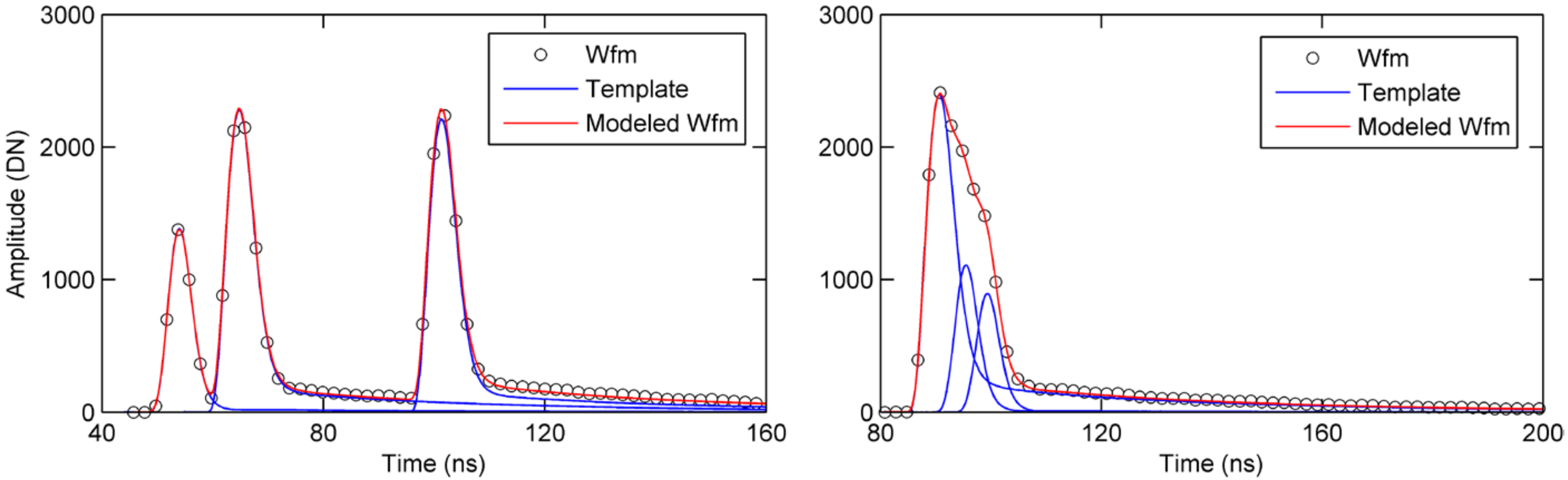
- Problem: The model is a table of numbers (no parameters)
- Requires assumptions about underlying “function model” (f)
  - Assumed function model is clearly non-linear
  - Partial derivatives of f w.r.t. amplitude (A) and time location (μ):

$$\frac{\partial f}{\partial A} = Normalized\ Template\ Waveform$$

$$\frac{\partial f}{\partial \mu} = -Slope\ Template\ Waveform$$

- Partial derivatives can be evaluated numerically from the calibrated system response data

Results: Least Squares Waveform Fit



- Each iteration utilizes a unique interpolated system response waveform from the calibrated model
- Elevated tail accommodated very well by calibrated system response model

➢ Enables analysis of deviations from standard system response

Future Direction

- Collect calibration data with additional laser wavelength
  - 1064 nm collection scheduled for May 2013
  - Examine potential for target identification via spectral analysis
- System response deviation analysis
  - Echo waveform deviation from fitted system response
  - Analysis for correlation to target properties
- Multi-target waveforms
  - Accommodate target cross-section for more relevant reflectance values in complex multi-target waveforms

Wrap-Up

1. Instrument calibration achieved via stored measurements of standard reflectance targets at multiple ranges.

2. Radiometric calibration enables estimation of target absolute reflectance.

3. System response calibration enables ideal waveform echo fitting for precise ranging and deviation measure.

4. The combination of target reflectance and echo waveform deviation will be investigated for enhanced target identification.

Thank you

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