Lecture 38. Target Lidar (3)

Laser Rangefinder – TOF Techniques

- Review Rangefinding Techniques and Principles
  1) Time of Flight
  2) Geometry-based
  3) Interferometry / Diffraction ranging
- Time of Flight (TOF) Techniques
  1) Pulsed laser rangefinding
  2) CW laser amplitude modulation
  3) CW laser chirp / Chirp pulse compression
- TOF: Altitude Determination and Error Budget
  1) Laser altimeter and Lidar bathymetry
  2) Waveform recording vs. micropulse photon counting

Review: Rangefinding Techniques

❑ There are several different approaches to determine range, including the triangulation method with a very long history. We introduce mainly three types of rangefinding techniques:

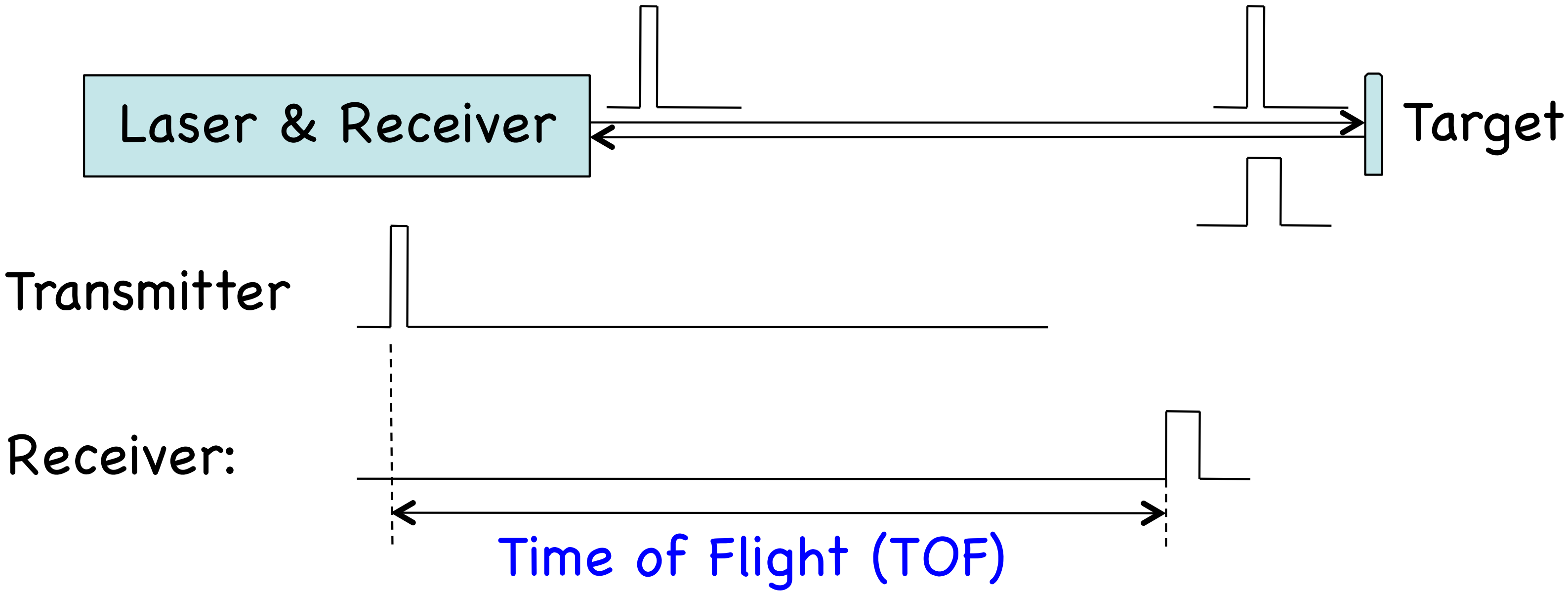
➢ (1) Time of flight technique is used for the majority of laser range finder including laser altimeter and lidar bathymetry;

➢ (2) Geometric-based rangefinding technique is a generalization of the classical triangulation method. By projection of a light beam onto a target, the range can be calculated from known geometry.

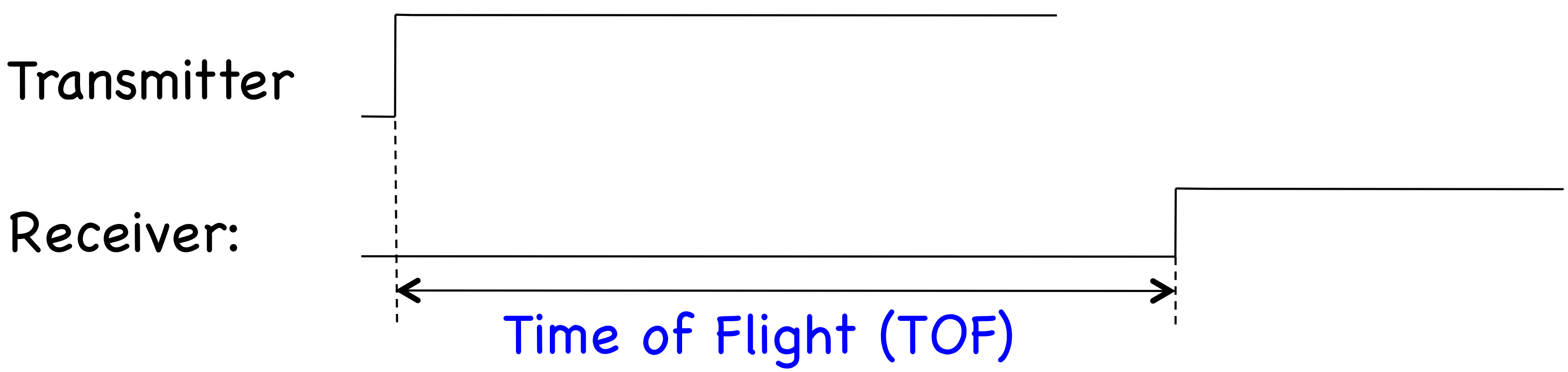
➢ (3) Interferometry: using interferometry principle to measure distance to high accuracy; Diffraction range measurement techniques, like speckle tech. and diffraction imaging.

Time Of Flight (TOF) Rangefinding

- Pulsed laser TOF rangefinding:



How about if the laser is a very long pulse?

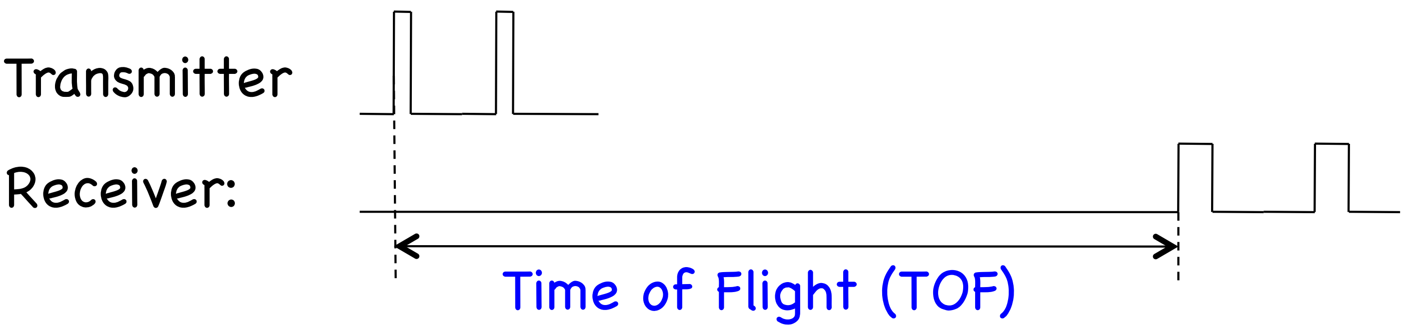


Time Of Flight (TOF) Rangefinding

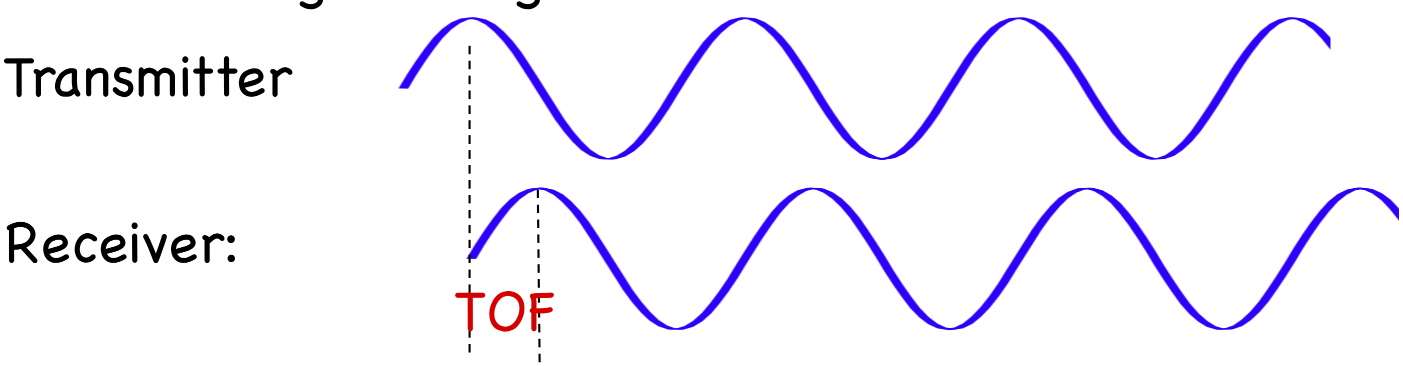
- Phase-shifting rangefinding technique: CW amplitude modulation

How about if you are given a cw laser, not pulsed?

Solution 1: Chop the cw laser beam to a pulsed laser beam

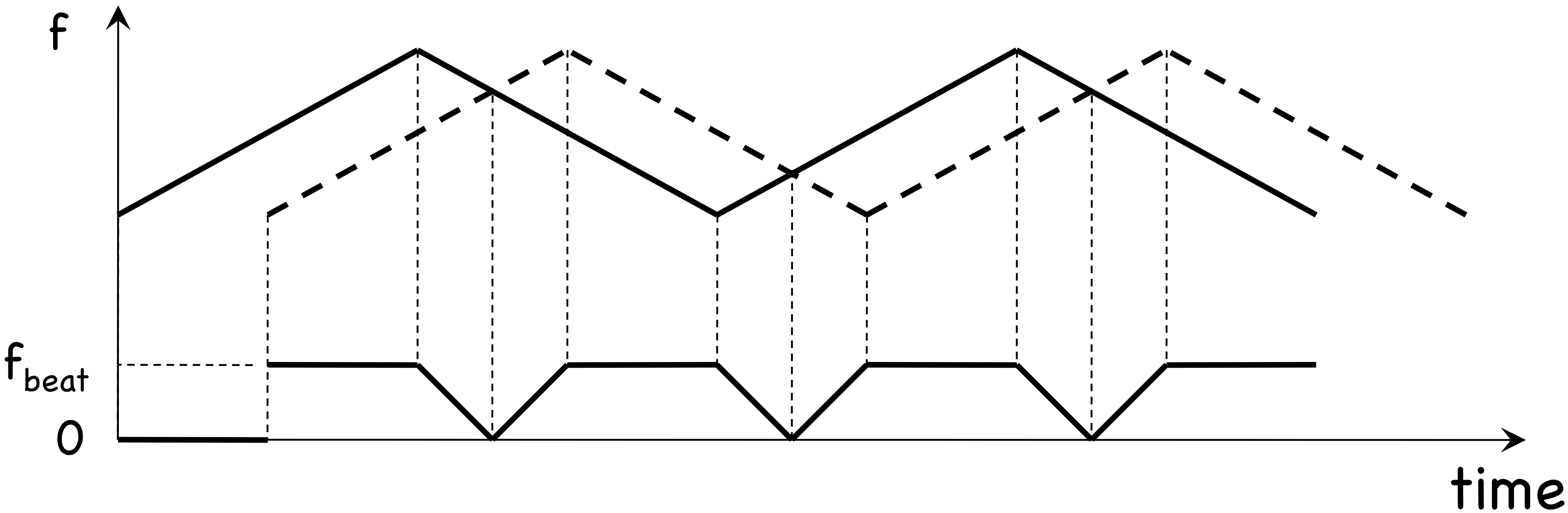


Solution 2: Modulate continuous wave amplitude, and then shift the received signals in time to maximize the correlation between the transmitted and received light. Random coding can help remove ambiguity when the range is longer than half of the modulation frequency/λ.



Time Of Flight (TOF) Rangefinding

- CW laser chirp: linear variation of frequency with time, and then take the beat frequency to determine TOF



$$f_{return} = f_0 + K\,t$$

$$f_{transmitter} = f_0 + K\,(t + \Delta t)$$

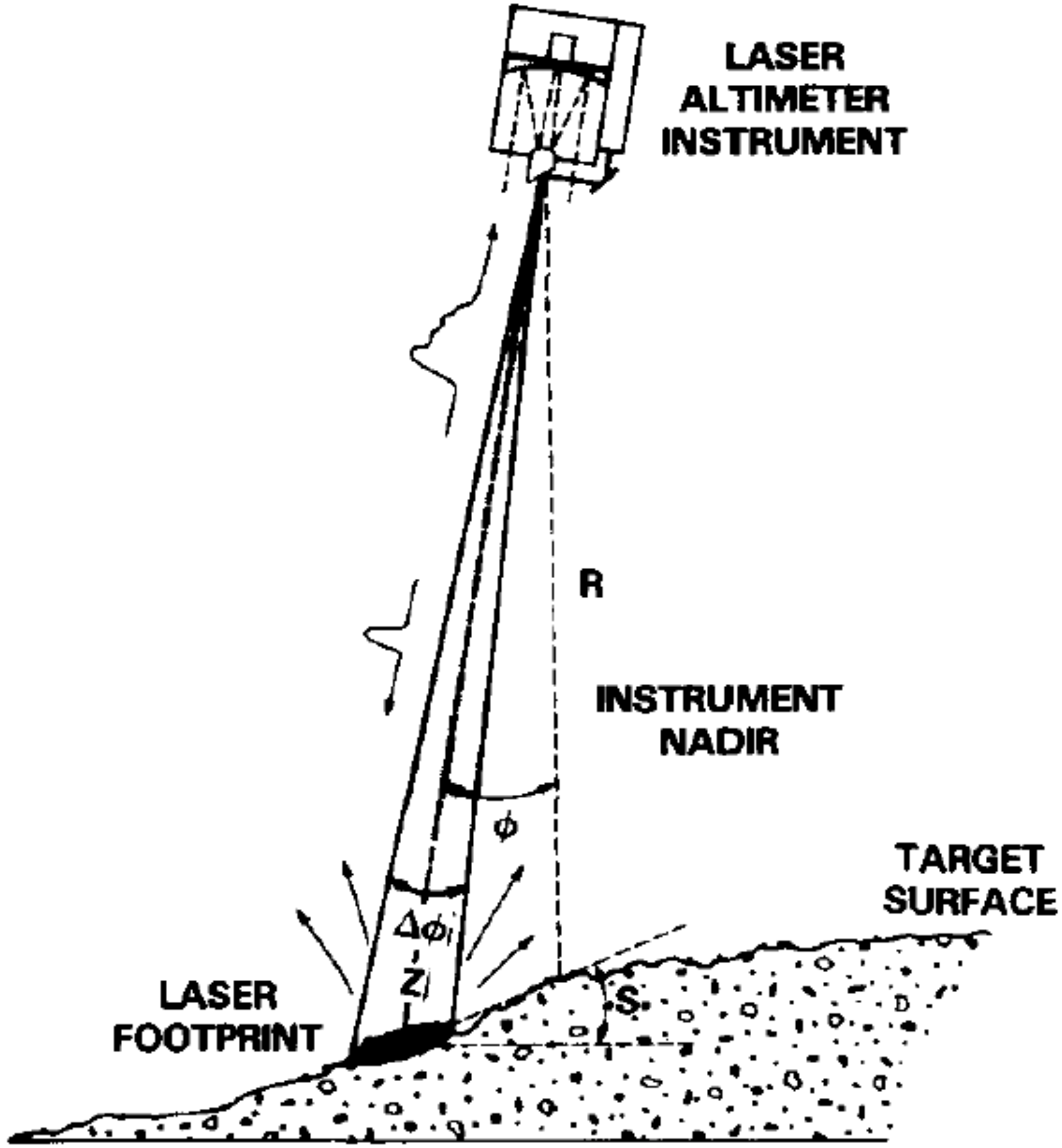
$$\Rightarrow f_{beat} = f_{transmitter} - f_{return} = K\,\Delta t$$

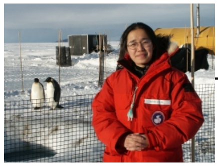
$$\Rightarrow \Delta t = f_{beat} / K$$

Laser Altimeter (Laser Ranging)

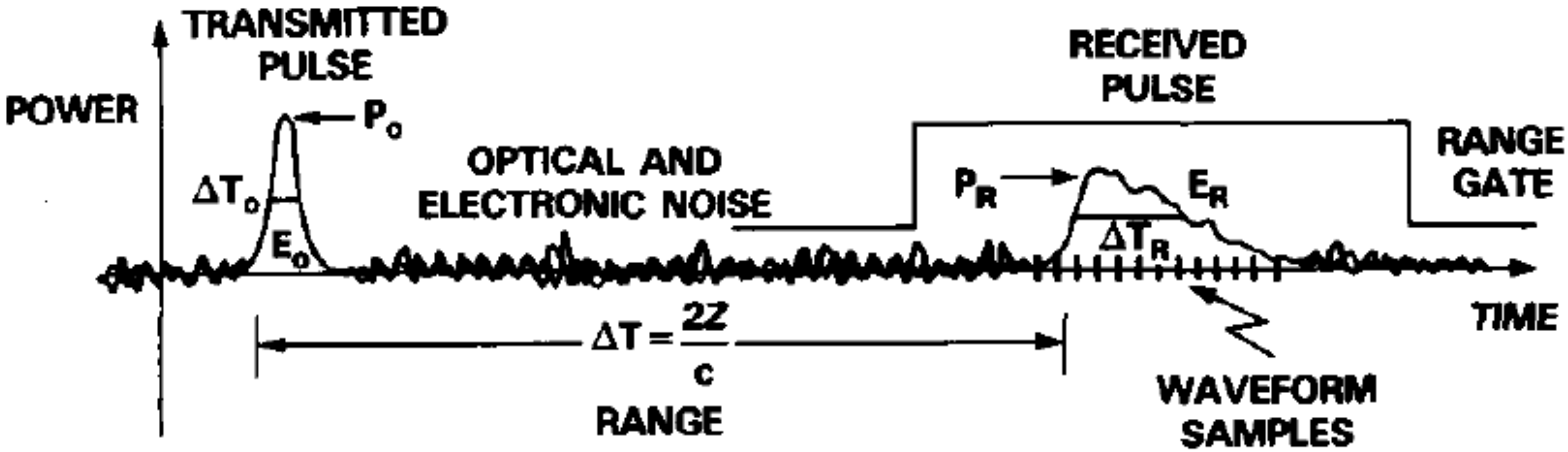
- The time-of-flight information from a lidar system can be used for laser altimetry from airborne or spaceborne platforms to measure the heights of surfaces with high resolution and accuracy.

- The reflected pulses from the solid surface (earth ground, ice sheet, etc) dominant the return signals, which allow a determination of the time-of-flight to much higher resolution than the pulse duration time.



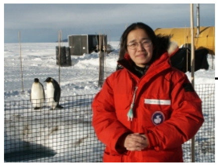


Altitude Determination



- ❑ The range resolution is now determined by the resolution of the timer for recording pulses, instead of the pulse duration width. By computing the centroid, the range resolution can be further improved.
- ❑ Altitude accuracy will be determined by the range accuracy/resolution and the knowledge of the platforms where the lidar is on.
- ❑ In addition, interference from aerosols and clouds can also affect the altitude accuracy.

Altitude = Platform Base Altitude – Range ± Interference of aerosols and clouds



Challenges in Laser Altimeter

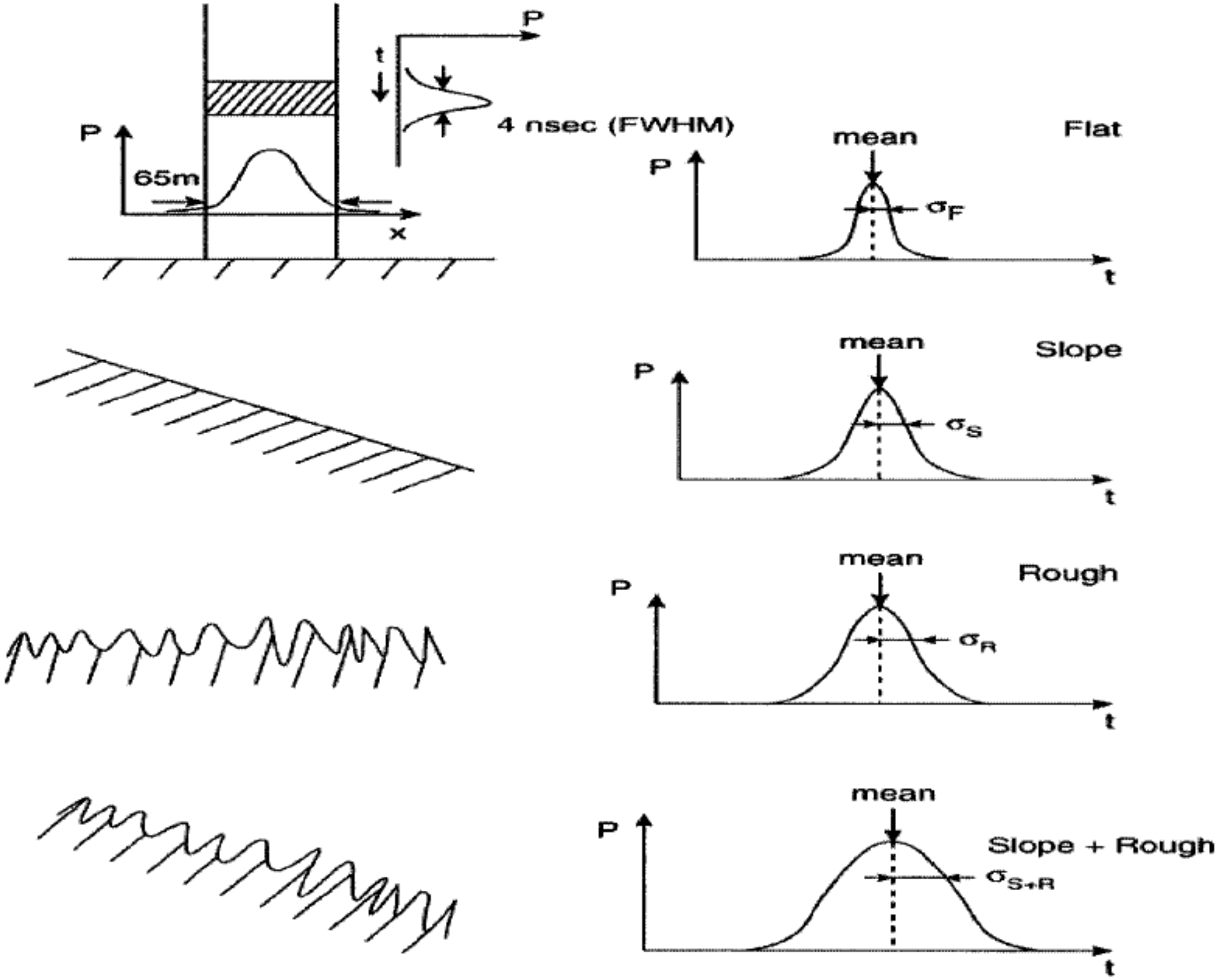
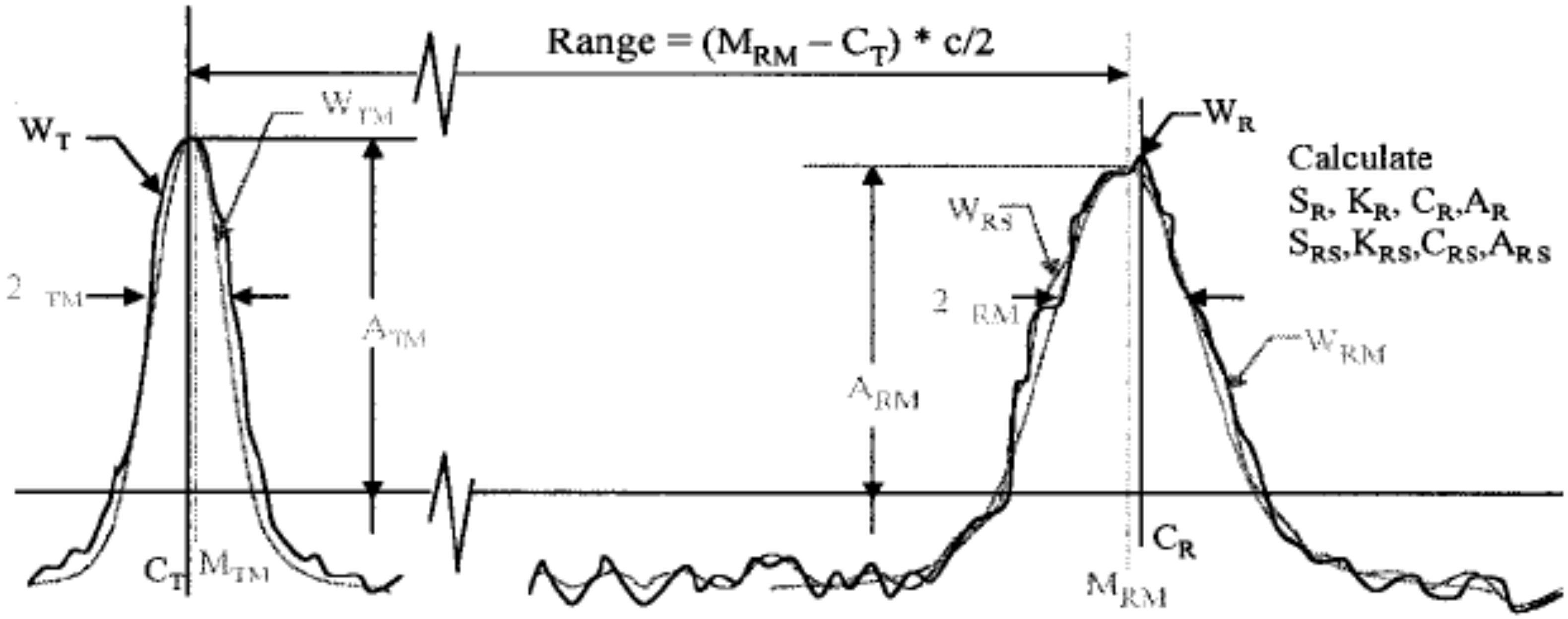


Figure 1 - Characteristics of returned laser pulse as a function of surface type. Presence of surface slope and roughness both broaden the pulse.

Signal Processing in Altimeter



A - Max Amplitude
W - Waveform
M - Gaussian Mean
   - Gaussian 1/e halfwidth
C - Centroid (abscissa value)
S - Skewness
K - Kurtosis

$(\ )_T$ - Transmitted Pulse
$(\ )_{TM}$ - Model of Transmitted pulse
$(\ )_R$ - Return Pulse
$(\ )_{RM}$ - Model of Return Pulse
$(\ )_{RS}$ - Smoothed Return Puls

Figure 3 - Characterization of transmitted and received pulse waveforms

[Brenner et al., GLAS Algorithm Theoretical Basis Document, 2003]

Other Challenges

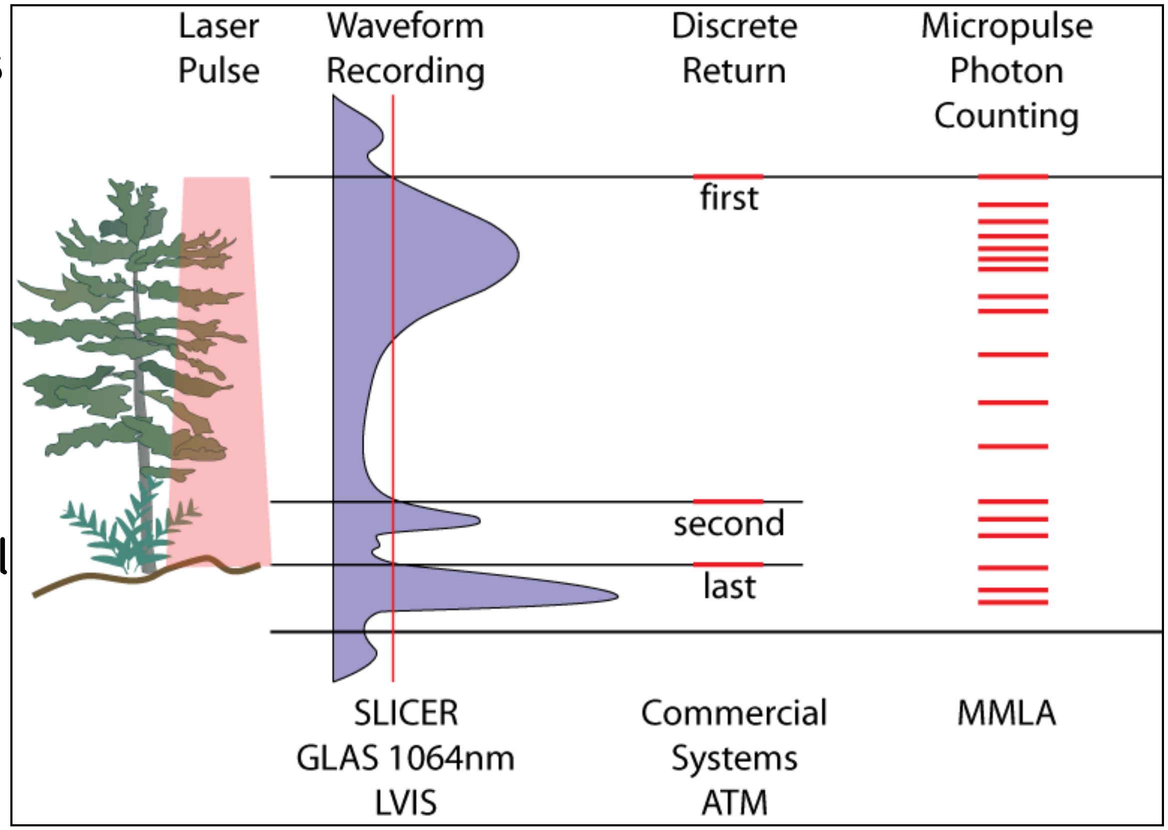
- Besides waveform distortions caused by surface slope and roughness, other factors that could affect the accuracy of laser altimeter include
(1) Orbit and attitude calculations for the platforms
(2) Corrections for atmospheric path-length delays
(3) Corrections for changes in the surface elevations due to tidal effects
(4) ……
(5) How will you have enough penetration and get the reflected signals?

Table 9.10 Ice Altimetry Error Budget

Source	Error type	Magnitude (cm)
Instrument	Single-shot accuracy (3° surface features)	<10
	Range bias	<5
	Laser beam pointing angle uncertainty (1 arcsec, 2° surface)	18
	Radial orbit uncertainty	5
	Clock synchronization (1 μsec)	1
Spacecraft	Distance uncertainty from S/C POD to GLAS zero reference point	0.5
Environment	Atmospheric error (10-mbar error, 0.23 cm/mbar)	2
	RSS error	0.20

Lidar Ranging Methods

- Discrete return
  - logs time when return intensity exceeds threshold
  - commercial airborne systems
- Waveform recording
  - records entire return intensity profile
  - vegetation, atmospheric applications
- Photon counting
  - digital recording of individual photon returns
  - low power requirements
  - good cloud penetration
- Profiling or scanning
  - scan patterns



courtesy Dave Harding, NASA/GSFC

TOF in Lidar Bathymetry

- Time of flight techniques: this is for the majority of laser range finder;