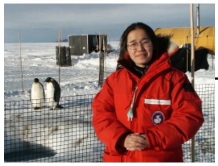


Lecture 37. Target Lidar (2)
Laser Rangefinding

- Introduction
- Rangefinding Techniques and Principles
  - Time of Flight
  - Geometry-based
  - Interferometry / Diffraction ranging
- Time of Flight Techniques
  - Pulsed laser rangefinding
  - CW laser amplitude modulation
  - CW laser chirp / Chirp pulse compression

Introduction

- Lidar remote sensing has two major functions:

  - One is to measure atmospheric or environmental species, density, temperature, wind, and waves along with their range distributions. These were covered in the first 36 lectures.

  - Another major function is to determine range - laser range finder. Laser altimeter is a special laser range finder.

- A good reference for laser rangefinding techniques is a paper collection book -- "Selected Papers on Laser Distance Measurements", edited by Brian J. Thompson, SPIE Milestone Series, 1995.

- Our textbook Chapter 8 "Airborne Lidar Systems" and Chapter 9 "Space-based Lidar" provide references for airborne and spaceborne laser altimeters.

- Other references could be found through web of science or SPIE related to the new laser altimeter projects.

Principles and Applications

- The basic principle of active noncontact rangefinding systems is to project a wave (radio, ultrasonic, or optical) onto an object and process the reflected signal to determine its range.

- If a high-resolution rangefinder (especially spatial resolution) is needed, an optical source must be chosen because radio and ultrasonic waves cannot be focused adequately.

- There are mainly four types of rangefinding techniques: (1) Time of flight techniques: this is for the majority of laser range finder; (2) Geometric-based technique: the classical triangulation by projection of a light beam onto a target; (3) Interferometry: using interferometry principle to measure distance to high accuracy; (4) Diffraction range measurement techniques: like speckle tech. and diffraction imaging.

- The main applications of laser rangefinding techniques, in addition to distance measurements, are obstacle detection for autonomous robots or car safety, nondestructive testing, level control, profilometry, displacement measurements, 3-D vision, and so on.

Rangefinding Techniques

- There are several different approaches to determine range, including the triangulation method with a very long history. We introduce three (or four) major rangefinding techniques.

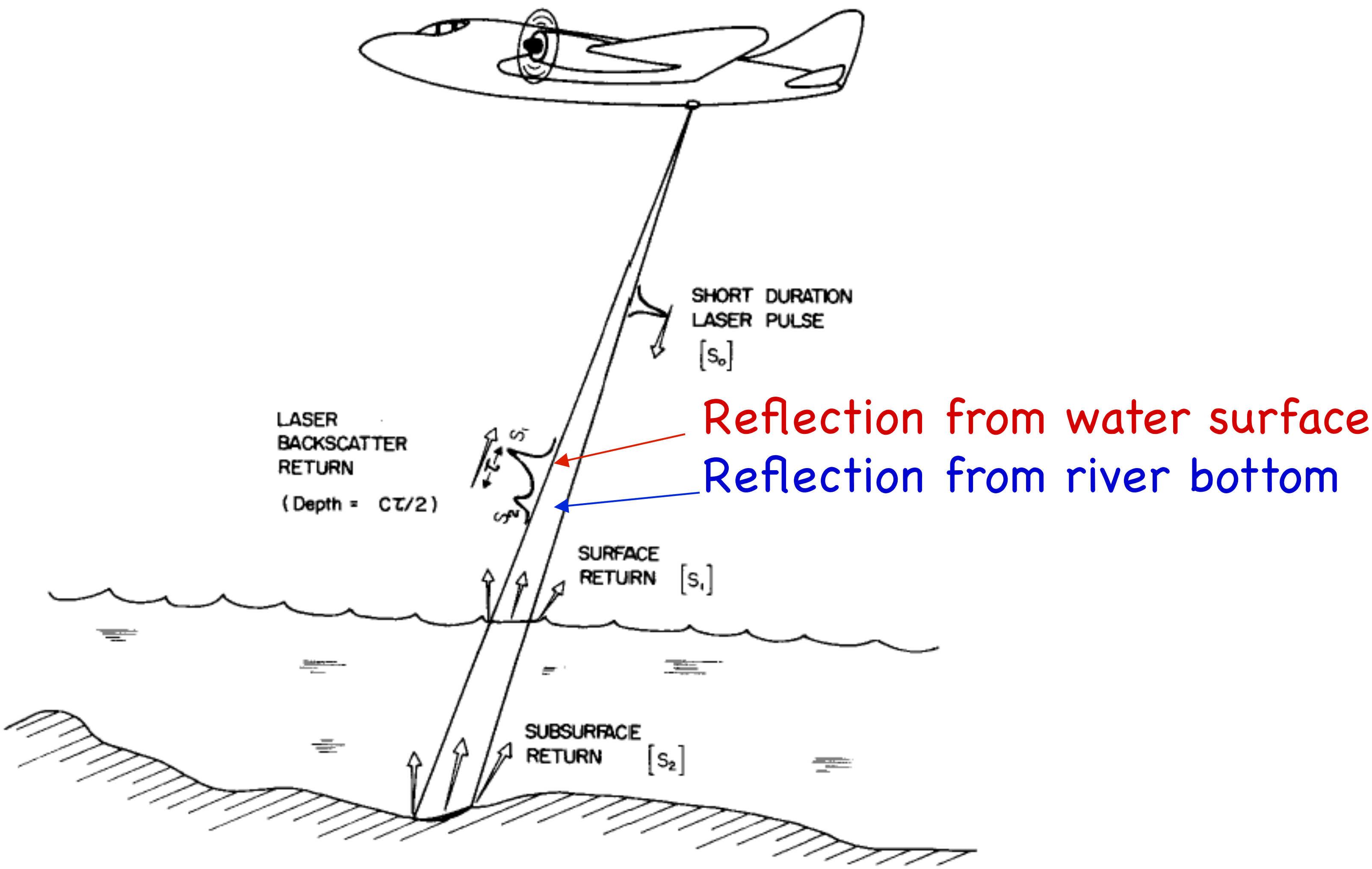
(1) Time of flight techniques: these are for the majority of laser range finders and laser altimeters.

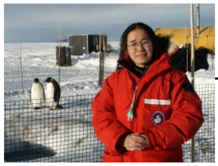
(2) Geometric-based technique: the classical triangulation by projection of a light beam onto a target.

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

Time of Flight Rangefinding

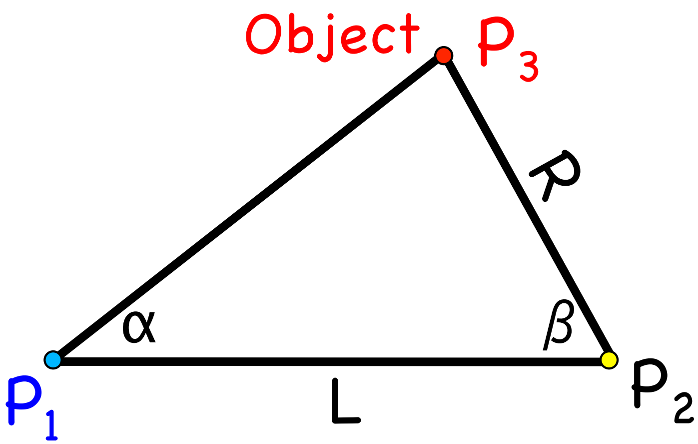
- Time of flight technique: this is for the majority of laser range finders;





Geometric-Based Rangefinding

- 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.
- Triangulation rangefinders all use the principles illustrated below:



From the law of sines, we have

$$\frac{R}{\sin\alpha} = \frac{L}{\sin[180° - (\alpha+\beta)]} = \frac{L}{\sin(\alpha+\beta)}$$

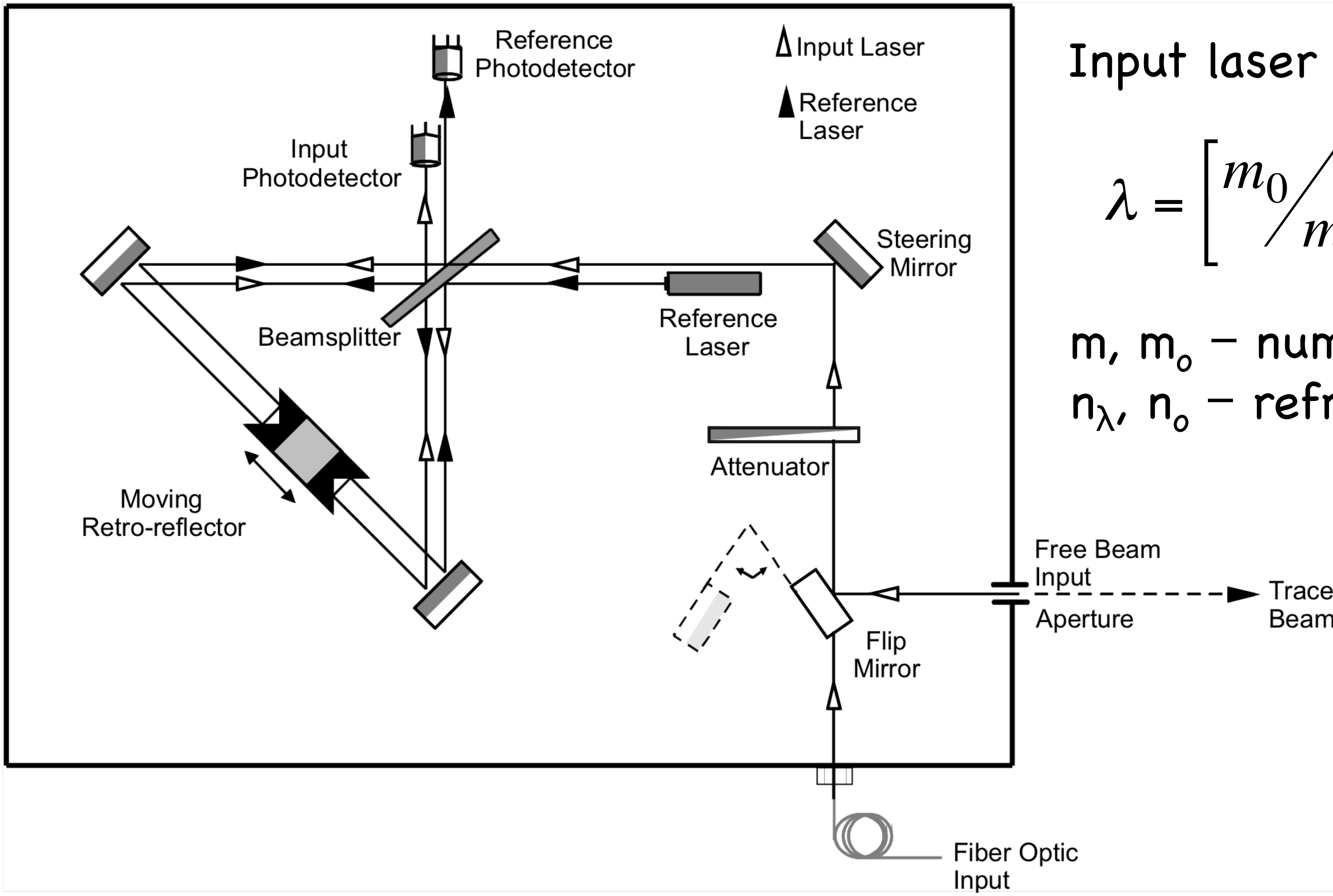
The range R is given by the range formula $$R = \frac{L\sin\alpha}{\sin(\alpha+\beta)}$$

The range error formula is $$\Delta R \approx \frac{R^2}{L\sin(\beta)}(\Delta\alpha + \Delta\beta)$$

[Pipitone and Marshall, J. Robotics Res., 1983]

Interferometry Rangefinding

- Interferometry: using interferometry principle to measure distance to high accuracy, e.g., using Michelson interferometer



Input laser wavelength λ

$$\lambda = \left[{}^{m_0}\!/_{m} \right] \left[{}^{n_\lambda}\!/_{n_0} \right] \lambda_0$$

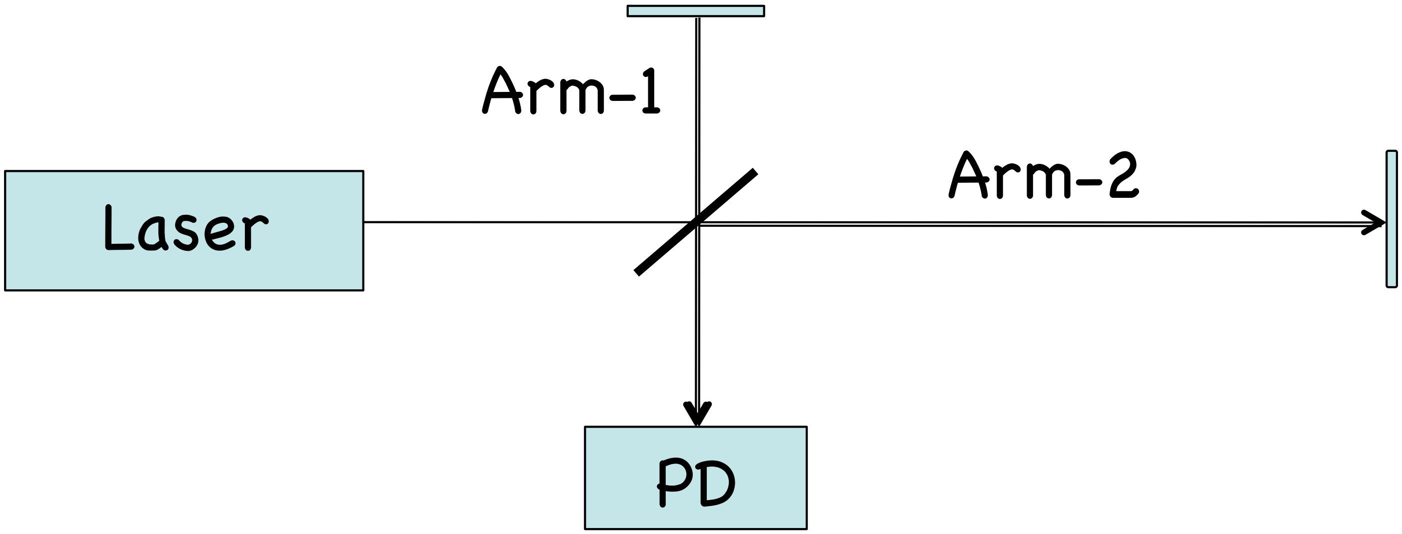
m, m_o – number of fringes

n_λ, n_o – refractive index

Michelson interferometer for cw laser wavelength measurements

Interferometry Rangefinding

- Michelson interferometer for laser rangefinding



Single wavelength $\phi = \frac{2\pi}{\lambda} 2nL$ $L = m(\lambda/2) + \varepsilon$

Multiple wavelengths $\Delta\phi = 2nL(\frac{2\pi}{\lambda_2} - \frac{2\pi}{\lambda_1}) = 2nL \cdot \frac{2\pi}{\lambda_1\lambda_2/(\lambda_2 - \lambda_1)}$

Interferometry Rangefinding

- Both interferometry and diffraction techniques utilize the multiple beam interference principles to generate interference fringes or diffraction patterns. By counting the phase difference caused by path difference, small range or range change can be determined to very precise degree. However, if only single wavelength is used, range ambiguity will occur beyond half of the laser wavelength ($\lambda/2$) range.
- To increase the range of detection or say to remove the range ambiguity, multiple wavelengths are used to generate various longer wavelength, called synthetic wavelength. For example, using two wavelengths λ_1 and λ_2, the synthetic wavelength is given by

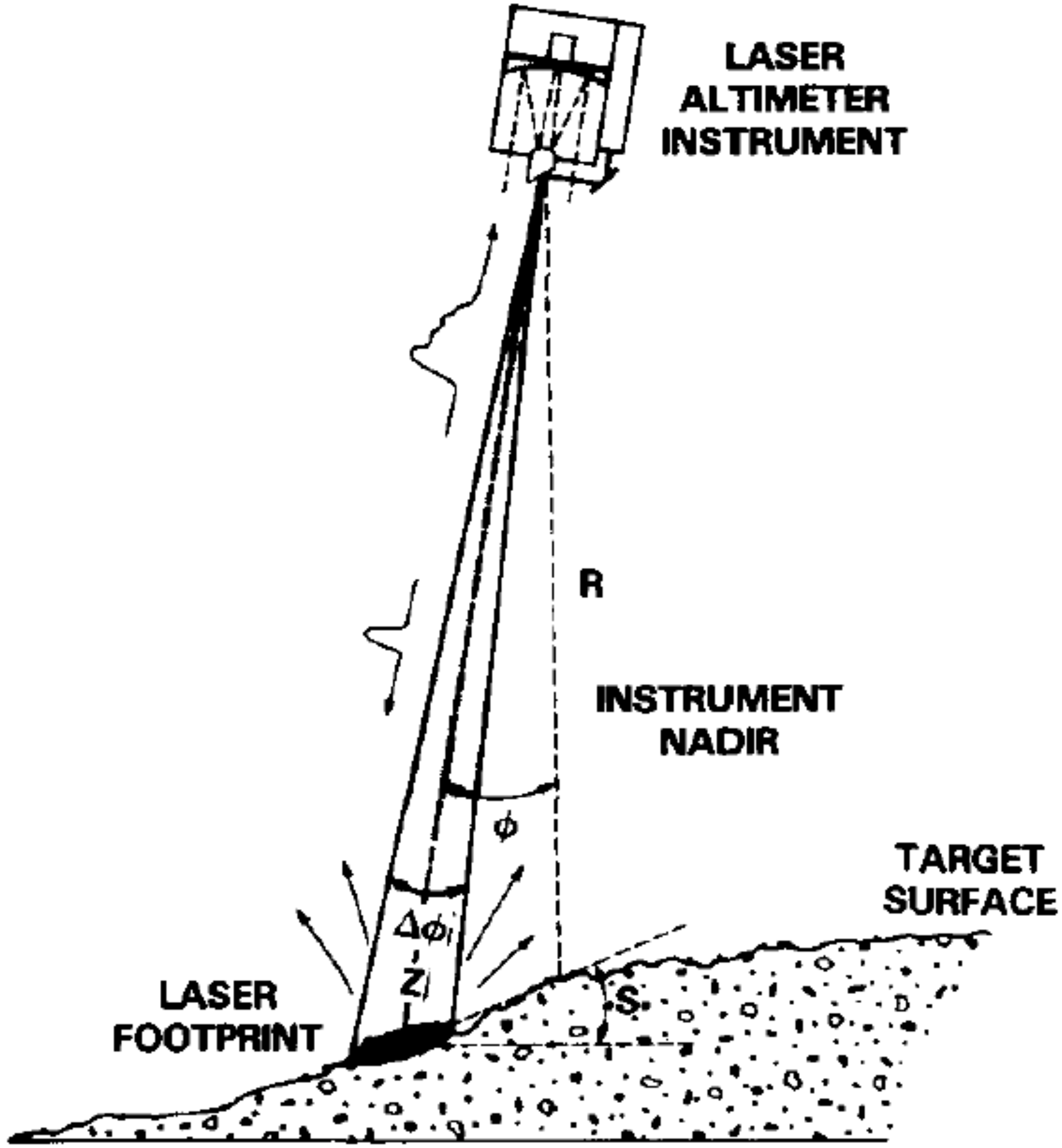
$$\lambda = \frac{\lambda_1 \lambda_2}{(\lambda_2 - \lambda_1)}$$

- By adjusting λ_1 and λ_2 values, the synthetic wavelength λ can be much larger than the original two wavelengths. Thus, the range to be determined without ambiguity can be enlarged to $\lambda/2$.

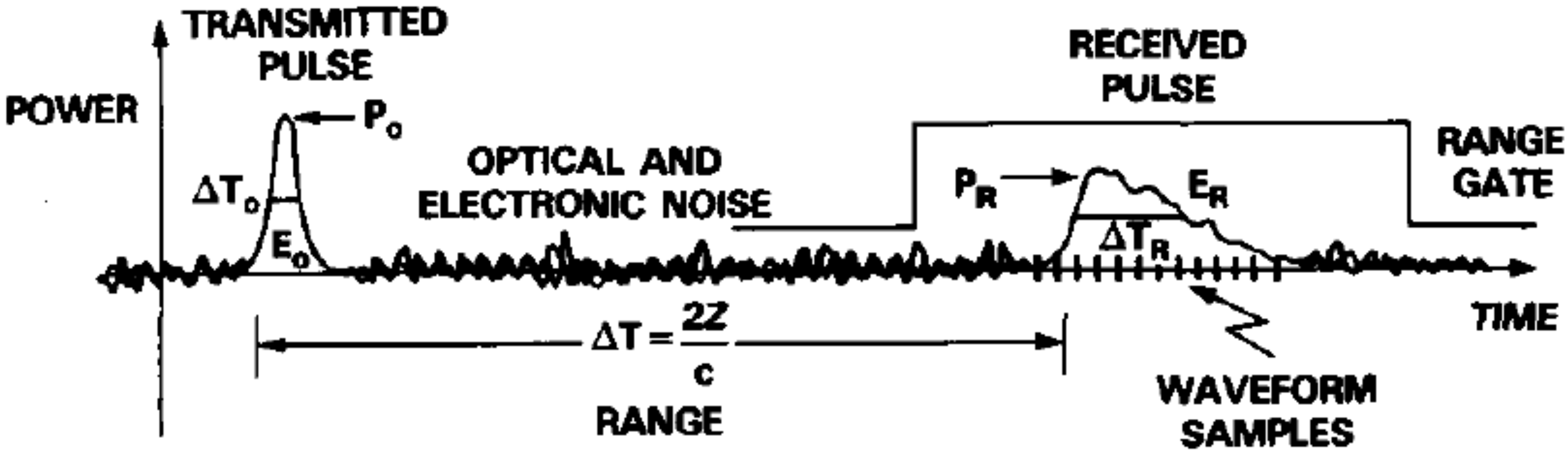
Laser Altimeter (Laser Ranging)

- 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

Summary of Target Lidar

- Target lidars, including fluorescence lidar, laser altimeter, hydrosphere lidar, ladar, fish lidar, etc, are an variant of atmospheric lidars. They share some of the same techniques used in atmospheric lidars.

- Laser altimeter and ladar use time-of-flight to determine the range of objects or surface. Many factors are involved.

- Fluorescence is used to measure species, organic materials, plants.

- Raman scattering by water is used to normalize the lidar returns.

- Target lidars face some different challenges and difficulties than atmospheric lidars. These challenges and difficulties also determines the growing points in this field.

- Target lidars have been deployed on different platforms for various applications. More efficient and compact target lidars on platforms like UAV, promise more applications.