Measuring Laser Beam Propagation in Maritime Environment

Svetlana Avramov-Zamurovic, USNA
Olga Korotkova, Univ. of Miami
MIDN Jeff Iiams, USNA

Objective: Learn how laser beam propagates in order to understand how to counter its effects

Education

- Mathematical models (Forward problems)
  - Characterizing Gaussian beam propagation in vacuum: beam divergence and irradiance (MATLAB)
  - Characterizing laser beam propagation in various environments:
    the change in the on-axis mean irradiance at the receiver plane caused by turbulence using Kolmogorov spectrum and van Karan spectrum in Rytov model (MATLAB)
- Experiment to <u>observe</u> laser beam propagation and compare the measurements with the models
  - Transmitter and receiver in HydroLab

Research

- Design an experiment to <u>precisely measure</u> the beam propagation in given environment.
  - Specification and characterization of
    - Laser transmitter and receiver
    - Medium in which laser beam propagates
- Define measurement uncertainty and integrate measurements into the model to enhance the model predictions.(COMSOL)

Mathematical models developed in MATLAB

Gaussian beam propagation in vacuum

- MODEL: Wave amplitude and phase at distance L for the given beam diameter and wave front curvature.
  - Andrews and Philips Chapter IV (Eq. 24)
- OUTCOME: These simulations provide estimate for the beam divergence and beam waist based on wave front curvature. The results should be valid for laboratory environment.

Mutual coherence function

- MODEL: Mutual coherence function evaluated at identical points for given turbulence parameters:
  - C_n^2 measure of the strength of turbulence (weak, medium, strong)
  - Rytov variance, σ, measure of atmospherically induced change in the mean irradiance profile in the traverse direction
  - Inner scale parameter l_0
  - Outer scale parameter L_0
  - Spectrum
    - Kolmogorov
    - Van Karman
  - Andrews and Philips Chapter VI
- OUTCOME: These simulations provide estimate for the beam size and irradiance at given distance for the variety of environments.
- The difference in irradiance (or laser beam power) is small between Kolmogorov and van Karman spectra and requires extremely precise sensors.
- Since the influence of the atmospheric disturbance (turbulence) requires long distances to develop beam diverges significantly on its own and the divergence caused by turbulence is obscured.
- Beam expansion is required in order to precisely measure the influence of the atmosphere on the beam propagation.

Experimental setup: Laser

- SAFETY: Student involvement with the equipment in laboratory and outside requires the laser power to be very low. Class IIIa was chosen as the highest power level that will be used in the experiments. This class require careful handling of the lasers but does not require special safety enclosures.

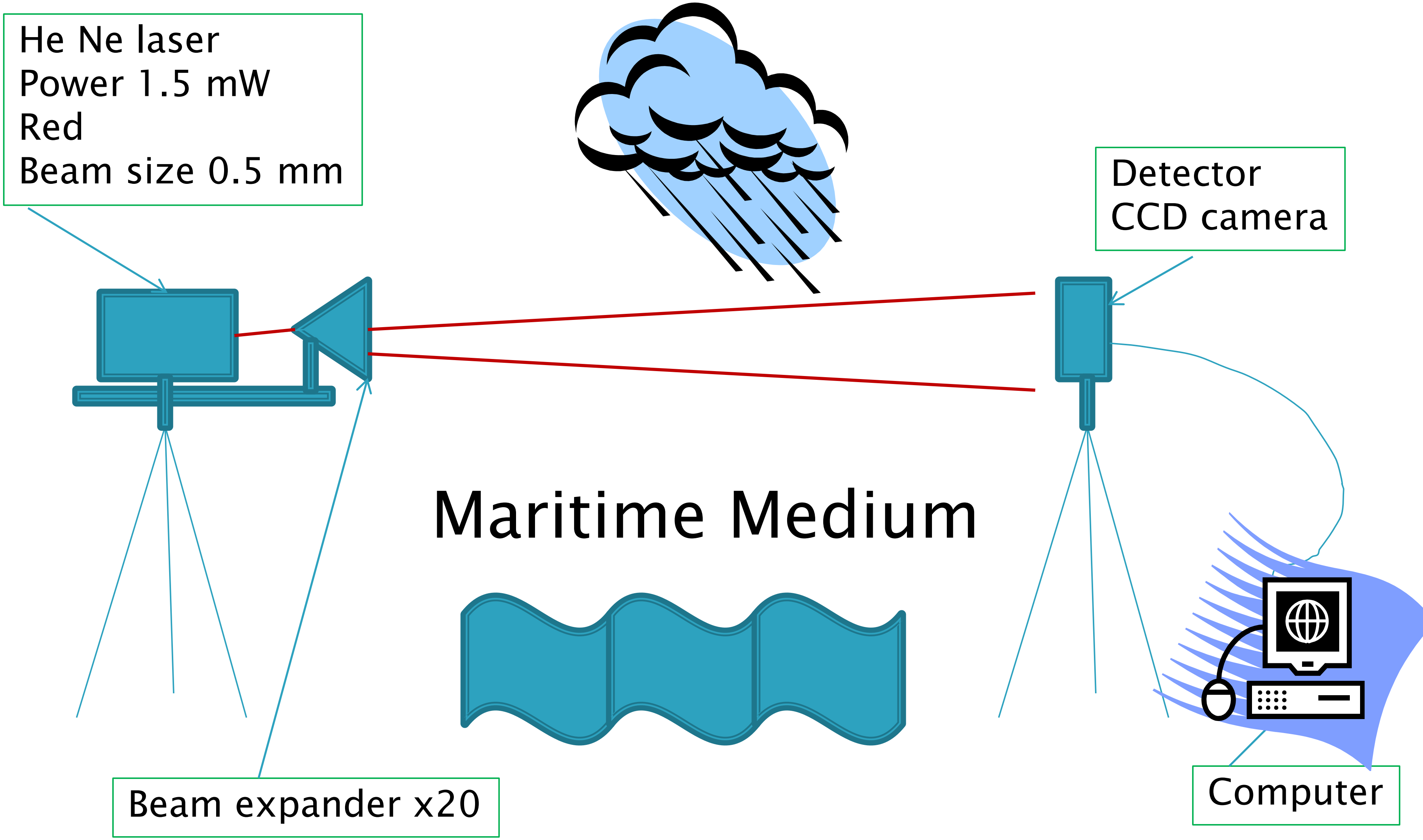
- Since we are interested in beam propagation over significant distance we need to see the beam in order to practically handle the experiment. Since we would like the sense the beam irradiance as far as possible from the transmitter we are interested in as high power level within the safety requirements. Red wavelength is chosen as balance between the human eye sensitivity and power.

- Intrinsic property of the gas He-Ne laser is a very good Gaussian beam profile. Good approximation of the Gaussian beam will have better agreement with developed mathematical models.
- This is the transmitter and it will be placed on a tripod.

- **LASER: 1.5 mW Red He-Ne with random polarization.**
  - **Beam size 0.5 mm beam divergence 1 mRad**

Experimental setup : Beam Expander and Detection

- Based on the experimentation with a 0.5 mW red He-Ne laser with 1 mRad divergence and filter attenuation of 1000 it was observed that beam could be detected at the distance of 10 m with the beam size of 1 cm.
- To have less beam divergence a 20x beam expander was chosen. This will provide an order of magnitude less beam divergence and thus allow us to have a beam at the order of 1 cm at 100 m.
- In order for this estimate to hold the laser beam power level has to be higher and detector has to be more sensitive because the laser power will be redistributed with beam expander.
- Selected laser power is 1.5 mW (the highest possible due to safety requirements)
- CCD cameras as detectors
  - Coherent detector sensitivity 15 μW/cm active sensor area 7x8mm
  - Thorlab detector sensitivity xx active sensor area 13x13mm
- Set of filters have been selected in order to observe the beam along the path. Six orders of magnitude is available in decade steps. The filter characteristic is provided by the manufacturer.


He Ne laser
Power 1.5 mW
Red
Beam size 0.5 mm
Detector
CCD camera
Maritime Medium
Beam expander x20
Computer