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PaGES5

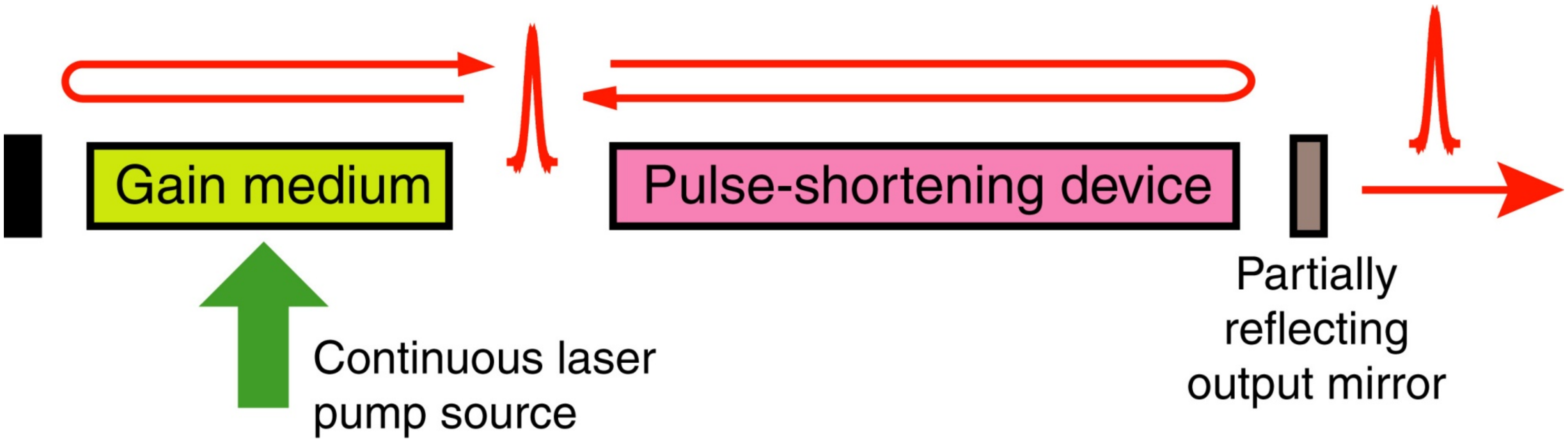
Planning, Management and Execution of a Scientific Experiment in an international research infrastructure

How to use a Michelson Interferometer to improve Laser Synchronization at FERMI

Paolo Sigalotti on behalf of
Laser Laboratory
Elettra Sincrotrone Trieste

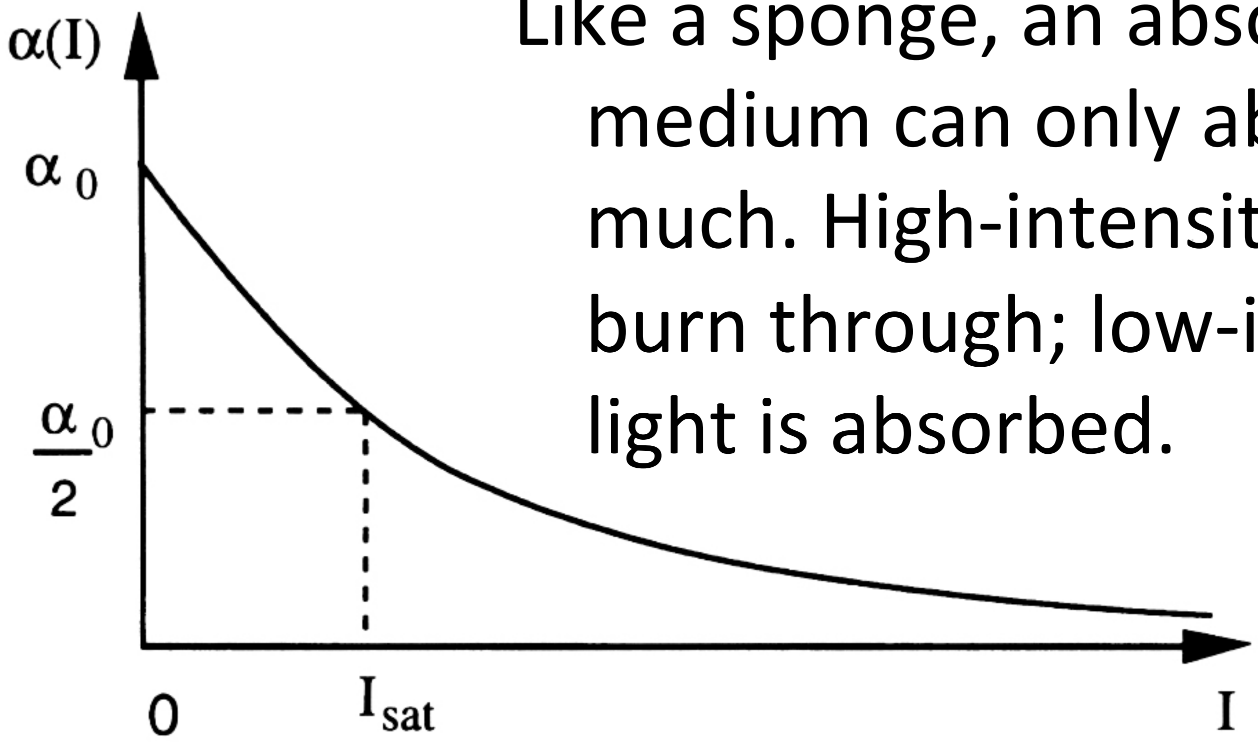
A generic ultrashort-pulse laser

- A generic ultrafast laser has a broadband gain medium, a pulse-shortening device, and two or more mirrors:



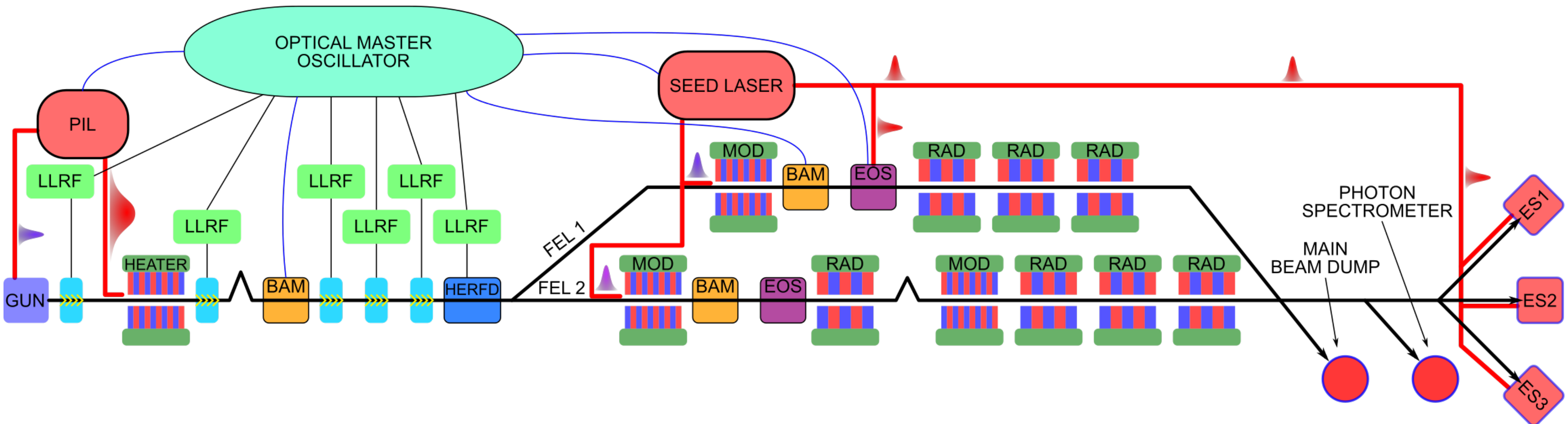
Many pulse-shortening devices have been proposed and used.

Passive mode-locking: the saturable absorber



Like a sponge, an absorbing medium can only absorb so much. High-intensity spikes burn through; low-intensity light is absorbed.

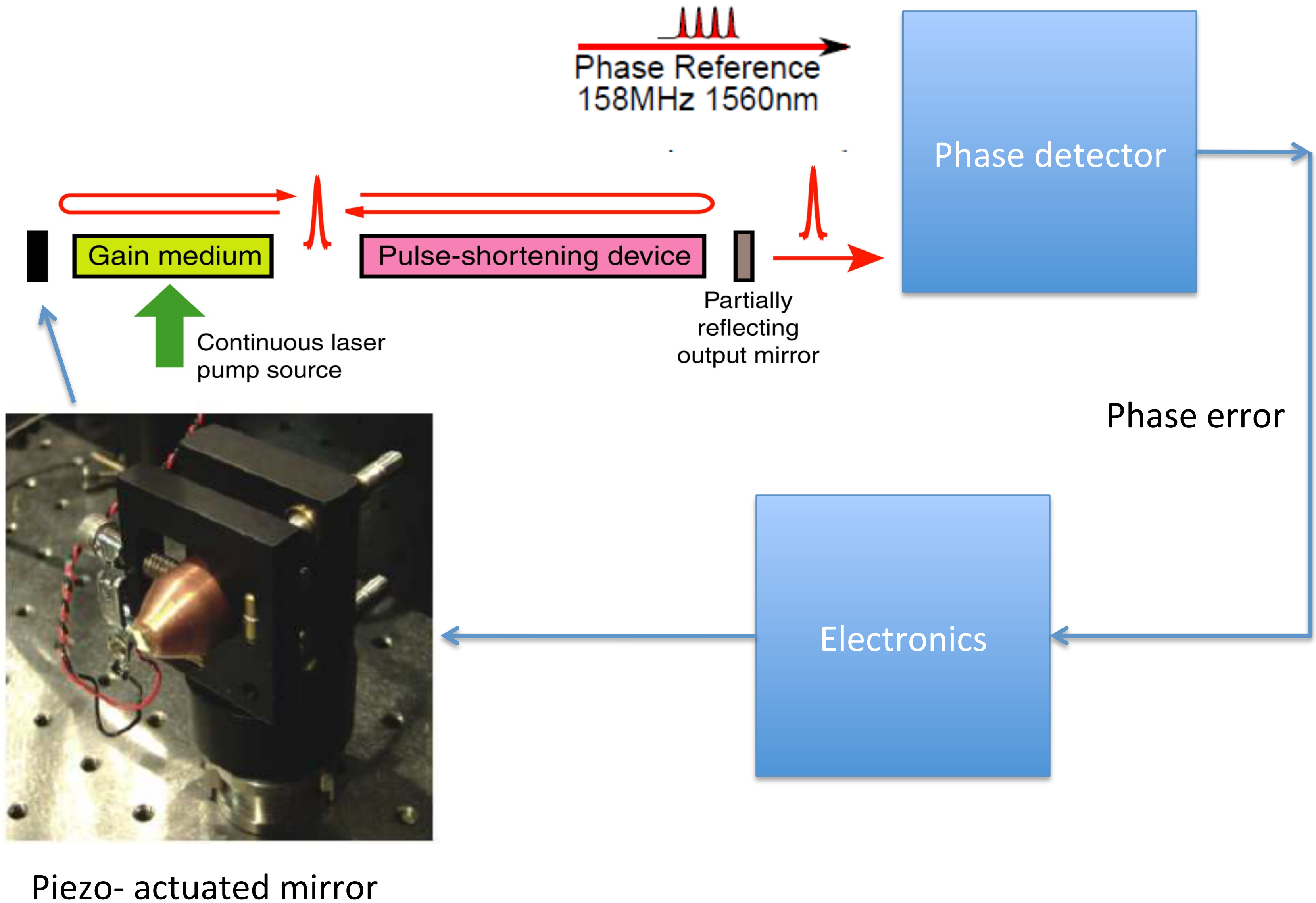
FERMI layout



The electron bunch is generated in the RF photoinjector and accelerated in a linear accelerator, then fed to a chain of undulators.
FEL and Seed Laser for Users pulses are delivered to the Experimental Stations.
Precision achived for laser synchronization at FERMI: 50fs$_{RMS}$ for Photoinector and 10fs for Seed Laser.
In 10fs light propagate 3µm
Fermi is 300m long, so it takes 1µs to light and electrons to pass throught.
We are keeping constant arrival time almost in every point of the machine as

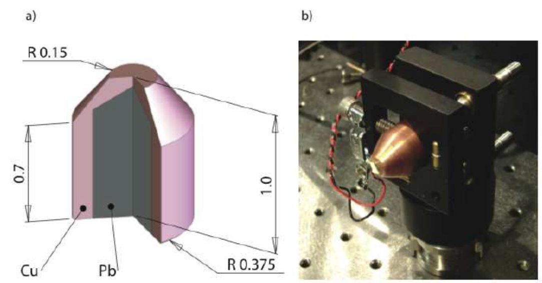
$$\frac{10\,fs}{1\,\mu s} = \frac{10\,fs}{100000000\,fs} = \frac{1}{100000000} = 10^{-8}$$

Laser Synchronization



Our Goal: build a piezo-actuated mirror having a fast and smooth frequency response

We will follow the suggestions and the recipes report in a scientific paper in order to avoid un-damped resonances:



Simple piezoelectric-actuated mirror with 180 kHz servo bandwidth

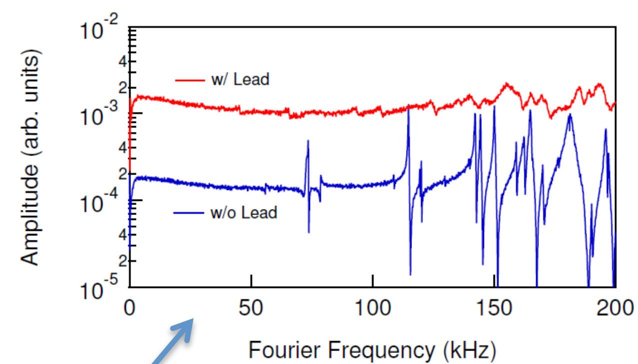
Travis C. Briles, Dylan C. Yost, Arman Cingöz, and Jun Ye

JILA, National Institute of Standards and Technology and University of Colorado Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

Thomas R. Schibli

Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

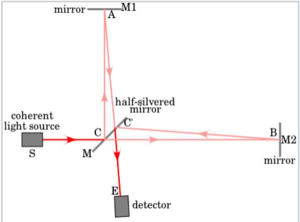
travis.briles@colorado.edu



Once assembled we will measure the frequency response:

- we will excite the piezo using an electronic sinewave generator
- we will record, frequency by frequency, the oscillation amplitude using a Michelson Interferometer

Michelson Interferometer

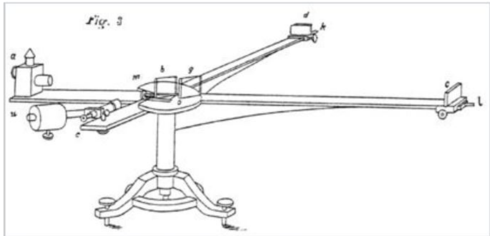


A. Importance of Michelson Interferometer (MI)

➢ Demonstration of a very basic physical optics phenomenon: light interference

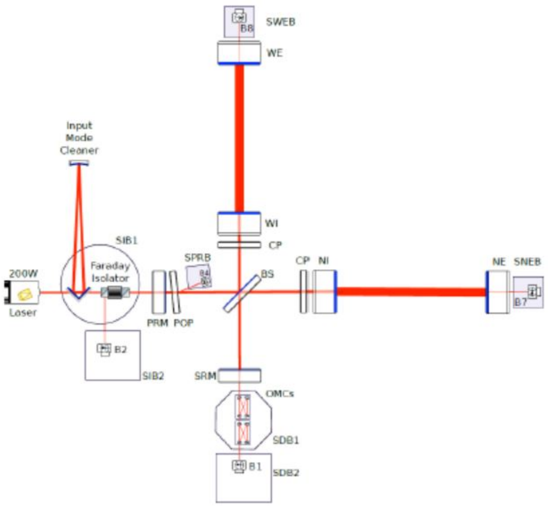
➢ Most famous scientific experiments based on MI

- Michelson-Morley (1887) experiment to verify the existence of *Aether (Nobel prize or Michelson in 1907)*



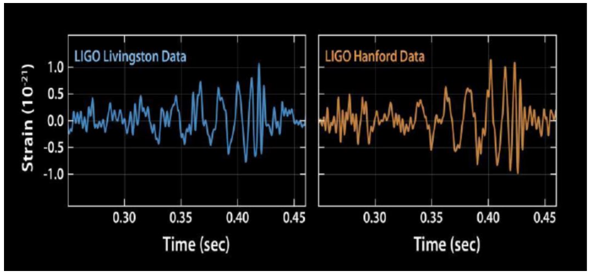
- Gravitational wave detection (LIGO,VIRGO-EGO,…) : extremely small effect on the distance between free masses :10^{-18} m on 1 km !!!

L1- Livingston – Louisiana state



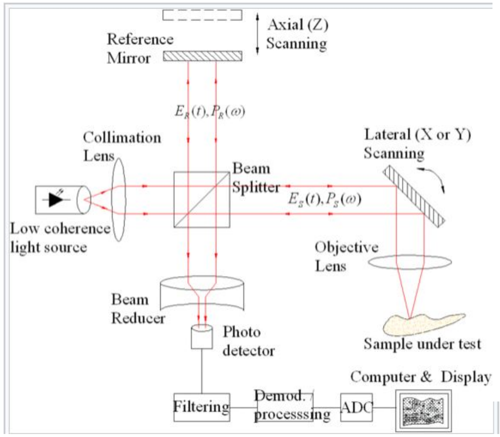
Advanced Virgo project baseline design

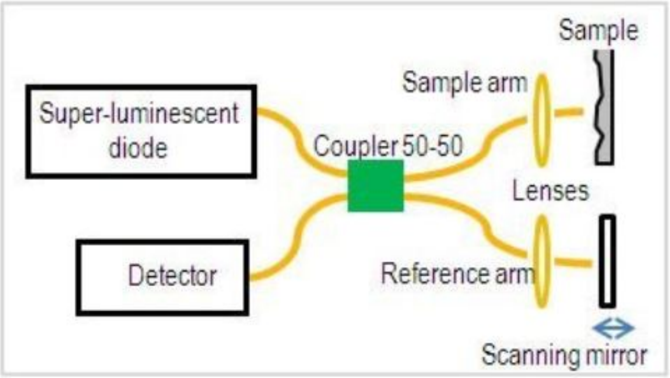
First LIGO signal observed Sept. 2015, probably generated by merging black holes; Nobel Prize in 2017

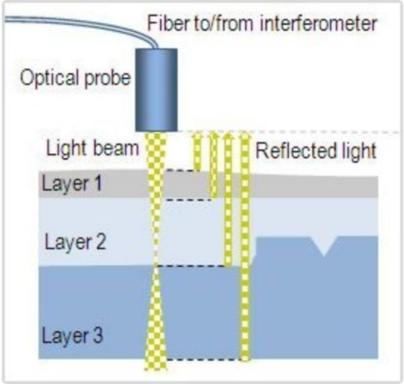


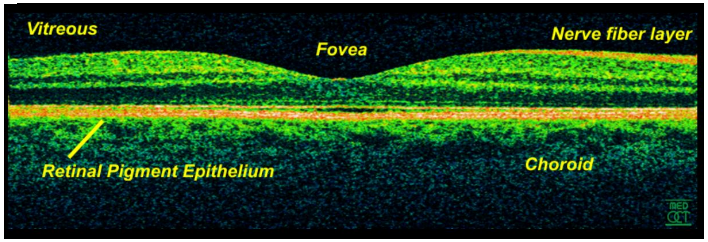
Michelson Interferometer

- Important practical applications: high accuracy length and shape measurements
  - High-coherence-laser based interferometry , measurement accuracy is a small fraction of the laser wavelength
  - Low-coherence laser or LED based interferometry (so called OCT), accuracy on the sub-micron scale, however allows to work in non-stabilized environment and has versatile fibre-optic based versions







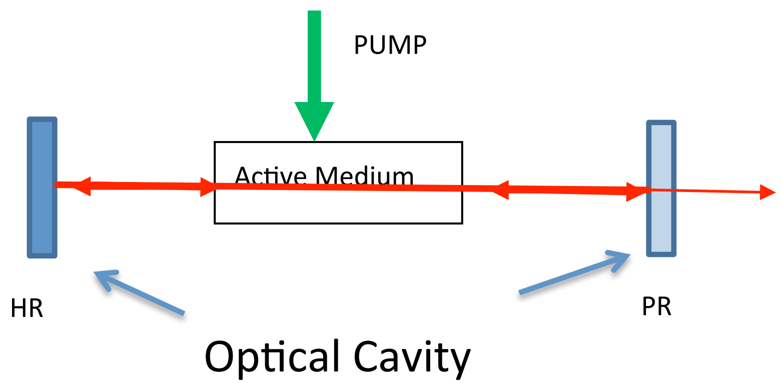


Michelson Interferometer

B. Background needed

- Basic theory of light and interference
  - Electric field amplitude, phase , wavelength, carrier frequency and intensity of monochromatic light
  - Wavelength and frequency range of visible light
  - Derivation of the expression for the interference of two monochromatic plane waves with equal frequency (intensity as a function of phase difference): $\mathbf{I=I_1+I_2+2(I_1I_2)^{0.5}cos(fi_1-fi_2)}$
  - Fringe visibility as a function of the ratio I_1/I_2 and of the phase difference
  - Optical path-length in a medium with refractive index *n*
  - Refraction of light in a prism (at least qualitative), light propagation in two anti-parallel prisms
  - Basic idea on what a LASER is and main properties of laser radiation

LASER : Light Amplification by Stimulated Emission of Radiation



Main ingredients:

- Active Medium where a Pump creates a Population Inversion

The Active Medium can be a Laser crystal , Gas, Semiconductor, Liquid, Doped Fiber

- Optical Cavity: the simplest version consists of a High Reflector (HR) and a Partial Reflector (PR)

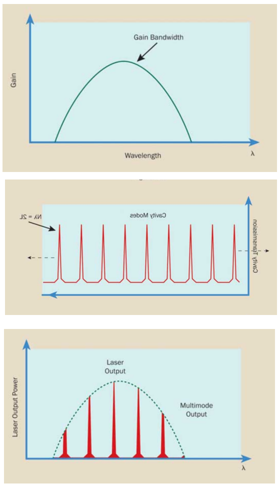
Main Laser Properties:

- Monochromaticity: determined by the gain bandwidth of the Laser Medium and the longitudinal modes of the cavity
- High Directionality: generates transverse modes determined by the

Cavity, the lowest mode called TEM00 has a gaussian shape and propagates with smallest divergence-> can be focused to a very small spot

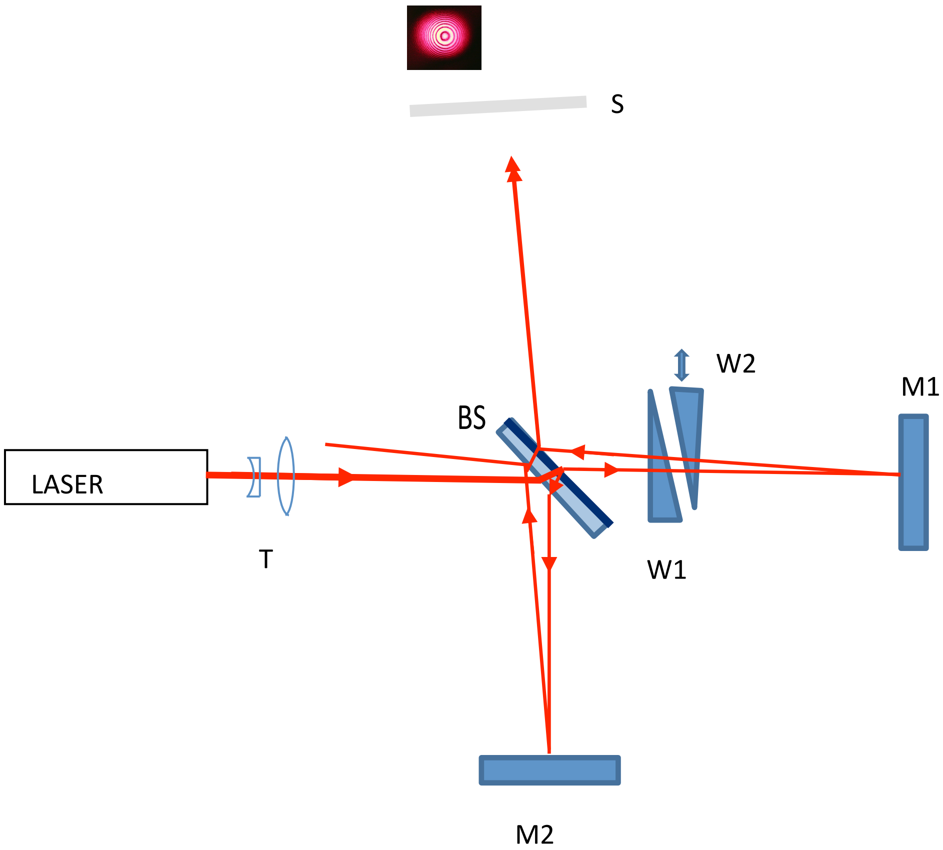
Very high Temporal and Spatial Coherence

- Can generate very short pulses and allow extremely high PEAK POWERS: PETAWATTS

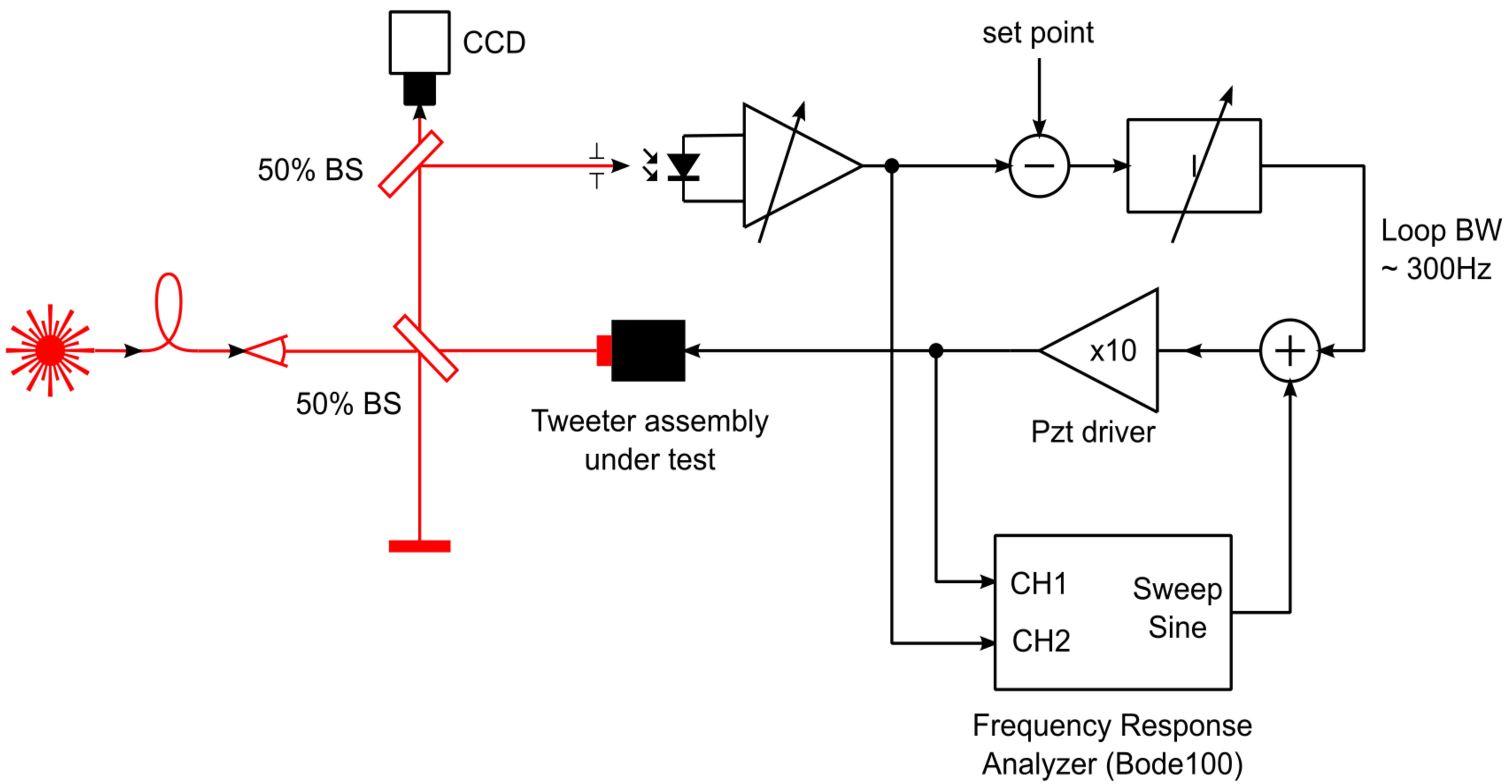


First application of Michelson interferometer:

Students will first have to perform the alignment of the interferometer using a He-Ne laser and observe the interference fringes.
After that, two fused silica wedges (prisms with small apex angle) will be inserted in one arm and the interferometer aligned. It will be observed that by translating one of the wedges the interference fringes alternate.
By measuring the wedge movement which leads to the alternation of an integer number of dark and bright fringes (e.g. 10) and knowing the wedge angle and wavelength of the He-Ne laser, students will be asked to calculate the index of refraction of the material of the wedges (fused silica).



Frequency response of a piezoactuated mirror



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Thank you

Paolo Sigalotti
paolo.sigalotti@elettra.eu