DSN Frequency and Time Scale Change From UTC to IAT or New UTC

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By international agreement, the UTC time scale was changed to parallel that of the atomic (A.1) scale. The new time scale is called New UTC 1972 or International Atomic Time (IAT). This change in time scale made it necessary to change the frequency and time standards at all Deep Space Instrumentation Facility stations. The existing offset of UTC from A.1 time was removed from the oscillators, and all clocks were retarded approximately 107,600 μsec. This article covers the background material leading to the change, problems dealt with during the planning for it, and the procedures used to implement the change.

I. Introduction

Since 1967, the second has been defined in terms of an atomic transition; however, time scales in general continued to be derived from the rotation period of the Earth. Since the rotation speed of the Earth is slowly decreasing, a discrepancy existed because the atomic second is constant in relation to the Earth-rotation-derived second. This discrepancy between related and measurable quantities resulted in an international agreement to a compromise time scale based on the atomic transition of the element cesium. The time scale called Coordinated Universal Time (UTC) was agreed to under the auspices of the International Radio Consultative Committee, with maintenance assigned to the International Bureau of Time (BIH). The UTC time scale operated at a frequency offset of -300×10^{-10} from the cesium (A.1) scale so that it would correspond more closely to time derived from the rotation of the Earth.

UTC, although offset from atomic time, is not exactly synchronous with Earth-rotation-derived time. The Earth's rotation not only is slowing down, but is decreasing in rotational speed at a varying rate. Because of the lack of exact correspondence between UTC and other time scales (UT, A.1, ET, etc.), periodic corrections were sent by time-keeping laboratories located throughout the world to the various users of precision time. Both radio (WWV, NSS, etc.) and mail corrections were made available to the users, depending on the urgency of their requirements.

Over the past few years, several offset or frequency adjustments were made to UT scales. This effort was troublesome to users requiring long-term constant scales. UTC was never known in real time and had to be solved for after the fact or predicted. Some agencies could afford the delay in the solution of the time errors, but users such as astronomers and deep space tracking networks could not.

To avoid disadvantages in trying to keep up with the old UTC, the DSIF changed its frequency offset on or about 00:00:00 GMT, January 1, 1972. The new UTC scale now in use operates with no frequency offset from the A.1 scale. New UTC time intervals are exactly 1 sec in duration, but offset in time about 10 sec from the A.1 scale.

II. Timing Subsystem Configuration

All DSIF stations, with the exception of DSS 71 and CTA 21, have atomic oscillators as frequency sources for their timing systems. The oscillators include two Varian rubidium gas types and one Hewlett-Packard rubidium type. Three stations in the DSIF also have available hydrogen masers that are used for MSFN experiments. The rubidium oscillators have a long-term stability specification of 1×10^{-11}, which, if measured at 1 MHz, indicates ± 0.864 Hz/day or approximately 1 μsec in time.

Time signals at each of the DSIF stations are generated by connecting a 1-MHz sine wave obtained from the atomic oscillators to a shaping network that converts them to square waves. The square waves are fed to a digital divider network that divides the 1-MHz input by 10^6. The resultant 1 pulse/sec (1 pps) is used to drive a digital counter that adds the pulses; the adding circuits are configured to operate as a digital clock. Additional circuits in the clock interpret the accumulated sum and provide outputs for visual display units, which continuously indicate the time of day to the second.

Adjustment circuits are provided within the clock to allow the setting of the clock to any calibrating source providing a 1-MHz signal. By using the adjustments available, it is possible to set the clock to within 1 μsec of the calibrating source. With the clock set to the source oscillator, time outputs are provided with an accuracy equal to that of the oscillator, which in the case of the DSIF is 1 μsec/day.

By tracking standard radio time sources at VLF frequencies, phase differences between the DSIF oscillators and the input of primary time-keeping laboratories can be detected. This daily phase comparison provides an accurate determination of how fast or slow the DSIF oscillators are running. All of the sources of time and frequency used in the DSIF are traceable to the National Bureau of Standards (NBS) and/or the U.S. Naval Observatory (USNO). (The NBS is the agency responsible for frequency, and the USNO is responsible for time in the United States.)

III. Change Preparation

Many detailed requirements were established during the first few months following the decision to change the DSIF from old UTC to new UTC. Major items dealt with included:

(1) Equipment in use or required.

(2) Non-interference with tracking.

(3) Preventing loss of epoch while obtaining correct differential and offset (from old UTC).

(4) Attaining maximum cumulative error of < 20 μsec between stations.

(5) Best time for change.

IV. Equipment Required

The first decision made was that the DSIF should replace the Varian Model V4700 rubidium oscillators. The V4700 oscillators had been in the network for well over 8 yr and were approaching their calculated life expectancy. Failure data indicated the units needed increasing amounts of service; some were so old and repair-ridden that repairs were excessively costly. To update the old type oscillators, a new gas cell was required at a high initial cost. In addition, the update work would have to be done at the DSIF Maintenance Facility because the factory agreed only to furnish the new cells.

The second type of rubidium oscillator used in the DSIF, the Varian Model R20, was considered good for a few more years, since these oscillators are only 4–5 yr old and in much better condition than their predecessor, the V4700. The R20s are equipped with a time increment changer, which allows frequency changes to be made by installing a different crystal in the synthesizer. The cost of the new crystals was minimal and warranted keeping this model and updating it to the new frequency.

A new type of rubidium oscillator, the Hewlett-Packard Model 5065A, was selected to replace the V4700. Enough units were purchased to supply one to each tracking station and place one spare at the complex level, i.e., Goldstone, Spain, and Australia. The HP5065A is equipped with a feature that allows changing frequency by simply setting thumb wheel adjustments in the synthesizer and adjusting the trim of the crystal. The entire change process takes less than 5 min to complete and can be done without powering down the oscillators or the clocks. The quick-change capability enabled stations to reset their clocks with microsecond recovery to the new epoch guaranteed.

V. Time Change Parameters

With the starting and ending configurations defined for each station in the DSIF, the next problem was to find the precise frequency change (rate) required and what time scale changes, if any, were to be made. Through coordination with the USNO and the NBS, a precise rate definition was generated and a precise time offset established. The general rules were defined as follows: (1) The frequency offset or rate will be 300×10^{-10} from old UTC; (2) the time offset will be 107,600 μsec at 00:00:00 GMT, January 1, 1972; and (3) the net result will indicate new UTC parallel to A.1, but retarded by 10 sec (Fig. 1).

VI. Equipment Change

The new rubidium HP5065A oscillators were checked for proper operation at the DSIF Maintenance Facility (DMF) before being shipped to the stations in the DSIF. A procedure was also developed so that the 300×10^{-10} change could be made smoothly and with a minimum effort at the station level. Each HP5065A oscillator was shipped to the station with an adjustment procedure, proper settings for old UTC, and proper settings for new UTC included in the package.

After the HP5065As were received by the station, the Model R20 rubidium oscillators were called in to the DMF for time-increment-changer update and frequency change. The R20 units were returned to the stations set on the new UTC rate. Stations were asked to plug the units in to insure operation and to keep power on until the time change was to take place. The new HP5065A and the updated R20s were sent to all stations between October and December, 1971

VII. Project Interface

The date selected for the change to new UTC coincided with the relatively critical orbit determination period of the *Mariner* Mars 1971 mission. To avoid interfering with station tracking requirements, it was decided that change parameters spanning a period of 30 hr would be supplied to the stations. The period between -10 hr to $+20$ hr from 00:00:00 GMT, January 1, 1972, was designated as the time to make the adjustments. Since the entire change, including verification of the results, required 2.5 hr or less to complete, the stations had more than adequate time to accomplish the task. The ground rules used to determine when the change would start were: If spacecraft tracking started prior to and continued through 00:00:00 GMT, January 1, 1972, old UTC would be used for that tracking pass; if tracking started after 00:00:00 GMT, January 1, 1972, new UTC would be used for that pass.

VIII. Document Support

Procedures were written for the three station configurations existing in the DSIF. Since the three stations at Goldstone (DSSs 11, 12, and 14) are each configured differently, the three procedures were all validated at Goldstone prior to their release. The general sequence of the change in time and frequency was accomplished as follows:

(1) Maintain old UTC GMT with the oscillator that was to be removed from the configuration (the V4700) and an offline clock (time code generator).

(2) Adjust frequency of new oscillator (or maser) to the new UTC rate by adjusting the unit's synthesizer to a predetermined number.

(3) Retard clocks that are being run by the new UTC oscillators by the predetermined number of microseconds (Fig. 2 or 3).

(4) Monitor both rates to insure that proper convergence between old UTC and new UTC of 108 μsec/hr was established correctly.

(5) Disconnect old UTC oscillator from system and replace with new UTC oscillator (HP5065A) to complete the procedure.

All stations in the network followed the procedure perfectly, and subsequent checks with portable clocks and Operational Time Synchronization (lunar bounce of radar) indicated that the stations performed the change within $\pm 1 \times 10^{-11}$ in frequency and ± 5 μsec in time synchronization. Reports from all stations through their respective DSN projects showed no degradation in data and no lost data; actually, the change was so flawless that there was no indication from the projects that the change was detected.

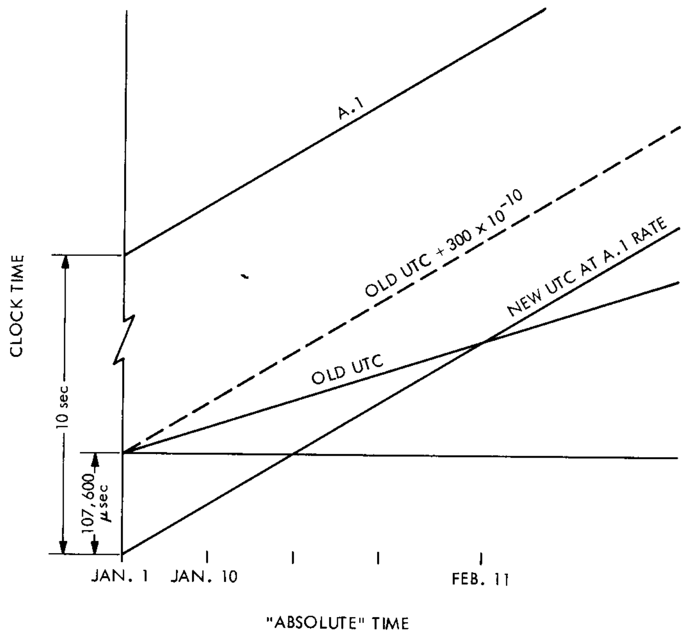

Fig. 1. Old/new UTC comparison

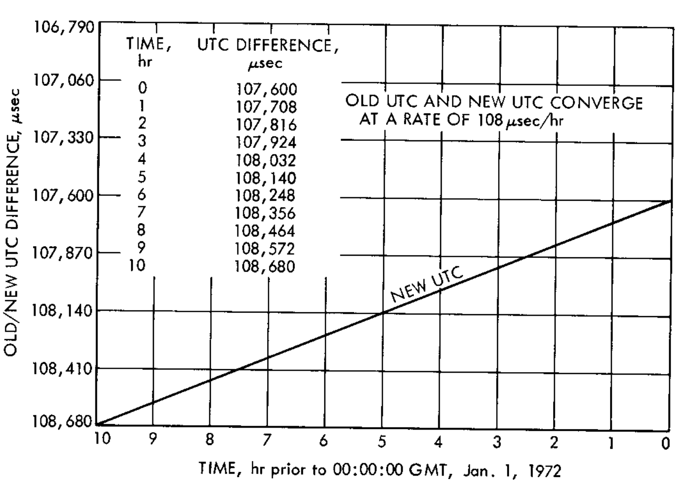

Fig. 2. Difference between old/new UTC with time: 0–10 hr prior to 00:00:00 GMT, Jan. 1, 1972

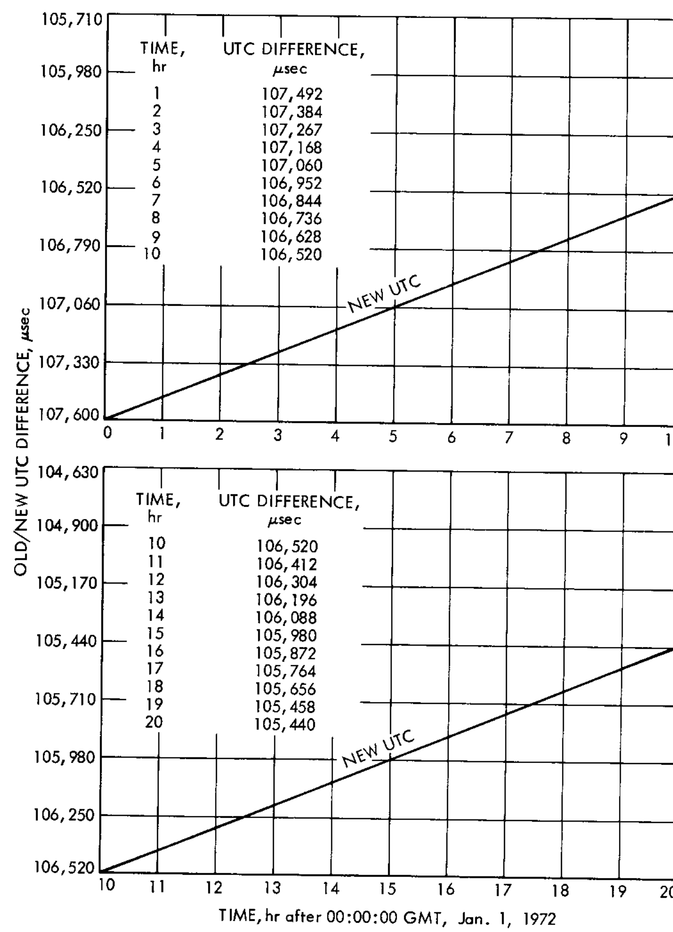

Fig. 3. Difference between old/new UTC with time: 0–20 hr after 00:00:00 GMT, Jan. 1, 1972