Disseminação do Tempo e Frequência no Campus Xerém do INMETRO e a melhoria do sistema JVS.

Frequency and Time dissemination throughout INMETRO Xerém Campus and the improvements on JVS system.

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Resumo: Esse trabalho apresenta a caracterização metrológica do enlace de cabo coaxial entre o laboratório de tempo e frequência e o laboratório Josephson. Esse enlace permitiu melhorias dos resultados do Padrão de Tensão Josephson nas comparações chave em 10V. Para um tempo de integração de 1000 segundos o enlace apresentou um desvio de Allan de $3x10^{-13}$ Hz/Hz. A disseminação de um sinal de 10 MHz exato e estável através de um cabo coaxial demonstrou ser útil, confiável e fidedigno. The JVS system can be upgraded up to the measured

Palavras-chave: Efeito Josephson, padrão primário, sistema padrão de tensão, padrão de frequência primário, relógio atômico de Césio.

Abstract: This paper presents the metrological characterization of the coaxial link between time and frequency laboratory and Josephson laboratory. This link enabled improvements on Josephson Voltage Standard results in 10 V Voltage key comparison. For an integration time of 1000 seconds the transfer link presented an Allan deviation value of $3x10^{-13}$ Hz/Hz. The dissemination of an accurate and stable 10 MHz signal by coaxial cable proved to be useful, reliable and dependable.

Keywords: Josephson effect, primary standard, voltage standard system, primary frequency standard, Cesium atomic clock.

1. INTRODUCTION

In 1962 Brian Josephson predicted that when a dc voltage V is applied across a superconductor junction it would generate an AC current oscillating at the frequency f = 2 e V/h, where e/h is the ratio of the elementary charge to Planck's constant. However, if an AC voltage at frequency f is applied to the junction, the junction's self-oscillation has a strong tendency to phase-lock to the applied frequency. During this phase-lock, the junction voltage must be equal V = h f/2 e

(AC Josephson Effect) and could be used as a quantum voltage standard [1].

Any error in the frequency reference that is used to measure and stabilize the microwave source translates directly into a voltage error. Therefore, Josephson-array standards rely on precise frequency standards that must be periodically calibrated to achieve the ultimate measurement limits.

1.1 INMETRO Josephson Voltage Standard (JVS) system

In 2006 the INMETRO JVS system was directly compared to the Bureau International des Poids et Mesures (BIPM) system at 10 V. The values obtained were enough for measurements of Zener voltage standards, but far from the expected JVS system values. One possible reason for this result was a mismatch of the 10 MHz signal used on the microwave synthesizer, for measuring the superconductor Josephson junction chip. The JVS system primary voltage standard must be supplied with a 10 MHz radio-frequency signal traceable to the BIPM with low phase noise and high stability.

The time and frequency lab (Laort) at Inmetro participates in periodical key comparisons, maintains the local time scale UTC(INXE) and can disseminate an accurate and stable 10 MHz signal to nearby laboratories.

In this work we present the establishment of a coaxial cable link between the JVS and Laort to disseminate the signal remotely. In order to assure the signal link quality, the Allan deviation and phase noise were evaluated and compared to the previous situation when the clock and the JVS system were in the same room.

2. MATERIAL AND METHODS

Until 2008 the 10 MHz signal reference for the INMETRO JVS system was provided by a GPS-DO HP 58503A that contains a quartz crystal oscillator disciplined by the GPS 1PPS (pulse per second) signal. When the GPS is locked to one or more satellites the frequency accuracy is better than 1×10^{-12} Hz/Hz on 1 day average and the Allan deviation is 5×10^{-11} for 100 s averages. The minimum acceptable value for the frequency accuracy in the microwave JVS system at 75 GHz is of 1.3×10^{-10} Hz/Hz.

It was detected that the GPS receptor and/or its antenna was not working properly, turning invalid the signal traceability hypothesis. The origin of the failure was not detected. Due to these failure, in 2009, the system signal was changed to a 10 MHz (1 V RMS @ 50 Ω) provided by a high performance commercial Cesium atomic clock (Symmetricom 5071A) with frequency accuracy of $\pm 2 \times 10^{-13}$ Hz/Hz and Allan deviation under $8{,}5 \times 10^{-13}$ in 100 s. A frequency counter (Agilent 52132A) was used to characterize the accuracy of the frequency standards.

The Cesium primary frequency standard and the JVS system were 70 m away from each other, connected with a low loss coaxial cable (Belden 9222 Triax, 50 Ω and 4.9 dB/100 m loss at 10 MHz). Care has been taken to avoid signal degradation from end to end, so a passive choke was used to filter off unwanted coupled low frequency signals. The cable meshes was grounded each one in a different laboratory, avoiding ground current loops.

The JVS system uses a counter (EIP 578B) that requires a 10 MHz, 1 V peak to peak signal with 300 Ω of input impedance. The impedance was matched from 50 Ω to 300 Ω, also enhancing the 10 MHz signal amplitude to 3 V peak to peak, measured at the counter entrance.

In order to measure the coaxial cable effects over the 10 MHz signal accuracy the signal from the Cesium atomic clock and the local Rubidium 10 MHz were compared using a frequency counter (Agilent 53132A).

The Cs primary standard was calibrated at the National Observatory (ON), responsible for keeping the Brazilian national time scale. In 2011 a common view GPS (CV-GPS) system was deployed using a geodetic GPS receiver to get real time traceability to both ON and BIPM. It meets the requirements of Mutual Recognition Agreement (MRA – CIPM).

Data exchange with BIPM were initiated in October 2012 and our laboratory (LAORT) started to participate on Circular-T under denomination UTC(INXE) [2], proving our capability to provide a reliable and traceable time scale. In figure 1, we can see the Allan deviation for UTC(INXE) in reference to UTC.

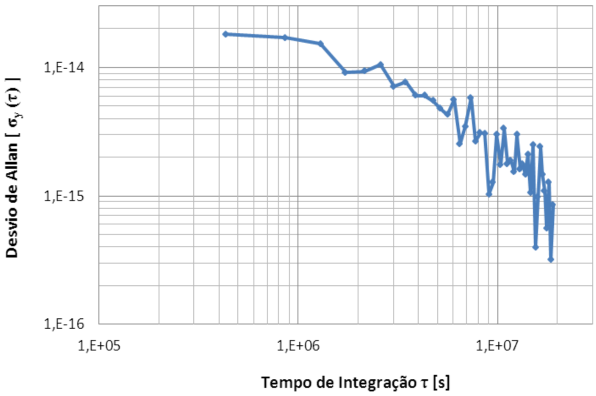

Figure 1: Frequency Stability - Allan deviation plot for UTC-UTC(INXE) comparison.

In figure 1 one can observe that the main noise present in the local time scale are flicker frequency noise (τ^{0}) and flicker phase and white phase noises (τ^{-1}).

3. RESULTS

3.1. Allan deviation measurement

The signals were introduced on a phase noise meter (Symmetricon 5125A) in order to obtain the Allan deviation and the phase noise spectra [3] for a period of time of 25 h. The 10 MHz signals were directly compared side by side with the standards (figure 2 blue curve) and at different laboratories using the coaxial cable by a period of time of 24 h (figure 2 red curve). Both curves present a $\tau^{-1/2}$ behavior corresponding to white frequency noise. It is possible to see a small change on behavior of the red curve for shorter times due to the local quartz oscillator filter effect used in the setup.

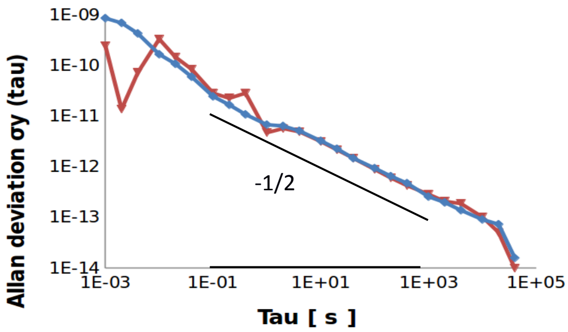

Figure 2: Allan deviation plot for direct (blue curve) and coaxial link (red curve) comparison of rubidium and cesium frequency.

There is an event (indistinctive bump) between 0.1 s and 10 s on the link curve but the noise correspondent to it cannot be identified in the Allan plot.

The gate time for JVS measurements is about 15 minutes, corresponding to an integration time of Tau = 1000 s. As one can see in figure 2, the deviation from the mean value is insignificant (2.6×10^{-13} versus 2.9×10^{-13}). The expected error level for a measurement at Tau = 1000 s on this system is 1.1×10^{-15}, showing a small inherent error and large reliability. It confirms that the link using coaxial cable do not introduce deleterious effects on the 10 MHz signal and the expected stability for 1000 s integration time is of 3×10^{-13}.

3.2. Phase noise measurement

Additionally to the Allan deviation, the phase noise was measured to support the quality of the link using coaxial cables. Figure 3 presents graphically the phase noise measured for direct comparison between rubidium and cesium frequency (blue curve) and comparison by using the coaxial link (red curve).

The spectral density of phase fluctuations is richer in noise information than the Allan plot. We can observe between 10^{-4} Hz and 10^{2} Hz that a noise corresponding to a f^{-2} behavior is present corresponding to the white frequency noise observed in the Allan Deviation Plot.

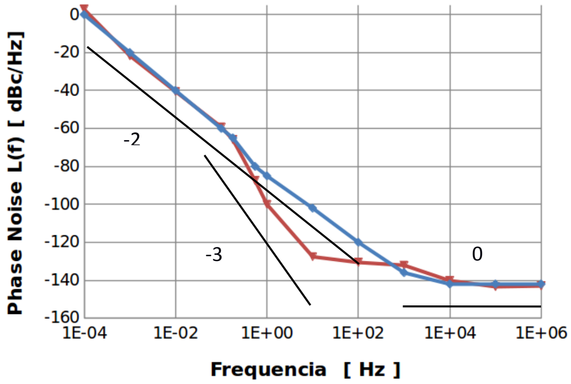

Figure 3: Phase noise for direct (blue curve) and coaxial link (red curve) comparison between rubidium and cesium frequency.

In the range 10^{-1} Hz and 10 Hz it can be observed a behavior of f^{-3}, corresponding to a flicker frequency noise (1/f noise for frequency fluctuations). This range corresponds to the indistinctive bump observed in the Allan deviation in 0.1s to 10 s. For larger frequencies than 10^{3} Hz the noise correspond to a white phase modulation and it can be associated to shorter time behavior in the Allan plot curve.

Considering the measurement accuracy level, the results satisfactorily agree indicating that background noise level increases but the accuracy was not degraded, and remained inside the 1.3×10^{-10} Hz/Hz minimum frequency accuracy for 75 GHz JVS system. The JVS system can be upgraded up to the measured 3×10^{-13} Hz/Hz link limit.

3.3. JVS accuracy improvement

After the improvements described on this paper, the INMETRO JVS system was directly compared to the NIST system and the difference at 10 V between them was 0.54 nV with the combined standard deviation of 1.48 nV. With the result of previous inter-comparison between BIPM and NIST we were able to determine the difference between INMETRO JVS system and BIPM, the obtained value is equals to -0.26 nV with standard deviation of 1.76 nV.

4. CONCLUSIONS

On this work we presented the improvements achieved by the INMETRO JVS system by implementing a link between the JVS system and the Cs primary standard, providing a low noise, high accuracy and stability 10 MHz signal traceable to DSHO-ON. This process enable an improvement of the inter-comparison with BIPM, showing a marked improvement from a difference of (19 nV±16nV) to a difference of (-0.26 nV±1.76 nV).

Recently special coaxial cables with low delay temperature coefficient were acquired and are being installed. It could decrease even more the deleterious effects on frequency dissemination. We are also implement links to other laboratories using monomode optical fibers and monochromatic lasers to achieve the theoretical limits on frequency transfer.

5. REFERENCES

[1] Landim, R. P et al, V; A 10 V Josephson Voltage Standard Comparison Between NIST and Inmetro as a link to BIPM; IEEE Transactions on Instrumentation and Measurement, v. 60, n. 7 (2011).

[2] CircularT, BIPM publication, http://www.bipm.org/en/scientific/tai/ftp_server/publication.html

[3] Handbook of Frequency Stability Analysis, W. Riley, NIST Special Publication 1065, 2008.