Long Term Experimental Results of a Rubidium Atomic Clock with Drift Compensation

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Abstract: This paper presents the results of two years of operation of an automatic system that compensates drifts of a rubidium atomic clock. This clock is the base of the Uruguayan National Time-Frequency Standard.

Key words: Cesium, frequency, primary standard, time dissemination, Allan deviations.

1. INTRODUCTION

Cesium atomic clock is a primary frequency standard. Its frequency does not change with time, but due to their high costs, at the time of purchase and at the moment to change parts, a rubidium option has been developed as a cheaper alternative.

Rubidium atomic clocks are not primary standards. Their frequencies change in time due to internal and external influence sources. The main one is the buffer gas they have, necessary for the operation. This gas reduces the velocity of the rubidium molecules, reducing the internal noise. The frequency shift depends on the amount and composition of this buffer gas and its temperature, and they vary in time changing the output frequency [1].

On the other hand, these clocks are much cheaper than cesium clocks, and their short-term internal noise is very low, in the order of 3×10^{-12} Hz/Hz for integration times of 100 s [2].

Another type of clock, called GPSDO (GPS disciplined oscillator) has a GPS connection that controls the oscillator (generally, of rubidium type). In long term, this type of clock does not have any drift, because the GPS system is controlled by a large number of cesium atomic clocks. However, commercial GPSDOs have high short term noise [3].

The proposal consists in jointing the high performance of free running rubidium clocks with the non-drift of the GPS system. In [4], a detailed description of the system is shown. It is used as the National Standard of Time and Frequency in Uruguay. For time standards, not only the frequency, but also the phase must be very stable. In the following sections the experimental results during two years of operation is discussed.

2. NOISE

Short term noise has been analyzed for a commercial free running rubidium clock [2]. Fig. 1 shows the frequency behavior in 80 h. Each vertical division corresponds to 5 parts in 10^{12}. Each point corresponds to the average of 1 s measuring time. The drift was calculated as -3.6×10^{-11} Hz/Hz/month. It is shown as the straight line in Fig. 1. This device has an electronic manual adjust to set the drift, but it is difficult to adjust it to better values at long term.

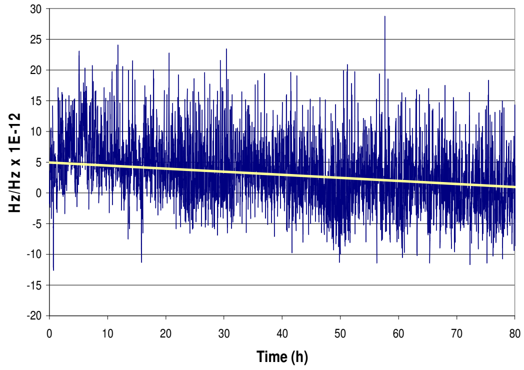


Fig. 1. Noise and drift of a free running rubidium clock.

Additionally, a GPSDO commercial clock with a single frequency (L1) and 8 channel of reception [3] has been tested. A GPS connection controls its rubidium internal oscillator. Its short term noise is shown in Fig. 2. Each vertical division represents 5 parts in 10^{11}. Note that the ordinate of this graphic is 10 times greater than the one in Fig. 1, so it is apparent that the noise is much higher than the previous device.

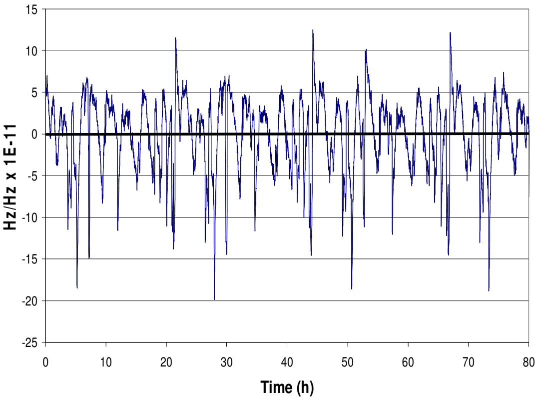


Fig. 2. Noise of a commercial disciplined rubidium clock.

However, the drift (horizontal line near zero in Fig. 2) during the observed time is much lower than the random noise. This parameter is also lower than the free-running clock, as expected.

3. PROPOSED SYSTEM

The proposed system has a GPSDO, a free running rubidium clock, a universal counter, an electronic control and a computer that runs all the system. Fig. 3 shows a block diagram of the system. The counter measures the phase difference between the signals of 1 pps (pulse per second) generated by the GPSDO and the rubidium clock. Its result data are sent to the computer via a GPIB link, and the control program sends a correction signal to the rubidium based clock, via the RS232 interface. Fig. 4 shows the internal diagram of this last unit. The output frequency (10 MHz) of the free running rubidium oscillator (on the top, to the left) can be lightly changed by a control voltage. This voltage is generated using a reference zener, a high precision resistive divider and a 16 bits digital to analogue converter (DAC). A microcontroller (PIC) sets the data in the DAC according to the computer control. An analog divider (4:1) is needed to adapt voltages between the voltage reference and the voltage control of the oscillator. A frequency divider generates 5 MHz, 1 pps and selectable decade values from 1 Hz to 10 MHz. When the algorithm calculates a new correction, the microcontroller sets new data on the DAC and a new analog voltage is sent to the oscillator, changing its frequency.

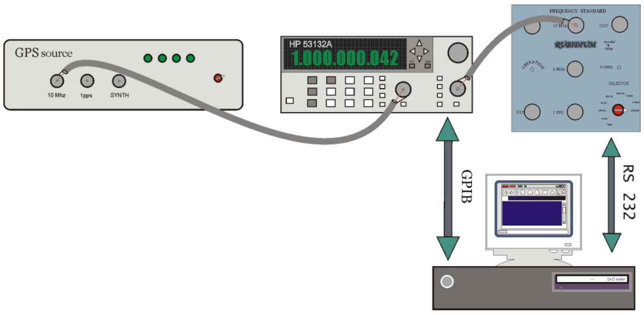


Fig. 3. Block diagram of the proposed system.

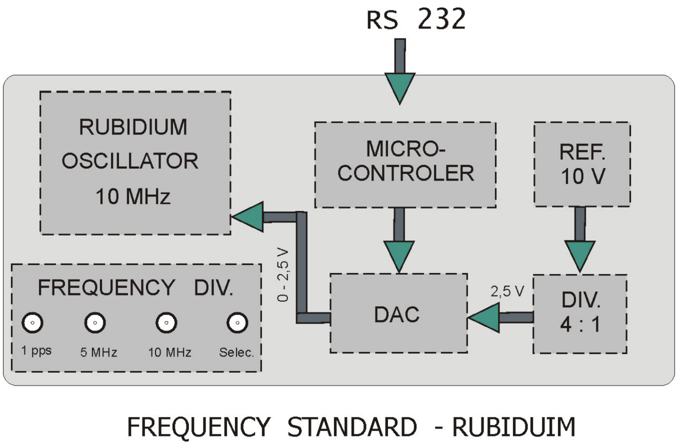


Fig. 4. Block diagram of the rubidium based clock.

4. EXPERIMENTAL RESULTS

The SIM Common View Time and Frequency Measurement System [5] allows to compare clocks of National Metrology Institutes (NMI) of American countries. Each 10 minutes, the values of the phase difference between all countries included in this system (nowadays 16 countries) are published. The display of the SIM equipment (see Fig. 5) can show a matrix with the phase difference, the historical values of the phase and frequency differences between two countries, graphics of these values, average values and Allan deviations. Additionally, this system shows a time scale called SIMT [6]. This time scale is calculated from data from all countries that have cesium clocks, averaged according to the weight of each one.

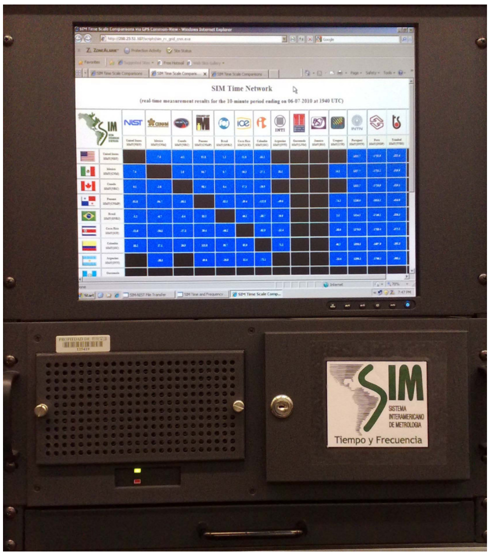


Fig. 5. SIM equipment for comparisons between different NMI.

The SIM information was used to calculate the difference between UTE (Uruguay) and other National Institutes [NIST (USA), CENAM (Mexico) and NCR (Canada)] during September of 2009 to June of 2011. Fig. 6 shows the results.

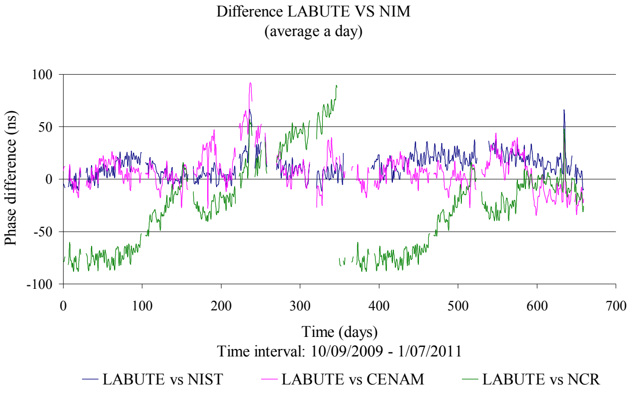


Fig. 6. Phase difference between UTE-NIST, UTE-NCR and UTE-CENAM.

Most of the phase differences between LABUTE and NIST, and LABUTE and CENAM were below ±30 ns of its average value; while the phase difference between LABUTE and NCR was about ±100 ns of its average value, which shows that NCR had a greater dispersion than LABUTE during this time interval.

5. CONCLUSION

A system that incorporates the low short-term-noise of free rubidium clocks and no drift of GPS systems was described. Its cost is ten times lower than a cesium clock, allowing many usages where these requirements are relevant.

During the time interval requires by a cesium atomic clock calibration (about four days), ours system has about a part in 10^{14} of fractional frequency deviation. In a time interval nearly two years, the phase stability was around 30 ns. Nowadays, this system is the Frequency Standard of UTE (designed NMI of Uruguay).

REFERENCES

[1] J. Vanier, R. Kunski, P. Paulin, J. Savard, M. Tetu and N. Cyr; "On the Light Shift and Buffer Gas Shift in Passive Rubidium Frequency Standard," 36th Annual Symposium on Frequency Control, pp. 348 – 354, 1982.

[2] *Temex Time manual*, model LCR-900, Nov. 2006.

[3] *SpectraTime manual*, model GPSource, Oct. 2007.

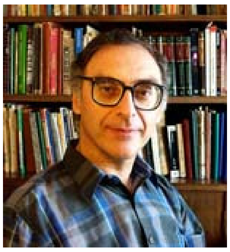
[4] L. Trigo, D. Slomovitz, "Rubidium atomic clock with drift compensation," Conference on Precision Electromagnetic Measurements (CPEM), pp. 472 - 473, 2010.

[5] *SIM common-view time and frequency measurement system manual*, http://tf.nist.gov/sim/simnet.htm

[6] J. M. Lopez-Romero and M. Lombardi "SIM time scales", Simposio de Metrología 2010, Querétaro México

Biography

Leonardo Trigo (M'98) was born in Montevideo, Uruguay, in 1969. He received the Technological Engineer degree from ITS (Instituto Tecnológico Superior), Montevideo, Uruguay, in 1993. Since 1994 he has been working in the Electrical Department of UTE Laboratory. Since 2004 he is in charge of the Time and Frequency laboratory.



Daniel Slomovitz (M'86–SM'89) was born in Montevideo, Uruguay, in 1952. He received the Electric-Engineer and the Dr. Eng. degrees from the Universidad de la República del Uruguay, Montevideo.

He is currently a Professor at the same university. In 1977, he joined the Laboratory of the National Electrical Power Utility (UTE), Uruguay as Engineering Assistant. Nowadays, he is the Head of the Laboratory. He has performed research in electrical measurements and high voltage testing, publishing more than 100 journal and conference papers, and two books.