International Infantry & Joint Services Small Arms Systems Section Symposium, Exhibition & Firing Demonstration

Sheraton Atlantic City Convention Center Hotel

May 13 – 16, 2002

DEFENCE R&D DÉFENSE

Feasibility of an Eye-safe Laser-based Crosswind Velocity Measurement System for Sniper Rifles

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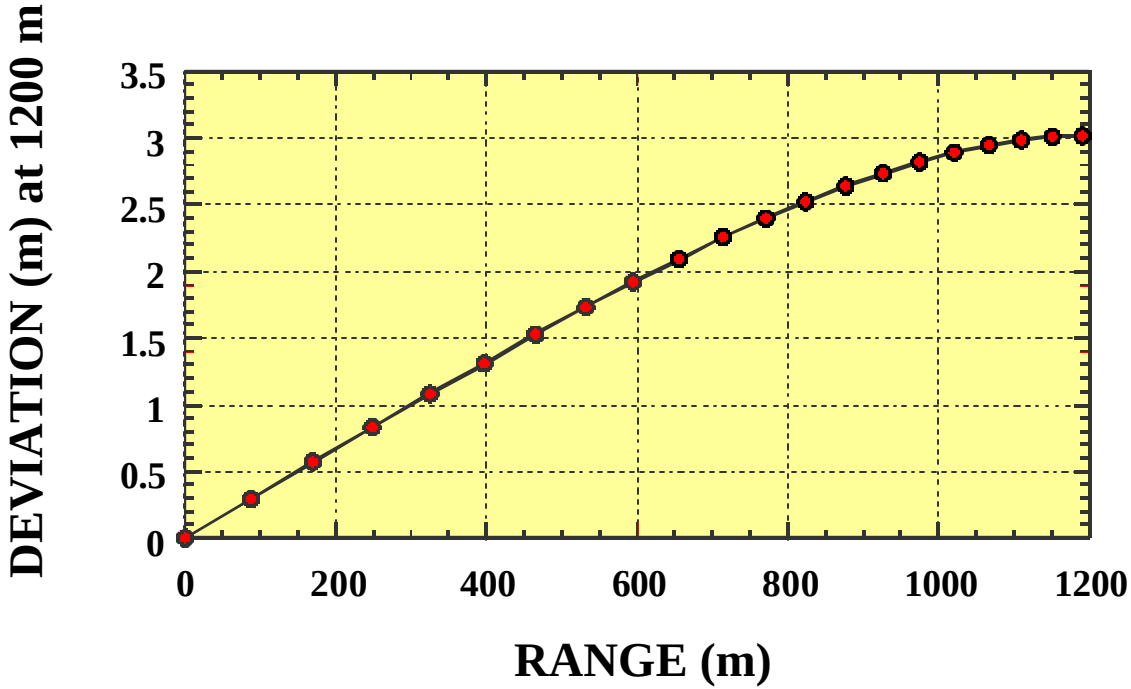
Content

- Crosswind influence
- Literature survey
- Coherent Doppler lidar system
- Performance analysis
- Conclusion

Crosswind Influence on a Bullet Trajectory

- Crosswind velocity = 4.47 m/s (10 mph)
- 0.338 Lapua Magnum bullet



Requirements for the Measurement System

- Range-resolved crosswind measurements
- Maximum range : 1500 m
- Range resolution : about 30 m
- Maximum crosswind velocity : 20 m/s (72 km/h)
- Velocity measurement accuracy : ± 1 m/s
- Measurement and computation time : ~ 1 s
- Eye-safe
- Autonomous
- Man portable

Crosswind Measurement Systems Analysed

- Coherent Doppler lidar
- Direct-detection Doppler lidar
  - Edge-filter technique
  - Multiple-channel technique
- Temporal cross-correlation lidar
- Other systems based on optical scintillations

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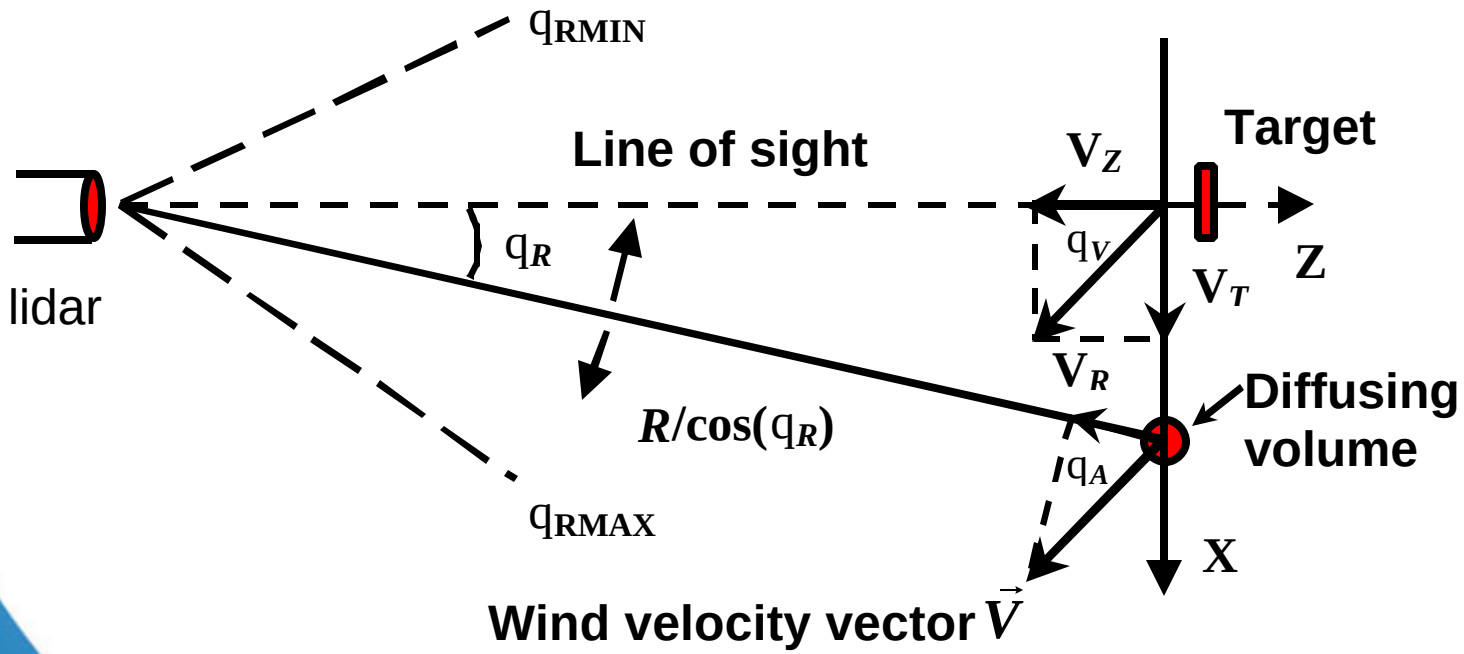
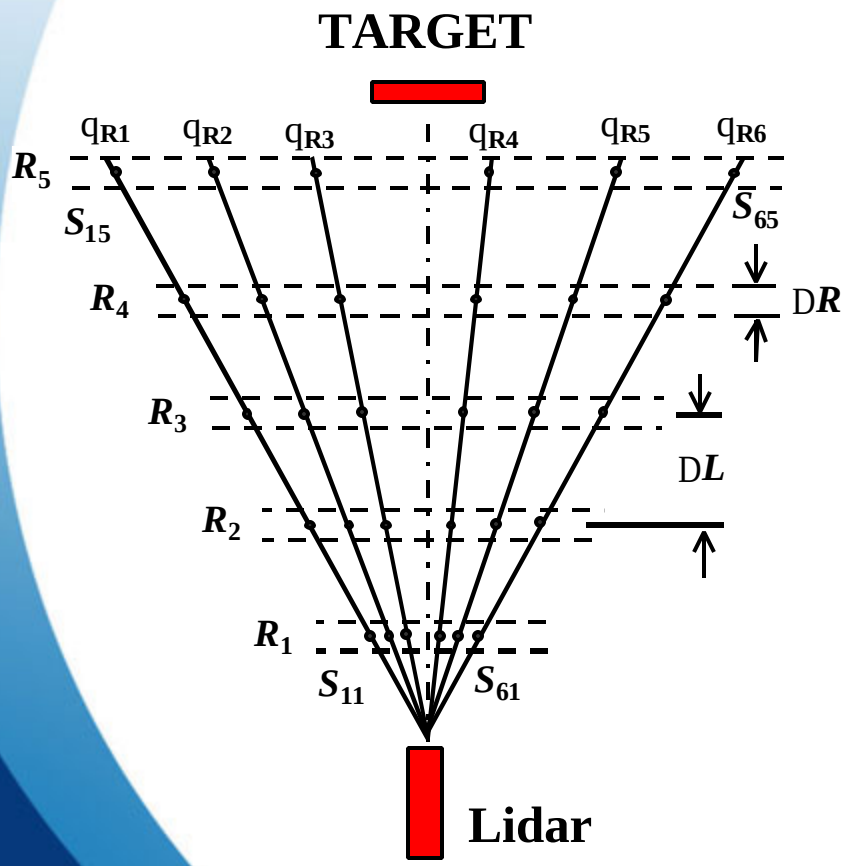
Crosswind Velocity Measurement: Basic Method

$$V_T = \frac{V_Z \cos(q_R) - V_R(q_R)}{\sin(q_R)}$$

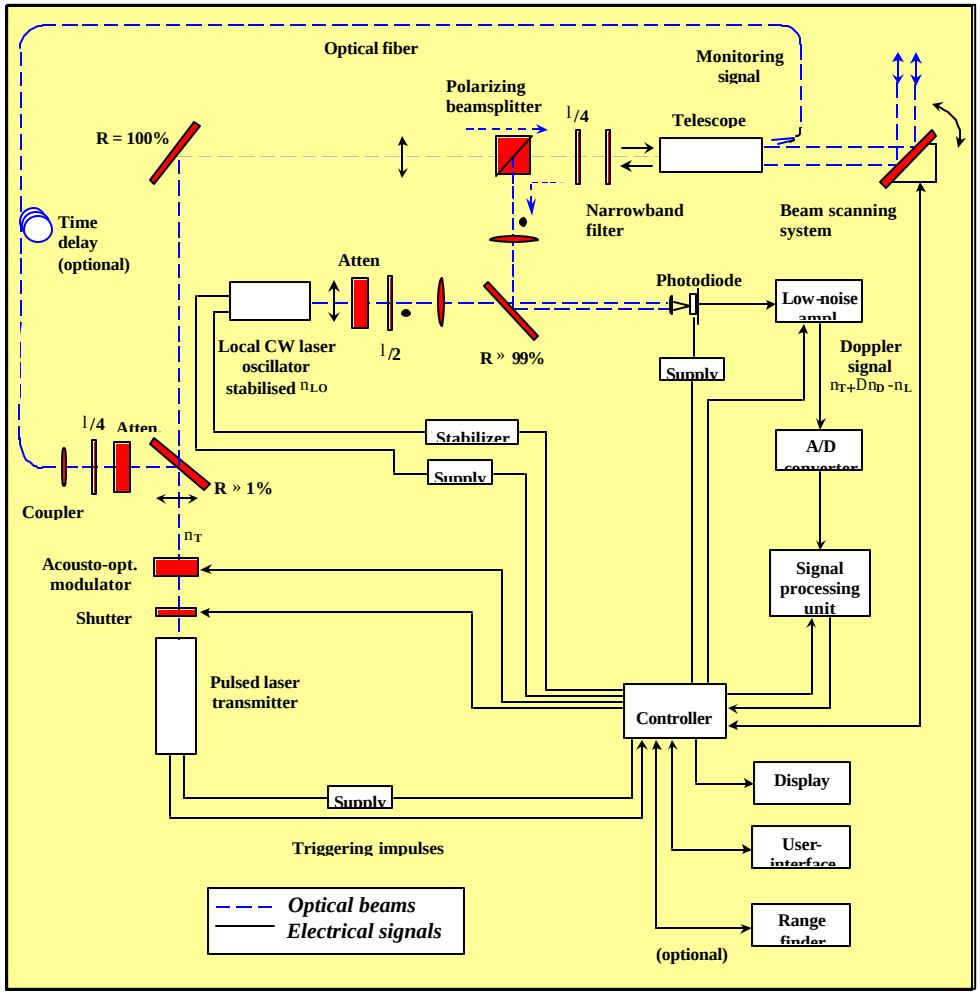


Crosswind Velocity Measurement: General Method

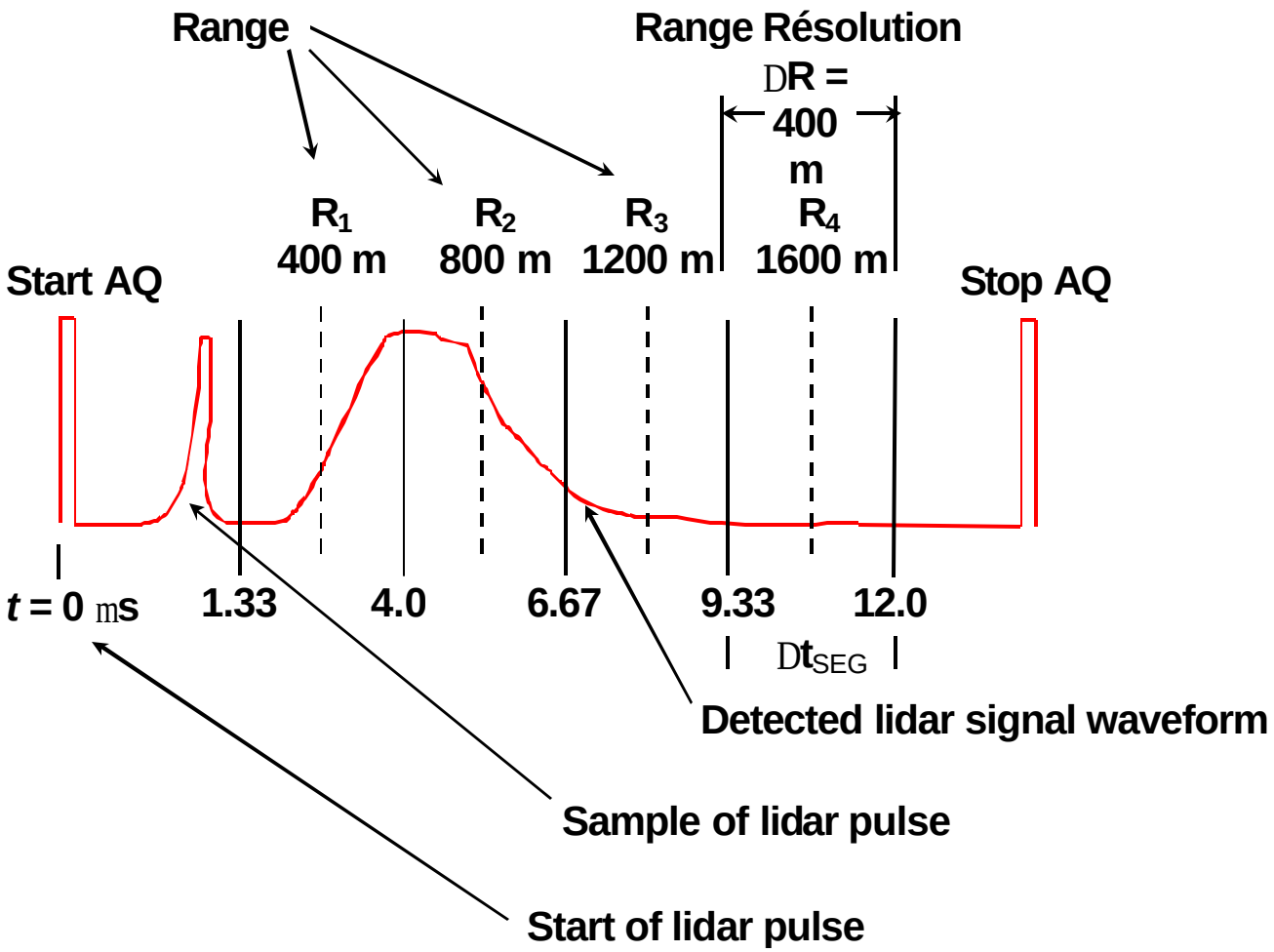


- At each range R_I:
  - Least-squares estimate of V_Z and V_T from the radial wind velocity measurements in each aiming direction
  - Variance calculation on the two estimated parameters

Assembly Diagram of a Coherent Doppler Lidar Crosswind Measurement System



Analysis of the Lidar Signal Waveform



Performance Equations

- Lidar equation

$$P_R(t) = P_E(t - 2R/c)\; b(p)\frac{A_e}{R^2}\left(\frac{c t_L}{2}\right) T_A(R)\, h_T\, h_R\, h_{SPEC}\, O_{FOV}(R)$$

- Signal to noise ratio

$$SNR = \frac{P_R h_Q h_{HET}}{h n B}$$

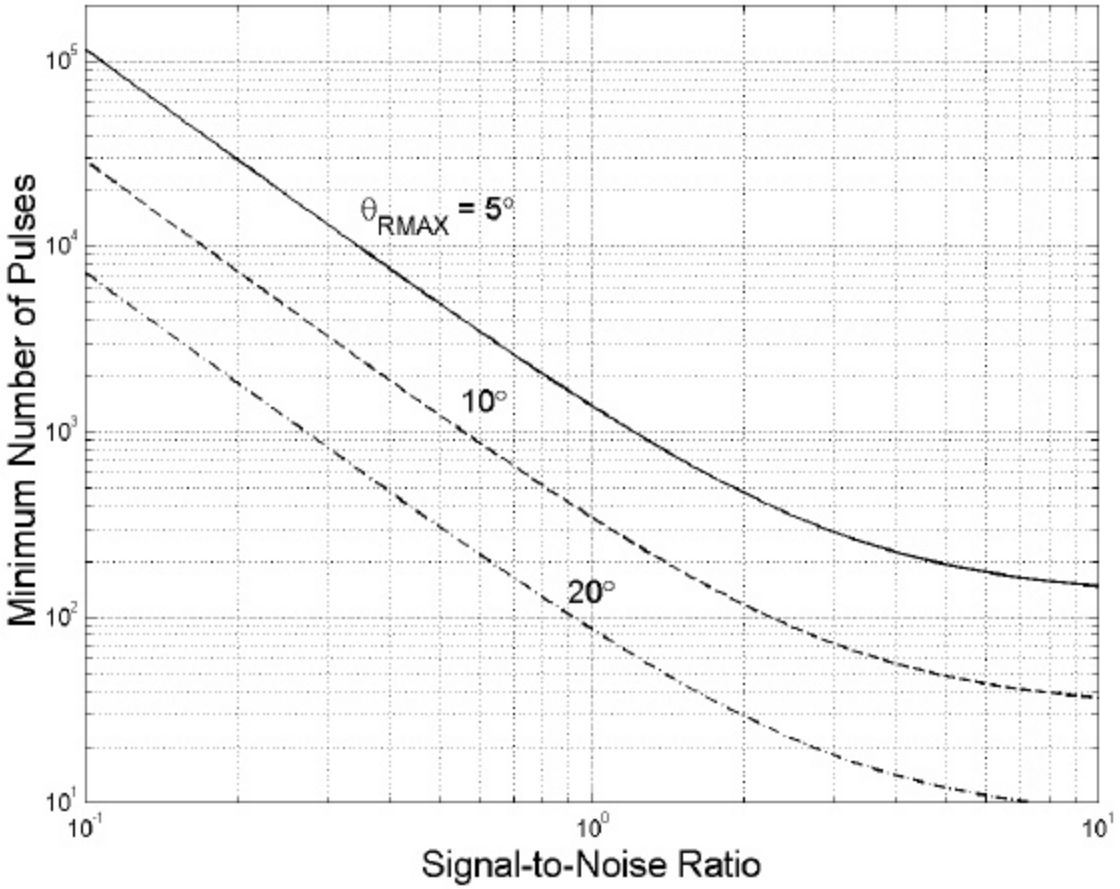
- Radial wind velocity measurement accuracy

$$s_{VFFT}(\text{m/s}) = \frac{l}{2}\left(\frac{f}{N_P t_D}\right)^{1/2}\left[\frac{W}{4\sqrt{p}} + \frac{2W^2}{SNR} + \frac{1}{12 SNR^2}\right]^{1/2}$$

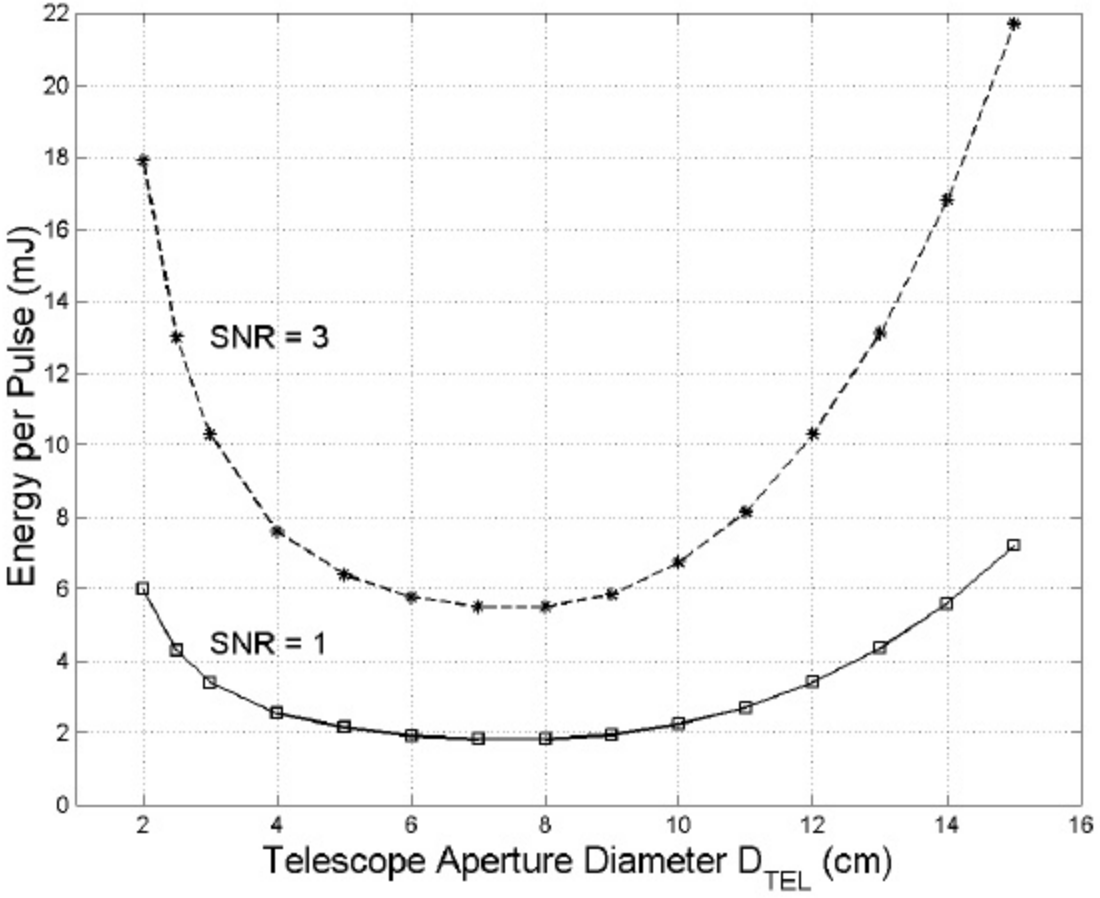
Critical Parameters

- Aiming angles q_{RMIN} and q_{RMAX} of the lidar with respect to the line of sight
- Number of laser pulses emitted in each aiming direction
- Lidar telescope aperture diameter
- Laser pulse energy

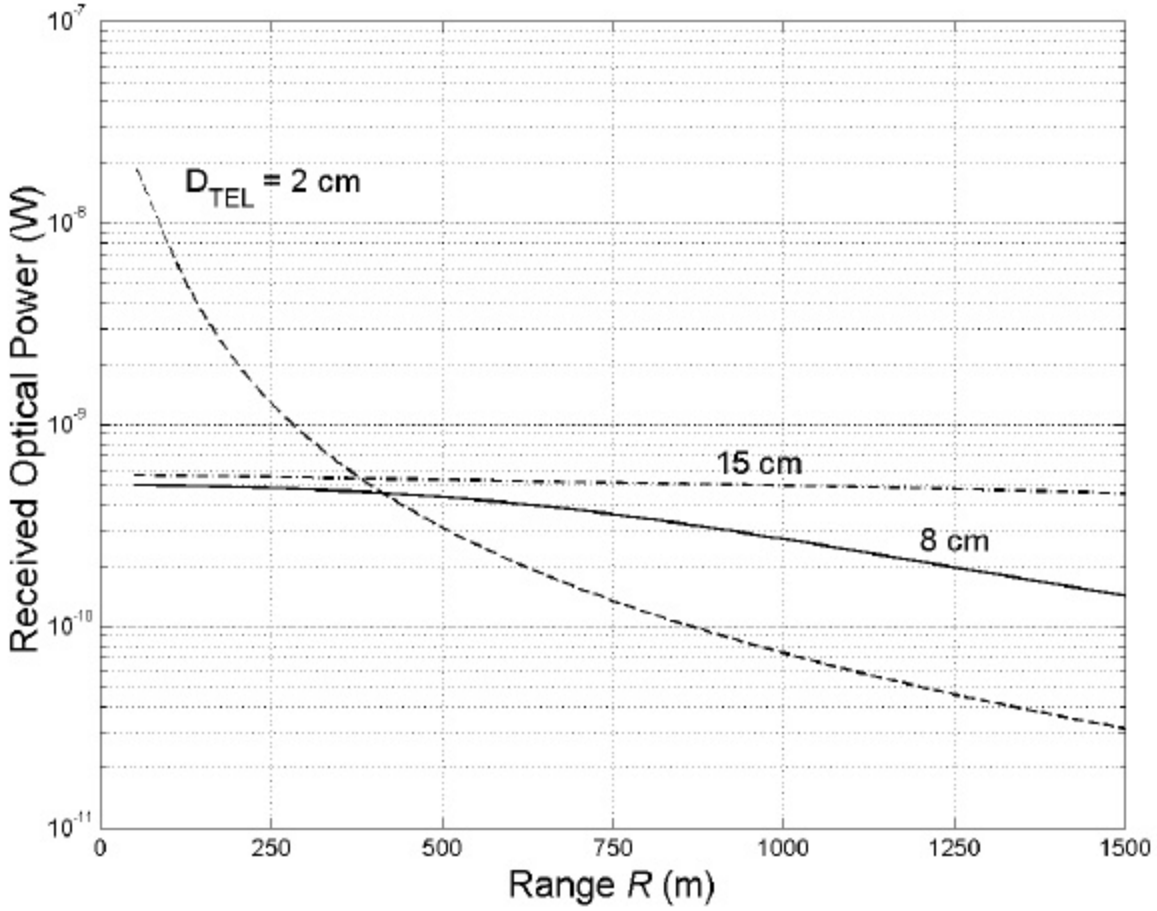
Required Number of Laser Pulses for Measuring the Crosswind Velocity within an Accuracy of ± 1 m/s



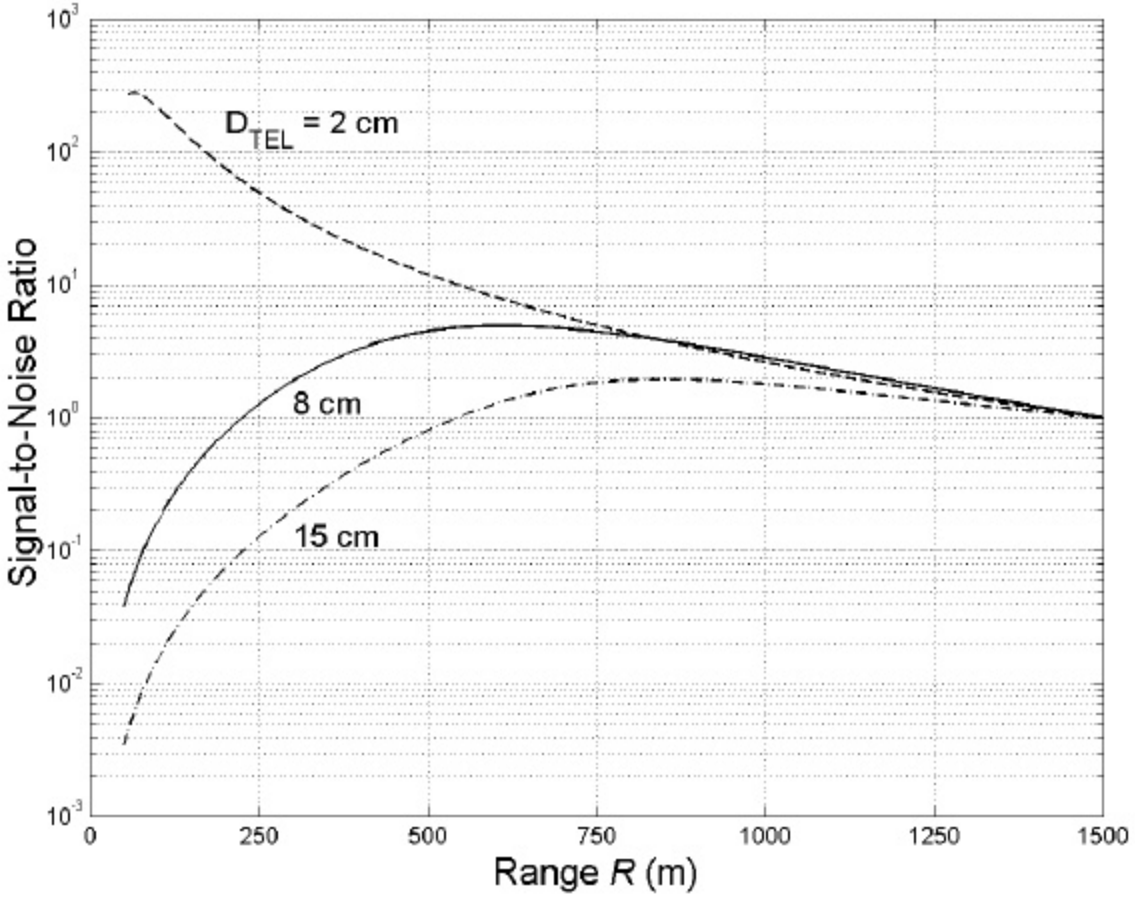
Required Laser Pulse Energy to Obtain a SNR of 1 and 3 at a Range of 1500 m



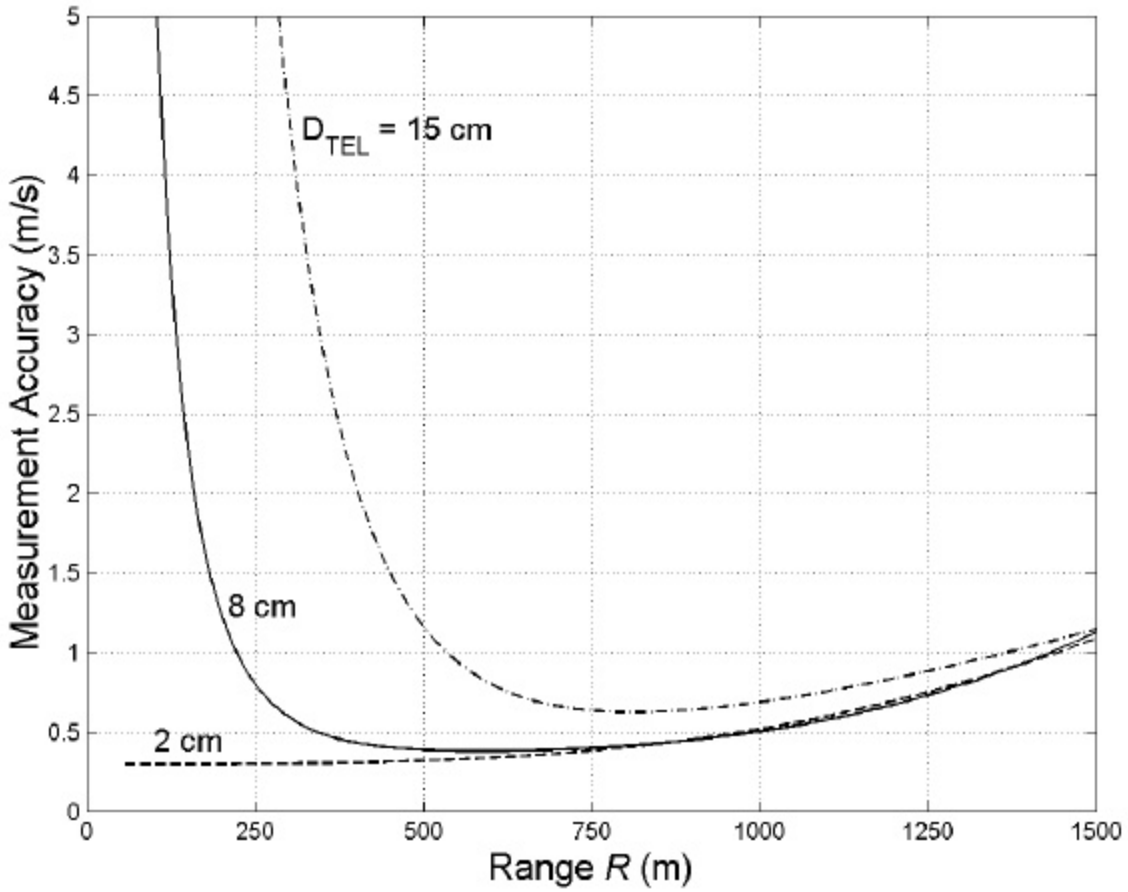
Received Optical Power at the Lidar Detector for Three Telescope Aperture Diameters



SNR for Three Telescope Aperture Diameters



Accuracy on Crosswind Velocity Measurement for Three Telescope Aperture Diameters



Conclusions

- Range-resolved crosswind velocity measurement is feasible, although much complex to perform
- Complex behaviour of the system performance as a function of range
- Eye-safe Tm:YAG laser (2.02 μm) emitting a few mJ of energy at a repetition rate of 100 Hz (telescope aperture diameter of about 8 cm)
- Typical measurement time from 5 to 10 s for seven aiming directions (± 20° with respect to the line of sight)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