INTRODUCTION

♦ Diode-pumped **Er-Yb bulk lasers** operating at 1.5 *m*m are very interesting **all-solid-state** sources for the following properties:

- Narrow linewidth (a few tens of kHz)
- High output power (a few tens of mW)
- Good beam quality (TEM_{00} mode)
- Wide wavelength tunability (a few tens of nm)

♦ Potential applications in **Optical Communications**, **Metrology and Optical Measurements**, **High-resolution Spectroscopy**

OPTICAL COMMUNICATIONS

- **HDWDM** communication systems
- **Coherent** communication systems
- **Comb-generation** by multi-longitudinal-mode oscillation

METROLOGY AND OPTICAL MEASUREMENTS

- Absolute **frequency references** at 1.5 *m*m
- **Distance** measurements
  with interferometric techniques
- **Distance and velocity** measurements
  with coherent radar-laser techniques
- **Eye-safe** optical measurements in free-space

HIGH RESOLUTION SPECTROSCOPY

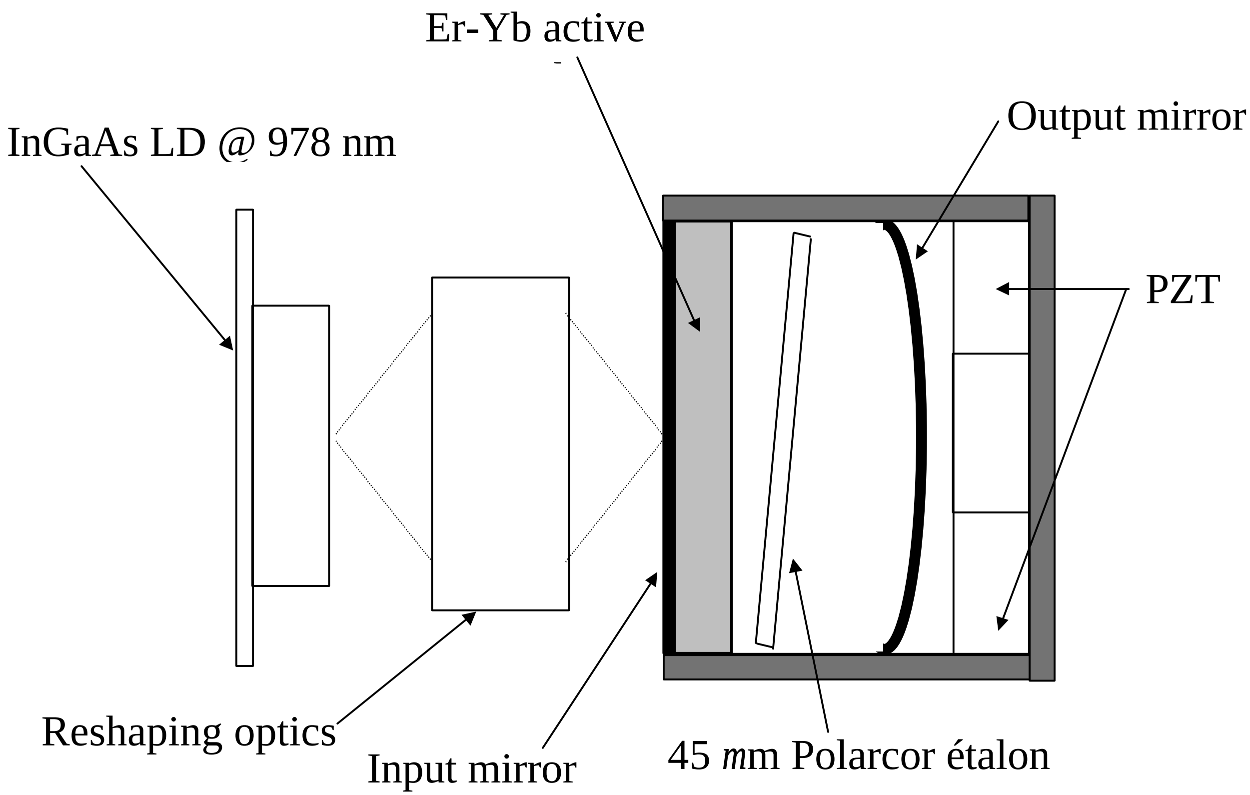
- **Widely tunable** single mode source
- **Narrow linewidth**
- **Frequency modulation** without amplitude variations

PURPOSE OF THE WORK

- ♦ Main goal: build Er-Yb microlasers stabilized with reference to absolute frequency standards
- Frequency standard: C_2H_2 transition lines around 1.5 *m*m (many deep and well resolved roto-vibrational lines)

- ♦ Preliminary requirement: new Er-Yb microlaser with
- High power in single mode operation
- Linearly polarized output
- Wide continuous spectral tuning range
- Narrow linewidth

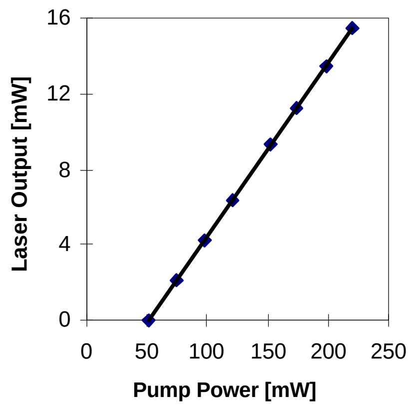
THE SINGLE-MODE ER-YB MICROLASER

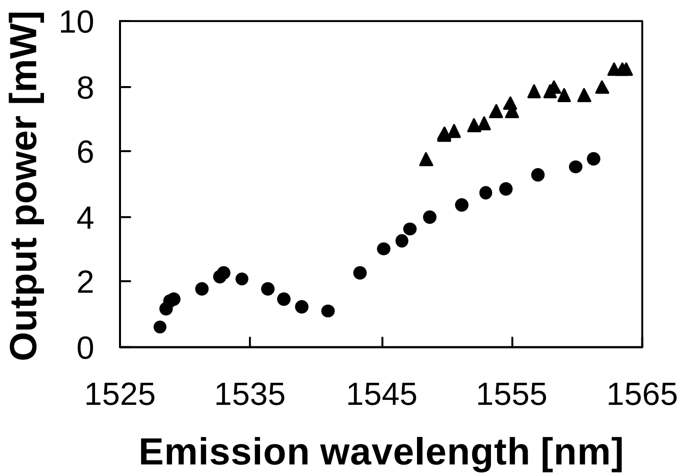


- Very compact cavity (L=5 mm)
- 45 *m*m Polarcor étalon: linear polarization + wide tunability
- PZT: frequency tuning for SLM operation

ER-YB MICROLASER PERFORMANCE

- High output power and Wide Tunability



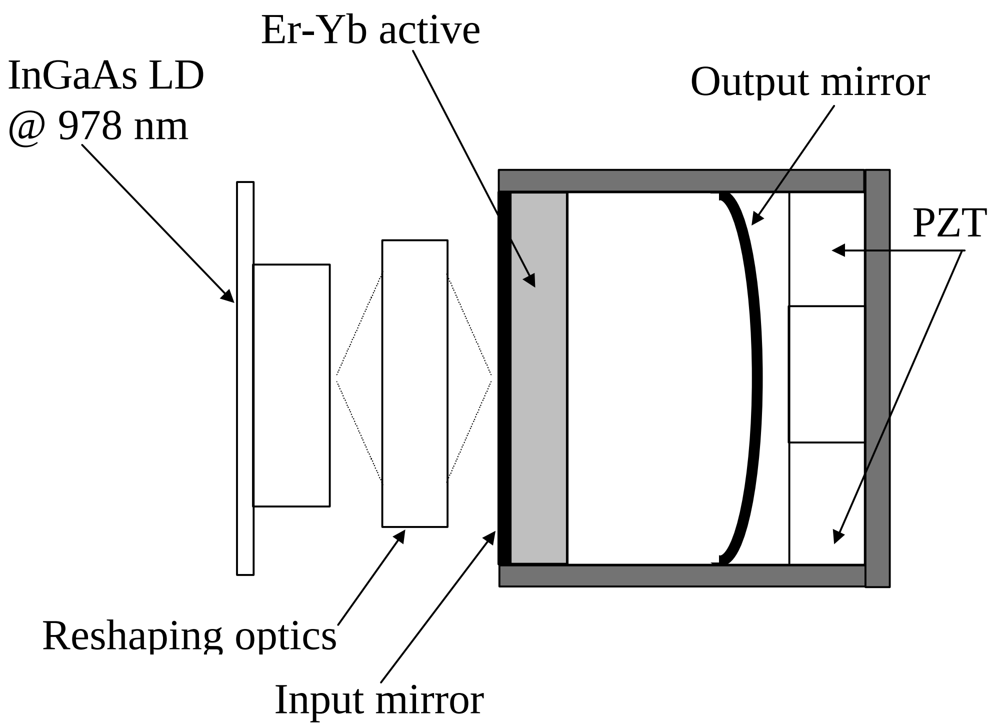


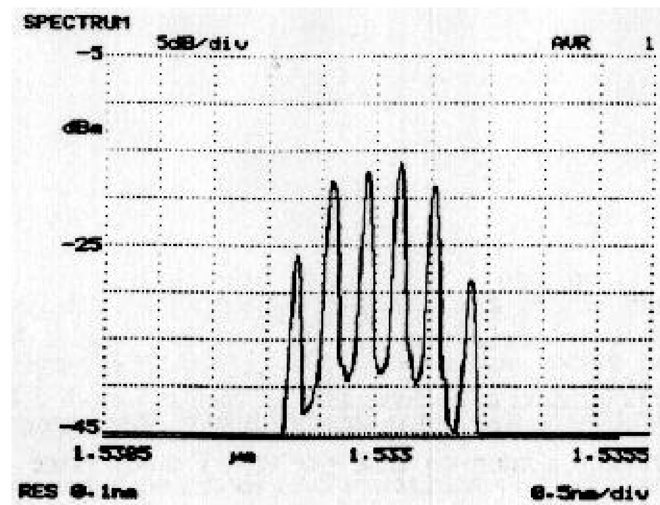
- >500:1 Linearly Polarized output

- Narrow Linewidth (~45 kHz)

Politecnico di Milano
Dipartimenti di Fisica e di Elettronica e Informazione

THE MULTI-MODE ER-YB MICROLASER FOR OPTICAL COMB GENERATION





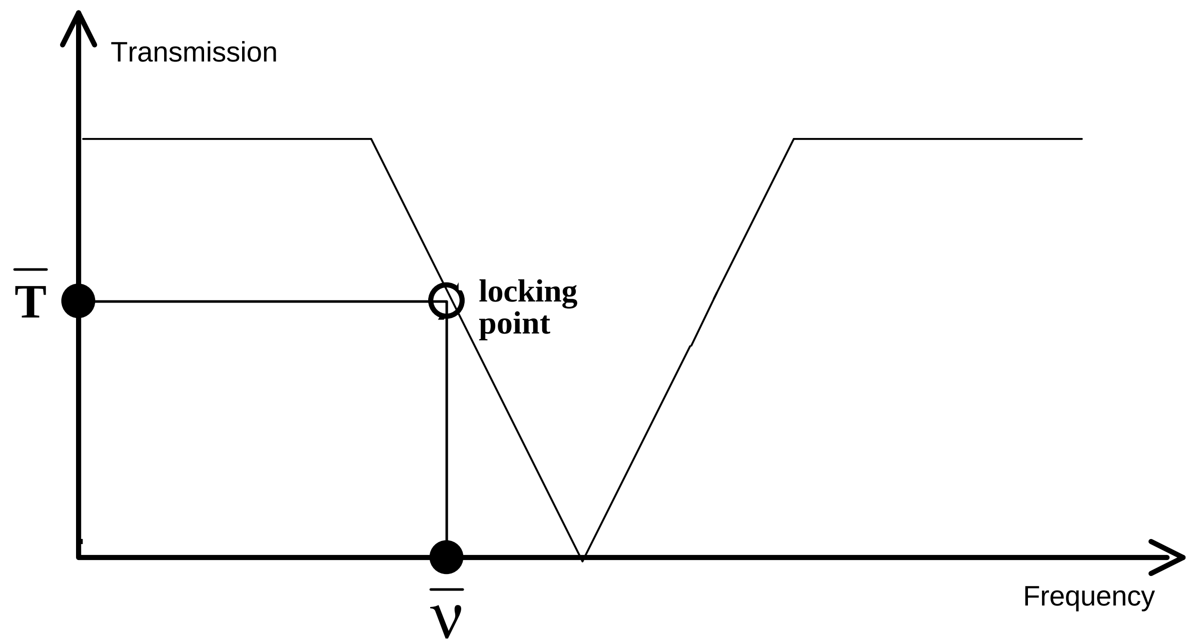
- Simultaneous oscillation over 5÷10 longitudinal modes with a frequency spacing of 40÷20 GHz.

STABILIZATION TECHNIQUES

- Absolute frequency stabilization against **C_2H_2 absorption lines**

- **Locking** by the ***fringe-side-locking*** technique
  Locking by the ***FM-eterodyne*** technique

THE FRINGE-SIDE-LOCKING TECHNIQUE

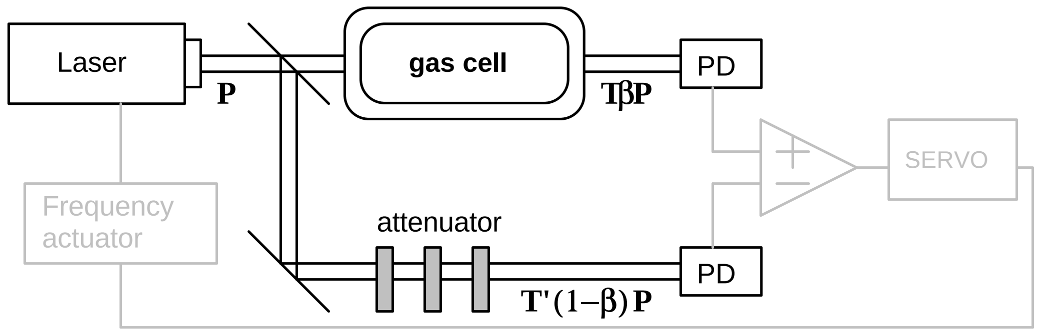


Transmission of the laser beam through a gas cell.

- The laser frequency is stabilized to the value $\bar{n}$ corresponding to the desired transmission $\bar{T}$ of the molecular resonance by keeping the transmitted power fixed to a desired value

Politecnico di Milano
Dipartimenti di Fisica e di Elettronica e Informazione

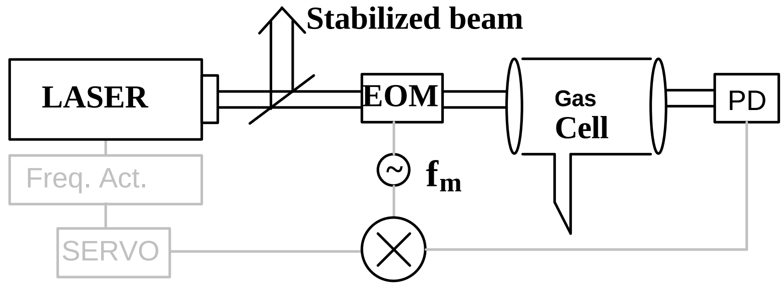
FRINGE-SIDE LOCKING EXPERIMENTAL SETUP



- The laser frequency is stabilized at the value $\overline{n}$ corresponding to a transmission $\overline{T}$ of the gas cell

- Error signal: $E = A\left\{T\beta P - T'\left(1-\beta\right)P\right\}$

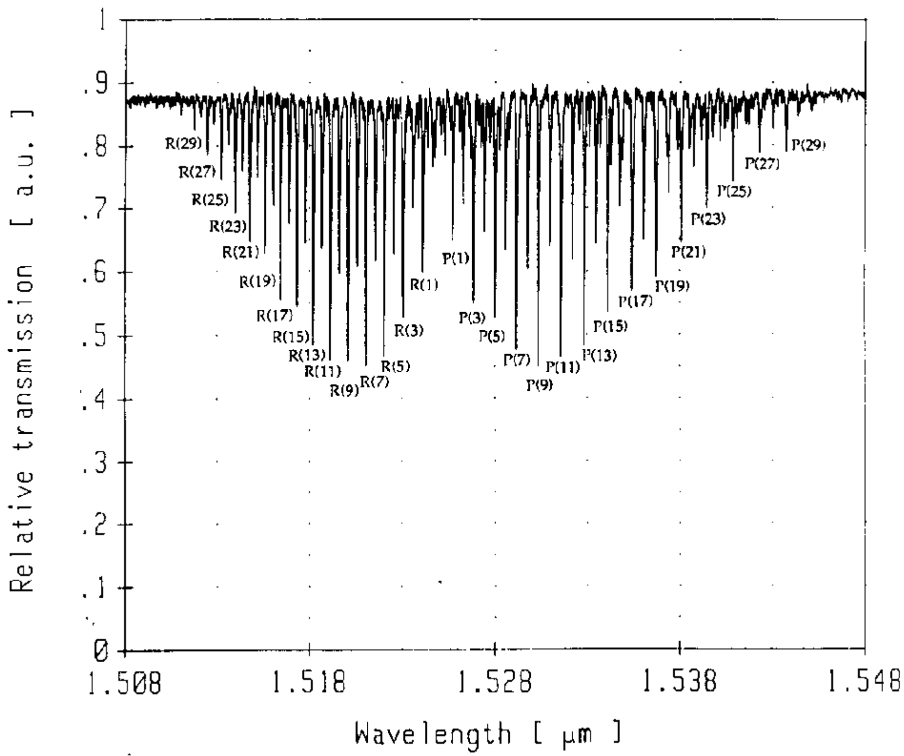
FM-ETERODYNE TECHNIQUE



- The laser beam is frequency modulated, at the modulation frequency f_m, before passing through the gas cell
- Synchronous detection of the signal after the resonance
- Error signal: odd harmonics of f_m

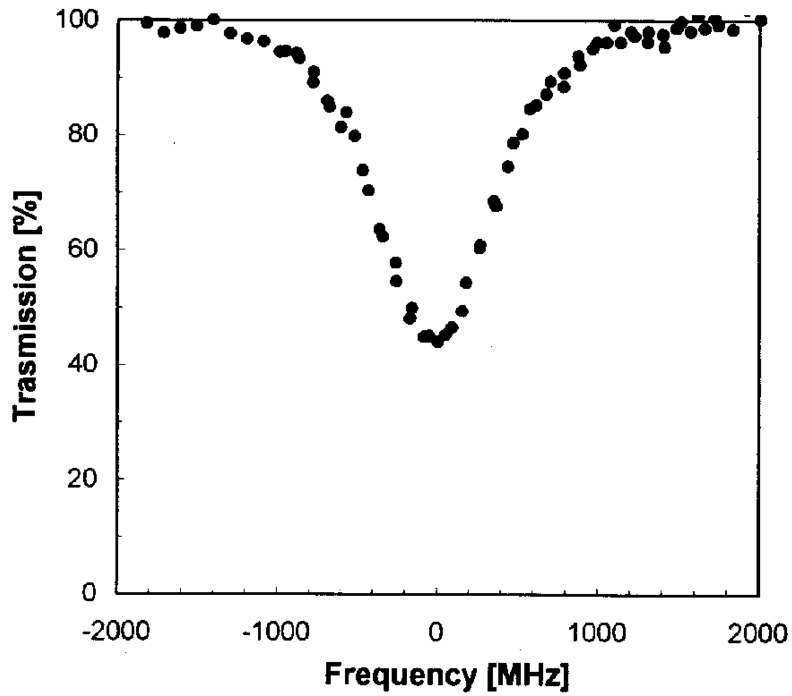
THE ACETYLENE MOLECULE

- **Acetylene** (C_2H_2): strong roto-vibrational absorption lines spaced of ~80 GHz in the **spectral region 1510-1540 nm**



MEASUREMENT OF THE TRANSITION LINE P(13) OF C_2H_2

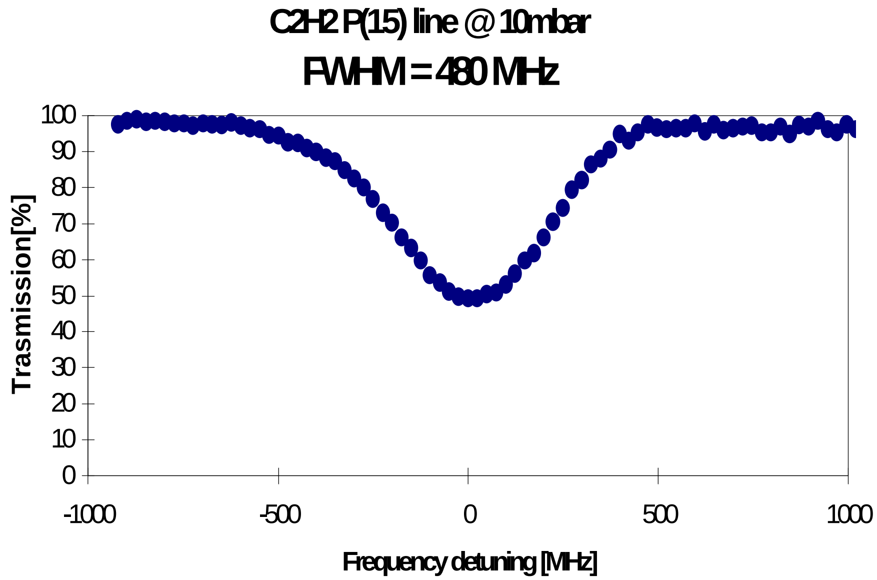
- The molecular transition of interest has been measured by the C_2H_2 cell upon frequency tuning the Er-Yb laser



- Measured linewidth of the line P(13) ~700 MHz (Doppler)

OTHER TRANSITION LINES OF C_2H_2 AND $^{13}C_2H_2$

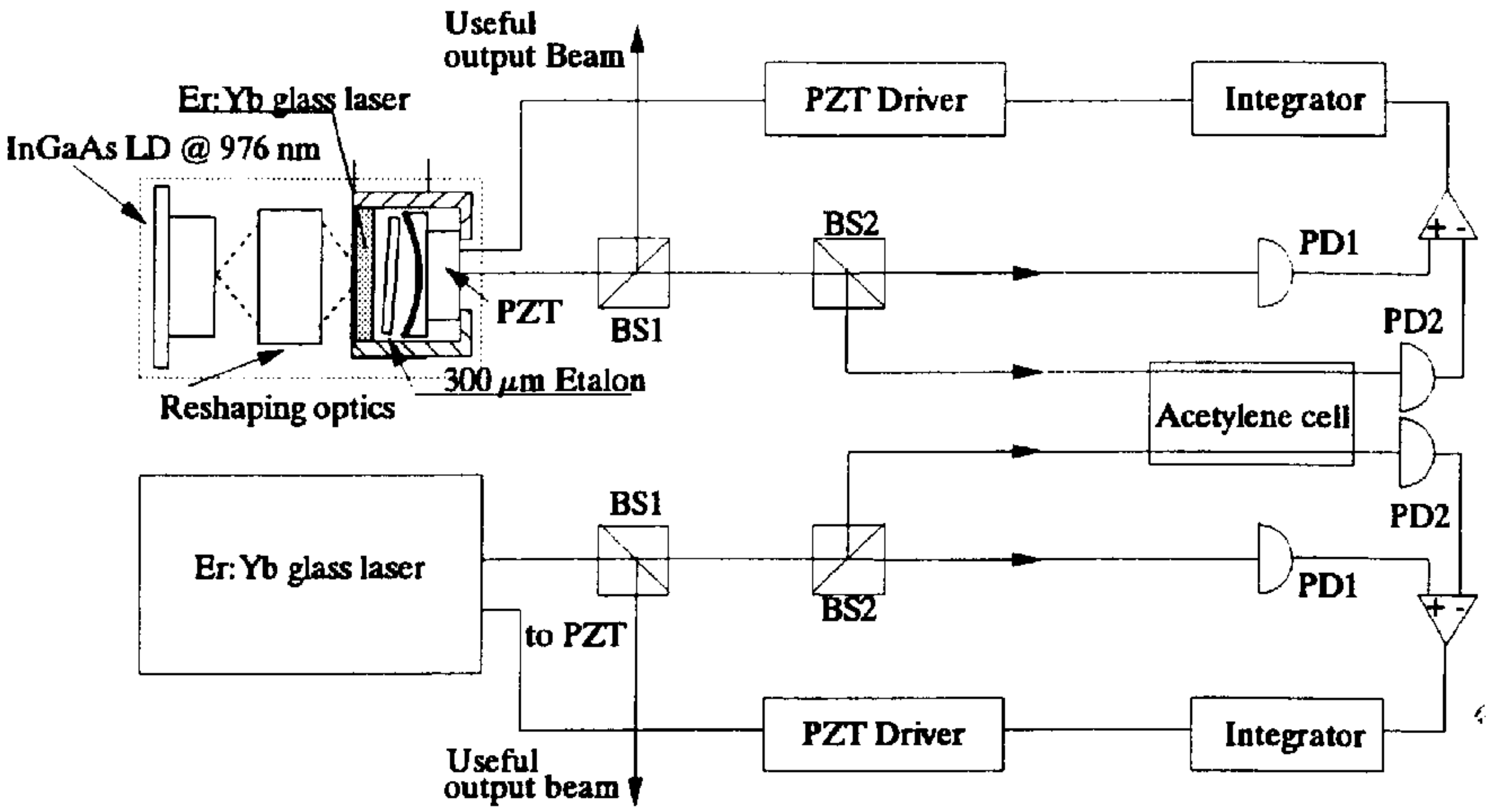
- Other molecular transitions of interest have been measured, both in C_2H_2 and $^{13}C_2H_2$ by the tunable Er-Yb laser



- In the 1540-1550 nm region, $^{13}C_2H_2$ lines from P(13) to P(29) have been measured (l=1540.057 nm ÷ 1550.870 nm)

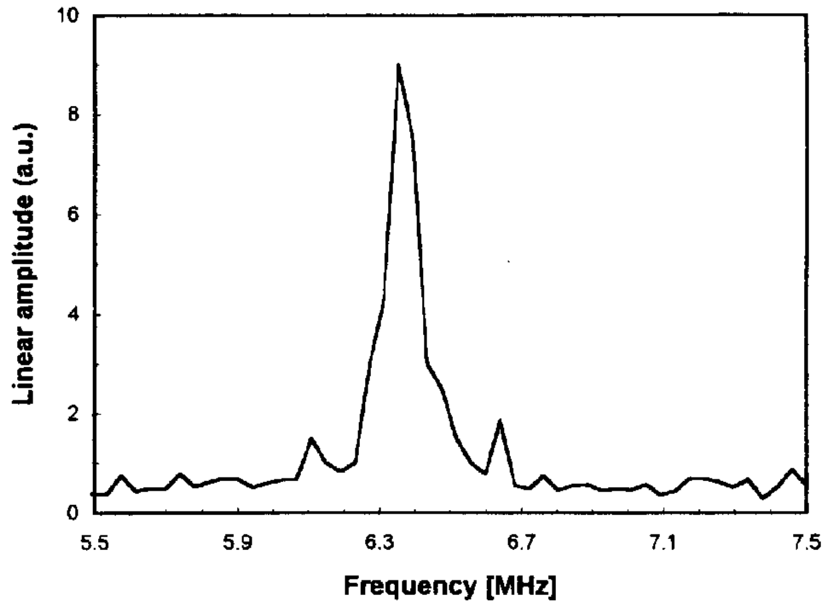
Politecnico di Milano
Dipartimenti di Fisica e di Elettronica e Informazione

FRINGE-SIDE-LOCKING STABILIZATION EXPERIMENT



♦ **Two identical laser cavities** have been locked to the **P(13) line** o C_2H_2 at a **1532.828 nm** wavelength

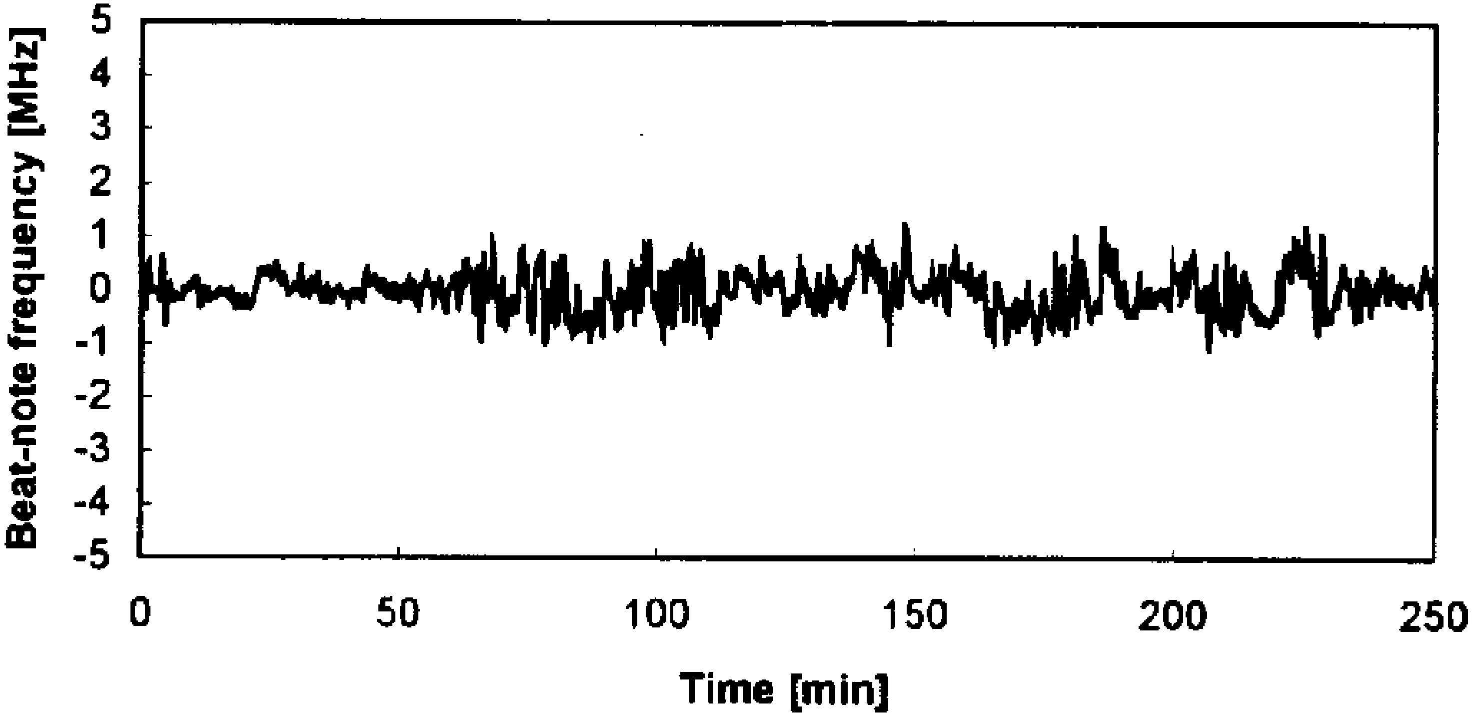
SHORT TERM FREQUENCY STABILITY



Spectral analysis of the two lasers beat note signal

- **Short-time frequency stability** (1 ms) ~ 45 kHz

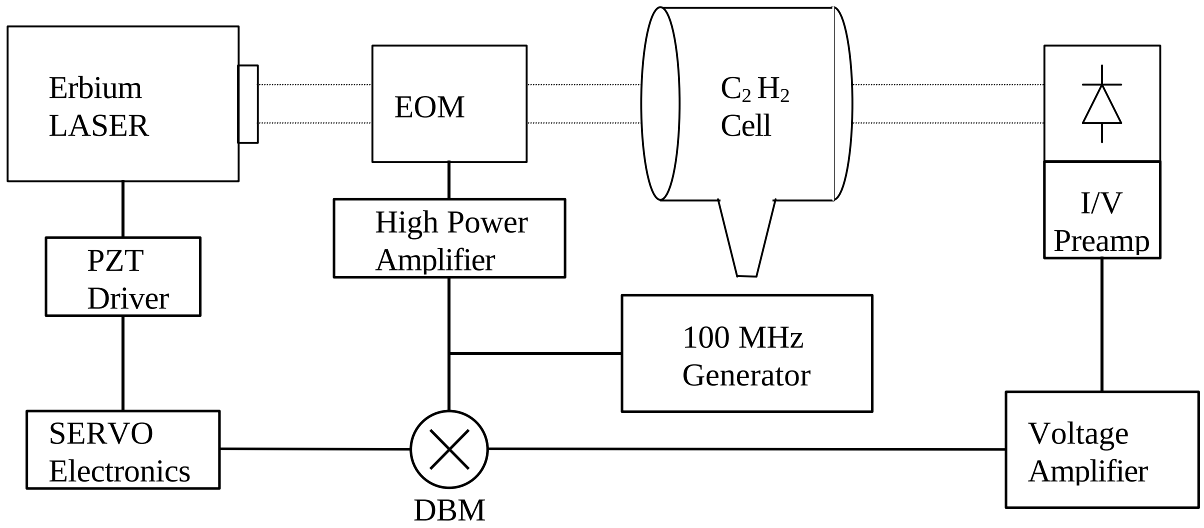
LONG TERM FREQUENCY STABILITY



Time behaviour of beat-note frequency

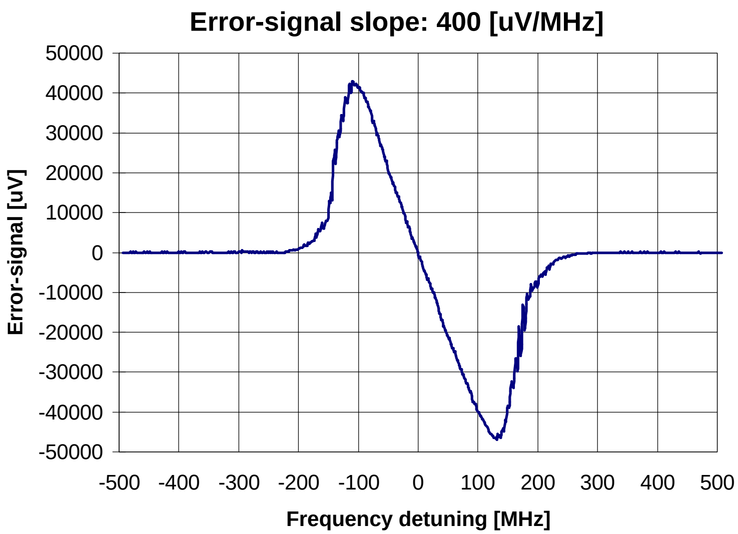
♦ **Long-time frequency stability** (4 hours) ~ 0.75 MHz

FM-ETERODYNE STABILIZATION EXPERIMENT

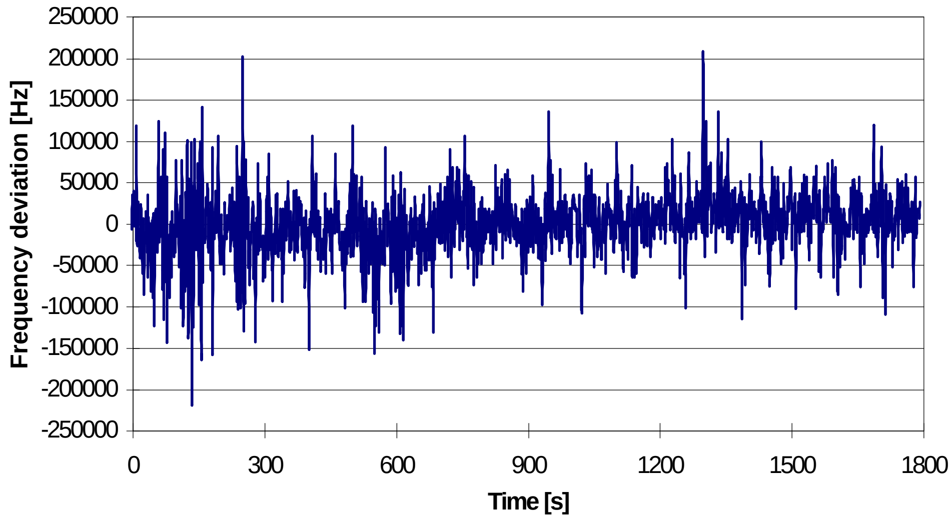


- Er-Yb microlaser locked to the **center** of **P(15) line** of C_2H_2 (λ**=1534.097 nm**)
- Error-signal, under closed-loop operation, observed to remain located to zero value ⇒ **frequency locking**

ERROR-SIGNAL ANALYSIS



Discriminator curve



Closed-loop error-signal

- **Frequency fluctuations** (0.5 hours) ~ 40 kHz rms ($D\nu/\nu$=2×10^{-10})

Politecnico di Milano
Dipartimenti di Fisica e di Elettronica e Informazione

CONCLUSIONS

- New **Er-Yb microlaser** provides **linear polarization**, **high power**, **wide tunability** (1528-1564 nm) in **single mode** operation
- **Fringe-side stabilization** of two Er-Yb lasers to **C_2H_2 molecule**
  short term stability (1 ms) ~ **45 kHz**
  long term stability (4 hours) ~ **0.75 MHz**
- **FM-eterodyne absolute frequency stabilization to C_2H_2 molecule** of a single Er-Yb laser: residual frequency fluctuations of ~ **40 kHz**

- The Er-Yb bulk microlaser is suitable for applications in **optical communications** (HDWDM, CATV), **spectroscopy** and **metrology**