DISTRIBUTING UTC(NIST) TO INDUSTRIAL TIME AND FREQUENCY USERS

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Abstract: The National Institute of Standards and Technology (NIST) maintains one of the world's most accurate and stable time scales, UTC(NIST), as well as the NIST-F1 cesium fountain, the primary frequency standard for the United States. These standards are continuously compared to other standards around the world to ensure traceability to the International System (SI) of units, and UTC(NIST) is continuously distributed to industrial and research facilities around the world through a variety of methods and mediums. The most accurate of these methods are remote calibration services that distribute UTC(NIST) to a relatively small number of paying customers. UTC(NIST) at lesser accuracy is freely distributed to many millions of users via NIST radio stations WWV/WWVH and WWVB, the Internet Time Service (ITS), the Automated Computer Time Service (ACTS), and the NIST web clock (time.gov).

1. INTRODUCTION

NIST maintains a Coordinated Universal Time scale, called UTC(NIST), that it distributes to industrial time users through a wide variety of activities. These activities range from remote calibrations conducted at state-of-the-art accuracy levels, to the operation of free broadcast services that directly benefit the American public by synchronizing many millions of clocks every day.

This paper summarizes how UTC(NIST) is generated, compared, and distributed. Sections 2 and 3 briefly describe how UTC(NIST) is generated and compared internationally to other time scales. Section 4 describes the remote calibration services that deliver UTC(NIST) to paying industrial customers with the most stringent measurement requirements. The free distribution of UTC(NIST) through radio broadcasts and computer time services is discussed in Sections 5 and 6.

2. THE GENERATION OF UTC(NIST)

UTC(NIST) is generated by an ensemble of atomic clocks. The number of clocks in the ensemble can vary, but it typically includes four cesium beam standards and six hydrogen masers. The output of the time scale is provided by a synthesizer referenced to a hydrogen maser, and is steered by an algorithm that uses a weighted average of the clocks in the ensemble [1]. The time scale is periodically calibrated [2] by applying rate corrections from NIST-F1 (Fig. 1), the latest in a long line of primary frequency standards designed and constructed at NIST [3]. The uncertainty of NIST-F1 has been reduced by nearly a factor of 10 since its introduction in 1998, and is currently (2009) about 3×10^{-16} [4].

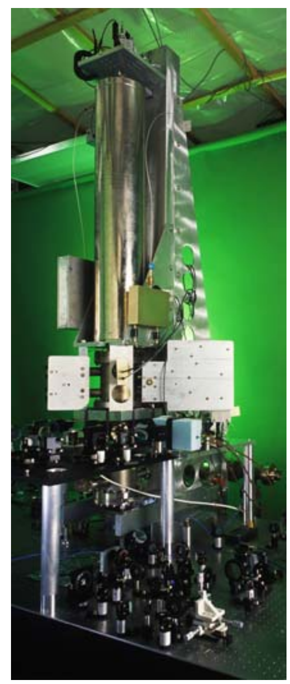

Fig. 1 *NIST-F1*

3. INTERNATIONAL COMPARISONS

Several measurement techniques are used to compare UTC(NIST) to other time scales, including two-way satellite time and frequency transfer (TWSTFT), and Global Positioning System (GPS) code-based and carrier-phase time and frequency transfer. These comparisons continuously validate UTC(NIST) so that users can be assured that all NIST signals are performing as expected and are traceable to the International System (SI) of units.

TWSTFT [5] is the primary link now used by NIST to contribute to International Atomic Time (TAI) and

Coordinated Universal Time (UTC) as calculated by the Bureau International des Poids et Mesures (BIPM). Currently, NIST participates in TWSTFT comparisons with 12 European laboratories. The NIST earth station consists of a 3.7 m motorized dish antenna with K_u band radio equipment including a spread spectrum satellite modem. The stability of the best transatlantic TWSTFT comparisons is less than 0.1 ns at τ = 1 day [6], when estimated with the time deviation (TDEV). The combined uncertainty, limited mostly by the calibration of TWSTFT earth stations, is less than 5 ns.

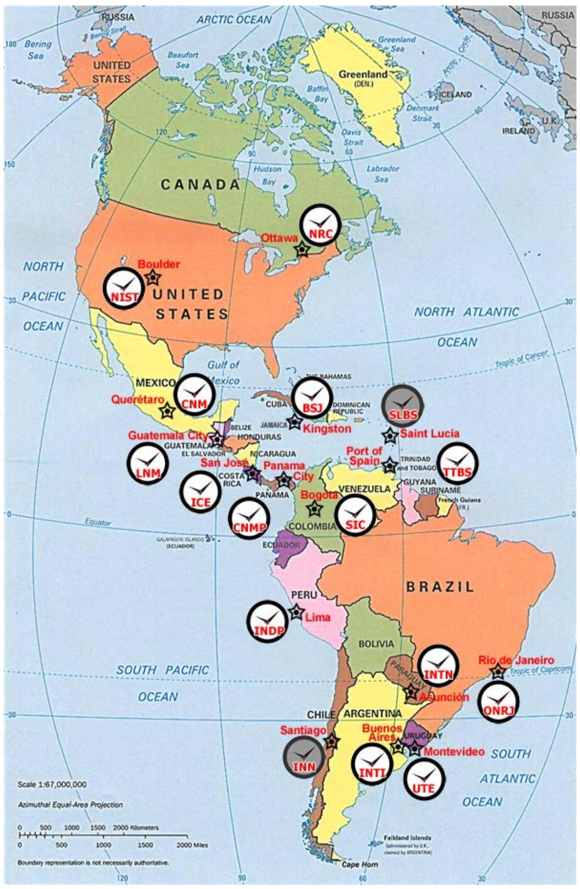

Fig 2 *The SIM Time Network*

The GPS common-view (CV) method is used as the backup link for TAI/UTC contributions, and because it has been so widely implemented, can be used to compare UTC(NIST) to nearly all of the world's timing laboratories. The original CV method using the coarse acquisition (C/A) code from the GPS L1 carrier was first developed at NIST (then called NBS) in 1980 [7]. This basic method has been enhanced for many years, and is still widely used internationally to compare clocks and time scales. For example, the Sistema Interamericano de Metrologia Time Network (SIMTN) provides continuous, near real-time comparisons between the national time and frequency standards located throughout North, Central, and South America, by utilizing the technology of both the Internet and C/A code CV measurements. As of September 2009, 14 nations are members of the network (Fig. 2), and two more nations are expected to be added in 2010. The stability of the best links (TDEV) is near 0.8 ns at τ = 1 day, and the combined time uncertainty (k = 2) is typically about 12 ns [8].

NIST participates in other GPS-based CV comparisons that require more data processing but offer improved performance. These comparisons are made using geodetic receivers that receive both the GPS L1 and L2 carriers. The CV data is post processed by applying the International Global Navigation Satellite System Service (IGS) measured ionospheric delay corrections (MSIO) and precise ephemeris corrections. The same geodetic receivers can be used to generate ionosphere-free code (P3) CV data. For comparisons between NIST and the United States Naval Observatory (USNO), separated by about a 2400 km baseline, the TDEV is about 0.3 ns at τ = 1 day for either method [9].

Even more stable comparisons with the USNO have been accomplished with GPS carrier-phase (CP) [10] measurements. For some CP measurements, TDEV has been less than 0.1 ns at τ = 1 day, a stability that rivals that of TWSTFT. Figure 3 is a simplified diagram showing how UTC(NIST) is generated and compared.

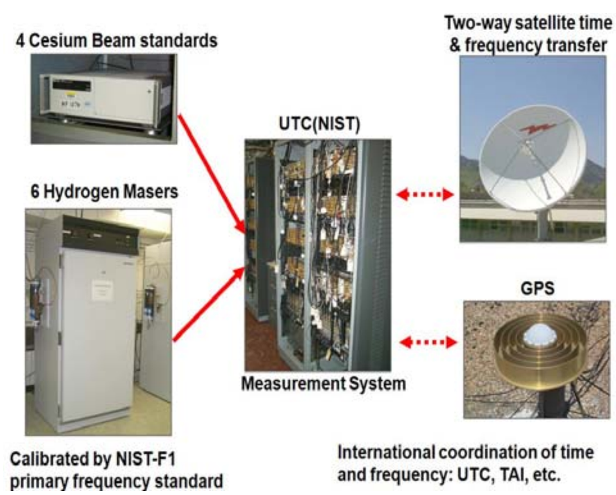

Fig 3 *Generating and Comparing UTC(NIST)*

4. REMOTE CALIBRATION SERVICES

Some industrial users, particularly calibration laboratories and research facilities, need to compare their standards directly to UTC(NIST) with the lowest measurement uncertainties possible. To meet the requirements of these users, NIST provides remote calibration services to customers that pay a monthly subscription fee. These services include the Frequency Measurement and Analysis Service (FMAS) and the Time Measurement and Analysis Service (TMAS)

The FMAS has served calibration and testing laboratories since 1984 by providing them with a convenient way to establish traceability for their frequency measurements. FMAS subscribers receive a five-channel measurement system (Fig. 4) that allows the measurement of any frequency from 1 Hz to 120 MHz. The FMAS measurement uncertainty (k = 2) is about 1×10^{-15} at τ = 1 day for direct comparisons between two oscillators and about 2×10^{-13} at τ = 1 day for oscillator to GPS comparisons [11]. Each customer receives a monthly calibration report that shows the performance of their house standard with respect to UTC(NIST).

Fig 4 *NIST FMAS measurement system*

The TMAS is based on the technology developed for the SIMTN (Section 3) and began operation in 2006. It allows customers to continuously compare their local time standard to UTC(NIST) and to view the comparison results in near real-time via the Internet. Each customer receives a time measurement system that performs the measurements and sends the results to NIST via the Internet for instant processing. Customers can then view their own standard's performance with respect to NIST in near real-time, with an ordinary web browser [12]. The TMAS measurement uncertainties are identical to those of the SIMTN.

5. RADIO BROADCASTS

NIST operates three dedicated time signal stations, the low frequency (LF) station WWVB (Fig. 5), and two shortwave stations, WWV and WWVH.

WWVB, located in Fort Collins, Colorado, broadcasts a digital time code on 60 kHz at an output power of about 70 kW. This time code serves as the synchronization source for radio controlled clocks (RCCs) throughout the United States, and parts of Canada and Mexico [13].

Fig 5 *NIST Radio Station WWVB*

WWVB RCCs [14] have become common consumer electronics items, and are sold at nearly every major department store in the United States, with wall and alarm clocks sometimes costing less than $10 USD. These clocks are commonly found on the walls of schools, stores, office buildings, and public facilities across the United States, and the number of WWVB clocks in operation is now believed to exceed 50 million.

WWVB wristwatches have also become commonplace. Casio*, a major watch manufacturer, estimates that 2 million watches capable of receiving WWVB will be sold in 2009. Some of these watches are multiband devices that can receive signals from LF time signal stations located in China

(68.5 kHz), England (60 kHz), Germany (77.5 kHz), and Japan (40 and 60 kHz), in addition to WWVB. Figure 6 is a photograph of a Casio* multiband watch with six-station capability.

Fig 6 *WWVB wristwatch*

WWV, located on the WWVB site in Fort Collins, Colorado, is one of the world's oldest radio stations, having begun the transmission of standard frequency signals in 1923. The station is best known for its voice announcements of UTC(NIST), which occur every minute and are simulcast on five carrier frequencies: 2.5, 5, 10, 15, and 20 MHz. The station is used primarily to manually synchronize clocks and watches, and as the reference for time interval calibrations of stopwatches and timers.

WWV's sister station, WWVH, is located on the island of Kauai in the state of Hawaii. Operational since 1948, WWVH (Fig. 7) provides services nearly identical to those of WWV and broadcasts on the same frequencies, with the exception of 20 MHz. WWV officially serves the continental United States, and WWVH serves the state of Hawaii, the Pacific Ocean, and the Pacific Rim. However, both stations can be received worldwide when signal conditions are optimal [13].

Fig 7 *WWVH 10 MHz antenna*

The number of users who obtain UTC(NIST) through WWV and WWVH is unknown, although is likely to number in the millions because the signals reach a large geographic area and can be heard with any shortwave radio. Audio simulcasts of both stations can also be heard by telephone through the NIST Telephone Time-of-Day Service (TTDS), which receives an average of about 2,000 telephone calls per day.

6. COMPUTER TIME SIGNALS

The synchronization of computer clocks is an important application well served by NIST through its exceptionally popular Internet Time Service (ITS). Microsoft Windows* and other computer operating systems have built-in utilities (Fig. 8) that can use the ITS for time synchronization. Some users are legally required to synchronize their computer clocks to UTC(NIST). For example, some financial institutions must comply with the National Association of Securities Dealers (NASD) Rule 6357, which requires all computer clocks to be within three seconds of UTC(NIST).

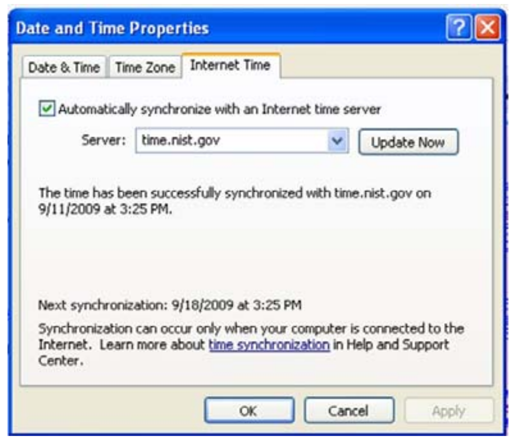

Fig 8 *NIST ITS access from Windows XP**

The ITS is one of the world's most widely used time distribution systems, handling over three billion (3×10^9) timing requests per day on peak traffic days. Many computers make multiple timing requests per day, but the number of computer clocks synchronized daily is still likely to be far more than 100 million. The ITS has grown steadily since its introduction in 1993 and now utilizes 22 time servers at various U. S. locations. It responds to several types of timing requests, but more than 90 % of the requests are in Network Time Protocol (NTP) format.

NIST also synchronizes computer clocks through its Automated Computer Time Service (ACTS), which distributes UTC(NIST) over telephone lines. ACTS originated in 1988, and currently handles about 5,000 telephone calls per day. Its uncertainty, usually less than 20 ms, is often less than that of the ITS because telephone networks normally have more stable delays than the Internet. ACTS reaches some computers missed by the ITS, such as those not on a network, and networked computers behind firewalls that block NTP access [15, 16].

The time.gov web site is another way for computer users to access UTC(NIST). The site does not synchronize computer clocks, but allows users to view the time with a web browser along with an estimate of the time's accuracy (with 0.1 s resolution). The site handles an average of about 400,000 timing requests per day.

Figure 9 illustrates how UTC(NIST) is distributed.

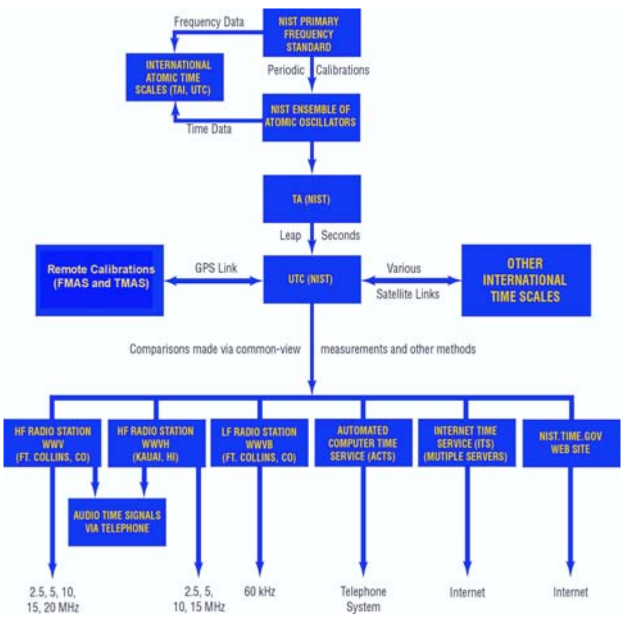

Fig 9 *UTC(NIST) Distribution*

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* *Commercial products and companies are identified for technical completeness only, and no endorsement by NIST is implied.*

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