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ULUSAL METROLOJİ ENSTİTÜSÜ

NATIONAL METROLOGY INSTITUTE (UME) of TURKEY

Time, Frequency and Wavelenght Laboratory

Ramiz HAMID

Contents

- Generation of the National Time and Frequency Scale with an uncertainty of $1x10^{-14}$
- Time and Frequency dissemination and its applications
- Measurement and Calibration Capability

- Stabilized Laser Sources in the Optical Spectral Range 532 nm – 3390 nm
  - Nd:Yag/I_2, 532nm,
  - He-Ne/I_2, 633 nm,
  - ECDL/Rb, Cs, 778 nm, 780 nm, 852 nm
  - He-Ne/CH_4, 3390 nm

- Ti:Sa fs Cobm and absolute frequency measurement
- Yb fiber Comb, 600 nm – 1500 nm

- EMRP Projects (Nanotrace, Sub-nano, EMF&SAR, Mikro Clocks, Angle)

- Laser Spectroscopy (magneto-optic effect, two-photon, selective reflection)
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- DROR in far and near field
- MW – Atom – Laser – RF interaction and EM field measurement

- Length Measurement with a Nanometer Uncertainty
- Displacement Measurement with a Picometer Uncertainty

- Publications

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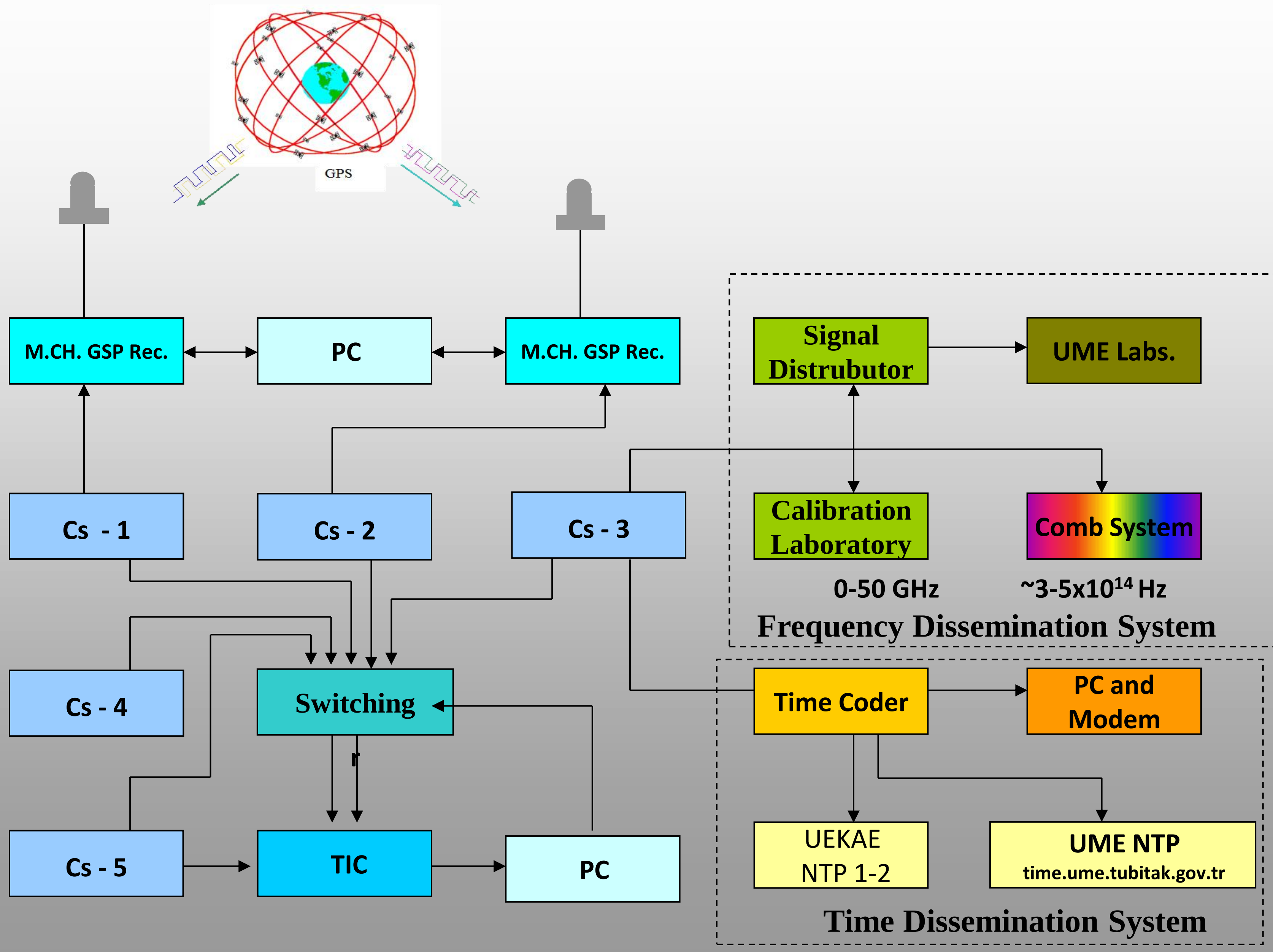
Time and Frequency System of UME



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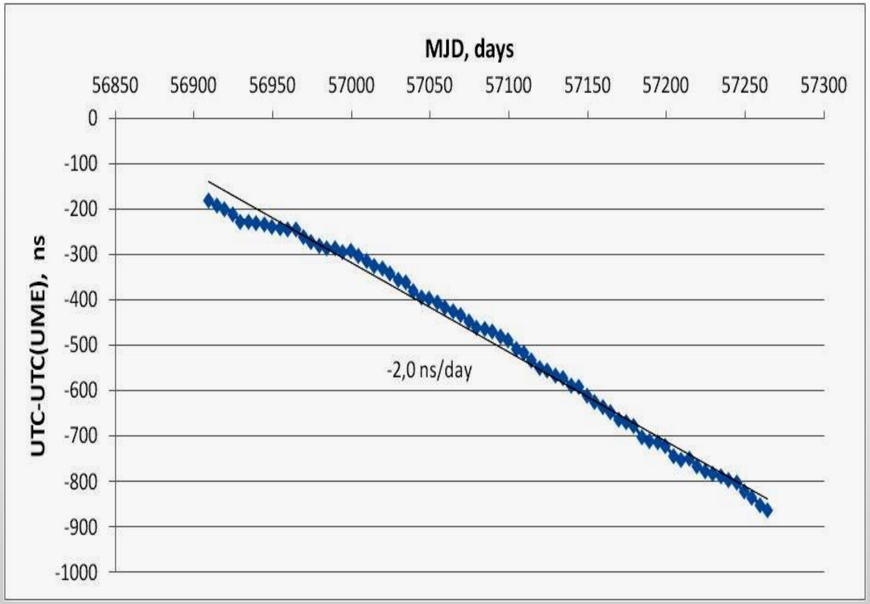
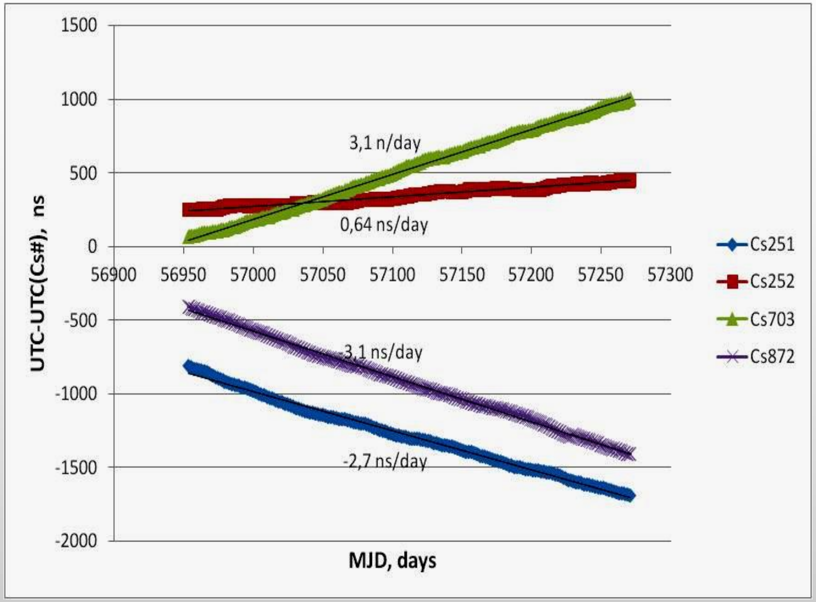
Time Scale Generation of UME





$\Delta t / t = -2.0$ ns/day $= \Delta f / f = 2.3 \times 10^{-14}$

5 Cs clocks and 2 GNSS (TTS-4, TTS-3) receivers.

Laboratory is a member of BIPM TAI club since 1994.

UTC (UME) time scale is generated
with type A uncertainty of 1 ns and
type B uncertainty of 7 ns.

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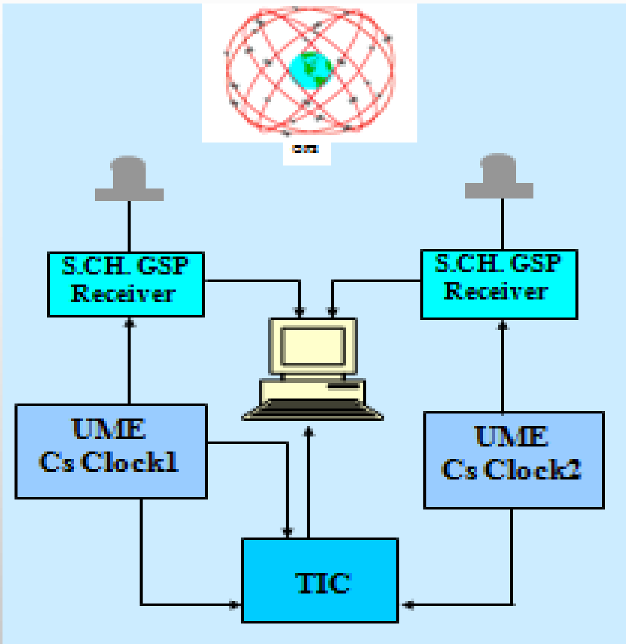
Comparison of Atomic Clocks using GPS CV and Time Interval Counter



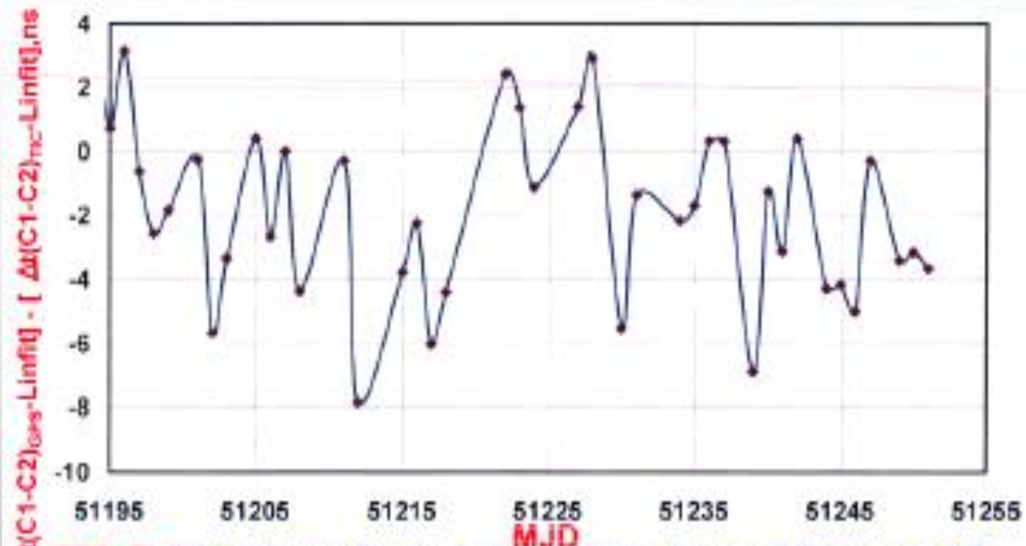
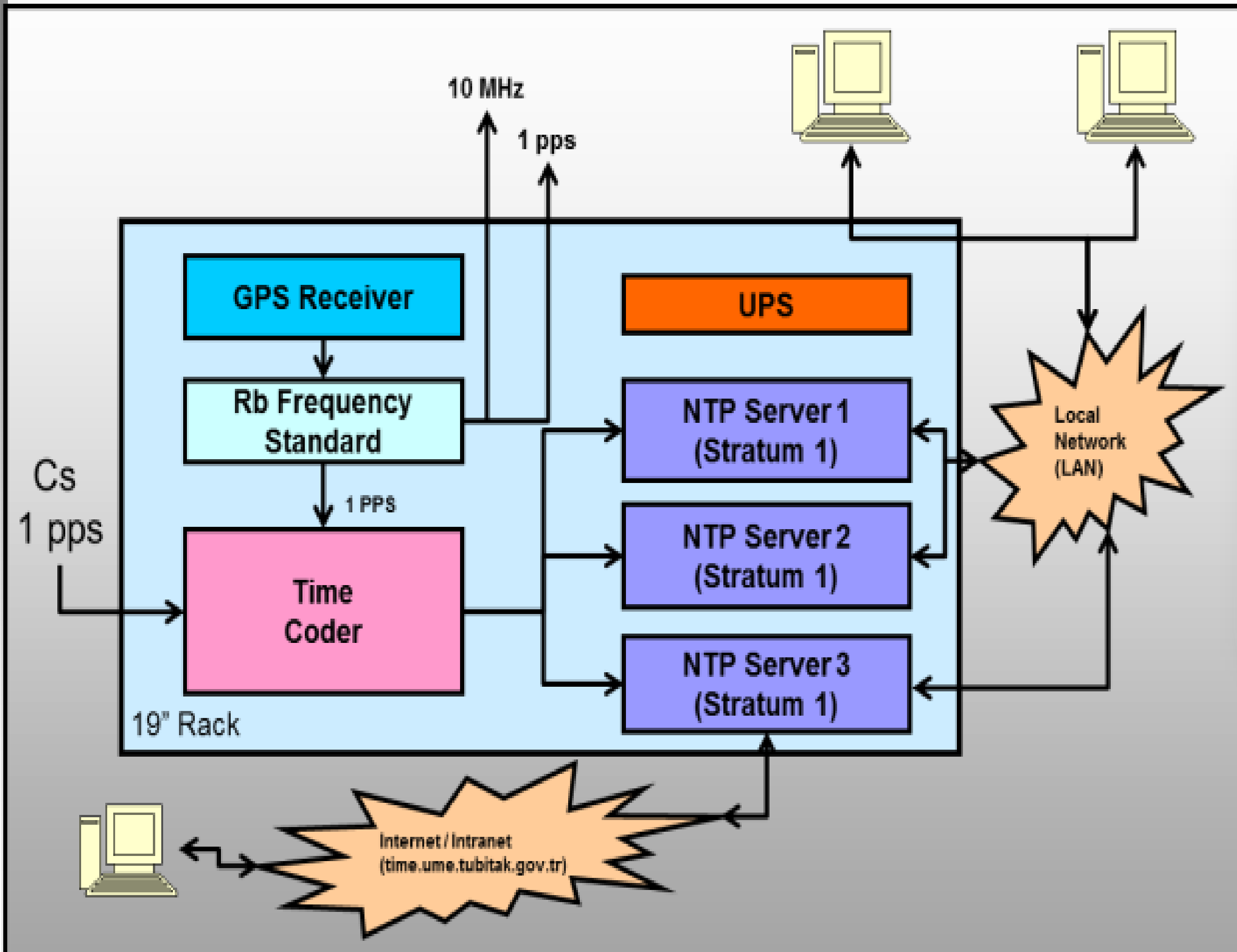


FIG.7. The linear fluctuation of the time difference of reference atomic clocks obtained using CVM and TIC

Two Cs Clocks time difference is measured at the same time interval using GPS Common View Method and Time interval counter. The linear fluctuation of time differences of atomic clocks in two types of measurement techniques is ± 4 ns.

R.Gamidov, M.Cetintas, Time and Frequency Measurement at UME, CPEM, 1998

NTP Time Dissemination



Time Dissemination uncertainty for LANs < 5 ms, for WANs < 50 ms
System is used in the national time stamp and electronic signature project

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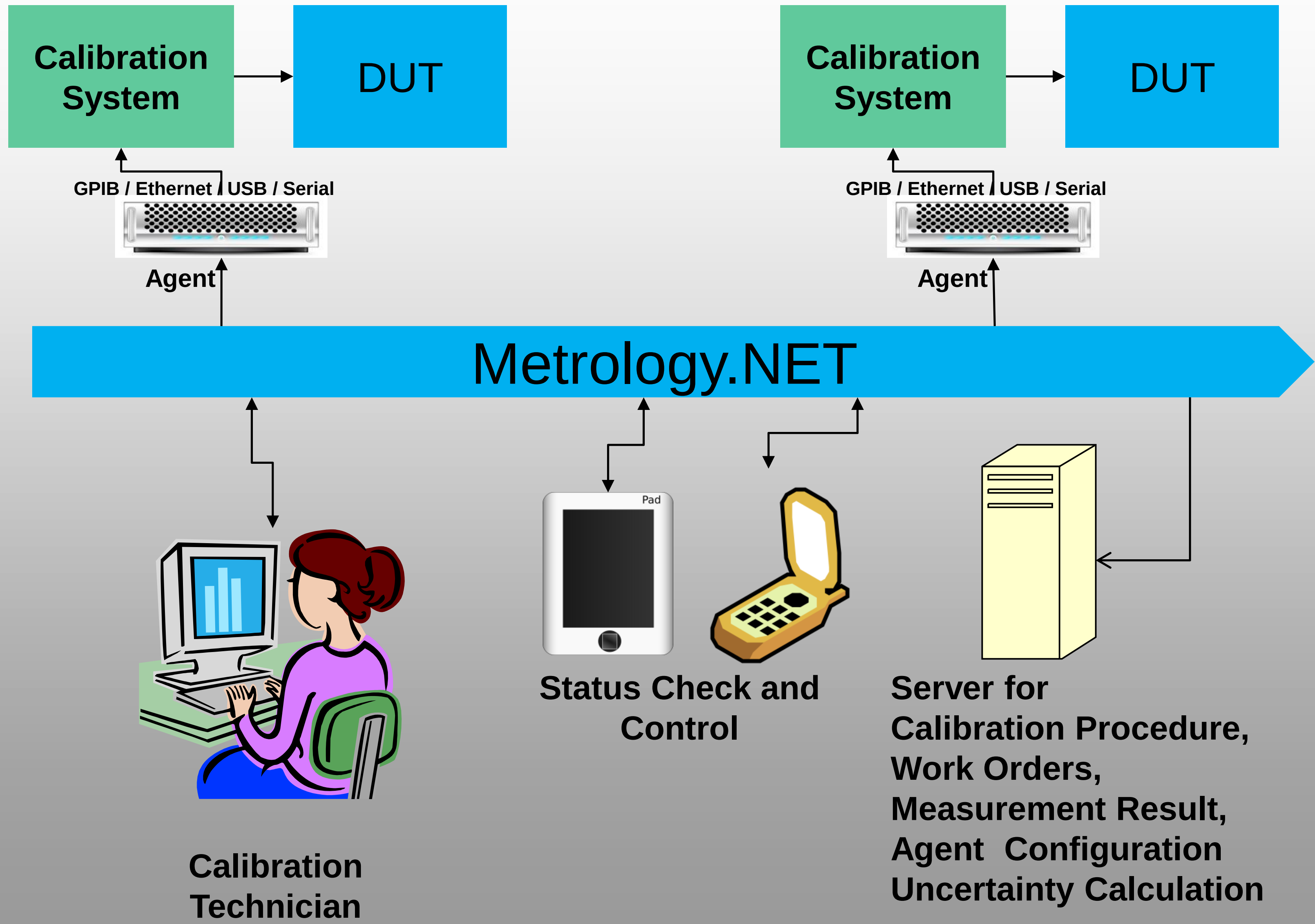
Automatic Calibration System



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Doopler Radar Calibration System

Uncertainty of Calibration: 0.2 km/h

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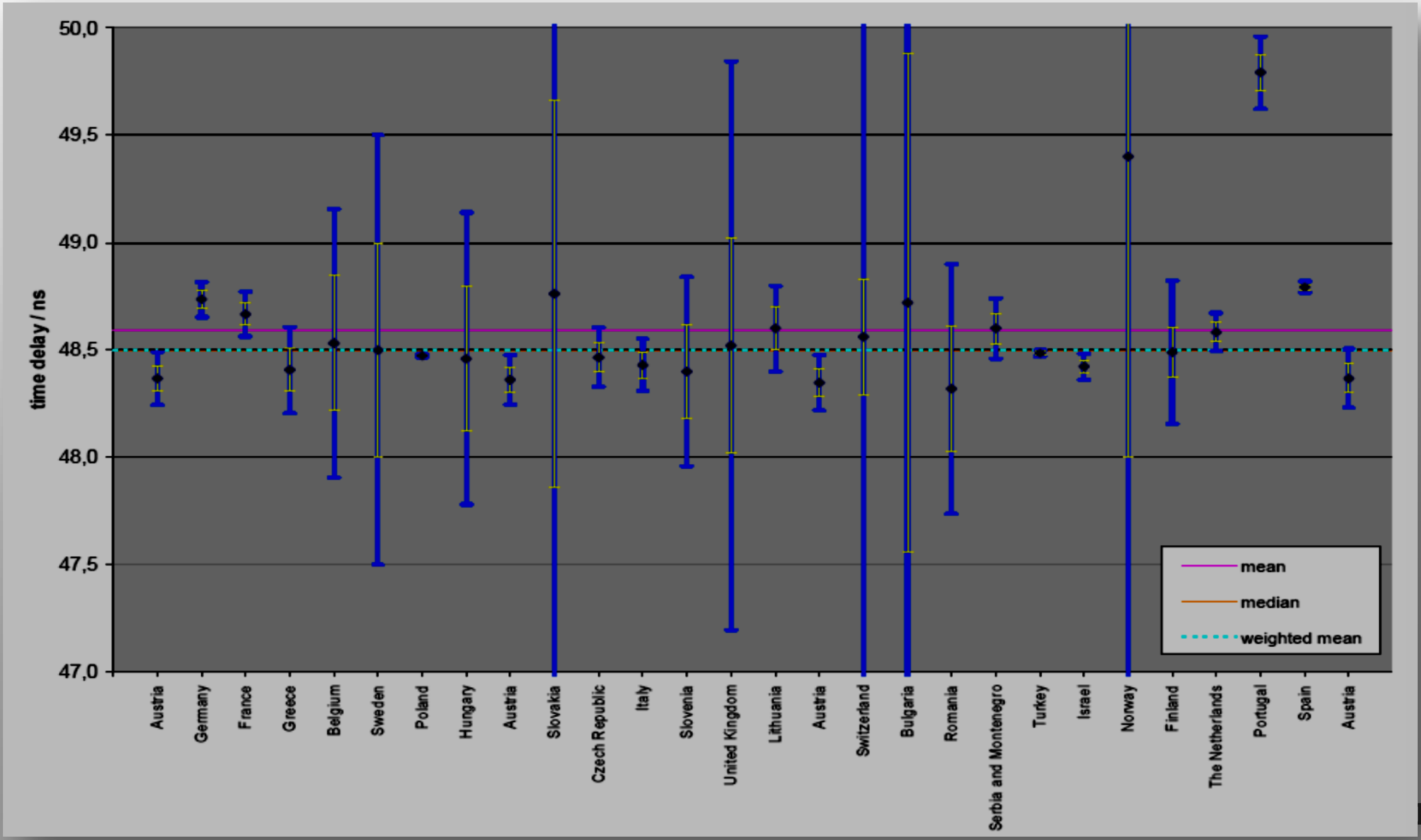
EURAMET Comparison of Time Interval Measurements

Project 828 and 1258; Comparison of Cable Delay and Time Interval Measurement

Measurements with < 10 ps uncertainty using calibrated 50 GHz oscilloscope



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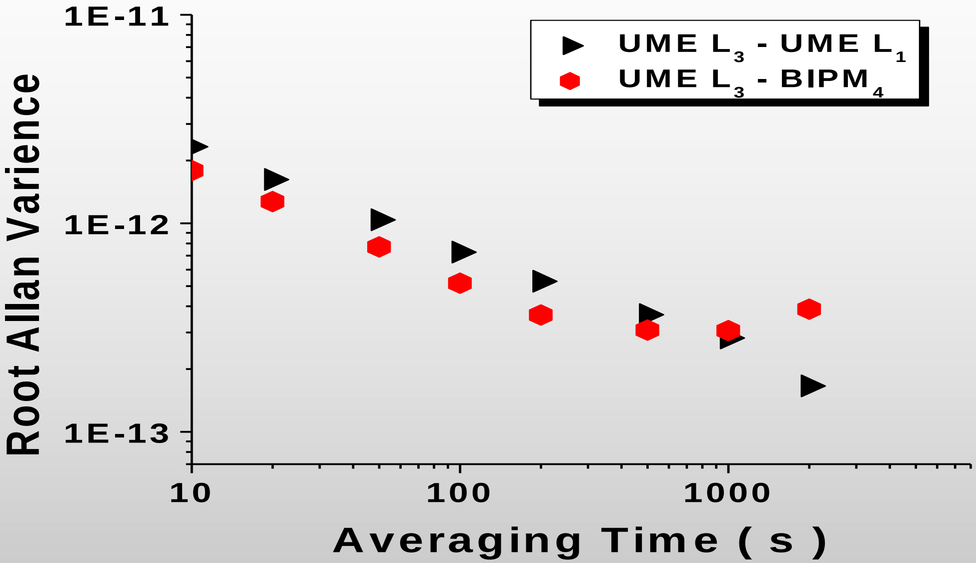
He-Ne/I_2 Laser Frequency Stability Measurements



(–8.0±0.1) kHz/Pa

(-0.15±0.01) kHz/µW

(–9.7±0.2) kHz/MHz

Metrologia, 2006, 2007, 2010, 2015

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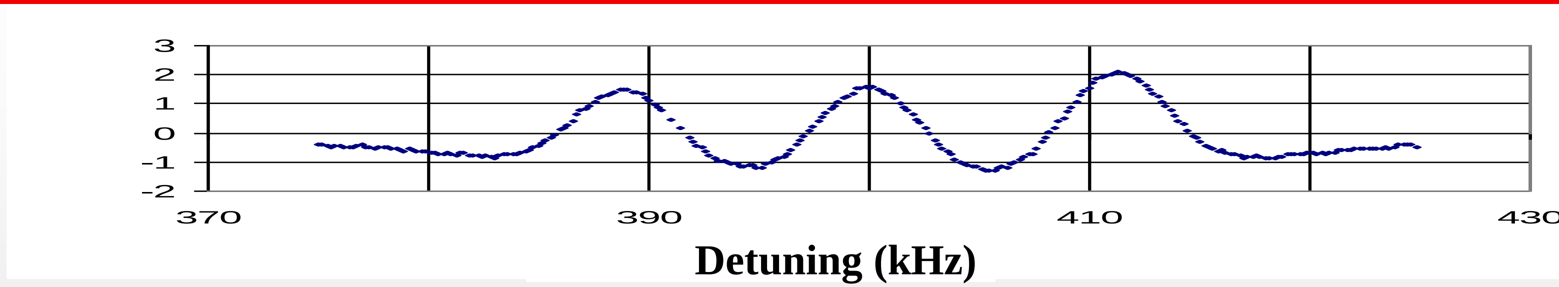
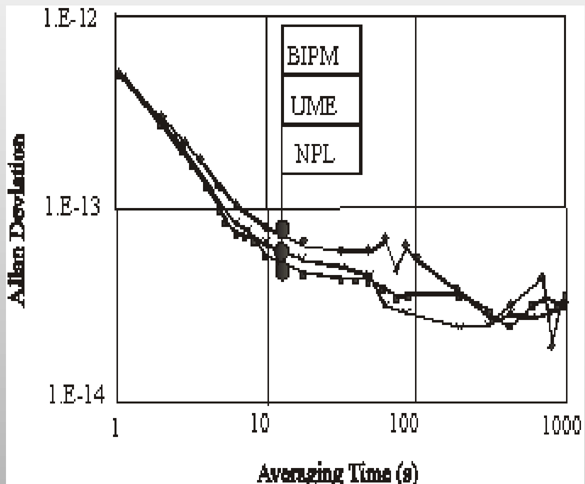
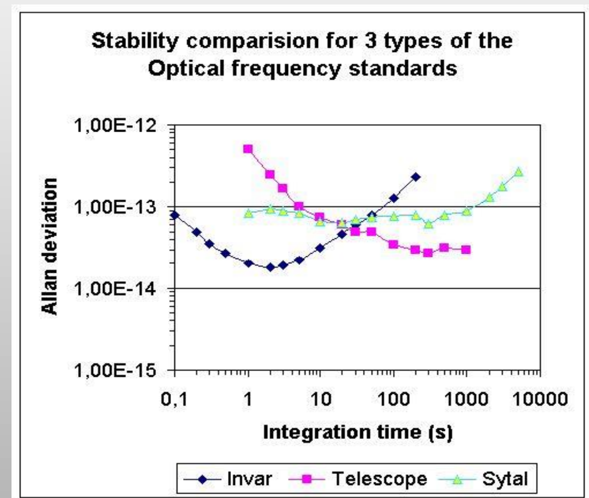
He-Ne/CH_4 Laser, $\lambda = 3390$ nm, $\omega = 88$ THz ± 30 Hz







Stability: 10^{-13} - 10^{-14} (10s – 10 ks)

Reproducibility: ± 30 Hz (3 x 10^{-13})

R. Hamid etal. Laser Physics, Vol.14, No:7, pp. 953-959, 2004

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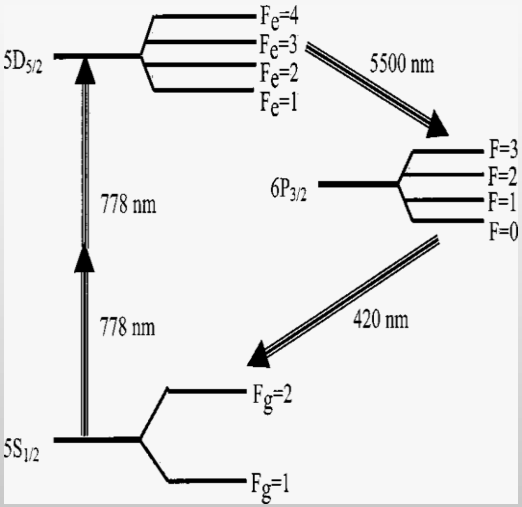
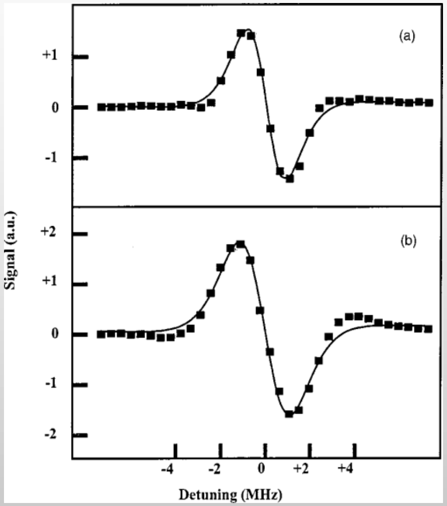
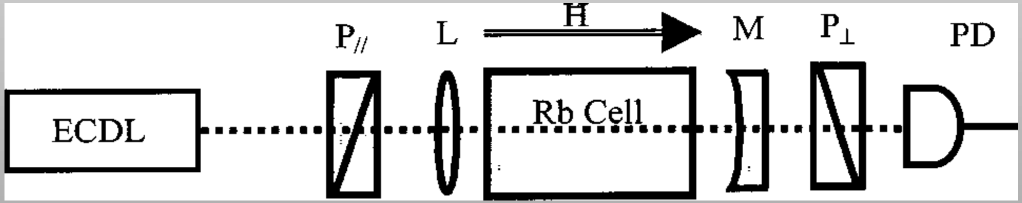
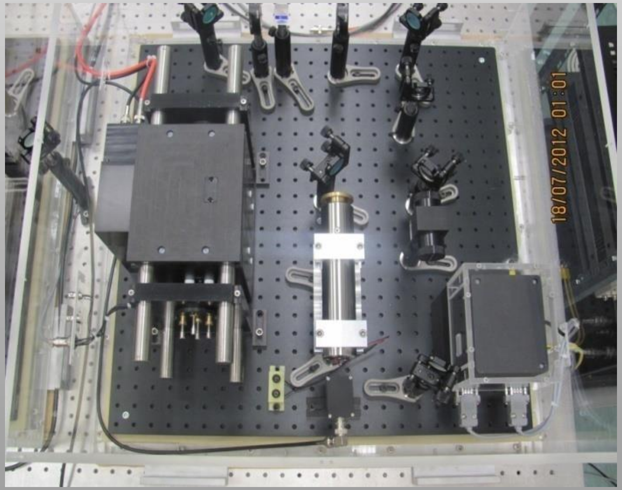
Rb two photon stabilized ECDL laser system (778 nm)

Stabilization of ECDL on S-D two photon transition (778 nm) of Rb atoms
Observation and investigation of Faraday resonances on S-D transition









$\gamma = \gamma_0 + \alpha N$,
$\alpha = (3.53 \pm 0.09) \times 10^{-10}\ cm^3\ Hz$
$\gamma_0 = (1.70 \pm 0.04)$ MHz

R. Hamid et al, Opt. Commun Vol.224, pp. 247-253, 2003
R. Hamid et al, Physical Review A, Vol. 70, pp.025805, 2004

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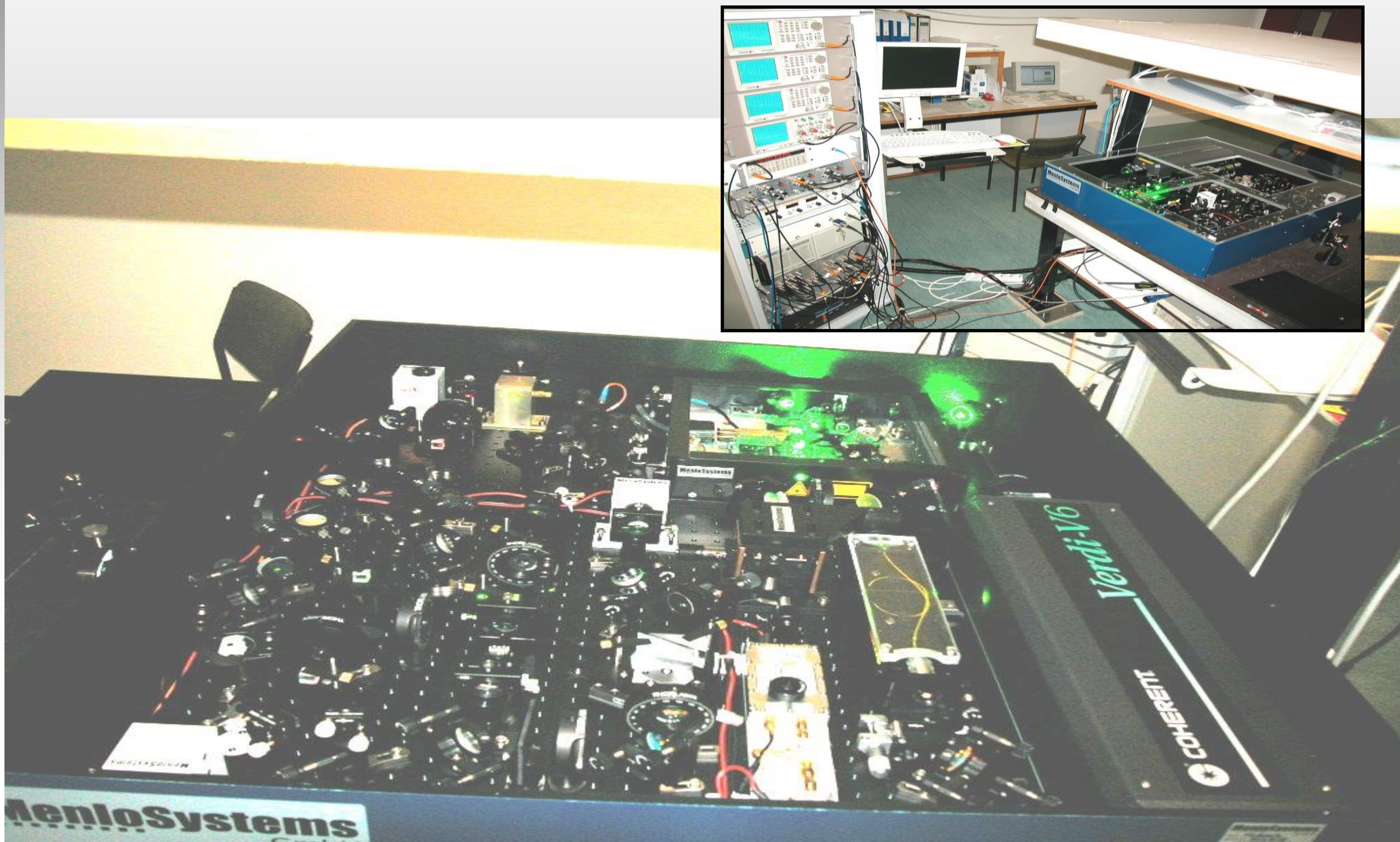
Ti:Sa fs Comb



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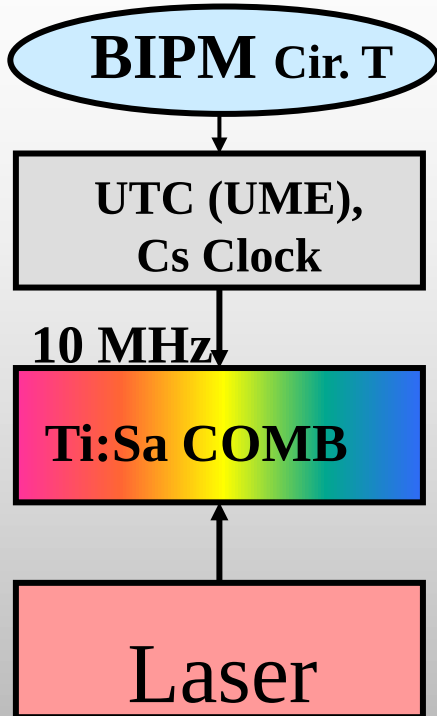
Absolute frequency measurement of He-Ne/I2 laser



UME He-Ne/I_2 (633 nm),

f-component

UME Comb

(473 612 353 601.6 ± 1.1) kHz

BIPM Comb

(473 612 353 602.3 ± 1.1) kHz

Δν(BIPM-UME) =0.4 kHz

$$\frac{\Delta\nu}{\nu} \cong 1\times10^{-12}$$

BEV Comb

(473 612 353 603,69 ± 2,85) kHz

Metrologia, (2006, 2007, 2010, 2015)

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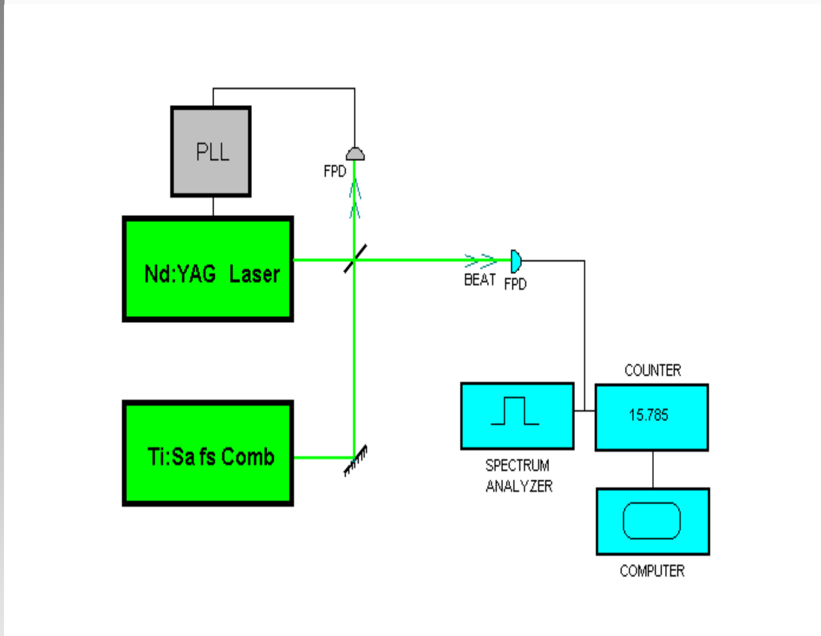
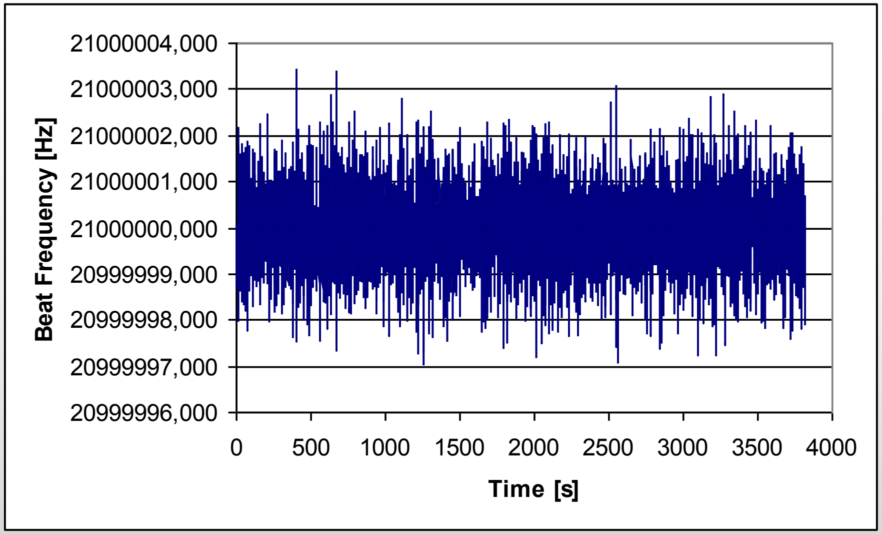
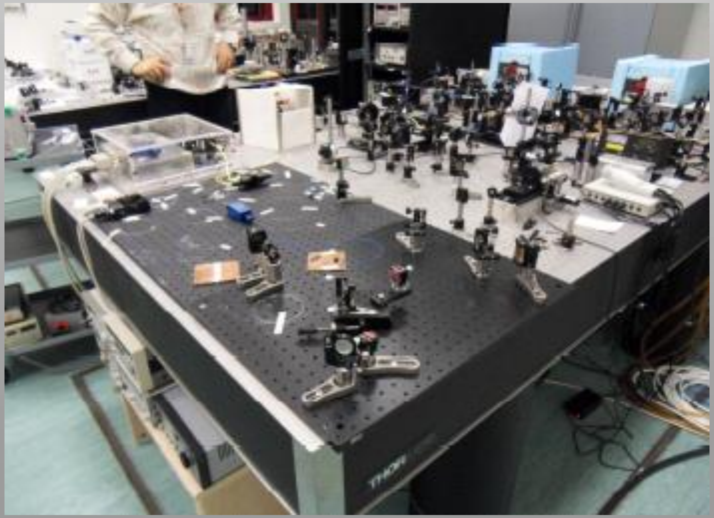
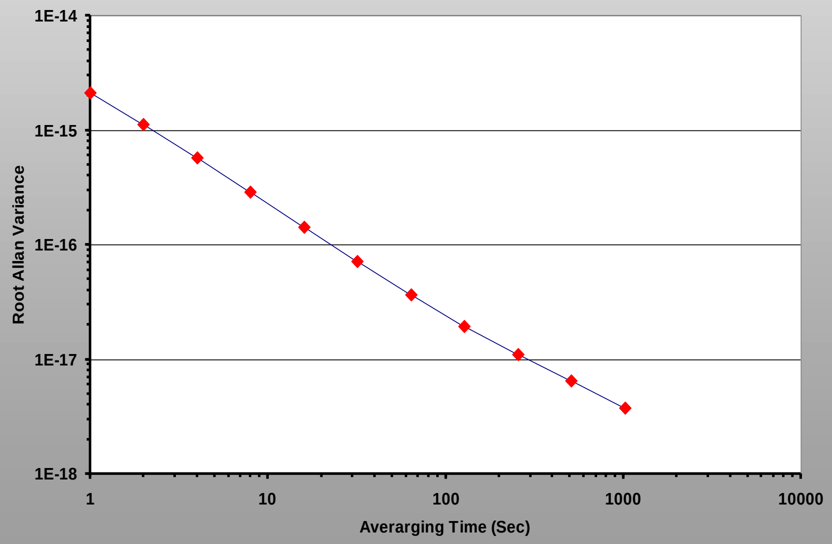
Phase lock of Nd:Yag laser to fs Ti:Sa Comb laser









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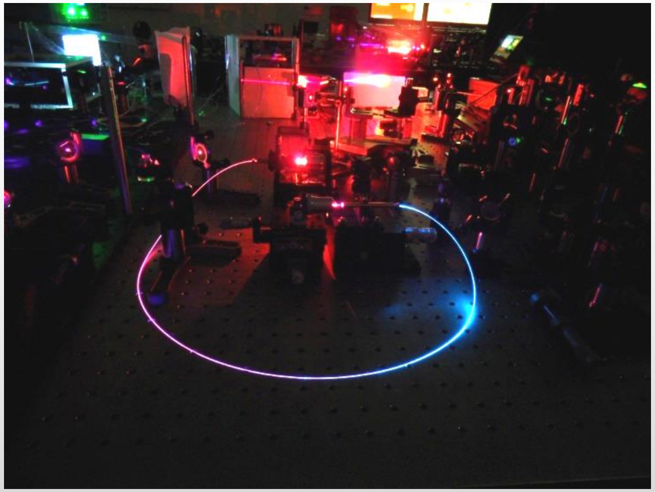
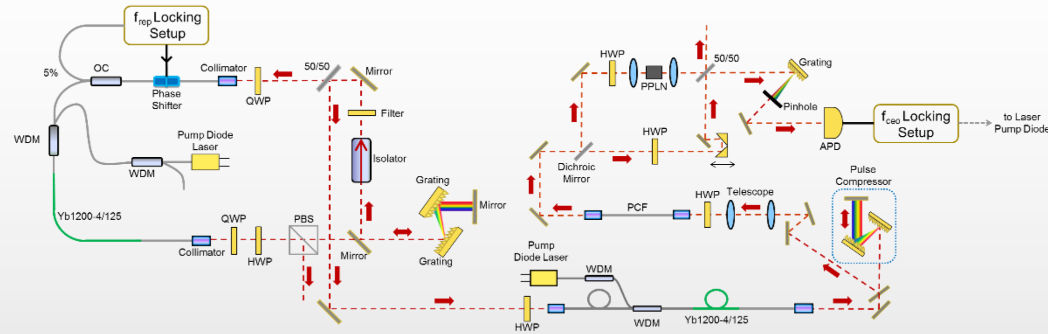
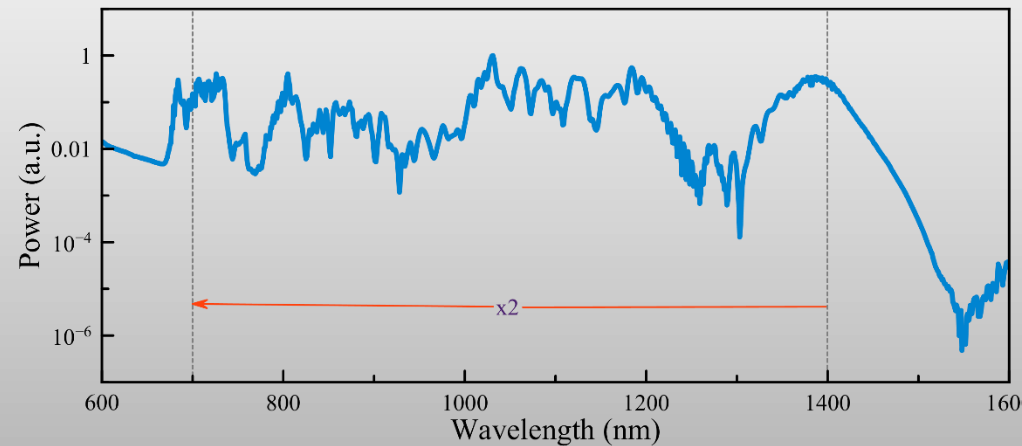
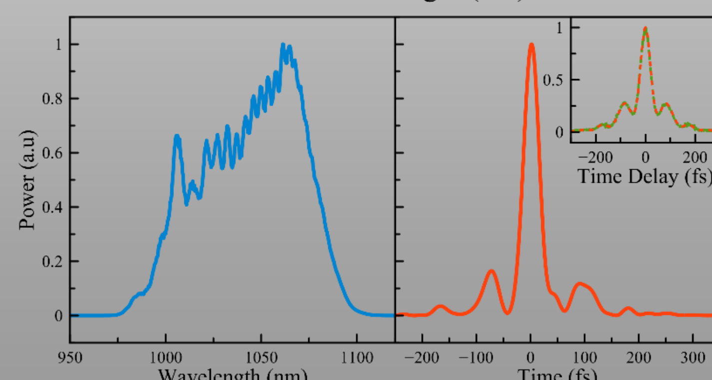
Yb Fiber Comb, 700 nm – 1400 nm





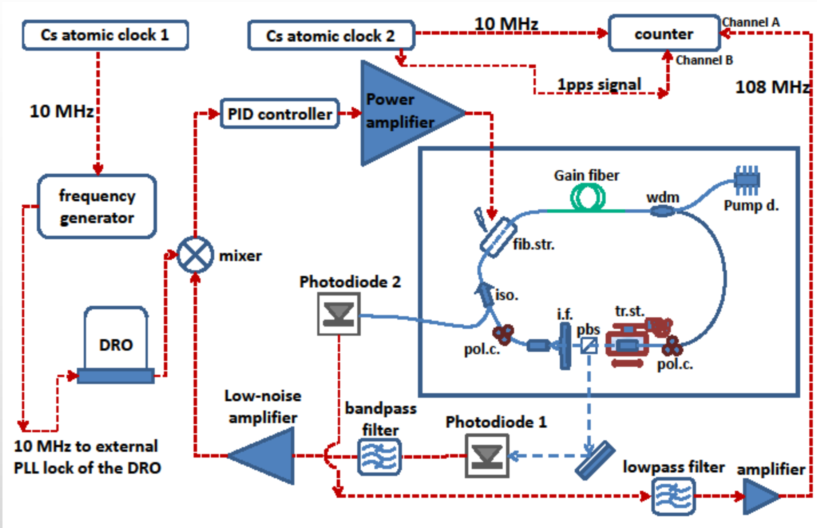


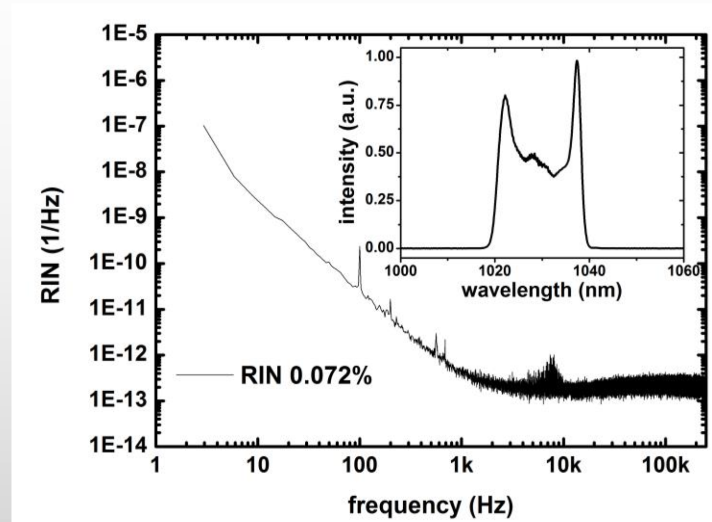


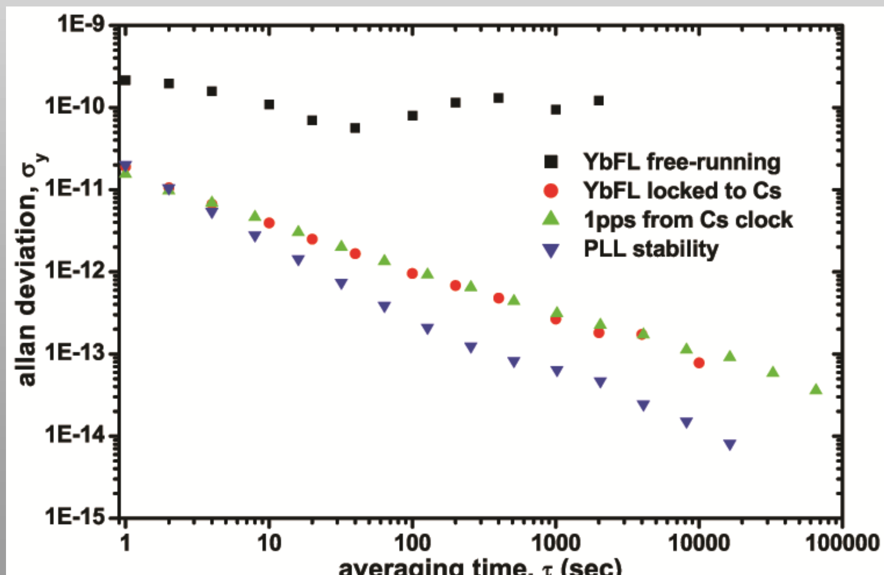
Ç.Şenel, F.Ö.İlday, R. Hamid et al.,CLEO/EUROPE (2013)

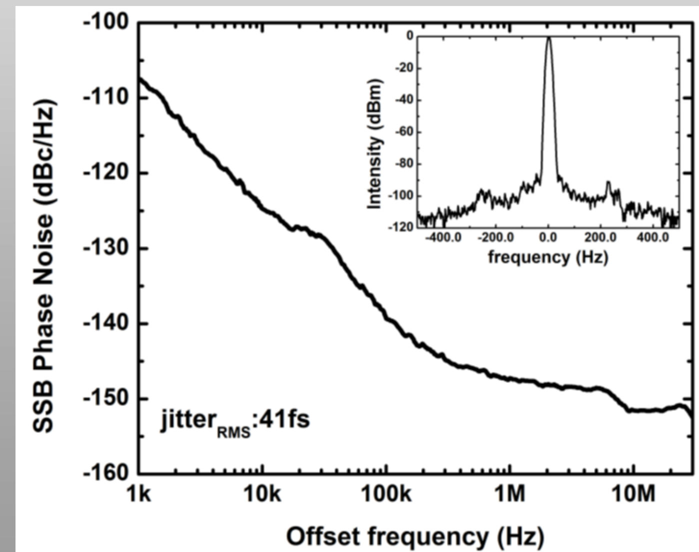
Compressed pulse duration of the laser: 33 fs

Frequency and Intensity Noise of Yb Fiber Laser









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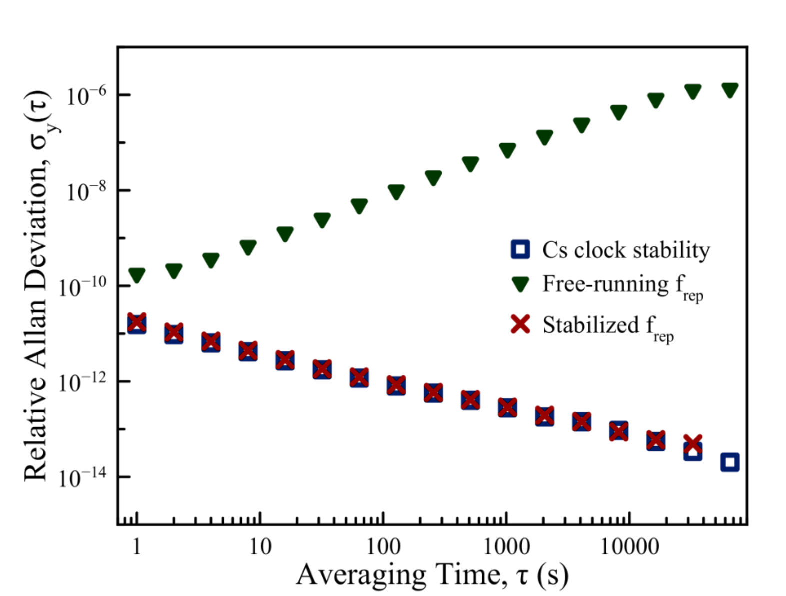
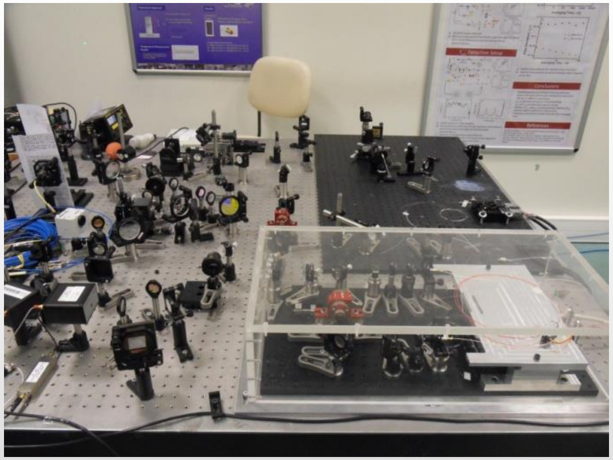
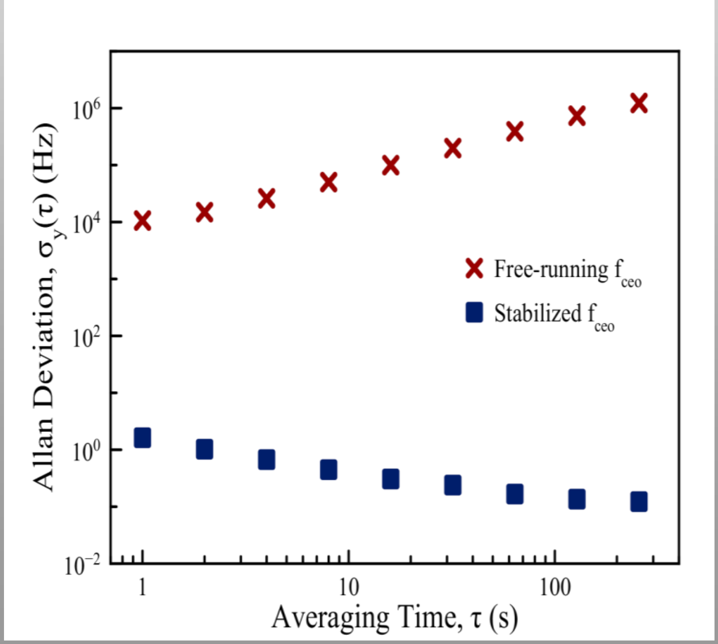
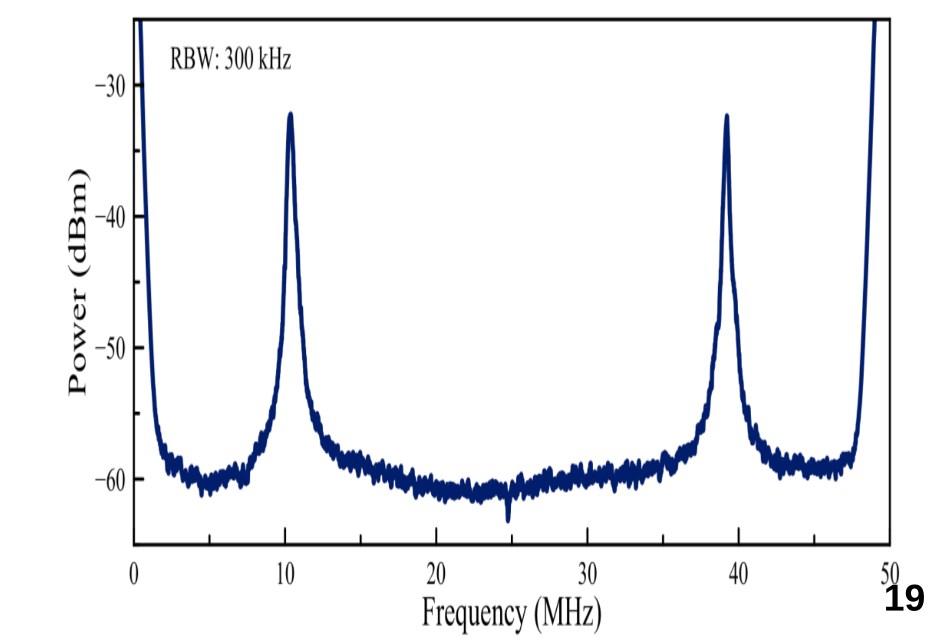
Repetition-Rate and fceo Stabilization



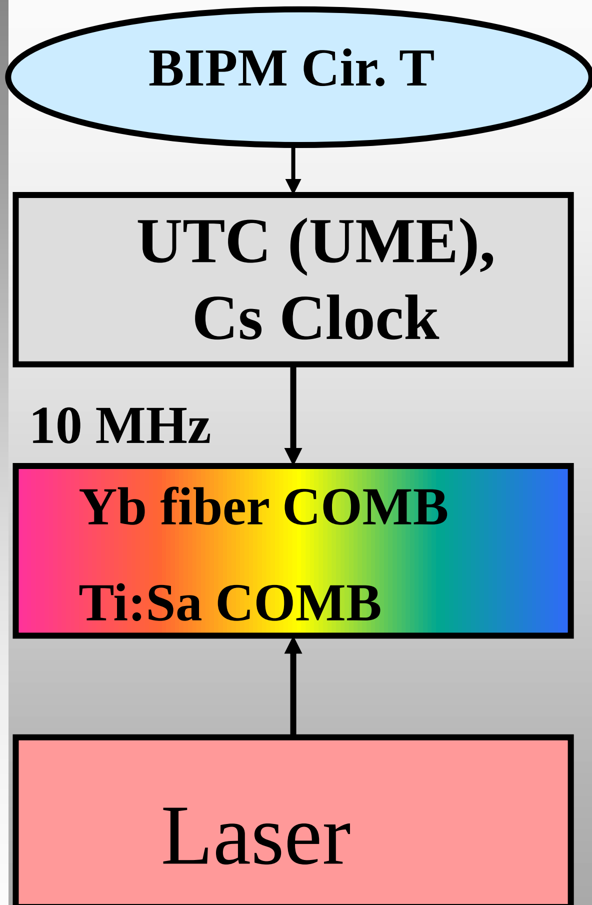


Width @ -20 dB: ~1.2 MHz





Absolute Frequency Measurement of Nd:YAG/I2 Laser



Nd:YAG laser that is stabilized to the a10 line of R(56)32-0 group

CIPM value:

532 nm, (563 260 223 513,0 ± 5,0) kHz

1064 nm, (281 630 111 756 500 ± 5 000) Hz

UME Ti:Sa Comb measurement result

(563 260 223 516,2 ± 5,0) kHz

UME Yb fiber Comb measurement result

(281 630 111 757 442 ± 333) Hz,

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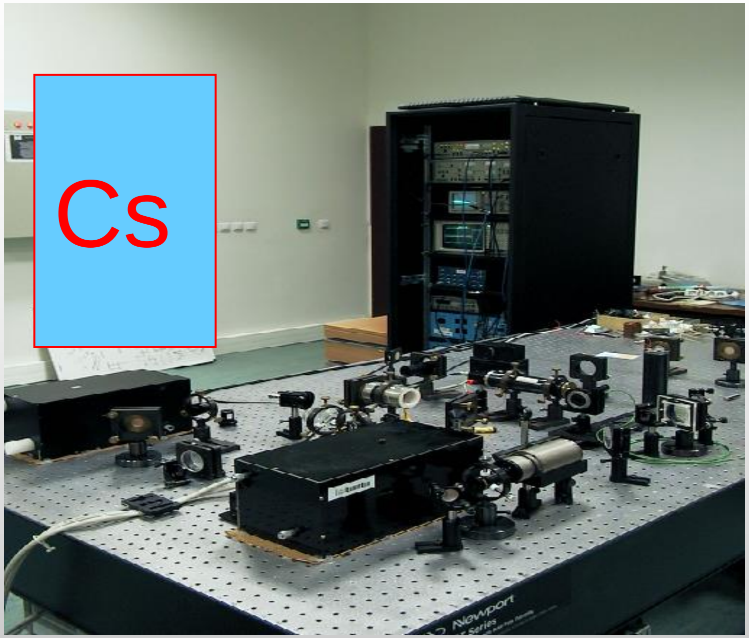
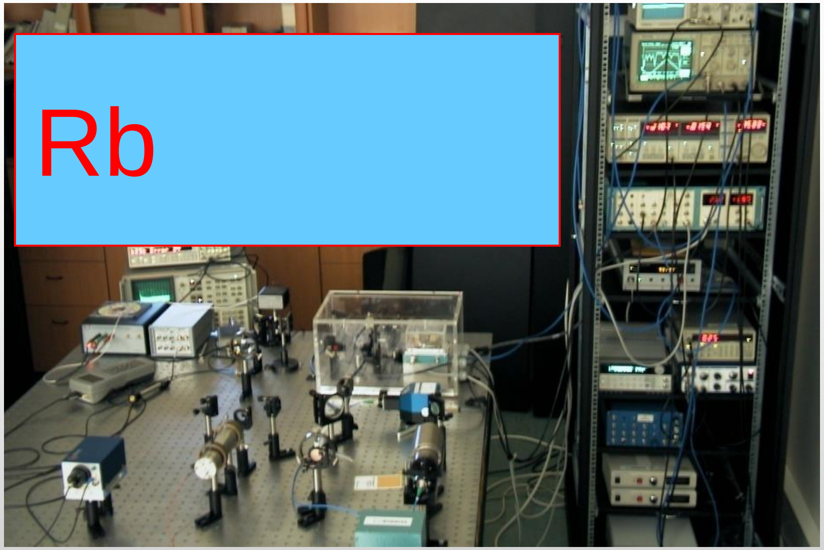
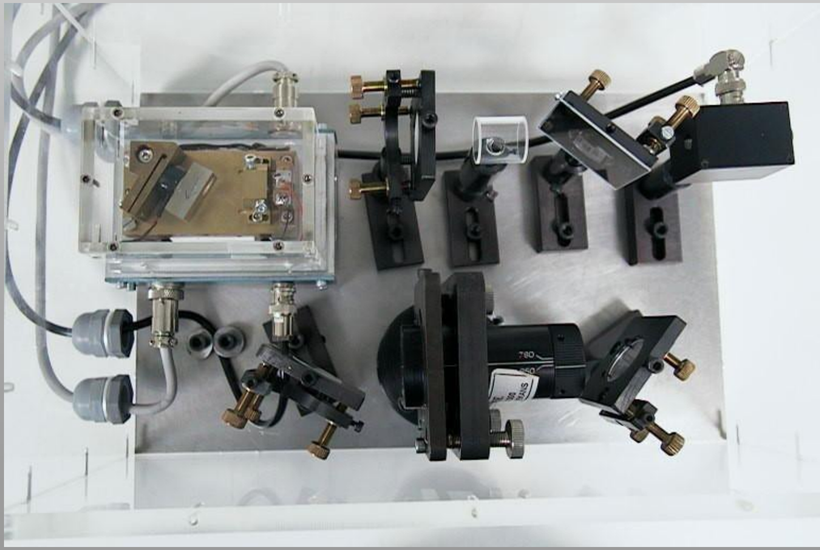
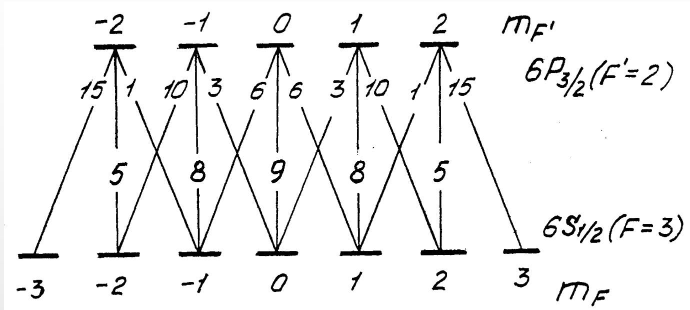
Experimental set-up for laser spectroscopy

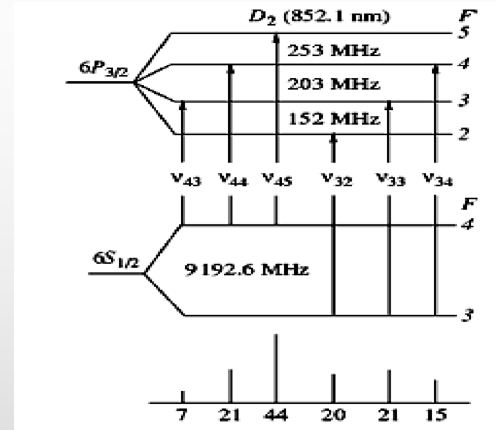


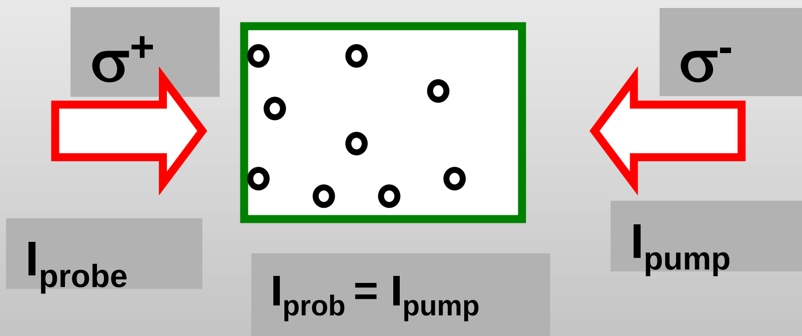




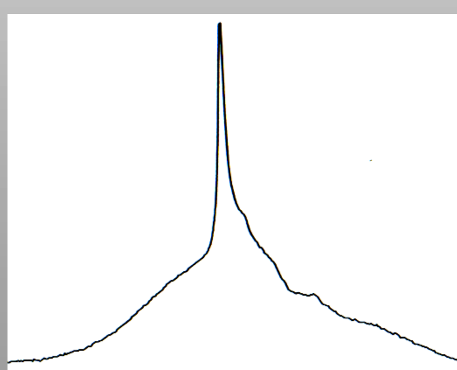
Resonant compensation of optical pumping on Cs atomic cell and laser cooling

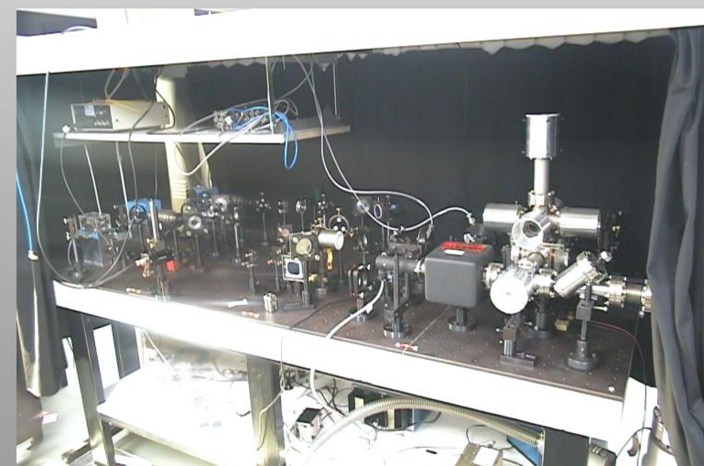






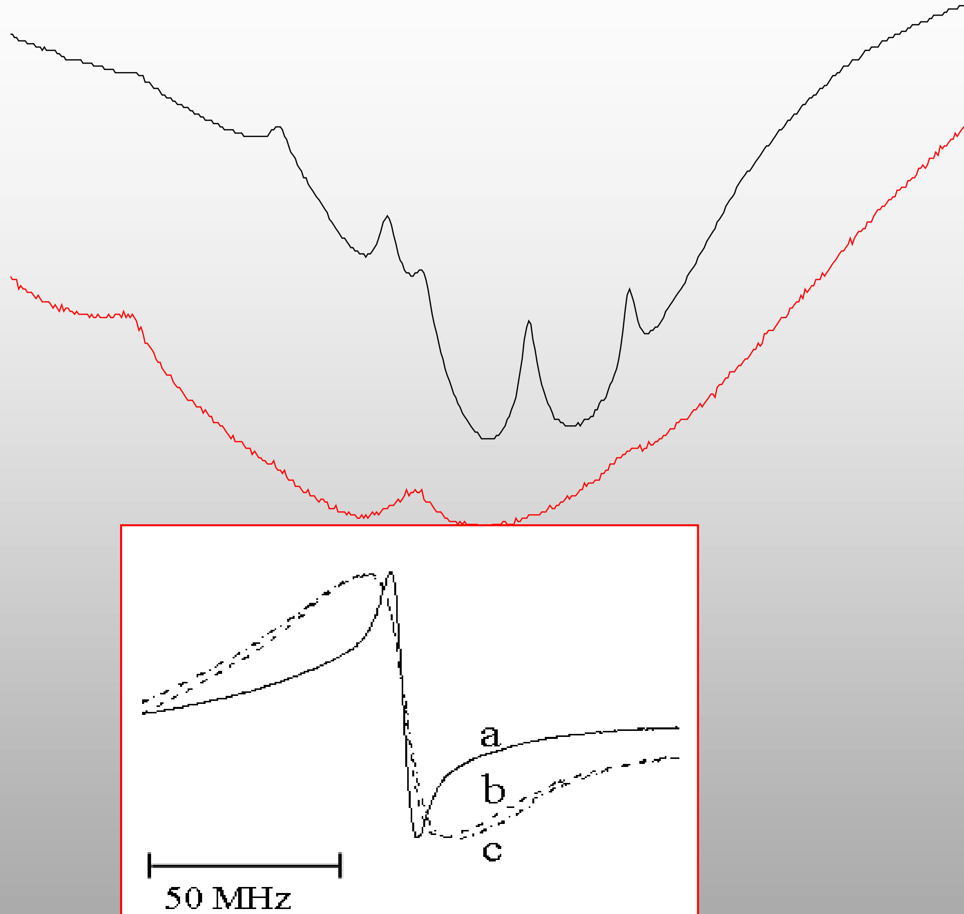
The experimental setup for cooling and trapping of Cs atoms

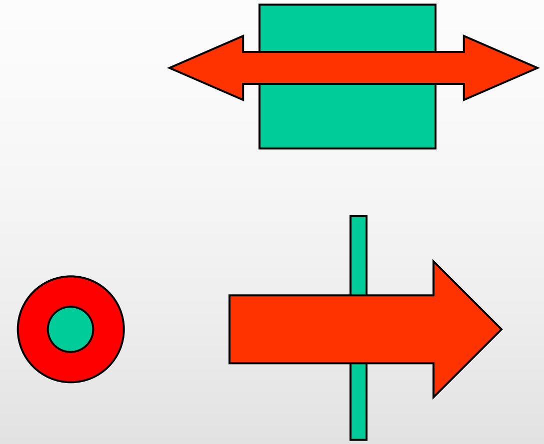




R.Hamid et al. Laser Physics, 1999

Laser spectroscopy on thin cell





Cs Cell length L=5 cm

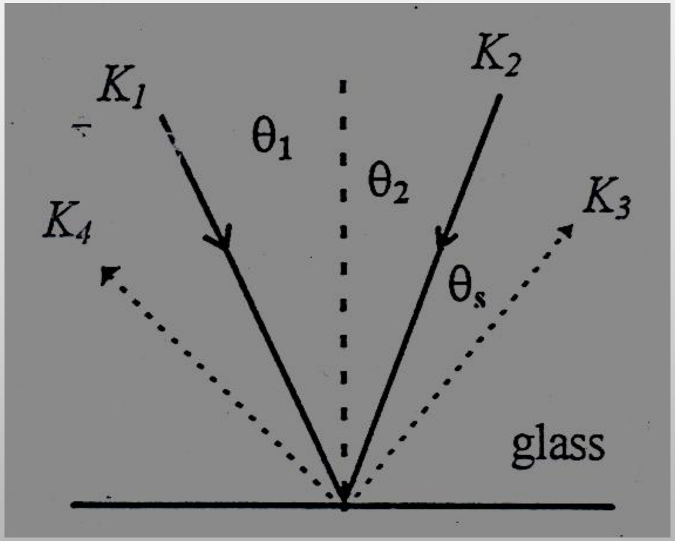
Cs Cell length L=0.12 mm

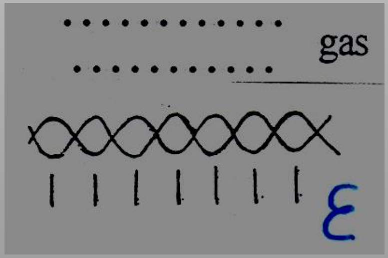
R.Hamid et al. Laser Physics, Vol.16, 2006

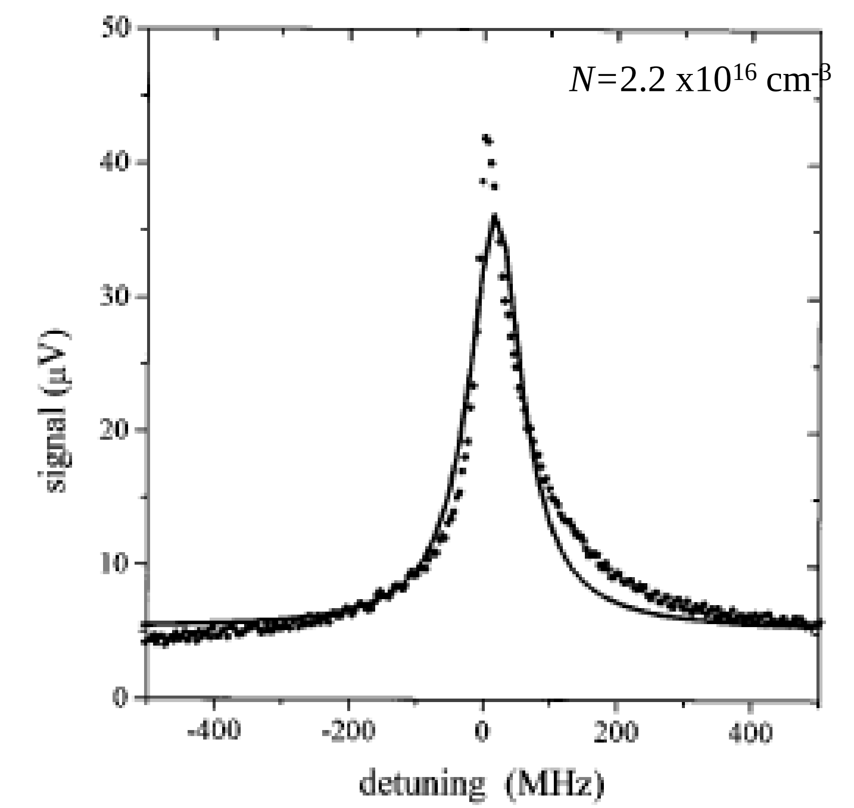
Four-Wave Mixing on atomic gas - glass interface

$$R = \left(\frac{n - \sqrt{\varepsilon}}{n + \sqrt{\varepsilon}} \right)^2$$

$$\varepsilon = 1 + 4\pi (x^{(1)} + x^{(3)} |E_2|^2)$$



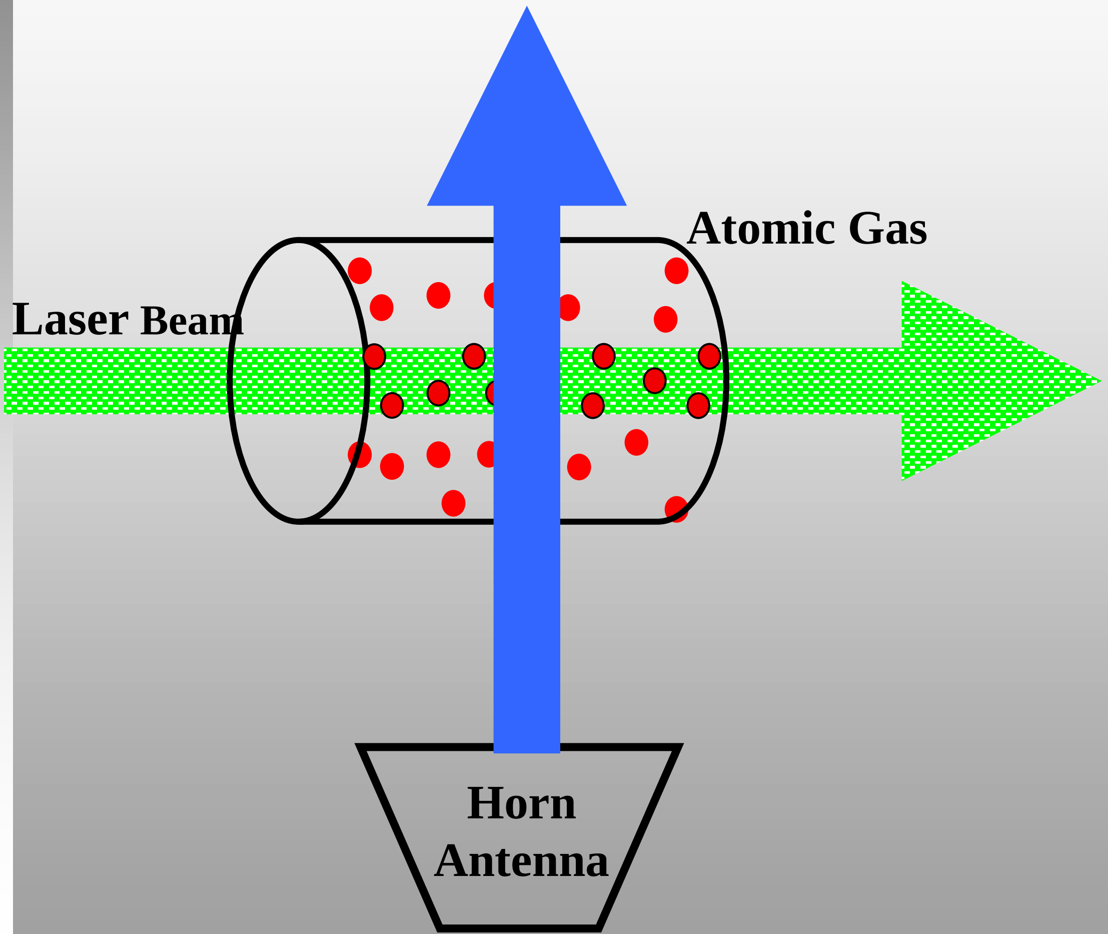


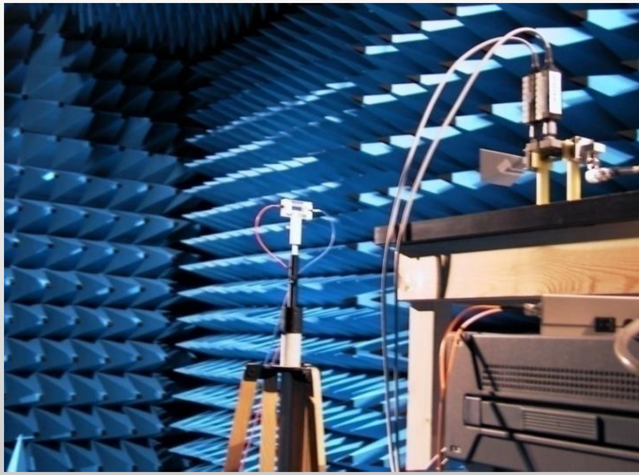


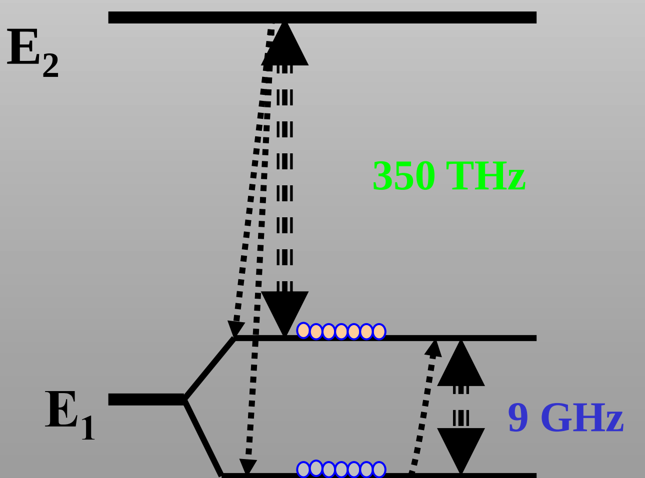
R. Hamid etal, Physical Review A, Vol. 55, N.4, pp. 3137-3142, 1997

EMRP EMF/SAR Project, EM Measurement based on Laser Spectroscopy Techniques

Laser-Atom-Microwave interaction

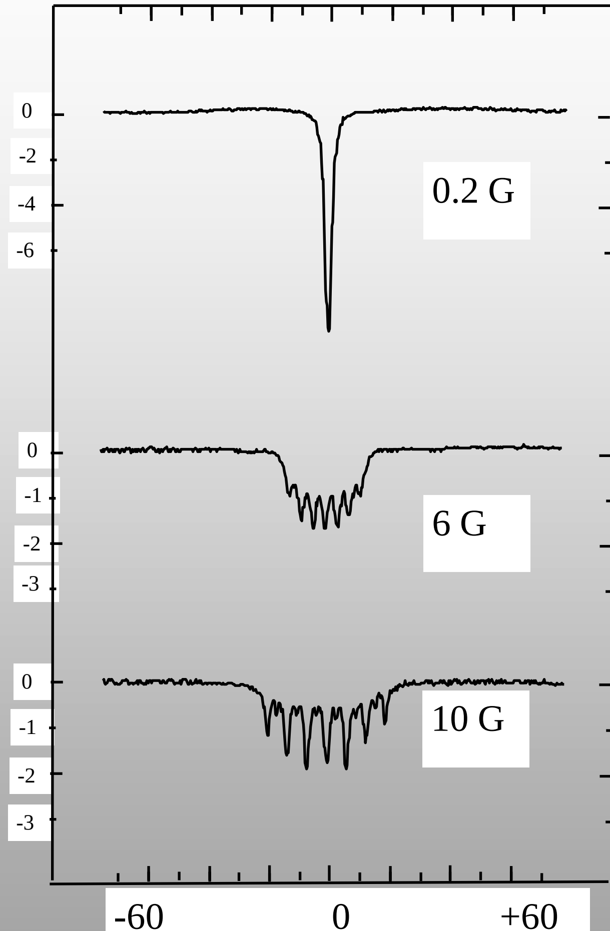


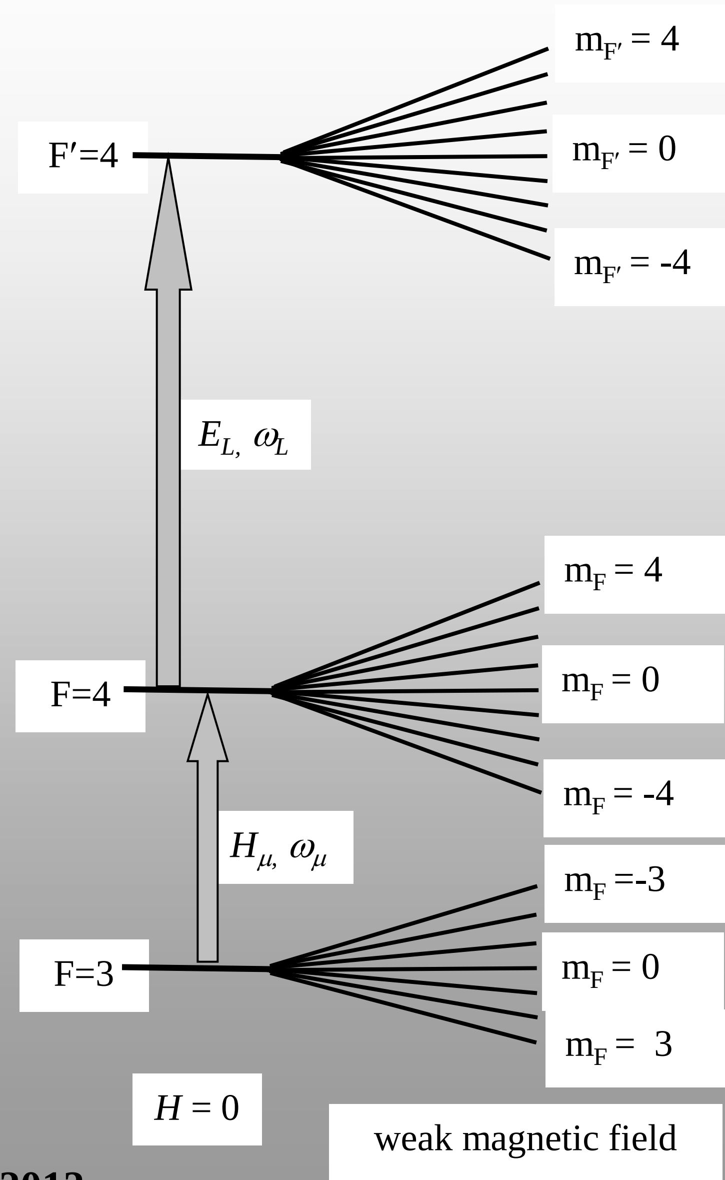




EMRP Project

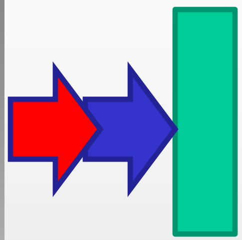
DROR signals detected on Zeeman sublevel

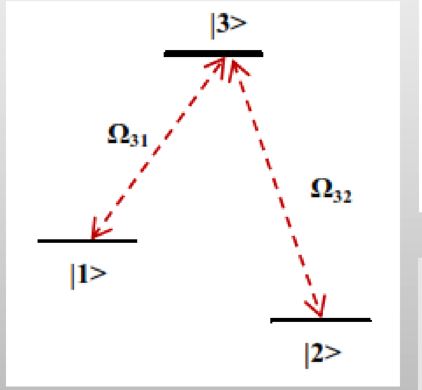


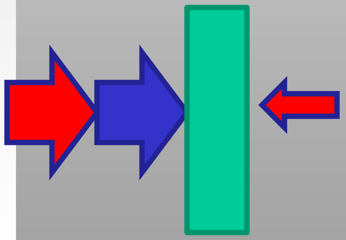


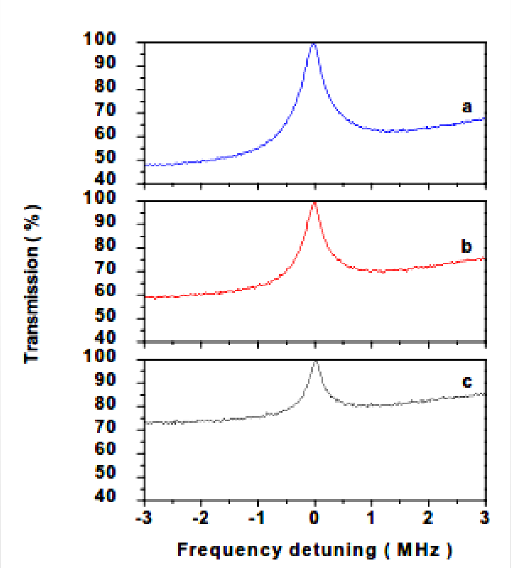
M.Çetintaş, R.Hamid etal, IEEE, 2010, 2011, 2012

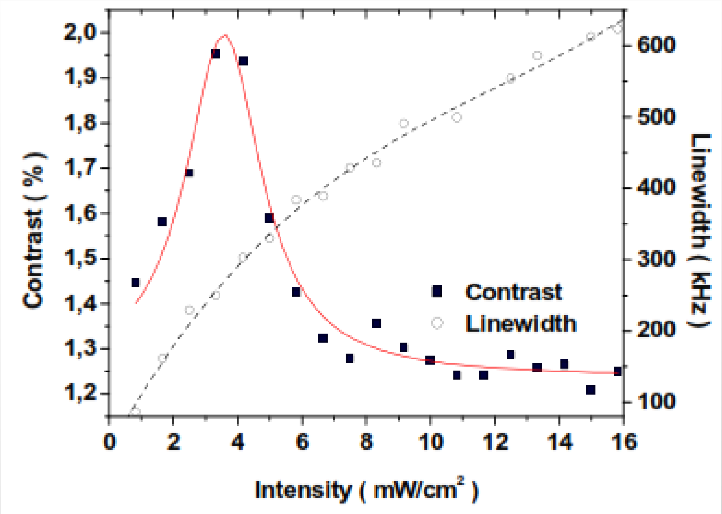
CPT resonances
in two frequency pumping and probe beam in configuration

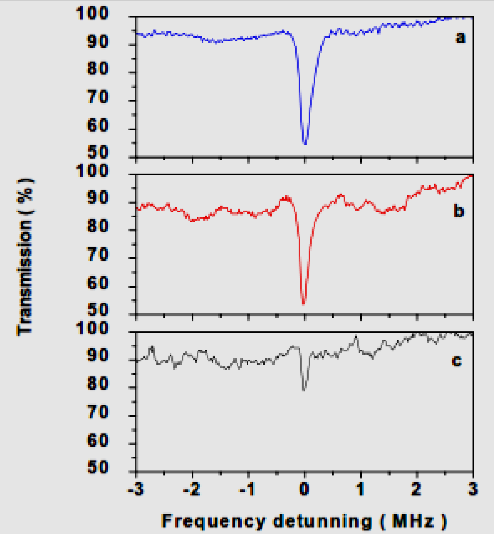


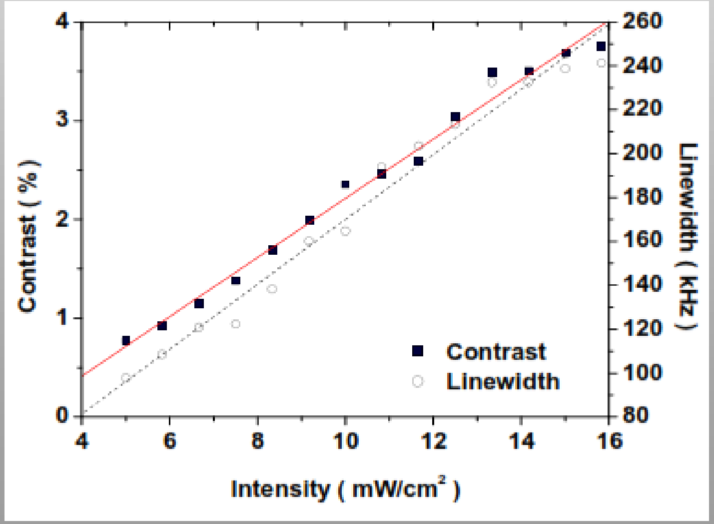












E.Şahin, R.Hamid etal, Laser Physics 2012, Quantum Electronics 2014

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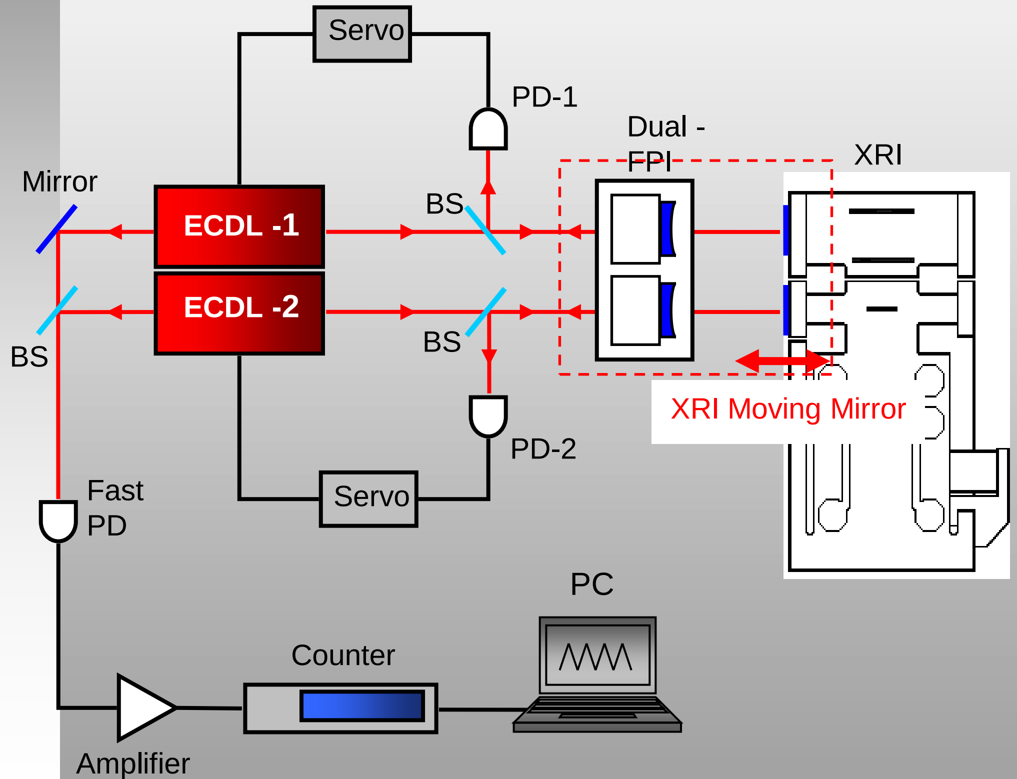
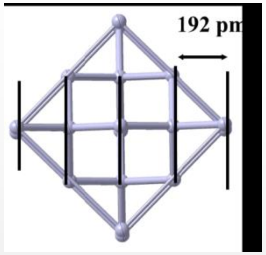
EMRP Project

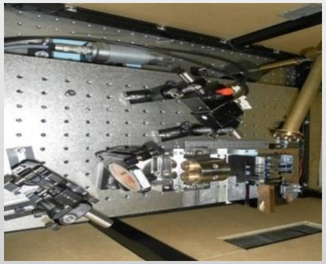
UME optical – NPL X-ray interferometer Comparison

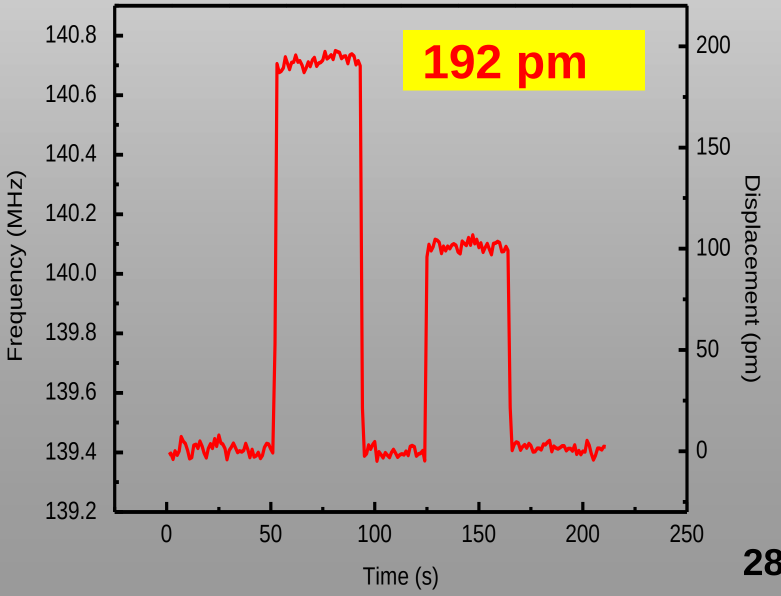
Picometer dicplasement measurement based on frequency measurement of lasers locked on DFPI interferometer

Sensitivity Limit: 1pm/5kHz







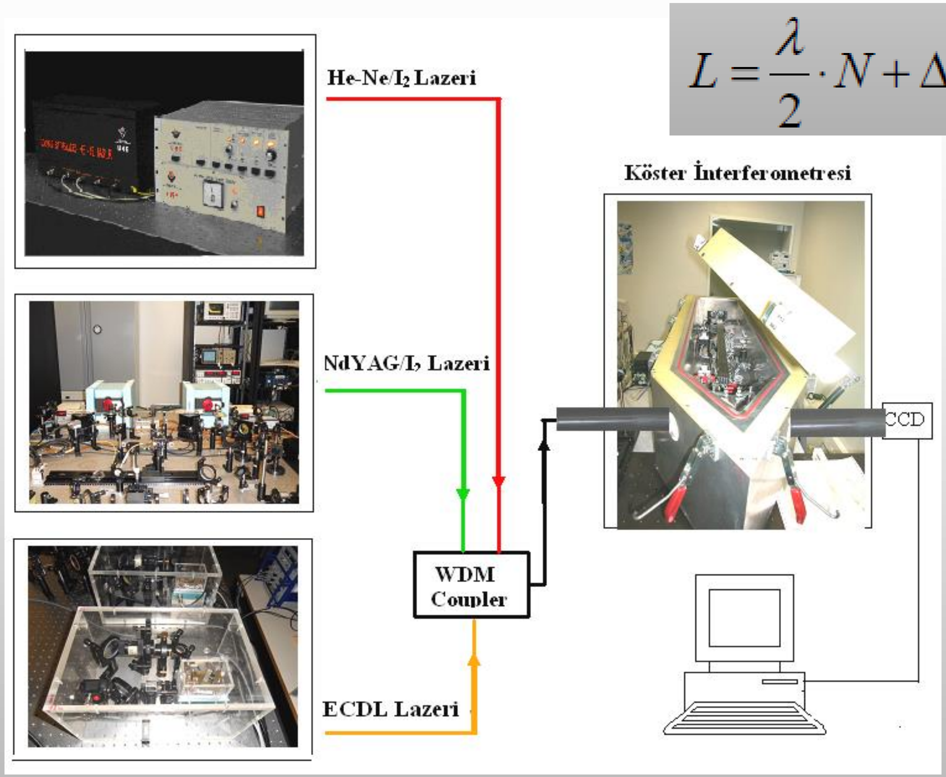


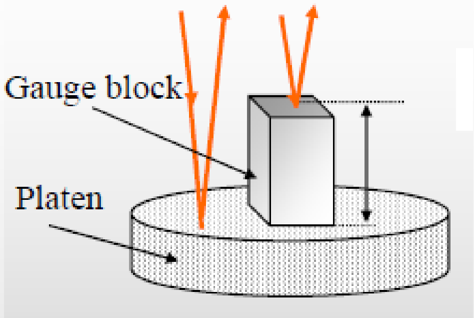
M. Çelik, R.Hamid et al, MST 2012
Metrologia 2012,

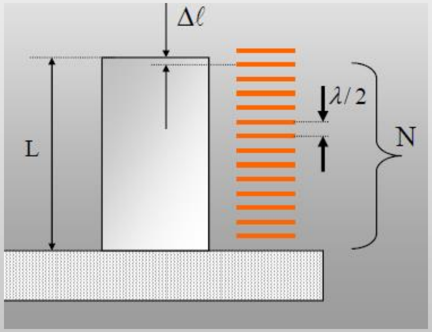
EMRP Project

Laser Wavelength Standards and Köster Interferometer

$$L = \frac{\lambda}{2} \cdot N + \Delta\ell$$







The temperatue fluctuation: **2 mK**

By using home-made developed lasers and Köster Interferometer system, the gauge blocks with lengths between 125 mm - 1000 mm are measured with an uncertainty of (45; 0.19L) nm.

Recently using this system the EURAMET.L-K1.2011 key comparison project was successfully completed

R. Hamid etal, Measurement Science and Technology, Vol. 16, pp. 2201-2207, 2005

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2. Ç. Şenel et.al, Frequency Measurements with Yb-Laser Comb, IFCS-EFTF, USA, 2015
3. U. Tegin et.al, Dissipative solitons generated from a mode-locked Raman Laser, CLEO, 2015
4. E.Şahin et al,Coherent Population Trapping resonances on lower atomic levels of Doppler broadened optical lines, **Quantum Electronics**, Vol 44, No. 11, pp.1071-1076, **2014**
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6. Z. Zhang et al,Sub-50 fs all-fiber Yb-doped laser with anomalous-dispersion photonic crystal fiber, **Optics Letters**, Vol. 38, No.6, pp.956-958, **2013**.
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8. M.Çelik etal,Picometre displacement measurements using a differential Fabry-Perot optical interferometer and x-ray interferometer,**Measurement Science and Technology, Vol. 23, 2012**
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11. S.Çakır et al,Sensing of RF magnetic field using zeeman splitting of double radiooptical resonance and a new approach to helmholtz coil calibration,**IEEE Sensors Journal, Vol.12, 2012**
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14. Ç. Şenel et al, Development and characterization of all-normal dispersion fiber laser for frequency comb generation, Advanced Solid-State Photonics (ASSP), 2011
15. C. Senel et al, All-normal-dispersion fiber lasers for frequency metrology, CLEO, 2011
16. M.Cetintas et al,Characterization of a Far-Field Microwave Magnetic Field Strength Sensor Based on Double Radio optical Resonance,**IEEE** Transactions on EMC, Vol.52, **2010**
17. Matus M.et al,Final report for the period 2007-2009 on the CCL-K11 ongoing key comparison, **Metrologia**, Vol.47, Tech. Suppl., 04009, **2010**
18. C. Ülgüdür et al,Long-Term Repetition-Frequency Stabilization of All-Normal-Dispersion Yb-Doped Fiber Laser to the Cesium Standard, CLEO, 2010
19. M. Çelik et, Sub-nanometer Displacement Measurements using Laser Beat Frequency Technique, Nanoscale 2010

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Conclusion

- **Time scale generation (7 ns)**
- **NTP time dissemination (5 ms)**
- **Automatic calibration system (DC-50 GHz)**

- **Laser Sources in the Optical Spectral Range (532 nm – 3390 nm)**
  Nd:YAG/I2 (532 nm, 1064 nm),
  He-Ne/I_2 (633 nm), He-Ne/CH_4 (3390 nm)
  ECDL/Rb (778 nm, 780 nm, 794 nm), ECDL/Cs (852 nm)
  fs Ti:Sa Comb (530 -1100 nm)
  fs Yb fiber Comb (600 -1500 nm)

- **Laser Frequency Stabilization on Atomic and Molecular Transitions**
- **Laser Spectroscopy**
- **Length and Displacement Measurement with a nm and pm Uncertainty**

- **MW-Atom -RF-Laser Interaction**
- **Measurement of MW Field Using Laser Spectroscopy Technique**

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Thank you for your attention

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