Centro Nacional de Metrología, CENAM

Report to the 19th meeting of the Consultative Committee for Time and Frequency (CCTF)

August 2012

Overview

This report of the Centro Nacional de Metrología, CENAM, of Mexico, to the 19th meeting of the CCTF describes the main time and frequency metrology activities and goals achieved since the previous 18th CCTF meeting in 2009. We briefly present main results organized on three major time and frequency metrology areas: i) Time scales, ii) microwave frequency standards and iii) optical frequencies. At the end of this report the most representative publications of the CENAM´s Time and Frequency Division are listed.

1. Time Scales

1.1 UTC(CNM)

The Coordinated Universal Time scale of the Centro Nacional de Metrología (CENAM), UTC(CNM), has been generated since 50143 MJD (March 1996). From 50143 MJD to 55044 MJD (August 1, 2009) the UTC(CNM) was generated by the 1 pps output of a single Cs high performance commercial clock, referred as Master Clock. After 55044 MJD the UTC(CNM) is derived from a time scale algorithm (J.M. López-Romero and N Díaz-Muñoz, "*Progress in the generation of the UTC(CNM) in terms of a virtual clock*", Metrologia **45** (2008), S59-S65.) and at least 3 Cs clocks and 1 Active Hydrogen Maser. The graph below shows the time differences between the UTC and the UTC(CNM) published on the Circular T of the BIPM from January 2009 to June 2012. On Saturday April 7, 2012, there was a fatal failure in one of our clocks that was fixed on the next Monday (April 9, 2012), however a significant time difference (around 100 ns) on UTC- UTC(CNM) was accumulated. UTC(CNM) remains most of the time no more than 20 ns apart from UTC.

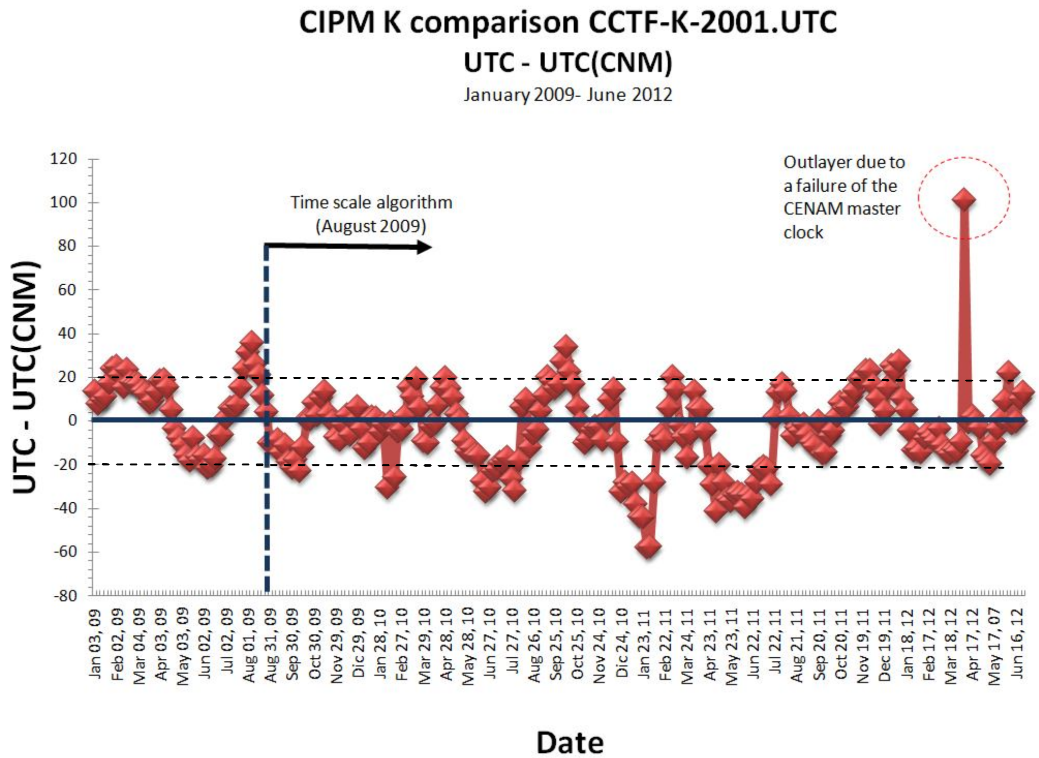

Figure 1. UTC – UTC(CNM) differences as published in the Circular T of the BIPM from January 2009 to June 2012.

1.2 Remote realization of the UTC(CNM)

By using the SIM technology related with SIM Time Network, the UTC(CNM) scales has been recently remotely realized in a location (LAPEM) which is nearly 100 km baseline from CENAM. At the remote location there is just a Rb clock and a SIM GPS system in order to achieve the real time comparison by the GPS common view technique between the 1 pps Rb clock signal and the UTC(CNM). The Rb clock at LAPEM is frequency steered by applying a correction computed by a dedicated software with the aim to maintain the time differences UTC(CNM) – LAPEM as small as possible. The first results of that remote UTC(CNM) realization just came out on August 30, 2012. In figure 2 below it is shown the time differences achieved during three days of operation of that remote realization.

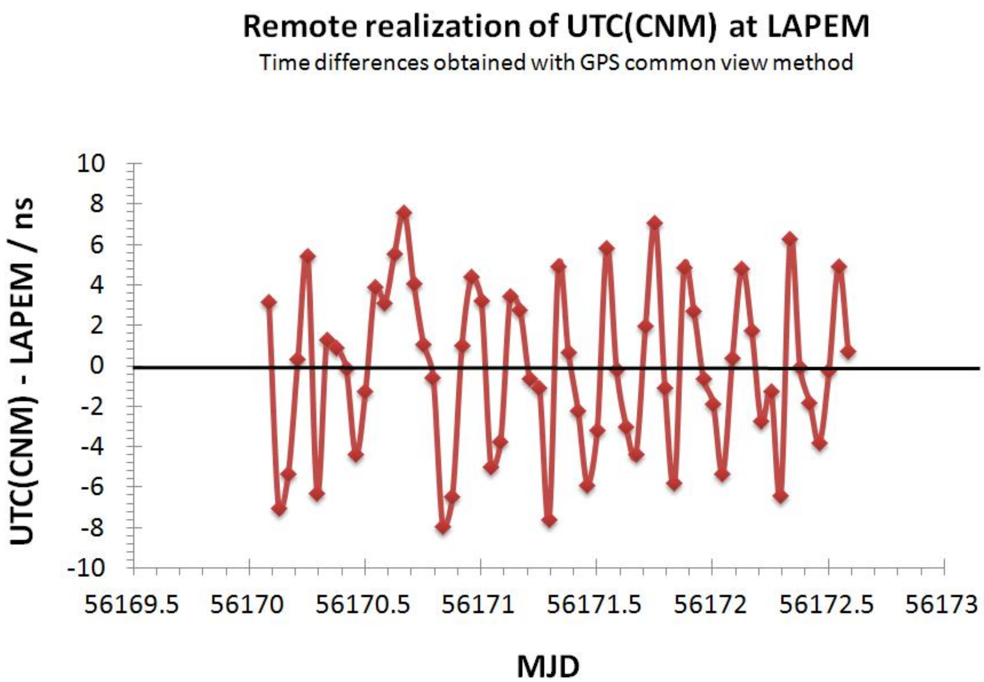

Figure 2. UTC – UTC(CNM) differences as published in the Circular T of the BIPM from January 2009 to June 2012.

1.3 SIM Time Scale, SIMT

The SIM Time Network (SIMTN) continuously compares the time scales of all SIM local time scales to each other, and produces measurement results in near real-time. The comparisons are performed via the Global Positioning System (GPS) common-view and all-in-view techniques with multi-channel, single frequency (L1 band) receivers. The measurement data are exchanged and published via the Internet. The SIMTN has operated continuously since 2005, and as of August 2012, 19 nations have joined the network. SIMTN servers located at NRC in Canada, CENAM in Mexico, and at NIST in the United States host identical software that processes and displays measurement data whenever requested by a user. All three servers are linked from the SIM time and frequency working group web site: http://tf.nist.gov/sim

About 25 cesium clocks and 10 active hydrogen masers now contribute to the SIMTN through their local SIM time scales. This large number of high performance atomic clocks made it attractive to generate a time scale (SIMT) that could be distributed and shared throughout the SIM region. Work on SIMT began at CENAM in early 2008 and it has been refined for several years, becoming an operational time scale in 2010. SIMT was designed with several characteristics in mind, specifically i) to be a continuously operated time scale that is made publicly available in real time via the Internet, ii) to be a virtual time scale (with no physical signal), iii) to include local NMI time scales, SIMT(k), as single “clocks” in the SIMT ensemble, and iv) to avoid dependence on any single clock.

SIMT is a real-time time scale, like the UTC(k) time scales. Therefore, it was designed with algorithms that are similar to those utilized at NIST and CENAM generate the UTC(NIST) and UTC(CNM) time scales, respectively. In such algorithms, exponential filtering is used to predict the time and frequency differences of the clocks with respect to the averaged time scale. Clocks are weighted by estimating their frequency instability in terms of the Allan deviation. However, the way that weights are assigned varies among different time scales. For SIMT, the weighting criteria are based on the inverse of the Allan deviation, ( ), which is computed by taking into account the previous 10 days of measurements. A 10 day averaging period was selected to minimize the influence of GPS link noise on the computation of SIMT. In the case of SIM laboratories that contribute to both UTC and SIMT, SIMT(k) and UTC(k) are generated by the same physical signal.

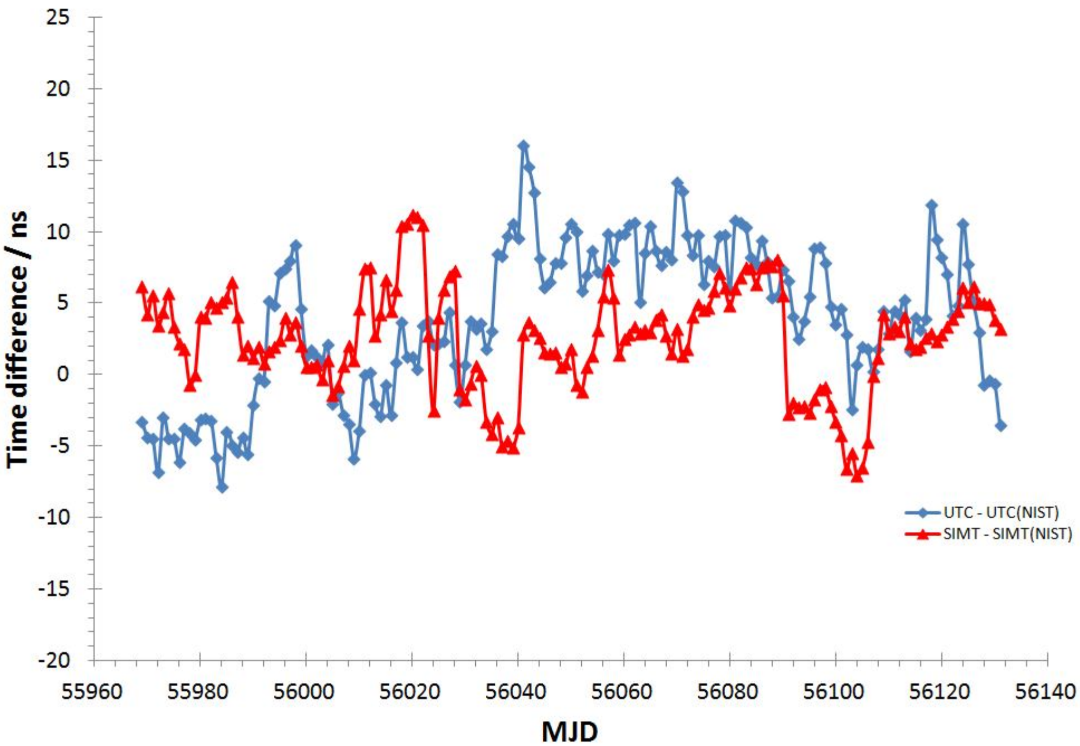

Figure 3. Time differences SIMT – SIMT(NIST) and UTC – UTC(NIST). Due to the excellent stability and accuracy of the NIST time scale here it is used to compare the SIMT scale respect to it.

2. Microwave frequency standards

The Centro Nacional de Metrologia, CENAM, has developed two thermal Cesium beam optically pumped frequency standard, the CENAM CsOP-1 and the CENAM CsOP-2, and one Cs fountain clock, CENAM CsF-1. In August 31, 2012, it has been recorded the first Ramsey fringes of the CENAM CsF-1.

2.1 Thermal Cesium beam optically pumped primary standards, CENAM CsOP

In 1998 CENAM started the development of a thermal Cesium beam optically pumped frequency standard named CENAM CsOP-1 with a short Ramsey cavity. In 2008 CENAM started the development of an improved version of the CsOP-1, the CsOP-2. The CsOP-2 is a thermal Cesium beam optically pumped clock with a Ramsey cavity of 310 mm long. The CsOP-1 is no more in use but the CsOP-2 still in use. On the 18th CCTF meeting CENAM reported some of the major characteristics of both CsOP-1 and CsOP-2, here only will be mentioned the most relevant parameters of the CsOP-2 frequency standard. It is important to mention that the evaluation of systematic errors and its uncertainties on the CsOP-2 are not completely achieved. However a complete evaluation of the systematic effects on the CsOP-2 is considered to be addressed in the near future.

Table 1. Operational parameter of the CENAM CsOP-2.

Oven temperature	380 K
Drift region length *L*	310 mm
Interaction length *l*	24 mm
Mean atomic velocity	215 m/s
Linewidth of microwave transition	300 Hz
C-magnetic field	7.6 μT

Below are the Rabi and Ramsey signals of the CsOP-1 and CsOP-2.

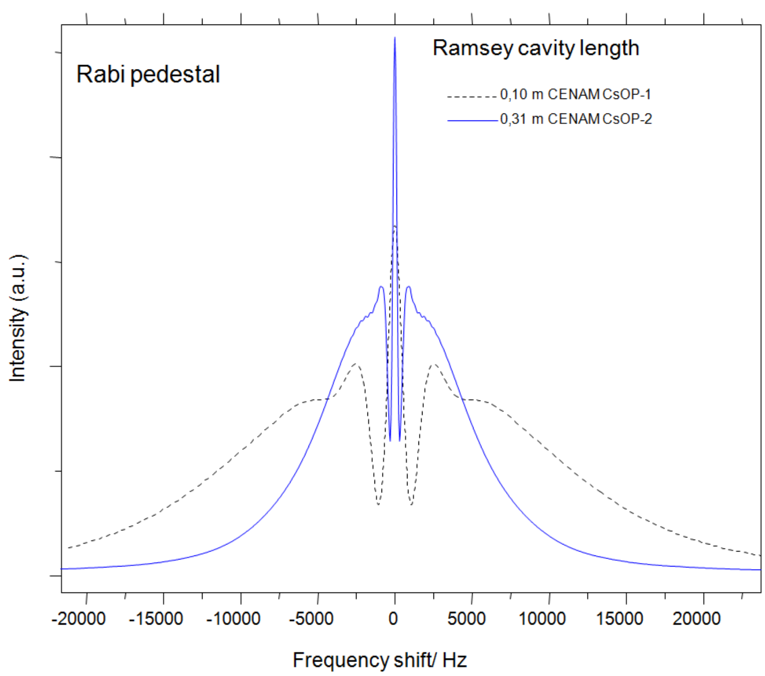

Figure 4. Rabi pedestal comparison between CENAM CsOP-1 and CENAM CsOP-2.

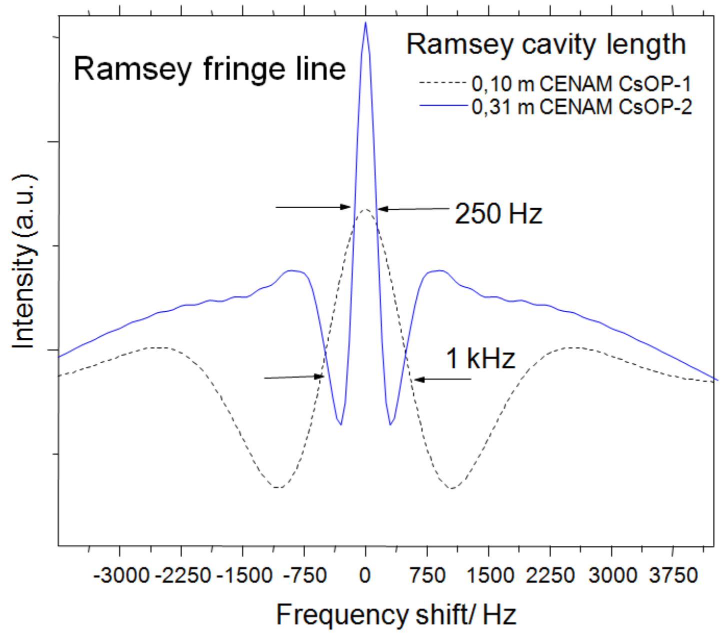

Figure 5. Ramsey fringe line comparison between CENAM CsOP-1 and CENAM CsOP-2.

2.2 Cs Fountain primary frequency standard, CENAM CsF-1

On the CENAM´s report to the 18th CCTF meeting there is a description of the main characteristics of the optical and mechanical systems of the CENAM CsF-1, so that information will not be included here. Instead, we would like to inform that we have addressed a systematic study about the temperature achieved on the on the CENAM CsF-1 and found values of 612(193) nK. As result of that we are proposing a new method to measure temperature in Cs fountain clocks, a contribution about this was presented at the CPEM 2012 (M. G. Espinosa, E. de Carlos, J. M. López, S. López, L. A. Lizama, **"***New Method for Temperature Measurement of Cold Atoms in Cs Fountain Clocks*", Proc. of the CIPM 2012). A paper on that new temperature measurement method to be published is currently in progress. On the other hand, we need to inform that on August 31 the first Ramsey signal on the CENAM CsF-1 was recorded. Those results are shown in figures 7 and 8. Width of the central Ramsey fringe of nearly 1.2 Hz is in correspondence with the time of flight of the Cs atoms above the microwave cavity which is around 433 ms. It must be mentioned that such Ramsey spectra of the CENAM CsF-1 are very preliminary and improvement on the signal to noise ratio is expected to be achieved in the near future.

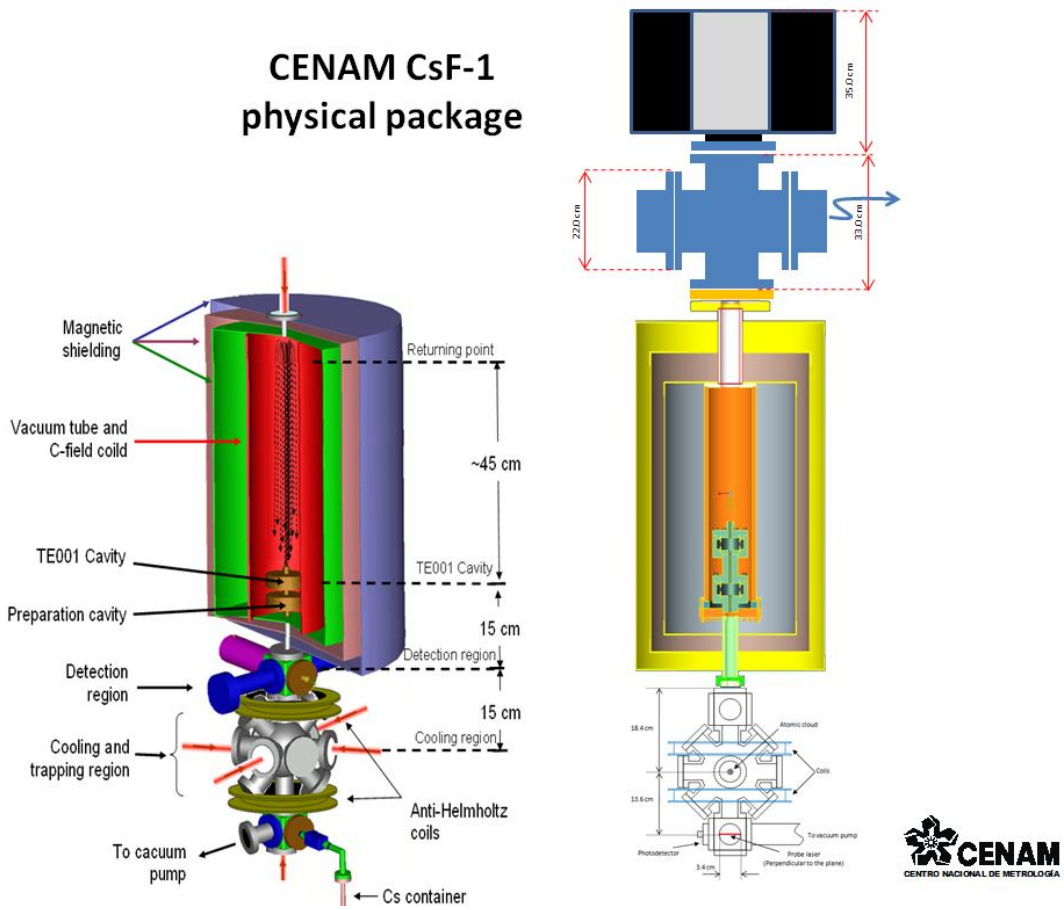

Figure 6. Schematic of the mechanical part of the CENAM fountain clock, CENAM CsF-1.

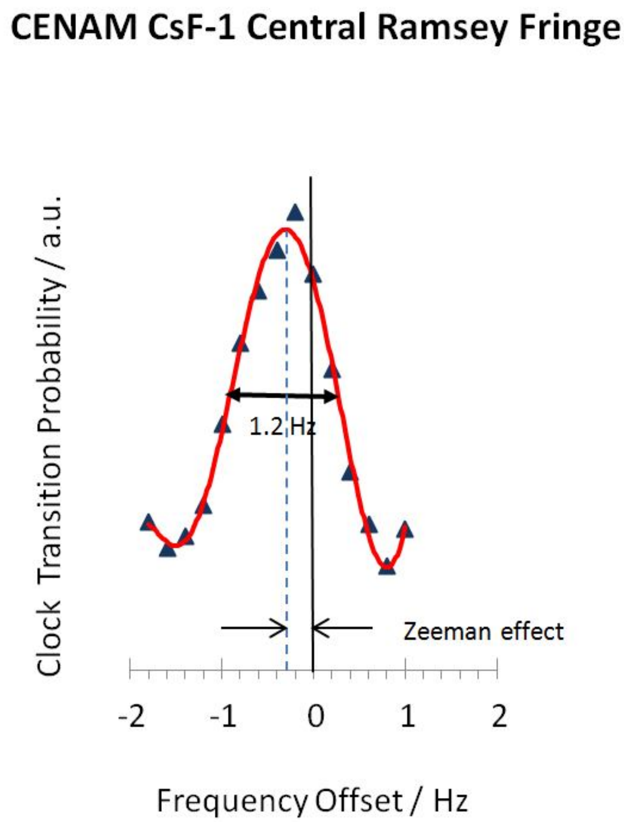

Figure 7. First Central Ramsey fringe obtained from the CENAM CsF-1 on August 31, 2012.

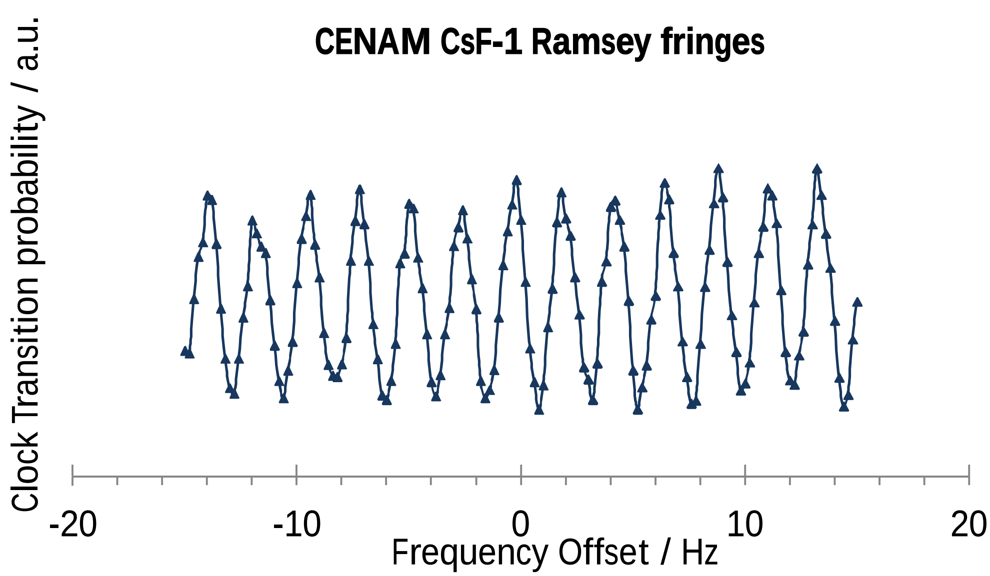

Figure 8. First Ramsey fringes obtained from the CENAM CsF-1 on August 31, 2012.

3. Optical frequencies

3.1 Ti:Sa Frequency comb

CENAM has developed a Ti:Sa frequency comb. A pumping laser of 8 W at 533 nm of continuous wave (Verdi) is used as pump laser. In figure 9 we present a schematic of the ring cavity for the Ti:Sa laser. Frequency repletion rate of 0.822 GHz has been obtained with pulse duration of about 35 ps. Train pulses is very robust and it is present during hours of operation without the necessity of alignment. A nonlinear optical fiber with nucleus of 1.8 μm and zero dispersion at 730 nm is used to expand the comb up to more than 1 octave as can be appreciated in figure 10. Currently the frequency stabilization of the comb is under progress and a ULE cavity is planned to be used to achieve that goal.

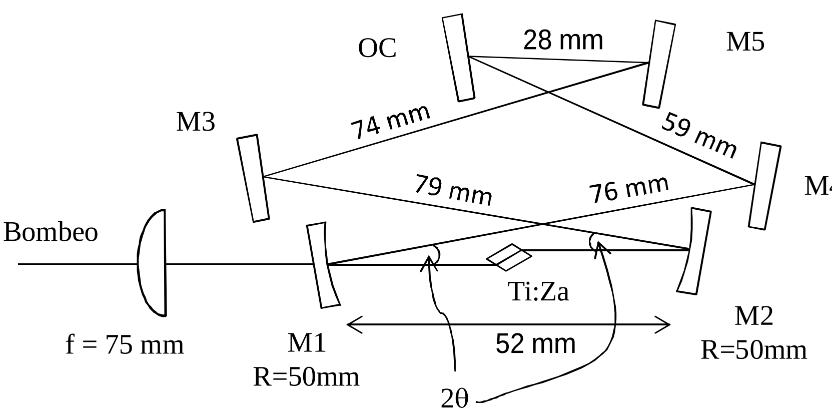

Figure 9. Schematic of the CENAM Ti:Sa ring cavity. Frequency repletion rate achieves is 0.8 GHz

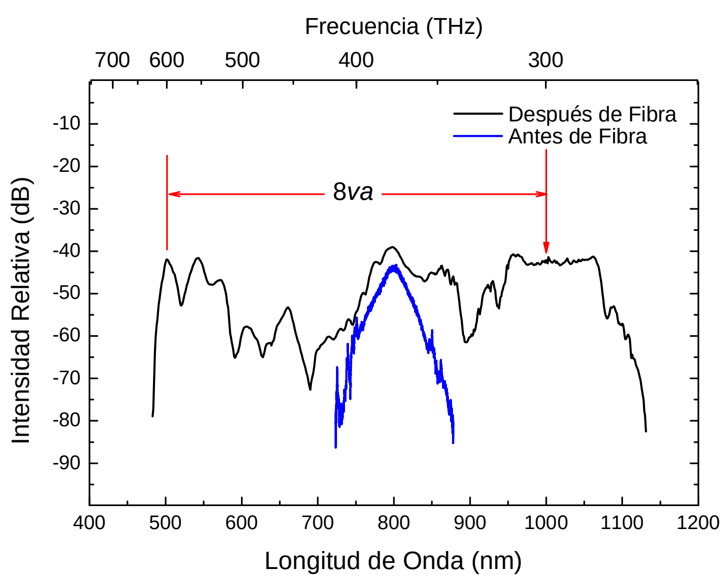

Figure 10. Spectra of the CENAM Ti:Sa frequency comb.

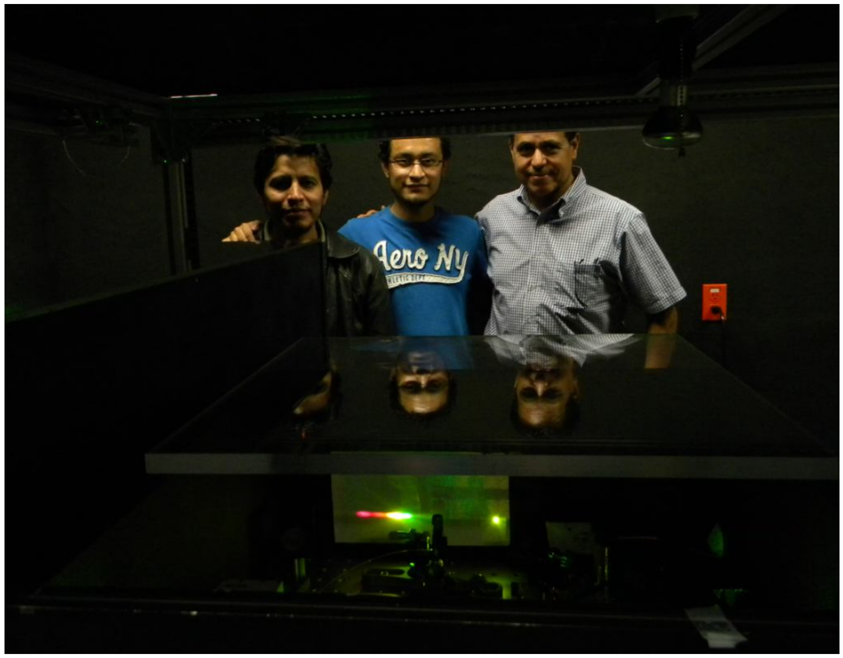

Figure 11. Picture of the CENAM Ti:Sa frequency comb rainbow. (Left to right) Eduardo de Carlos, Adin Minguela and Mauricio López.

3.2 Sr optical lattice frequency standard

CENAM is considering developing a ^{87}Sr optical lattice clock. On September 24, 2012, a member of the CENAM Time and Frequency Division will start a stay at NIST-Boulder as guest researcher with the aim to gain practical experience working on optical clocks.

Recent publications

2012

J.M. López-Romero, M.A. Lombardi and N. Díaz-Muñoz, "*Automated Clock Comparisons and Time Scale Generation in the SIM Region*", MAPAN: Volume 27, Issue 1 (2012), Page 49-53.

2011

J.M. López Romero and R. J. Lazos Martínez, "*Constantes fundamentales: la última frontera para el Sistema Internacional de Unidades*", *Revista Mexicana de Física* **57(5)** (2011), pp 460–469, Octubre 2011, ISSN: 0035-001X

Michael A. Lombardi, Andrew N. Novick, J. Mauricio Lopez R, Francisco Jiménez, Eduardo de Carlos et al, "*The SIM Time Network*", Journal of Research of the NIST, Volume **116**, Number 2, pp 557 – 572, March-April 2011, ISSN: 1044-677X

2010

M. López-Romero and M. A. Lombardi, "*The Development of a Unified Time and Frequency Program in the SIM Region*," Measure, vol. 5, no. 3, pp. 30-36, September 2010

Nicolas A. Shtin and José Mauricio López Romero, "*Medium Power C-Band Array Amplifier Featured Ultra Low Residual Phase Noise"*, Microwave and Optical Technology Letters / Vol. **52**, No. 2 February 2010

Nicolas Shtin, Jose Mauricio Lopez Romero, "*Ultra Low Phase Noise C-band Oscillators with Combined Frequency Stabilization*", Proceedings of Asia-Pacific Microwave Conference 2010.

2009

Hernández-Hernández, E. Méndez-Martínez, A. Reyes-Reyes, J. Flores Mijanjos, J. Jiménes-Mier, M. López, E. de Carlos, "*Polarized velocity selective spectroscopy of atomic rubidium using counterpropagating beam*", Optics Communications 282 (2009), pp 887-891.

Nicolas A. Shtin, José Mauricio Lopez Romero, and Eugene Prokhorov, "*Theory of fundamental microwave absorption in sapphire"*, JOURNAL OF APPLIED PHYSICS **106**, 104115 (2009).