FMCW LiDAR

Bridger's distance measurement technology is based on frequency-modulated continuous-wave (FMCW) LiDAR shown in Figure 1. Light from a frequency-swept, or "chirped", laser is split into two portions; one portion (Tx) is transmitted to the target while the second portion (LO) is kept local and does not travel to the target. The laser light returning from the target (Rx) is interferometrically recombined with the LO and detected. Figure 1 (top right), shows the LO (black) and Rx (gray) optical frequencies (linear chirps) as functions of time. Because the Rx has traveled to the target and back, it is simply a time-delayed replica of the LO waveform. The time delay, τ_D, is related to the target range (distance), R, through the relation

$$\tau_D = 2R/c, \quad (1)$$

where c is the speed of light. A detector measures the heterodyne beat (difference frequency) between the two optical fields. The heterodyne beat frequency is given by

$$f_{beat} = \kappa\tau_D, \quad (2)$$

where κ is the chirp rate. Figure 1 (bottom right) shows the Fourier transform of the heterodyne beat on a logarithmic vertical axis, with the horizontal frequency axis converted to range. This representation is referred to as the full-waveform range profile. Eqns. (1) and (2) can be combined to determine the target range through the equation

$$R = f_{beat}c/2\kappa, \quad (3)$$

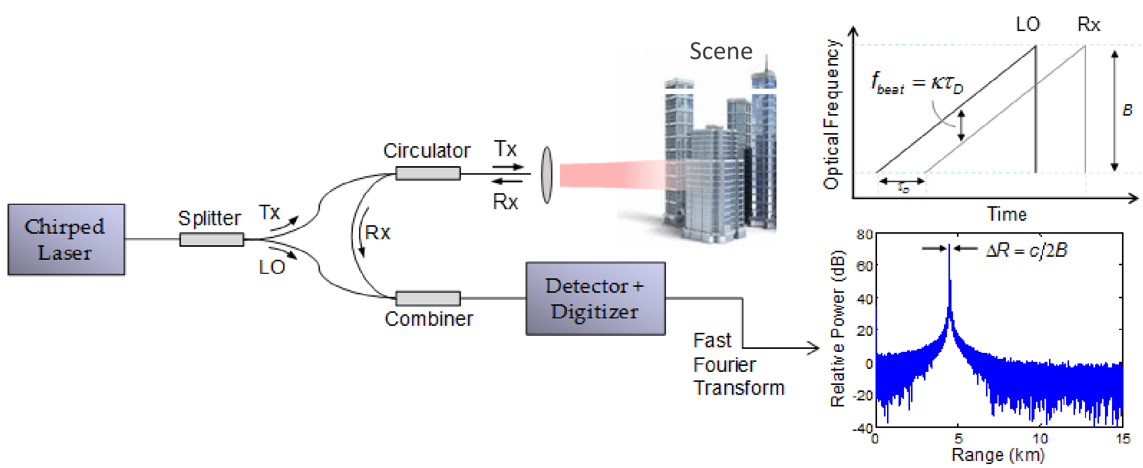

Figure 1. A conceptual diagram of FMCW ladar.

Often times, one desires to know the range to one or more targets along the beam path. Figure 2 shows a range profile, this time with a linear vertical axis, with three targets on the same bearing, but at different ranges. The following definitions follow from those of the radar community.

As shown in Figure 2, the **range resolution** is defined as the minimum resolvable separation (full width at half maximum) between two targets on the same bearing, and is given by

$$\Delta R = c/2B, \quad (4)$$

where B is the information bandwidth (chirp bandwidth for this case). However, it is often possible to determine the range of a target much more precisely than the resolution.

As shown in Figure 2, the **range precision** is defined as the standard deviation of a statistically meaningful number of range measurements of the same target under the same conditions, and is given by the Cramér Rao lower bound,

$$\sigma_R \approx \Delta R/\sqrt{SNR}, \quad (5)$$

where *SNR* is the signal-to-noise ratio (in RF power) of the measurement. The beauty of Eqns. (4) and (5) are that they apply to any LiDAR system. To determine the range to a target with the best precision, one simply desires large information bandwidth and high signal-to-noise ratio.

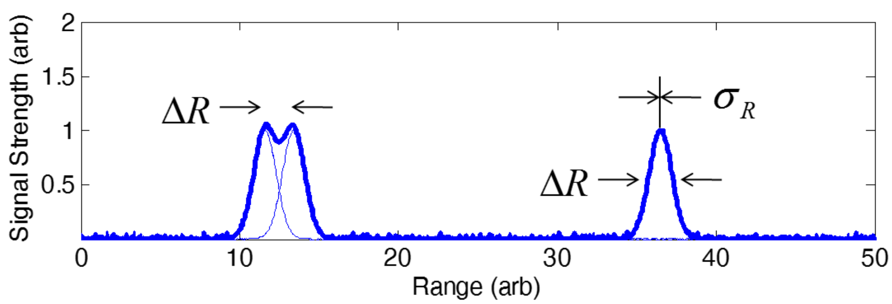

Figure 2. A conceptual diagram of FMCW ladar.

A portion of Bridger's intellectual property includes methods to actively linearize very broadband frequency chirps, which is important for achieving the fundamental limits of resolution, precision, and measurement range.

The FMCW LiDAR technique can offer a number of advantages over conventional "direct detect" LiDAR techniques including:

1. **Improved range resolution**, enabling the measurement and separation of multiple closely spaced surfaces.
2. **Improved dynamic range**, enabling the measurement of both bright and dim objects simultaneously.
3. **Single-photon sensitivity**, enabling small apertures, long range operation, and obscurant penetration.
4. **Velocity sensitivity**, enabling the ability to detect and quantify motion.

