FUTURE DEVELOPMENTS IN U.S. NAVAL OBSERVATORY TIME SERVICE

Gart Westerhout
U. S. Naval Observatory
Washington, D. C.

ABSTRACT

During the next 10 years, the U. S. Naval Observatory will be embarking on several new programs. These programs are intended to improve the U. S. Naval Observatory clock system in order to meet the stringent requirements of future systems and to improve time transfer and monitoring techniques. A descriptive review of these programs and their implementation will be given. They include radio astrometry methods to determine UT0 and polar motion and to do VLBI time transfer, incorporation of hydrogen massers in the clock system, development of GPS monitoring equipment, and additional smaller programs.

INTRODUCTION

The U.S. Naval Observatory (NAVOBSY) is charged, by DoD directive, with sole responsibility for establishing, coordinating and maintaining PTTI capabilities. Increasingly accurate time information is needed for both navigation and communication. Since the development of capabilities for better accuracy takes time, the Naval Observatory must, of necessity, always be many years ahead of deployment of new systems requiring accurate time. This paper will review some of the plans to implement new and more accurate methods of time determination and time transfer.

THE RADIO ASTROMETRY PROGRAM

The Naval Observatory plans to utilize the inherently more accurate information obtainable through radio interferometry in its overall effort of obtaining more accurate positional reference frames. Of interest at this meeting, of course, is the determination of UT0. The main task of the NAVOBSY Time Service is operational: providing daily values of time and Earth rotation parameters. In Table 1, various methods of determining these data are compared. The first part lists the optical determinations for four different instruments, visual zenith telescope, photographic zenith telescope, astrolabe, and the NAVOBSY 65-cm photographic zenith telescope. The internal mean errors listed in the second column are averages over one night using the observations of approximately 20 to 40 stars. The third column, giving external mean errors, providing averages over many nights. Note that

Table 1

OPTICAL DETERMINATIONS OF UT0 AND POLAR MOTION

	m.e. (internal)	m.e. (external)
VZT	± 0"20 (PM)	± 0"13 (PM)
PZT	0"04 (PM) 4 ms (UT0)	0"09 (PM) 7 ms (UT0)
Astrolabe	0"06 4 ms	0"10 10 ms
65-cm PZT	0"03 3 ms	
	Average over one night, 20-40 stars	Average over many nights

RADIO DETERMINATIONS OF UT0 AND POLAR MOTION

	m.e. (internal)
35-km Interfer.	± 0"01 expected 1 ms
VLBI	0"002 expected 0.1 ms

AVERAGE CURRENT DETERMINATIONS

	m.e. (internal)	
IPMS	± 0"01	(40 observatories)
BIH	0"015 1.2 ms	(50 observatories, one month)
Doppler	0"012	(10-20 stations, 2 days)

in a number of cases the external mean error is larger than the internal mean error. This is due to systematic errors caused by refraction effects of a local nature which cannot be corrected for by the standard methods. Another cause for systematic errors is the fact that on different nights and in different seasons of the year different groups of stars are used; these stars are tied to a reference system which has errors that can amount to 0.1 to 0.2 arc seconds, and the errors are caused to a large extent by the poor knowledge of the proper motions of the stars. Methods are being developed to better determine atmospheric refraction and there are extensive efforts underway to considerably improve the internal consistency of the stellar reference frame. It is especially in this latter effort that radio interferometry, as well as optical interferometric methods, might eventually play a very important role.

In the second part of Table 1 are listed the expected mean errors using two different types of radio determinations of UT0 and polar motion. The 35-km interferometer referred to is the connected-link interferometer of the National Radio Astronomy Observatory in Green Bank, WV. The expected mean errors are based on a limited series of observations of a few days each of a small number of radio sources. Similarly, the expected very long baseline interferometric values are based on a few experiments that have taken place in the last few years. "Expected", in this context, means that, with proper care and with extended observations, it is hoped that eventually such accuracies will be obtained on a routine basis. In particular, it is hoped that development of equipment especially geared to polar motion and UT0 will increase the accuracies considerably.

In the third part of Table 1 are listed the average mean errors of polar motion and time published by the International Polar Motion Service (IPMS) and the Bureau International de l'Heure (BIH). It will be noted that averages over a month's observations using many different observatories provide approximately the same accuracy that a radio interferometer can reach in a few hours of observation. Doppler and laser ranging techniques provide approximately the same kind of accuracies as expected from the 35-km interferometer. Daily values of UT and polar motion to this precision are basically unknown. It should be noted that 1 millisecond of time is equivalent to 1½ feet. Obviously the improved accuracy is needed for geodesy, surveying, and the physics of the interior of the Earth.

The NAVOBSY, in collaboration with the Naval Research Laboratory, hopes to acquire and operate the Green Bank 35-km interferometer for daily measurement of UT0 and polar motion starting in FY79.

TIME TRANSFER VIA VERY LONG BASELINE INTERFEROMETRY (VLBI)

The inherent capability of a VLBI system to synchronize two oscillators at each end of a network is better than 1 nanosecond. This is an inherent capability - it has not been proven that this accuracy can be realistically utilized. No system yet exists to calibrate or check this value.

It is important to realize that the most accurate time transfers with portable clocks have accuracies of approximately 25 nanoseconds. In very special cases, using multiple trips, it is possible to obtain 10 nanoseconds accuracy. One experiment, which used an entire clock ensemble and provided extremely carefully controlled pressure and temperature surroundings, claims to have maintained an accuracy, during transport of the clocks over a period of 15 hours, of the order of 1 nanosecond. Transportation of a clock ensemble in this manner may make it possible to verify the VLBI accuracies.

In order to reach such accuracies with VLBI, all antenna system delays have to be very carefully calibrated on each end. It seems possible to set up an internal VLBI system with sub-nanosecond accuracy, but eventually the system will have to be tied to other time systems. It is dependent, therefore, on currently existing time transfer mechanisms, such as Loran-C, which presently provides accuracies of, at most, 100 to 150 nanoseconds. Hopefully, more accurate continuous time transfer techniques will be developed in the course of the next few years.

The advantage of VLBI time transfer is, of course, its great inherent precision. There are many possible locations for VLBI stations using existing antennas; it is relatively inexpensive to construct new stations at the existing antennas if such are required; and the system spans intercontinental baselines with ease. Another great advantage is that there is no direct reliance for time transfer on vulnerable satellites. A disadvantage is that clocks get synchronized ex post facto; the digital tapes acquired at each of the VLBI stations have to be transported to a central location for processing. Experiments have been run where the data has been transferred via satellites and these will be reported on elsewhere in this volume. This technique, of course, does give instantaneous results but depends, again, on satellite availability which is expensive.

Requirements now demand an accuracy of 10 nanoseconds for time synchronization around the globe. It is clear that in order to reach that type of accuracy, the Naval Observatory needs to be able to transfer time to approximately an order of magnitude better. So in order to even reach the current requirements for communication and navigation we already are required to transfer time to the order of 1 nanosecond.

It is especially for these reasons, and because the NAVOBSY is responsible for this work as far as the DoD is concerned, that we are pushing so hard towards making systems like this operational. We simply cannot afford to remain in an experimental state for too long.

MASTER CLOCK IMPROVEMENT

The requirement exists for an improved operational master clock system. The current Naval Observatory Master Clock is an ensemble of more than 20 cesium clocks interrelated via a computer. Presently, the computer calculates a provisional mean and controls a real-time clock which differs from the provisional mean by 5 nanoseconds, on the average. A final mean is later calculated, and the difference of the provisional mean from the final mean can sometimes be as high as 40 nanoseconds. The noise of the final mean is only a few nanoseconds. Obviously, correcting the time provided by the real-time clock a few days later is a very cumbersome method. NAVOBSY's goal is the calculation of a real-time final mean and to have a real-time clock which differs from this mean by no more than 1 nanosecond. Two things are required in order to reach this: (a) improved algorithms in the calculations and, (b) improved oscillators in order to eliminate noise and to obtain greater inherent stability. The NAVOBSY is in the process of studying: (a) the acquisition of a clock ensemble consisting of hydrogen masers and, (b) the feasibility of using super-conducting cavity oscillators or other high performance cryogenic oscillators. Again it should be noted that accuracy of a real-time clock of 1 nanosecond is a requirement that is here now. Users come to the NAVOBSY with their portable clock and expect accuracies of better than 10 nanoseconds; they do not want to later correct their time transfer from provisional to final mean time. We need an operational system with 1 nanosecond accuracy.

DEVELOPMENT OF GLOBAL POSITIONING SYSTEM (GPS) TIME TRANSFER UNIT

In order to utilize the GPS system for time transfer and clock synchronization, a single channel time transfer unit is now being developed and will be tested at the NAVOBSY. The unit will be available commercially. The NAVOBSY will monitor on a regular basis the GPS satellite clocks for comparison with the improved master clock system which, hopefully, will be stable enough as a comparison standard.

Comparable work has been done using the Transit Satellite system, in conjunction with the Navy Astronautics Group. To improve time distribution around the world, a timing receiver was developed that can provide time anywhere with an accuracy of a few microseconds. This receiver is commercially available at nominal cost. It is hoped that the GPS receiver now under construction will allow time distribution several orders of magnitude better.

IMPROVEMENT OF TV TIME TRANSFER

Details concerning NAVOBSY's efforts in this area are published elsewhere in this volume. The TV Time Transfer system which has been operational in the Washington, D. C. area for some time is now being implemented in the Los Angeles area as well. Currently, work is underway to use this system for very precise navigation in local areas.

INCREASED LORAN-C COVERAGE

Due to the expansion of the Loran-C system, the NAVOBSY, which monitors the Loran-C timing, will have to increase its monitoring capabilities. Improvement in the 100 to 150 nanoseconds accuracy of Loran-C is not expected as efforts for improving accuracies are going into other systems. The very large area of coverage of the Loran-C system is its major benefit.

LASER TIME TRANSFER

A program is underway, in collaboration with NASA, to perform an experiment using the space shuttle. This system is the reverse of the normal laser timing experiments in that the laser will be on-board the space shuttle and the retro-reflectors will be on the ground. The ground stations record the time of arrival and, using the on-board clock on the space shuttle it is possible to transfer time with extremely high accuracy. In fact the accuracy expected is such that the only method we see of checking it is by VLBI techniques and, therefore, it is planned to mount ground stations at various VLBI sites. Of course this will work only if we already have proven the inherent accuracy of the VLBI system.

CONCLUSION

The NAVOBSY continues to improve its determination of the Earth's rotational parameters as well as its master atomic clock and time transfer techniques. It is important to point out that the various efforts in these directions should be coordinated as closely as possible. All factors, whether they be astronomical, technological, or geodetic, influencing time and time transfer should be considered. It is hoped that the efforts being made for closer coordination will continue.

QUESTIONS AND ANSWERS

MR. LAUREN RUEGER, Johns Hopkins University, Applied Physics Lab:

You indicated Doppler measurements were only integrated for a couple of days and you take your interferometer measurements for a month. Is there some reason you discriminate against the Doppler?

DR. WESTERHOUT:

No, I didn't discriminate against the Doppler at all. I was simply saying that typically the Doppler values that are published are averages over 10 or 20 stations over a few days, and they have the same accuracy as what one expects to get out of the 35-kilometer interferometer.

MR. RUEGER:

Our experience has been that we get a substantially better mean for month averages.

DR. WESTERHOUT:

Thank you.