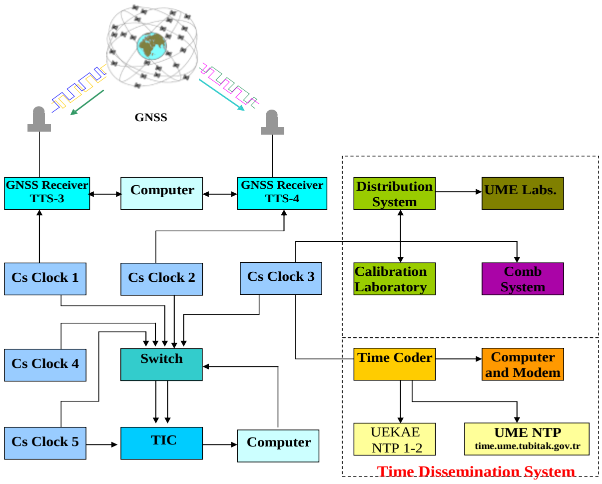
Report of the UME to the 20th Session of the CCTF

Time, Frequency and Wavelength Laboratory
National Metrology Institute (UME) of Turkey

September 1, 2015

1. Time Scale Generation and Traceability

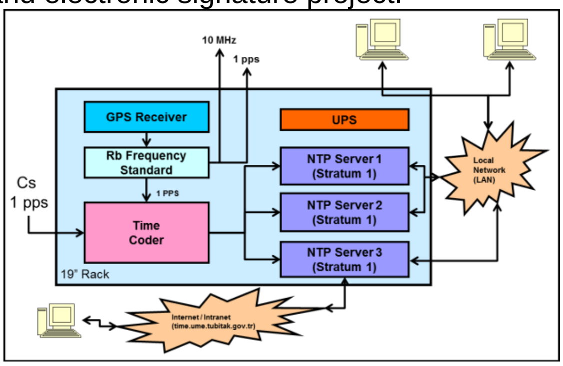
In Time and Frequency Laboratory of UME, time keeping and dissemination systems were developed using commercially available 5 Cs clocks and 2 GNSS receivers. This laboratory is a member of BIPM TAI club since 1994. UTC (UME) time scale is generated with type A uncertainty of 1 ns and type B uncertainty of 7 ns. 10 MHz and 1PPS signal from time keeping system is used as reference for calibration laboratory, time dissemination system and femtosecond frequency comb for laser frequency measurements (Figure 1).



Time Keeping and Dissemination System

2. Time Dissemination

Time Dissemination System was developed for distribution of generated time from Cs atomic clocks among local area networks (LANs), wide area networks (WANs), and internet/intranet by using of network time protocol (NTP) at stratum - 1 level. By using this system, time dissemination is realized with an uncertainty better than 5 ms for LAN and better than 50 ms for WAN. Developed NTP Time Dissemination System include local Rb frequency standard and simple GPS receiver for initial time synchronization. This system is used in the national time stamp and electronic signature project.



NTP Time Dissemination System

3. Calibration and Measurement Capability

In time and frequency laboratory of UME, the calibration systems (DC-50 GHz) for calibration of atomic clocks, frequency counters, signal generators, spectrum analyzers have been developed. Rise time calibration of high frequency oscilloscope realised by using femtosecond Er fiber laser and 100 GHz photodiode. Cable delay is measured with an uncertainty better than 10 ps using fs laser calibrated 50 GHz oscilloscope. Absolute frequency measurement of frequency stabilised lasers is measured by fs Ti:Sa and fs Yb comb which are externally triggered from Cs clock. The measurement capabilities of time and frequency laboratory of UME are given below:

Frequency Measurements:

DC-2 GHz ($\pm 1x10^{-11}$ x f Hz)
2 GHz - 50 GHz (±1 Hz)
530 nm - 1100 nm (±100 Hz)

Time Measurements:

Local Clock < ± 20 ns (1 day average)
Remote Clock < ± 50 ns (1 day average)

Time Interval Measurements:

3 ps - 100 ns (±10 ps)
1 ns - 10^{10} s (±100 ps)

4. Frequency Stabilized Lasers

In the Time, Frequency and Wavelength laboratory of UME, different pairs of lasers have been developed and they have been stabilized to the Rb (780 nm, 778 nm) and Cs (852 nm) atomic transitions, I_2 (532 nm, 633 nm) and CH_4 (3390 nm) molecular transitions with an instability of $1x10^{-11}$ - $1x10^{-14}$ for averaging time 1 s – 10 ks. The parameters influencing the frequency of the He-Ne/I_2, He-Ne/CH_4 gas lasers, Nd-YAG/I_2 solid state laser and the ECDL/Rb, Cs semi-conductor lasers have been investigated and analyzed. The photograph of developed Rb S-D (778 nm) 2 photon stabilized ECDL system is given below. Recently Cs atomic clock stabilized 33 femtosecond Yb fiber comb have been developed and used for absolute frequency measurements. A new Yb fiber laser and amplifier were designed for generation of very short pulses. The laser operates at net-zero cavity dispersion and produces pulses that are compressed to 33 fs outside the laser cavity. Laser’s noise performance is characterized by relative intensity noise and phase noise measurements. A Cs clock stabilized Yb frequency comb that covers the spectral region of 700 nm -1400 nm is produced using the developed laser and used for absolute frequency of a stabilized Nd:YAG/I_2 laser.

2 ECDL laser systems stabilised on S-D two-photon transition of Rb atoms

5. High-Resolution Laser Spectroscopy

Using the frequency tuneable lasers, selective reflection on the D_2 line of Cs atoms, wave mixing, laser pressure on the resonances, optical pumping on the Zeeman levels, coherent population trapping effects have been investigated. Free space microwave-atom-laser interaction and radio-optical coherent resonances have been investigated. Research on the polarization and Faraday effects on the S-D 2-photon-transitions of Rb atoms have been carried out. Influence of the light intensity and gas pressure on the absorption resonances of the I_2 and CH_4 molecules have been investigated. Recently coherent population trapping resonances on Cs atomic levels was investigated in pump-probe beam configuration.

6. Absolute Frequency Measurements of Stabilized Lasers with Femtosecond Comb

Absolute frequency of frequency stabilized He-Ne/I_2, Nd-YAG/I_2 and ECDL/Rb, Cs lasers was measured by femtosecond Ti:Sa comb (530 - 1100 nm) that is externally triggered by the 10 MHz signal of Cs atomic clock. In the laboratory Yb fiber based femtosecond comb working in the 700 nm - 1400 nm range and generating 33 fs pulses has been developed. The repetition and offset frequency of the developed Yb comb system has been locked to the 10 MHz reference signal of Cs atomic clock.

Yb fiber based femtosecond comb and supercontinium spectrum generation in PCF

The absolute frequency of the He-Ne/I_2 (633 nm) stabilized on the f line of the iodine molecules has been measured by using UME Ti:Sa comb (473 612 353 600.6 ± 1.1 kHz) and BIPM Ti:Sa comb (473 612 353 602.0 ± 1.1 kHz).

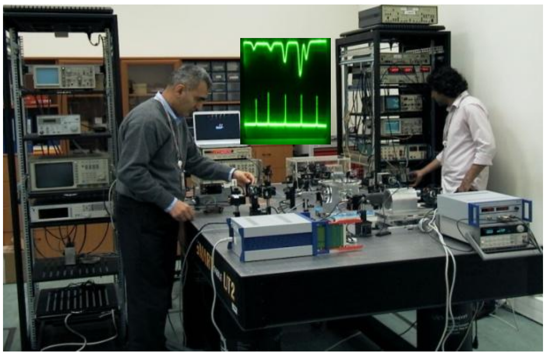
Absolute frequency of developed ECDL lasers which are locked to the Cs (852 nm) and Rb (780 nm) D_2 atomic lines, 2-photon S-D lines of Rb atoms (778 nm) was measured by using Ti:Sa comb.

Recently frequency of the Nd:YAG/I_2 laser which is stabilized on a_{10} line of R(56)32-0 transition I_2 gas is measured by using home-made Yb fiber comb. All laser and gas parameters are set to the values that are recommended by CIPM. For averaging time of 445 seconds, the absolute frequency of the 1064 nm output of the Nd:YAG/I_2 laser is measured as (281 630 111 737 442 ± 333) Hz, which is within the limits given by CIPM.

7. Length Measurement using stabilized Lasers and Köster Interferometer

Köster Interferometer is a system which can measure the length of the gauge blocks with a resolution of 10^{-9} meter. In this system the laser beams from three different stable lasers are transferred with fiber cables into the interferometer where the gauge block is placed. The interference fringes observed at the CCD camera are analyzed and the lengths of the gauge blocks are obtained. 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.

8. Sub-nanometer Displacement Measurement Based on Frequency Measurement Technique



TUBITAK UME time, frequency and wavelength laboratory within the European Metrology Research Programme (EMRP) projects Nanotrace, Sub-Nano and Angle, developed differential Fabry-Perot interferometer and laser system and applied to small displacement and angle measurements with 10 pm an 1 nrad uncertainty. All displacement and angle measurements based on beat frequency measurements technique of stabilized lasers. UME differential Fabry - Perot interferometers have been compared with the NPL x-ray interferometer generating traceable reference displacements. The half and one fringe (192 pm) displacements of the x-ray interferometer have been measured with an accuracy of less than 5 pm with the developed system.

9. EMRP Projects

- Compact and high-performing microwave clocks for industrial applications
- Angle Metrology
- Traceability of sub-nm length measurements
- NANOTRACE-New Traceability Routes for Nanometrology
- EMF&SAR Traceable Measurement of Field Strength and SAR for the Physical Agents Directive

10. Publication List

Peer-Reviewed Journals

1. R.G. Gamidov, A.Ch. Izamailov, H.Uğur,
On the structure of sub-Doppler absorption resonances on an atomic transition from a ground degenerate level,
Optics and Spectroscopy, Vol.77, N. 1, pp.6-10, 1994,

2. R.G. Gamidov, İ.Taşkın, M.Çetintaş, V.Sautenkov
Unmodulated external-cavity diode laser stabilized on cesium D2 line,
IEE Proc. Science, Measurement and Technology, Vol. 143, N.4, pp.263-264, 1996.

3. V.A. Sautenkov, R.G. Gamidov, A.Weis,
Observation of narrow resonances inside homogeneously self-broadened lines in pump-probe reflection experiments,
Physical Review A, Vol. 55, N.4, pp. 3137-3142, 1997.

4. R.G. Gamidov, A.Ch. Izmailov, and M. Çetintaş,
On the influence of laser beams diameters on Sub-Doppler resonances of the saturated absorption,
Laser Physics, Vol.9, No.3, pp.672 - 679, 1999.

5. Ramiz Hamid (Gamidov), Mustafa Cetintas, Mehmet Celik
Polarization resonance on S-D two photon transition of Rb atoms,
Optics Communications, Vol.224, pp. 247-253, 2003.

6. R. Hamid, C. Erdogan, E. Sahin, G. Kramer, B. Lipphardt, D.A. Tyurikov
Comparative Characterization of the Different Methane Stabilized Optical Frequency Standards and Absolute Frequency Measurements,
Laser Physics, Vol.14, No:7, pp. 953-959, 2004.

7. R.Hamid, M. Cetintaş, M. Celik,
Observation of Faraday resonances on the S-D two-photon transition of Rb atoms,
Physical Review A, Vol. 70, pp.025805-1-025805-4, 2004.

8. R. Hamid, D. Şendoğdu, C. Erdogan,
Temperature Stabilization and Temperature Measurement of Köster Interferometer,
Measurement Science and Technology, Vol. 16, pp. 2201-2207, 2005.

9. R. Hamid, E. Şahin, M. Celik, G. Özen, M. Zucco, L. Robertsson, L.S. Ma,
10-12 level reproducibility of an iodine stabilized He-Ne laser endorsed by absolute frequency measurements in the BIPM and UME,
Metrologia, Vol. 43, pp.106-108, 2006.

10. R. Hamid, M. Celik, E.Sahin, A.Izmailov,
Sub-Doppler absorption resonances of the ring shaped laser beams in the thin vapor cell
Laser Physics, Vol.16, No:10, pp.1-4, 2006.

11. L. Robertsson, R. Felder, F. Bertinetto, P. Cordiale, J.P. Wallerand, H. Suh, H. Hussein, R. Hamid, E. Sahin
BIPM, INRIM, LNE-INM/CNAM, KRISS, NIM, UME Results from the CII-2006 campaign at the BIPM of the BIPM.L-K11 ongoing key comparison
Metrologia, Vol. 44, Tech. Suppl., 04003, 2007.

12. L. Robertsson, M. Zucco, R. Felder, L.-S. Ma, J. Quin, X. Liu, Z. Liu, H. Inaba, J. Ishikawa, R. Hamid
BIPM, NIM, AIST/NMIJ, UME Results from additional measurements carried out within the BIPM.L-K11 ongoing key comparison
Metrologia, Vol. 44, Tech. Suppl., 04004, 2007.

13. Matus M., Nyholm K., Madej A.A., Bernard J.E.,Walczuk J., Crepinsek Lipus L., Castillo H.A., Pichardo Vega R., Bastida K.B., Griselda Mingolla M., Malinovski I., Tarelho L., França R., Hamid R., Sahin E., Katic M., Simunovic V., Robertsson L.
Final report for the period 2007-2009 on the CCL-K11 ongoing key comparison,
Metrologia, Vol. 47, Tech. Suppl., 04009, 2010.

14. M.Cetintas, R.Hamid, O.Sen, S.Cakır
Characterization of a Far-Field Microwave Magnetic Field Strength Sensor Based on Double Radio-optical Resonance
IEEE Transactions on Electromagnetic Compatibility, Vol.52, No:1, pp.21-31, 2010.

15. S.Çakır, R.Hamid, L.Sevgi
Loop-Antenna Calibration
IEEE Antennas and Propagation Magazine, Vol. 53, No. 5, pp.243-254, 2011.

16. M. Çetintaş, S. Çakır, R. Hamid, O. Şen,
Towards absolute measurements of far-field microwave magnetic field by atomic sensor based on Double Radiooptical Resonance,
IEEE Transactions on Electromagnetic Compatibility, Vol.54, No.1, pp.225-227, 2012.

17. S.Çakır, R.Hamid, M.Çetintaş, G.Çakır, O.Şen
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, No.7, pp.2465-2473, 2012.

18. E.Şahin, R.Hamid, C. Birlikseven, G. Özen, A.Ch.Izmailov
High contrast resonances of the coherent population trapping on sublevels of the ground atomic term,
Laser Physics, Vol.22, No.6, pp.1038-1042, 2012.

19. M.Pisani, A.Yacoot, P. Balling, N. Bancone, C. Birlikseven, M. Çelik, J. Flügge, P. Kochert, U. Kuetgens, G.B.Picotto, M. Tedaldi, P. Kren, A. Lassila, R. Hamid, E. Şahin, J. Seppä, C. Wiechert,
Comparison of the performance of the next generation of optical interferometers,
Metrologia, Vol. 49, pp.455-467, 2012.

20. M.Çelik, R.Hamid, U. Kuetgens, A.Yacoot,
Picometre displacement measurements using a differential Fabry-Perot optical interferometer and x-ray interferometer,
Measurement Science and Technology, Vol. 23, pp. 085901(6pp), 2012.

21. Z. Zhang, Ç. Şenel, R. Hamid, F.Ö. Ilday
Sub-50 fs all-fiber Yb-doped laser with anomalous-dispersion photonic crystal fiber,
Optics Letters, Vol. 38, No.6, pp.956-958, 2013.

22. E.Şahin, G. Özen, R.Hamid, M.Çelik, A.Ch.Izmailov
Coherent Population Trapping resonances on lower atomic levels of Doppler broadened optical lines,
Quantum Electronics, Vol 44, No. 11, pp.1071-1076, 2014

23. K. Gürel, P. Elahi, L. Budunoğlu, Ç. Şenel, P. Paltani, and F. Ö. Ilday
Prediction of pulse-to-pulse intensity fluctuation characteristics of high power ultrafast fiber amplifiers,
Applied Physics Letters, vol. 105, No. 1, 2014

Conference Proceedings

1. R.G. Gamidov, İ.Taşkın, M.Çetintaş,
Time and frequency standard system and time dissemination at (UME) National Metrology Institute of Turkey,
7th British Electromagnetic Measurements Conference (BEMC-95) Digest, pp.20.1-4, Malvern, UK, 1995.

2. V.Sautenkov, R.G. Gamidov, İ.Taşkın,
Optical pumping and light pressure induced deformation of Doppler-free resonance on cesium cycling transition,
Proceedings of the12th Conference on Laser Spectroscopy, Island of Capri, Italy, 1995.

3. R.G. Gamidov, İ. Taşkın, V. Sautenkov,
Influence of saturation beam parameters on laser frequency locked to the cesium cycling transition,

Proceedings of the IEEE International Frequency Control Symposium, San Francisco, USA, pp. 149-151, 1995.

4. R.G. Gamidov, İ.Taşkın, V.Sautenkov,
Shift of diode laser frequency which locked to cesium D2 line by the FM or ZM stabilization technique,
Proceedings of the Fifth Symposium on Frequency Standards and Metrology, Woods Hole, Massachusetts, 1995, USA,
Published by World Scientific Publishing Co Pte Ltd, Editor James C. Bergquist, pp.445-449, 1996.

5. R.G. Gamidov, M.Çetintaş, E. Sadıkhov, V.Sautenkov,
Diode lasers with external optical feedback for small displacement measurements,
Conference digest of Conference on Precision Electromagnetic Measurements (CPEM-96), pp.126-127, Braunschweig, Germany, 1996.

6. R.Gamidov, E. Sadikov, M. Çetintaş,
Optical feedback in diode laser for sound pressure measurement
Proceedings of SPIE Vol. 3411, pp 624-629, 1998.

7. R. Gamidov, M. Çetintaş, A.Ch.Izmailov,
High Contrast Doppler-Free Resonance on cycling transition F=3-F=2 D2 line of Cesium Atoms,
Proceedings of the 1999 Joint Meeting of The European Frequency and Time forum and The IEEE International Frequency Control Symposium, Vol.1, pp.114-117, 1999.

8. R. Gamidov, M. Çetintaş,
Time Comparison of atomic clocks using counter and GPS system
Proceedings of the 1999 Joint Meeting of The European Frequency and Time forum and The IEEE International Frequency Control Symposium, Vol.1, pp. 228-270, 1999.

9. R. Gamidov, M. Çetintaş, H. Karacadağ, A. Gedik, M. Yoğun, M Çelik,
Measurement of electromagnetic radiation from GSM base station in Turkey
Conference digest of Asia – Pasific Radio Science Conference, Japan, 2001.

10. M. Gubin, C. Erdoğan, R. Gamidov, P. Gill et all,
The Absolute Frequency Measurements with a Set of Transportable He-Ne/CH4 OFS and Prospects for Future Design and Applications,
Proceedings 6th Symposium on Frequency Standards and Metrology, pp. 453-460, Editor P.Gill, World Scientific, 2001.

11. R. Gamidov, M. Çetintaş
Frequency Shift of Diode Lasers Stabilized on S-D Two Photon Polarization Resonance on Rb Atoms,
Proceedings of the IEEE International Frequency Control Symposium, Louisiana, USA, 2002.

12. R. Hamid, M. Cetintaş, H. Karacadağ, A. Gedik, M. Yoğun, M. Çelik, A. Fırlarer,
Measurement of Electromagnetic Radiation from GSM Base Stations
Proceeding of IEEE International Symposium on EMC, Turkey, 2003.

13. R. Hamid, M. Cetintaş, H. Karacadağ,
EMC Test Facilities at UME
Proceeding of IEEE International Symposium on EMC, Turkey, 2003.

13. R. Hamid, E. Sahin, M. Celik M.Zucco, L. Robertsson and L.S.Ma,
Absolute Frequency Measurement and Comparison of UME and BIPM He-Ne/I2 Lasers
Conference digest of Conference on Precision Electromagnetic Measurements(CPEM), UK, 2004.

14. R. Hamid, D. Sendogdu, C. Erdogan
The Kösters Interferometer For Long Gauge Block Length Measurements
Conference digest of Conference on Precision Electromagnetic Measurements (CPEM), Italy, 2006.

15. Matus, A. Niessner, P. Balling, P. Kren, P. Klapetek, A. Lassila, A. Yacoot, G. B.Picotto, M. Pisani, J. Flügge, U. Kuetgens, M. Celik, R. Hamid,
Optical interferometry with 10 pm level accuracy - the Project Nanotrace,
NanoScale 2008, 22.-23. September 2008, Turin, Italy.

16. R. Hamid, M. Çetintaş, S. Çakır, O.Şen, S. Acak, H.Karacadağ
EMC Measurements and Tests at National Metrology Institute of Turkey (UME),
Conference Digest of 20th International Zurich Symposium on Electromagnetic Compatibility, Zurich, Switzerland, 2009.

16. A.Yacoot, M. Pisani, G. Picotto, U. Kuetgens, J. Flügge, P. Kren, A.Lassila, S. Seppä, R. Hamid, M. Celik , M. Matus, A.Nießner,
NANOTRACE: the investigation of non-linearity in optical interferometers using x-ray interferometry
Proceeding of 9th International Symposium on Measurement Technology and Intelligent Instruments (ISMTII-2009), pp. 216- 221, Saint-Petersburg, Russia, 2009.

17. C. Ülgüdür, F. Ö. Ilday, R. Hamid,
Long-Term Repetition-Frequency Stabilization of All-Normal-Dispersion Yb-Doped Fiber Laser to the Cesium Standard,"
Proceeding of Conference on Lasers and Electro-Optics (CLEO), OSA Technical Digest (CD) (Optical Society of America, 2010), paper JWA44., San Jose, USA, 2010.

18. M. Çelik, R. Hamid, C. Birlikseven, E. Sahin, L. Yağmur,
Sub-nanometer Displacement Measurements using Laser Beat Frequency Technique,
Proceeding of 9th Seminar on Quantitative Microscopy (QM) and 5th Seminar on Nanoscale Calibration Standards and Methods, Nanoscale 2010, Brno, Czech Republic, 2010.

19. Ç. Şenel, F. Ö. Ilday, O. Kara, R. Hamid, C. Erdoğan,
Development and characterization of all-normal dispersion fiber laser for frequency comb generation" 2011 Advanced Solid-State Photonics (ASSP), paper AME3, Istanbul, 2011.

20. C. Senel, F. O. Ilday, O. Kara, C. Birlikseven, C. Erdogan, and R. Hamid, "All-normal-dispersion fiber lasers for frequency metrology," in CLEO:2011 - Laser Applications to Photonic Applications, OSA Technical Digest (CD) (Optical Society of America, 2011), paper CFM2.

21. C. Senel, R. Hamid, F. O. Ilday,
33 fs Yb-Doped Fiber Laser with Net-Zero Cavity Dispersion, National Optic, Electro-Optic and Photonic Conference, Koç University, Istanbul, 2012.

22. C. Senel, R. Hamid, F. O. Ilday, C. Erdogan, M.Çelik, C. Birlikseven, O. Kara,
33 fs Yb-Fiber Laser Comb for Metrology Applications,
National Optic, Electro-Optic and Photonic Conference, Koç University, Istanbul, 2012

23. C. Senel, R. Hamid, C. Erdogan, M.Çelik, O. Kara, F. O. Ilday,
33 fs Yb-fiber laser comb for optical frequency metrology applications,
UFO, 2013

24. C. Senel, R. Hamid, C. Erdogan, M.Çelik, O. Kara, F. O. Ilday,
33 fs Yb-fiber laser comb locked to Cs atomic clock,
CLEO-EUROPE, 2013

25. Ç. Şenel, R. Hamid, C. Erdogan, M. Çelik, and F. Ö. Ilday
Frequency Measurements with Yb-Laser Comb,
IFCS-EFTF, USA, 2015

26. U. Tegin, P. Elahi, Ç. Şenel, E. Ergeçen, and F. Ö. Ilday
Dissipative solitons generated from a mode-locked Raman Laser,
CLEO-EUROPE, 2015