Benchmarking the Developed Timescale at the Bureau of Standards Jamaica with NIST and CENAM

Terrence A. Jones[(1)], Andrew Novick [(2)] Hunston Hunter* [(1)], Garfield Morgan[(1)] Ryan White[(1)]
(1) Bureau of Standards, Jamaica, 6 Winchester Rd, Kingston, Jamaica https://bsj.org.jm
(2) National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA, https://tf.nist.gov

Abstract

The Bureau of Standards Jamaica (BSJ) is establishing a national time and frequency laboratory to improve the accuracy of time measurements in the country. This initiative addresses the reliance of Jamaican businesses on Global Navigation Satellite Systems (GNSS) like Global Positioning System (GPS). The laboratory, which has undergone development and acquired new equipment, aims to provide internationally standardized traceable measurements of time, reducing errors and enhancing operational reliability. The BSJ Time and Frequency laboratory has submitted cesium clock data to international comparisons, and it has now aligned Jamaican time standards with global benchmarks, for the future benefit for businesses and consumers. The rise of high-frequency trading in Jamaica has prompted the development of services like authenticated network time protocol (NTP) and the calibration of time-base instruments. The BSJ collaborated with other laboratories to create a world-class time and frequency facility, equipped with cesium oscillators and NTP servers capable of providing time to the public within 50 ms and maintaining a timescale to within 100 ns.

1. Background

The Bureau of Standards Jamaica (BSJ) serves as the National Metrology Institute (NMI) for Jamaica, maintaining national standards for measurement traceability. Reliable and traceable measurements are crucial for global trade, financial transactions, telecommunications, power distribution, and various other applications. The time and frequency metrology field supports everyday activities, financial markets, telecommunications, power grid monitoring, and more. NMIs, like the BSJ, establish a timescale based on Coordinated Universal Time (UTC) to ensure accurate time dissemination and calibration services. The international standard, International Atomic Time (TAI), is maintained by the Bureau International des Poids et Mesures (BIPM) near Paris, France, using data from numerous atomic clocks at NMIs worldwide.

2. Statement of the Problem

Over the past few decades, Jamaica has seen significant progress in Information and Communication Technology (ICT) with notable increases in the trades published by the Jamaica Stock Exchange (JSE) and financial transactions in the financial sector. Despite this growth, the country lacks the necessary infrastructure and legislation to ensure accurate and internationally traceable time and frequency measurements. Furthermore, there is no standardization regarding the time source each entity is using for timestamping of financial transactions. In response, the BSJ, functioning as the National Metrology Institute, is intensifying its efforts to establish a National Time and Frequency Laboratory. This facility aims to provide traceable measurements to international standards, reducing measurement errors and instilling confidence in investors and consumers.

3. Objective

Business entities often depend on time produced by Global Positioning System (GPS) to carry out their time dependent services. This technology is perceived as a free resource and users do not worry or have no knowledge about the possible implications of depending entirely on GPS, mainly those critical applications, such as telecommunications, electrical networks, financial services and security. GPS can be seen as vulnerable to environmental conditions, spoofing and jamming. Most time and frequency laboratories are responsible for generating the local prediction of Coordinated Universal Time (UTC), the international time standard called UTC(*k*), as well as their respective official times of their countries. This research will seek to demonstrate that BSJ's time source from its developed lab is capable of meeting BIPM requirements for UTC recognition. Additionally, a comparison among the National Institute of Standards and Technology, (NIST), the National Metrology Center of Mexico (CENAM) and the Bureau of Standards Jamaica (BSJ) will be conducted to benchmark BSJ's results with those established NMIs.

4. Literature Review

The invention of the atomic clock resulted in the BIPM formulating the Coordinated Universal Time (UTC) timescale in 1972. UTC is recognized as the official world timescale and according to [1] this is produced through the participation of timekeeping laboratories which operate atomic clocks and share data with the BIPM. [1] further stated that currently, more than 70 timing laboratories are contributing data from more than 450 atomic clocks to the BIPM, and UTC is obtained by taking a weighted average of all of the submitted clock data. Additionally, the local UTC timescales are referred to by the BIPM as UTC(k), where k is the acronym of the laboratory. On a monthly basis, the BIPM publishes a Circular T document that shows the UTC – UTC(k) time differences for each laboratory that contributes to UTC. A time difference value, along with the measurement uncertainty associated with the value, is provided for each laboratory every five days. The Circular T document allows each participating laboratory to know the recent difference of its local UTC time scale with respect to UTC, and to thus establish traceability to UTC and to the SI second.

The SIM Time Network (SIMTN) started operating in May 2005, initially comparing the National Institute of Standards and Technology (NIST), the National Metrology Institute of Metrology Mexico (CENAM), the National Research Council for Canada (NRC). Over time, it expanded to include all interested SIM NMIs, with now seventeen laboratories as polled from the SIM time grid as of 2024. SIMTN integrates GPS common-view time transfer and the Internet, allowing for automatic measurement transfer and public access to results. The measurement grid, updated every 10 minutes, displays the current time differences between participating SIM laboratories and can be viewed online [2].

Local timekeeping laboratories that contribute to UTC produce local time that can be used as measurement references for real-time applications, such as providing time to financial markets, telecommunication sector, aviation sector, etc. UTC(NIST) is the official time for financial exchanges in the United States. Because UTC(NIST) is a close real-time approximation of UTC, it can also be utilized as an official time source for financial exchanges throughout the world. While it is possible to verify the accuracy of the time transmitted by these services, it is usually not possible to verify the accuracy of the received time for documentation purposes. Thus, to meet the accuracy requirements of HFT platforms and to verify that NIST time is accurate when it reaches the customer, it was necessary to replicate UTC(NIST) at financial market sites.
Transactions that occur in the Financial Sector are critically dependent on the accuracy of the time for such activities. The computers used to conduct the various operations must keep accurate time. There are two time code protocols used to transfer accurate time to stock market computers.

These are:
1. The Network Time Protocol (NTP), which is distributed via the Internet
2. The Precise Time Protocol (PTP)

Time information is transferred by both protocols by data packets containing time stamps over network connections.

Verification of Time Accuracy

Time accuracy can be verified by comparing the laboratory's UTC with that of the UTC Timescale. Subsequently, a comparison is then made with each of the time stamp packets transmitted by the NTP and PTP servers to that of the timekeeping laboratory's UTC. However, the fact that NIST setup NIST Disciplined Oscillator (DO) at customers site to increase the accuracy being delivered to such customers is cause for the BSJ to conduct an assessment of the time the BSJ currently uses with that of the Time & Frequency Laboratory's Precise Timescale System (PTSS).

5. Methodology

Various time and frequency laboratories achieve the objectives using various instrumentation and methodologies but all operate from the same working principle. In this section we will briefly summarize and demonstrate how both the National Institute of Standards and Technology (NIST) and The National Metrology Center of Mexico (CENAM) realize the second, then explain the BSJ's laboratory development and its chosen method.

How UTC(NIST) Works

The UTC(NIST) system operates by continuously running a collection of atomic clocks in controlled environmental conditions. These clocks are regularly measured to assess their stability, and the measurement data is used in an algorithm called AT1. This algorithm generates a combined solution called TA(NIST), which serves as the main oscillator for the UTC(NIST) time scale. TA(NIST) offers advantages in reliability and performance compared to individual clocks. It can continue running even if some clocks fail and is more stable than any individual clock. However, it is important to note that TA(NIST) is not the same as UTC(NIST); it's an independent time scale that operates without adjustments. To ensure synchronization and frequency agreement with UTC, coordination adjustments are applied to TA(NIST) to generate UTC(NIST). Similarly, the BIPM employs a time scale algorithm called ALGOS, similar to AT1, to compute a free-running atomic time scale known as EAL, which is analogous to TA(NIST). The key distinction is that UTC(NIST) produces physical signals, whereas UTC does not. These physical signals, such as one pulse per second (PPS) signals for time and 5 MHz signals for frequency, are distributed via distribution amplifiers in NIST laboratories. A reference point for the 1 PPS timing signals marks the exact "on time" position. Leap seconds can be inserted into both UTC and UTC(NIST) time codes when necessary but do not affect the physical UTC(NIST) signals.

Generation and Maintenance of Mexico's UTC(CNM)

The maintenance for the CENAM Primary Time and Frequency Pattern involves sending the Weekly Report and the Monthly Report to the BIPM. It also includes determining the reference value of the pattern and adjusting UTC(CNM) to minimize the difference with UTC of the BIPM. Similar to UTC(NIST), UTC(CNM) relies on an averaged time scale created from an ensemble of atomic clocks and a mathematical algorithm that optimally combines their metrological characteristics. The outcome is a Virtual Clock, which outperforms individual clocks in terms of reliability, stability, and accuracy. The CENAM averaged time scale, known as ETP-1, employs an algorithm similar to the NIST AT1 averaged time scale. ETP-1 operates in real time, generating differences between each ensemble clock and the virtual clock. To transform the virtual clock into a real clock, a Micro-Phase Stepper (MPS) with zero weight is introduced to the clock assembly, using the frequency of one ensemble member clock as input. The ETP-1 algorithm measures fractional differences, averaging times from one hour to one day, between the MPS output and the virtual clock. This information is then used to automatically correct the frequency feeding the MPS, ensuring the ETP-1 incorporates an automatic control to align the MPS output frequency with the virtual clock frequency.

The BSJ Timescale Solution

The BSJ employs the use of Microchip's Precise Time-Scale System (PTSS) shown in Figure 1, which is a turnkey timing system that is comparable to the international laboratories using commercial hardware and software. The system is capable of establishing a real time synchronization source for communications and navigation systems as well as establishing a national timing reference. The system in its full configuration is used by the BSJ and is equipped with every feature and capability used by similar international timing laboratories today such as NIST and CENAM as discussed above.

System Description

The PTSS offers a turnkey timing system. The system integrates multiple high-performance frequency standards into a coherent time scale. Utilizing a precision Global Navigation Satellite System (GNSS) receiver, the PTSS aligns its output with Universal Coordinated Time (UTC) and generates GPS common view data for reporting to the BIPM, ensuring inclusion in the international time scale. It is equipped with two cesium frequency reference standards and a 5-day time constant, the PTSS exhibits stability, allowing it to maintain accuracy for a period in the absence of GNSS data. The system aims for a recovery of UTC within 25 nanoseconds root mean square (RMS) under normal operating conditions. Beyond accurate time recovery, the PTSS can propagate signals such as 5 MHz, 10 MHz, 1 PPS, and AM/DC IRIG-B. Additionally, the PTSS provides two Network Time Protocol (NTP) servers for network time distribution. It delivers phase noise, frequency stability, and availability in an integrated system, housed in one or more instrument racks. The primary objective of the PTSS is to establish an extremely stable frequency reference precisely synchronized with UTC. Through relative measurements between independent clocks, the system creates a stable and accurate system frequency compared to individual clocks. This involves assigning specific weights to each component clock in the ensemble based on their performance levels.

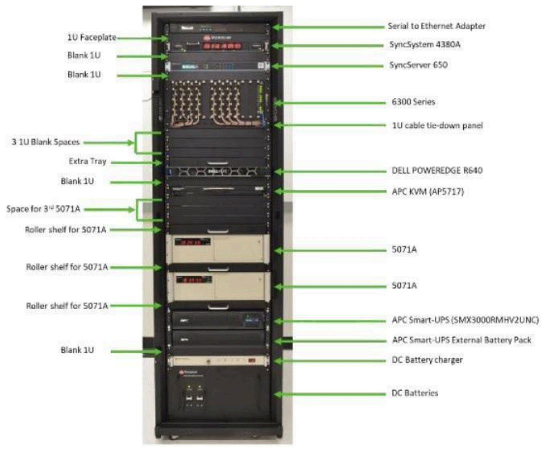

Figure 1. The turnkey Precise Time Scale System (PTSS).

The main brain of the PTSS is the 4380A-TS by Microchip. It comes equipped with a GNSS receiver, proficient in performing measurements necessary for generating a Receiver Independent Exchange (RINEX) file. This file enables the lab to conduct post-processing on GNSS data, facilitating the precise determination of antenna position within a few meters. The GNSS receiver is also designed to support reception from various constellations and satellite bands. Within the PTSS system, the GNSS receiver integrated into the 4380A-TS is employed to produce GNSS common view reports. These reports play a crucial role in computing the site offset to UTC and ensuring accurate synchronization of the system.

4380A System and Timescale Clocks

The 4380A conducts picosecond phase measurements on the ensemble of clocks currently linked to the clock system. This unit houses the GNSS receiver and software responsible for creating UTC(BSJ). Utilizing GNSS and local clock measurements, the 4380A establishes the local time scale. Additionally, this unit has the capability to generate output signals such as 5 MHz, 10MHz, 1 PPS, Time of Day (TOD), and AM/DC IRIG. At the heart of the system are two (2) 5071A cesium frequency atomic clocks to produce both short and long-term frequency stability.

6. Results – Findings and Analysis

The SIM TFMWG (Time and Frequency Metrology Working Group) maintains the SIM timescale (SIMT), a continuously updated multinational ensemble timescale that supports time and frequency metrology in the Americas. SIMT, updated every hour and complements Coordinated Universal Time (UTC) by providing real-time support for operational timing and calibration systems in the SIM region. SIMT is more stable than most local time scales in the SIM region and offers a reliable approximation of UTC timing accuracy (±15 ns). Data submitted by the BSJ, NIST and CENAM taken from the website history will be used to show our findings.

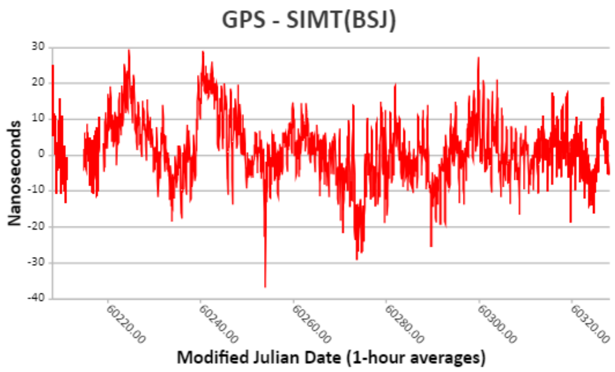

Figure 2. The difference between GPS and SIMT(BSJ) over a 120-day period from mid-September 2023 to mid-January 2024. It has a mean time offset of 1.86 ns, range of 66.25 ns and frequency offset of 1.0×10^{-15}. The mean time offset is determined from the 10-minute averages recorded from each satellite. The range is the difference between the maximum and minimum time offset values. The frequency offset is the estimated offset of the satellite clock with respect to SIMT(BSJ). This estimate is obtained by fitting a least squares line to all of the recorded data.

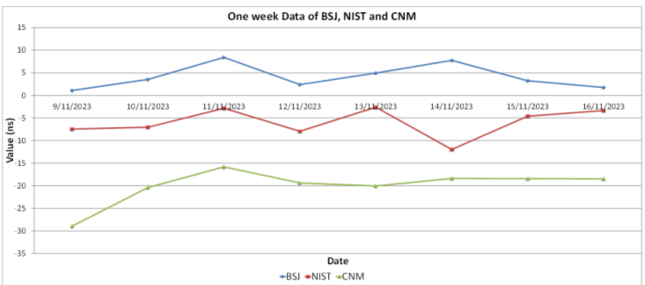

Figure 3. The time differences of BSJ, NIST and CENAM with GPS as reference as seen by the SIM timescale. All three timescales operate below 100 ns from GPS as well as operate within 40 ns of each other.

The data displayed currently shows the uncertainty of the BSJ's timescale. It can be concluded that the system is capable of realizing and maintaining an uncertainty to within 100 ns. This conclusion can be drawn from data taken from the SIM timescale to which the BSJ timescale has been consistently submitting data over the past 4 months.

7. Future Work

The BSJ is submitting time to the SIM TFMWG through the donation of a Time Measurement Analysis System (TMAS). This system was designed by NIST and donated over 15 years ago to the BSJ. Currently, the system is being redesigned with an updated L1/L2 antenna and GPS receiver and will be sent to the BSJ for beta-testing for its development. This system should be capable of making more accurate common-view comparisons.

8. References

[1] M. Lombardi, "A NIST Disciplined Oscillator," in *2010 NCSLI International Workshop and Symposium*, Providence RI, 2010.

[2] F. J. T. JM López-R, "Five years of international comparison UTC(CNM) vs. UTC:ensuring the generation of a world-class time scale for Mexico," in *Metrology Symposium Memoirs 2001 B1-1 – B1 -5*, Queretaro, Mexico, 2001.

[3] A.N.J.L.I.J.J.B.P.R. d. C. R. S. C. D. H. S. M.A. Lombardi, "The SIM Time and Frequency Network," in *Informative Bulletin of the Interamerican Metrology System -OAS*, 2008.

[4] M. Lombardi, " The Use of GPS Disciplined Oscillators as Primary Frequency Standards for Calibration and Metrology Laboratories," *Measure: The Journal of Measurement Science* , 2008.