MULTIPLE MIRROR TELESCOPE OBSERVATORY

Smithsonian Astrophysical Observatory *and* Steward Observatory, University of Arizona

Reply to: MMT Observatory
University of Arizona
Tucson, Arizona 85721
(602) 621-1558

December 31, 1986

Mr. Roger E. Beehler
Time and Frequency Division
United States Department of Commerce
National Bureau of Standards
325 Broadway
Boulder, CO 80303

Dear Mr. Beehler:

Thank you for your letter of December 11 in which you offer to incorporate a higher resolution in the transmission of UTI-UTC (DUT) time code information.

The service you have offered would transfer a manual procedure duplicated at several receiver locations to a single transmitter location, insuring a uniform correction for DUT at all receiving sites and reducing the possibility of local error, time services traditionally provided by NBS.

The estimated cost of $2000 per year for this service that you project amounts to $8.26 per working day, since the code would not be updated on weekends or holidays, or a rate of $50 per hour for the 10 minutes per day of attention that you estimate. This cost implies some increase in manpower and overhead requirements at your site, where certainly no manpower or overhead savings would be realized at any receiving site to offset such a cost. The cost of administering a subscription for this service would incur cost however, both at your site and ours. I encourage you to review the requirement for a subscription fee to see if it cannot be eliminated. Perhaps a one time setup fee could be substituted.

As an alternate suggestion, would you entertain a request to provide only two digits of DUT instead of three? The accuracy offered by two digits of DUT (as apposed to the three originally requested and to the one now transmitted) would be sufficient for most applications. DUT data from the U.S.N.O. NEOS Bulletin show that during the period 10 December 86 to 15 January 87, the second digit of DUT is predicted to change an average of every 9 days. Assuming this average is typical of the entire year, the code would require updating 40 times a year.

In any case, I sincerely appreciate your kind attention to this matter and I am looking forward to your reply. I have forwarded a copy of this correspondence to other sites with existing or planned altitude azimuth mounts having pointing requirements of 2 arcseconds or better.

Sincerely,

Clinton Janes

Clinton C. Janes
Asst. Director for Engineering

CCJ/cp

xc: L. Barr, NOAO
M. Clark, Mt. Wilson/Las Campanas
P. Jeweil, NRAO
H. Lewis, Keck
R. Nagel, Steward
W. Sigmund, ARC

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
325 Broadway
Boulder, Colorado 80303

Reply to the attention of:

11 December 1986

Mr. Clinton Janes
MMT Observatory
University of Arizona
Tuscon, AZ 85721

Dear Mr. Janes:

This is in reply to your earlier letter requesting that we modify our broadcast format on the WWVB time code to include the DUT1 correction values to a resolution of 1 ms. I apologize for the delay in answering, but we had to consider a number of hardware and software implications and to consult with some of our higher management at NBS.

Our basic conclusion is that we can probably provide the 1 ms resolution on the WWVB code subject to certain scheduling and financial constraints. Since our time code generation equipment does not have the capability for automatic updating of this coded information, a certain amount of staff time will be needed each time the value needs to be changed. At the 1 ms resolution level, this is likely to require daily changes. While we feel we can accommodate this added burden during normal working hours, there is no way we can arrange for updating on weekends and holidays. I assume that this would not be a serious problem for you, since the quoted uncertainties on the predicted values for UT1 - UTC as given by the U. S. Naval Observatory are in the range of 3-10 ms.

Assuming that the station staff is required to spend an average time of 10-15 minutes per day in accessing the DUT1 prediction information, updating the time code generator switches, and recording the data entries, the additional time required amounts to about $2000 per year. In the current federal environment we are constrained to provide such ancillary services to small, readily identifiable user groups only when the incremental costs are reimbursed to NBS. Accordingly, we would have to ask for funding support of $2000 annually in order to implement the additional service.

If you and your colleagues would like us to proceed with the implementation of this service, please let me know what the source of funding would be and how you plan to transfer the funds to NBS. I have verified with the U. S. Naval Observatory that they plan to keep on providing the predictions we would use and since the time code generators at Ft. Collins are essentially ready, we could begin the revised procedures without much delay once we receive your approval. Meanwhile, if you need any further information, please feel free to contact me at (303) 497-3281.

I am sending a copy of this response to Hilton Lewis, Walter Siegmund, and Maynard Clark, who have also written with the same general request.

Sincerely,

Roger E. Beehler

Roger E. Beehler
Time and Frequency Division

Courtesy Maynard Clark, Mt Wilson Obs.

DUT1, What is it?

UT

The classic definition of Universal Time is Newcomb's equation, which ives a linear relation between the Greenwich Sidereal Time and the Greenwich Mean stronomical Time. The GST is the observed hour angle of actual stars transiting the meridian, while the GMAT is the civil time indicated by a "perfect" clock. Adding 12 hours to the GMAT gave the Greenwich Civil Time, and adding a time zone correction, usually an integral number of hours, gave the Standard Time. For the first half of the 20th century, this scheme was quite satisfactory, and clocks were nowhere near as accurate as the rotation of the earth.

EARTH ROTATION

It was recognized in the late 19th century that the earth was slowing down in its rotation, and Newcomb's equation incorporated a secular term to account for the average rate of change of earth rotation time with respect to time defined by the orbital motion of the earth.

TIME SIGNALS

When radio time signals were first broadcast, the time basis was the Standard Time, and the accuracy was measured in milliseconds. As the accuracy of clocks rapidly improved, their rate was adjusted to keep the broadcast time signals as close as possible to the actual standard time. It soon became obvious that the standard time defined by Newcomb's equation, the observed Sidereal Time, and the uniform time being delivered by the improved atomic oscillators were not all the same. Short period noise in the rate of earth rotation could be observed when the quartz crystal time bases were replaced by atomic clocks.

ATOMIC TIME

Modern time standards all use Cesium beam atomic clocks, which are several ders of magnitude more stable than the rotation of the earth. In 1972, the major ime standard organizations agreed to broadcast time at a uniform rate, with a uniform definition of the length of the second. Thus, the length of the second was no longer related to the rotation of the earth, but to International Atomic Time.

EPHEMERIS TIME

As noted above, it has long been recognized that the earth rotation was not uniform, but the orbital motion of the earth and other solar system bodies does produce uniform time to observational accuracy. This time scale is called Ephemeris Time to distinguish it from time based on earth rotation, which is called Universal Time. The actual difference between ET and UT is obtained from comparing transit observations with planetary positions, and can be deduced with varying accuracy over centuries. By design, the rate of International Atomic Time is that of Ephemeris Time to the best observational accuracy obtainable in 1972.

LEAP SECONDS

Since the broadcast time is known to be different from earth rotation, and what is really needed for practical civil timekeeping is the position of the earth, it was decided to introduce discontinuities in the civil time reconing of integral seconds, and to do this at announced times. The result is that the time signals broadcast would be uniform atomic time (useful to physicists doing short-term experiments), and the seconds would be labeled in a fashion very similar to the earth rotation time. Any second pulse broadcast would be within 0.7 seconds of that same named second of earth rotation time.

DUT

This scheme would then short-change the celestial navigator and the astronomer by up to plus or minus 0.7 seconds by broadcasting a uniform time unrelated to the actual earth's rotational position. Since the earth rotates by 15 arc seconds in a second of time, this gave a 10 arc second error, and a navigational error of about 1000 feet. Fortunately, this difference is known quite well by observations, the Naval Observatory tracks the difference to millisecond accuracy. This difference is needed to schedual the insertion of leap seconds. Since the difference is known, and since earth rotation time is important to celestial navigation and astronomy, the time broadcasts include the difference between their atomic seconds and the current earth rotation position. This information is currently given to an accuracy of 0.1 second, which is sufficient for navigational purposes. The time broadcast format allows for the difference to one millisecond, and the astronomical community (at least those using accurate alt-azimuth mountings) is requesting the National Bureau of Standards to supply this accuracy on their broadcasts.

POLAR WANDERING

Before deciding what accuracy is needed, we should consider what accuracy is obtainable. The other limit to accuracy in earth position at the arc second level is the location of the earth's crust with respect to the rotation axis. The actual instantaneous axis of rotation is very stable in space, its position being given by precession and nutation corrections to the milli-arcsecond level. Fluid motions within the earth allow the crust and thus all observatories to wander in a complex manner by about one arc second. There are two effects, one is a slight change in the latitude of the observatory, and the other a change in local sidereal time. Both have a full amplitude of about one arc second. This cannot be included in the DUT time correction however, because the effect is opposite in sign for two observatories on opposite sides of the earth. Without current information on the polar position, an observatory's observed zenith position will be uncertain to about plus or minus 0.5 arcsecond (0.03 sec. time).

ACCURACY OF ALT-AZIMUTH POSITION

In the world of perfect mechanisims and textbook problems, the alt-azimuth telescope is pointed by first obtaining the position of the zenith in the sky, then transforming the desired position in the sky to the mount coordinates and moving the telescope to that position. But, life is not like that. The computer will need to know the errors in the mounting, its axis orientation, encoder errors, flexure, etc. Once all those are removed, we are left with the error in the position of the zenith axis in the sky. Clearly there will be an error in the east-west and north-south positioning due to the construction of the mount, and this is indistinguishable from a slight uncertainty in the latitude and longitude of the site. Polar wandering changes both latitude and longitude, and the available knowledge of current sidereal time changes the effective longitude. Any long-term ground motion also changes this position, and the sismologists routinely measure tilts of several micro-radians occuring in time scales of weeks in active regions. To achieve an absolute pointing accuracy of 0.1 arcsecond, one would need to know UT to 6 miliseconds, and polar wandering to 0.1 arcsecond, and ground tilt variations to 0.5 microradian. All this is obtainable, but at some cost in labor and instrumentation. In practice, a few stars will be observed and the pointing corrections established by the computer, probably each night, or at least once a week. Long term accuracy without re-computing the local zenith corrections cannot be better than about one arc second.

ACCURACY OF DUT VALUES

While the DUT correction is quite smooth on the 0.1 second level, at the illisecond level there is considerable noise. Weather systems can change the oment of inertia of the earth slightly, and there are well defined seasonal variations in rotation rate. One dramatic effect in the rotation rate of the solid earth results when the global average wind has a net flow east or west.