CURRENT TIME SCALES AND CHALLENGES: GPS 1999 WNRO AND THE YEAR 2000

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ABSTRACT

This paper describes the current internationally recognized atomic time scales of International Atomic Time (TAI), Coordinated Universal Time (UTC), and Global Positioning System (GPS) Time as well as solar based Universal Time. The concept of Leap Seconds and the differences between the time scales are discussed. A brief history of the international agreements that created organizations responsible for maintaining these time scales is provided. A brief review of the GPS 1999 (Week Number Roll Over) WNRO with its potential GPS user problems is provided. Prudent personal precautions are proposed for the Year 2000 (Y2K) Rollover.

KEY WORDS

International Atomic Time (TAI), Coordinated Universal Time (UTC), GPS Time, Leap Seconds, Y2K Precautions

INTRODUCTION

This paper is intended to introduce and contrast four different commonly used time scales and discuss responses to two current timing problems. The time scales discussed include solar based Universal Time and atomic based International Atomic Time (TAI), Coordinated Universal Time (UTC), and GPS Time. Precautions to prevent problems with the 1999 GPS WNRO (Week Number Roll Over) in user GPS receivers and recommended personal preparations to make for the Year 2000 are provided.

INTERNATIONAL AGREEMENTS LEADING TO OUR CURRENT TIME SCALES

In 1875 the Convention du Metre was held in Paris. The result was a diplomatic treaty signed by seventeen nations to set up a structure to agree on standards of measurement. The Bureau International des Poids et Measures (BIPM) was established to do the metrological work under the supervision of the Comite International des Poids et Mesures

(CIPM) and the ultimate approval by the Conference General des Poids et Measures (CGPM).

In 1884 the International Meridian Conference voted to set up 24 Time Zones worldwide with the prime meridian at Greenwich, England. It is interesting to note that although this conference was held in Washington, D.C. and that the U.S. and Russia were the two major countries with railroads extending over multiple time zones, the zones (although used) were not officially approved in the U.S. by Congress until the Standard Time Act of March 19, 1918.

Over the next 30 years National Standards Bureaus were set up in different countries. The U.S. National Bureau of Standards was set up in 1901. In 1913 following a scientific conference in 1912, representatives of 32 nations agreed to the idea of an Association International de l'Heure but it was not ratified due to World War 1. In 1919 the International Astronomical Union (IAU) was created which approved forming the Bureau International de L'Heure (BIH) effective as of January 1, 1920. The BIH was to gather information about the earth's rotation and disseminate time, since from the first CGPM in 1889 (which defined the meter and kilogram and implied the second as 1/86,400 of the mean solar day), the constancy of the earth's rotation was assumed as the basis for time.

By the 1940's it had become apparent from the improvements in time keeping with quartz oscillators that the Earth's rotation rate was not constant. A new, more uniform timescale based upon astronomical observations in Newcomb's Tables of the Sun and Planets was proposed. The new timescale would be called Ephemeris Time since it depended upon the ephemerides of astronomical bodies. Following the lead of the 1955 IAU General Assembly and the 1956 CIPM, the 11th CPGM in 1960 redefined the second. Instead of 1/86,400th of the Mean Solar Day, 1/ 31,556,925.9747th of the tropical year starting 1900 January 0, 12 hours Ephemeris Time was selected. (This date is equivalent to 0000 hours January 1, 1900, since the ephemeris day began at noon.)

With the use of cesium atomic standards in standards labs starting in 1955, the Consultative Committee for the Definition of the Second was established in 1956 to coordinate the work done by physicists and astronomers. The second was redefined in 1967 by the 13th CGPM as "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the caesium-133 atom" (per Proceedings of the IEEE, Vol. 79, No. 7, July 1991, p. 1070) at sea level. Thus the astronomical ephemeris second was now defined in terms of a stable, reproducible atomic standard which is the primary metrological unit of the International System of Units (SI).

In 1959 the Administrative Radio Conference in Geneva allocated frequencies in the 2.5 to 25 MHz region to time and frequency standard services and requested the International

Radio Consultative Committee (CCIR) study the issue of creating and maintaining a worldwide frequency and time standard service by radio. While the National Bureau of Standards in the U.S. had provided such a service since 1923, between 1962 and 1971 a number of other standards labs broadcast a time and frequency service over radio. (This was typically a Universal Time (see below) known as UT2, which was an averaged UT1 which eliminated seasonal fluctuations.) The CCIR worked along with the BIH, IAU, and other international bodies to agree on and coordinate time standards and dissemination.

INTERNATIONAL ATOMIC TIME (TAI)

In 1971, the 14th CGPM agreed to take the atomic time scale used at BIH since 1955 and establish International Atomic Time (TAI) as the official atomic time scale. The origin point where TAI was matched closely in phase with UT1 was selected as 1 January 1958 (0000) with a time scale continuous from that point in time. TAI is actually a "paper clock". It is a post processed weighted average of a large number of primary frequency standards from many National Standards Labs using an intermediate time scale (EAL) and a correction factor for the duration of the scale unit to make it close to the SI second with the final value not available until some time (over 60 days) later. It does provide a very stable time scale suitable for scientific work and is the basis for all other accepted atomic time scales.

In 1987 with the recommendation of the IAU, the 18th CGPM took over responsibility for TAI from BIH. This was appropriate because maintaining atomic time is a standards lab rather than observatory matter. BIPM at Sevres, France has maintained TAI since 1987.

UNIVERSAL TIME

Universal Time denotes a family of time scales following the diurnal movement of the sun. The actual definitions are quite particular, but do mathematically relate Universal Time to Sidereal Time or the position of the equinox. UT0 is the raw measurement of the observed rotational time, but it varies with location. UT1 is the most used of these time scales as it corrects UT0 so that the time scale is not location dependent, but does follow the variable rotation of the earth. Thus, it closely approximates what was known as Greenwich Mean Time (GMT) which was the basis for navigational almanacs and until more recently, civil time as maintained by the Royal Greenwich Observatory. (Since British civil time is now based on UTC rather than UT1, the use of the term Greenwich Mean Time has become ambiguous. The time scale should be specified as UT1 or UTC.) This rotational time scale shows irregularities several orders of magnitude greater than the atomic time scale of TAI, but is useful because navigation, astronomy, and humanity all relate to the perceived motion of the sun. UT2 is an averaged UT1 (adjusted for seasonal variations) and was used for a period of time in the 1960s and early 1970s as the primary internationally

disseminated time scale (and was even sometimes called UTC during that period). While still disseminated, with the advent of UTC (as now defined), UT2 is no longer a primary time scale since UT1 is more useful for navigators than an averaged rotational scale and UTC has atomic regularity.

COORDINATED UNIVERSAL TIME (UTC)

To coordinate successfully the stability and precision of TAI with the rotational UT1, UTC was established as an official time scale. Most national standards organizations started using it effective 1 January 1972. CCIR Recommendation 460-2 proposed all organizations adopt UTC by 1 January 1975.

The elements of UTC are twofold. First, UTC is simply an offset of seconds from TAI. Thus it runs exactly syntonized with TAI (Frequency TAI = Frequency UTC) and with the on time mark exactly coincident. Second, UTC is closely synchronized to UT1 (Time UTC = Time UT1 in Close Approximation).

The earth's rotation relative to the sun currently is slower than TAI by about 2 milliseconds per day or a second every 500 days. This is a rate difference due primarily to tidal friction slowing the earth from the time period of the calculations used for defining the Ephemeris second, which in turn became the SI second. It is actually a complicated choice of definition because the Ephemeris second was defined as a fraction of the tropical year 1900 using Newcomb's tables of the motion of the Sun because it brought observations into accord with Newtonian theory. However these same tables were based on an average of astronomical observations from 1750 to 1892 and thus the year in which the Mean Solar Day probably actually had exactly 86,400 of our SI seconds was 1820. For a more detailed account, see the "Leap Seconds" @ tycho.usno web site (full address listed in References). To compensate for this, a Leap Second is periodically inserted (roughly every 18 months) under UTC Time. While this is the main reason behind adding leap seconds, there are other irregular variations in the rotation of the earth and having the ability to add or delete leap seconds with respect to TAI is useful.

Thus, the UTC Time Scale differs from TAI only by an integral number of seconds. On January 1, 1972 the difference between UTC and TAI was exactly 10 seconds (essentially the accumulation of time or phase drift between 1 January 1958 when TAI was set equal to UT1 and the introduction of UTC on 1 January 1972). Since January 1, 1972 twenty-two Leap Seconds have been added (no subtractions yet), so as of 1 January 1999 until (probably) June 2000, UTC is behind TAI by exactly 32 seconds.

A leap second can be added or dropped at the end of any month, but June or December are the first choices and March or September are the second choices to introduce a leap

second. Only June and December have been used thus far. (The last 4 leap seconds have been added every 18 months since June 30, 1994.) The way the seconds within a UTC minute are counted and labeled is 0 to 59. When a second is added (retarding UTC with respect to TAI) the sequence runs 58, 59, 60, 0. If a second were to be dropped (advancing UTC with respect to TAI), the sequence would be 57, 58, 0.

In accordance with the CCIR Recommendation, UTC is maintained within a maximum of nine tenths of a second of UT1. As an example, UT1 is allowed to retard from UTC by up to nine tenths of a second before a leap second is inserted into UTC. IERS (formerly BIH) promulgates the predicted and then post processed actual difference to UT1 (DUT1) in tenths of a second (8 tenths/second maximum DUT1 plus one tenth/second error). DUT1 = (approximately) UT1-UTC, thus when leap seconds are added the sign of DUT1 changes from negative to positive.

On January 1, 1988 the BIH was formally disbanded. Its atomic time duties had already been transferred to BIPM, while a new organization with a broader mission, the International Earth Rotation Service (IERS) was established in its place at the Paris Observatory. IERS is the organization that now decides when to add or delete a leap second to UTC.

Thus UTC keeps closely in tine with the rotation of the earth and so keeps noon at the middle of the day (in the center meridian of the time zone on average) and yet is a stable atomic time as well. UTC is now the basis for all civil time, rather than UT1 (or what was previously known navigationally as Greenwich Mean Time).

GPS TIME SCALE AND 1999 WEEK NUMBER ROLL OVER (WNRO)

The GPS Time Scale is a repeating Time Scale of 1024 weeks. It is a continuous time scale since its origin point coincident within one microsecond of 0000 January 6, 1980 UTC Time. GPS time is disseminated by the GPS system using a 10 digit count of weeks (0 to 1023) and a 19 digit time of week count of 403,200 intervals of 1.5 seconds which provides 604,800 seconds. The GPS system is intended as and considered to be a coordinated time to UTC and TAI and is currently a prime source of time dissemination. Like TAI there are no leap seconds, so there is a fixed offset of 19 seconds from TAI. As there are no leap seconds, GPS Time can slowly advance from UTC Time as seconds are added to UTC Time. Currently there have been 13 leap seconds added to UTC Time since the start of GPS time and so the second GPS Epoch or Cycle of 1024 weeks will start on August 21, 1999 at 23:59:47 UTC. Week 1023 will reset to Week 0 and Second 604,800 will reset to Second 0. Per the GPS-SPS Signal Specification, users must account for the fact that it is actually the week 1024 or more from the start of the GPS cycle. This is

known as the Week Number Roll Over (WNRO) or End of Weeks Rollover. Another rollover will occur again in 1024 weeks.

As this paper will not be published until after the Week Number Roll Over, most problems with any non-compliant receivers will be discovered before ITC. However, depending on the actual OEM receiver firmware and the software conversions created by the integrator or users, it is possible that the user may see problems separately for Y2K on January 1, 2000 or GPS/Y2K related problems with the February 29 Leap Year. Users may also see problems with receivers that have been in storage or have had batteries changed affecting their non-volatile memory. It is still advisable for each user to confirm both the Y2K and WNRO status of his or her receiver with the hardware manufacturer or software integrator. Most manufacturers have web sites listing product compliance for both Y2K and 1999 WNRO issues. Users must be very careful to ensure that their specific serial number or revision number of the product is covered in the compliance list. In many cases, older versions of the same model or part number will not be compliant, but new versions will be compliant.

Y2K OR YEAR 2000 PROBLEM: OVERVIEW

By ITC, you will all be aware of the Y2K problem. Years ago, because computer memory was very expensive decisions were made to save space and money by using just two digits instead of four to denote years. In some PCs for example, certain BIOS chips have a hard-coded 19 for the century. In other cases operating systems or user software cannot handle Year 2000 dates and may consider the year to be 1900 instead. If the computer thinks it is 1900 instead of 2000 then day of week calculations are wrong. In 1900 January 1was a Monday, but in 2000 its a Saturday. Unlike 1900, 2000 is a leap year.

One technique of remedying Y2K problems is by sorting dates with a hundred-year window. For example one window is 1930 to 2029 so that any 2 digit year 30 or up will be considered to have a 19 in front of it while a 29 or lower will be considered to have a 20 placed in front of it. In some programs these will be converted to four digit years format (which is the recommended solution), in other programs they will not be converted. There are problems if the correct date is not within the original window, or if another program working on the same data original or processed data interprets using a different window such as 1980 to 2079 for example. Your system may be fully Y2K compliant, but if you feed bad data in, your system can process and send erroneous data out. Embedded processors are another potential problem. Some of these control such items as chemicals in the water supply.

Y2K OR YEAR 2000 PROBLEM: PERSONAL COMPUTERS

Users need to be concerned with hardware (BIOS and Real Time Clock), software (Operating System and Applications), and data. Typically the web sites of the various hardware and software manufacturers will list exactly which products are compliant or can be made compliant. Make sure you check for the exact revision of your software. The Federal Reserve Board web site and other government and private web sites listed in References are helpful and have references to other web sites. As a general rule, only the most recent software (1999) is compliant as you purchase it, most other software must be patched or upgraded to achieve compliance. Since many applications use the windowing technique described above to deal with two digit years, it is a good idea to check each application to verify its window date criteria. For the Microsoft Windows family it is strongly advised to set the Regional Settings in the Control Panel Menu to four digit years, so that after data is created or sorted, it will be in the four digit year format.

Y2K OR YEAR 2000 PROBLEM: FAMILY PRUDENCE

After ITC there are only two (2) months left to get ready. While most experts now believe that serious problems will be localized in nature and many web sites state that all will be well with their products, these same web sites issue disclaimers against relying on their advice. It is true that there are a number of pessimists and even alarmists hawking the end of the world or at least a huge crisis. While I am not a bona fide expert on Y2K, I am outlining an approach below that is like a fire insurance policy. It is better to prepare or pay a little bit to have some protection in the event of even an unlikely catastrophe, than take no precaution at all. After all if you are in the area of a “localized problem”, it could still be a BIG Problem for you! Also, ideally you want your issues resolved so you are in a position to help others.

Part of the problem with Y2K is that due to the synchronizing effects of the time scales above that we now all use, there is a simultaneity to the problem unlike many previous problems. When television commercials first came out and the networks synchronized the commercials and program breaks so that viewers could not easily switch channels without getting another commercial, many apartment houses had plumbing breakdowns. The effect of large numbers of people visiting the bathrooms simultaneously rather than distributed more uniformly caused pipe bursts because they had not been designed for that volume of usage at once. While one or two accidents at rush hour can cause slowdowns in any major city, multiple accidents can create gridlock across the city. The non-availability of assets to deal with the problem quickly becomes in itself a problem and then unresolved problems lead to other problems. Solutions that would normally be available are not available. The bottom line here is be prudent and prepare to do what you can in the next two months to

make sure the problems you deal with are minimal, rather than major or catastrophic for you or those you care about.

For family prudence start with the basics. Based on my research, I believe two weeks is a prudent time frame. A reasonable way to look at this is to pretend it is a two week camping trip taken in your living room. Another scenario is how would you prepare for a two week flood or ice storm situation where you are left on your own resources? Two weeks is most likely longer that you would need, but if you are well prepared for two weeks, you could probably make those supplies last longer if needed. What is critical for you and those you love, including your extended family, both the elderly and the very young?

1. Air: Without air we suffocate very quickly. Normally this is NOT a problem. However, if you are in an airtight bunker relying on fans for air and the power goes out for an extended period, it is a problem.

2. Critical Medical Items: Are you and those you care about able to walk up or down from their high rise apartment when the elevators are out? Are their pacemakers Y2K compliant? How about dialysis equipment that they use? Are they stocked up on insulin (over half of which comes from Denmark) and any other drugs or medical supplies that they must have? For those items, a one or two month supply may be a wise idea since inventory disruptions may persist for some time after immediate problems are resolved. Start stockpiling immediately on these items. The Food and Drug Administration (FDA) plans to complete an assessment of critical medical devices that may have problems by October 1, 1999.

3. Water: One gallon per day per person is the recommended amount. There are a number of ways to store water including 2.5 or 5 gallon plastic containers and reused soda bottles. Iodine or chloride tablets are available at camping stores and filters are available in most grocery stores. Remember, embedded processors control many water supply functions. What if there is a sewer problem that contaminates the water supply? Floods and hurricanes have created similar problems in the past.

4. Heat: In the North, heat is vital in the winter. If the heat is out due to lack of power, fuel, or other disruption what will you use as an alternative? Firewood, kerosene, propane, or butane stoves, sterno, solar methods, sleeping bags, and blankets are all possibilities.

5. Light: Plan to spend time in sunlit rooms during the day. Solar rechargeable flashlights or other such solar lighting is a great choice. Candles, Coleman lanterns, and battery run lights are other possibilities. Fuel or batteries and matches are required sundries.

6. Power for Other Items: Even if you have medical items, heat, and light power requirements taken care of, do you need power for security systems, computers, telecom or other communication equipment such as radios (AM-FM and short-wave) or walkie talkies? If you do not already have a portable generator, it is likely too late to get one and properly install it. Judicious use of a well stocked battery supply is your best alternative. Car batteries and an inverter are a possible choice. Will your refrigerator defrost, spoil all the food inside, and melt into a foul smelling water problem?

7. Food: It's a two week camping trip in winter. There is no forage and no animals to hunt. While many of us including myself could survive two weeks without food, it would not be pleasant. Stockpile items that you actually do eat that require little maintenance to cook or keep from spoiling. Nowadays a variety of canned and bottled drinks and other easily stored items such as meal substitute bars, rice cakes, peanut butter, nuts, dried fruits, and meats are readily available. It is recommended that you start building and rotating your stockpile now and actually test out consumption of the foods before you have the real requirement. Again, consider it as a two week camping trip.

8. Garbage, Trash, and Other Waste Disposal: While total waste generation will be down, if the garbage disposal, toilet, and trash pick up are not available, what will you do? A boaters or camping chemical portable potty is a possible short term solution. A biological potty may be better. An entrenching tool and plenty of paper for the paperwork is a wise idea. A good supply of various size ziplock and trash bags for food, trash, and other waste products is a prudent idea.

9. Emergency items: Fire fighting supplies and a well stocked emergency medical kit including a good guide book and some light to read it are a minimum. Include sterile cloths and sterilizing liquid.

10. Personal Hygiene and Minor Medical: Baths and sinks may not be available, but wash cloths and waterless soap should be stocked along with minor medical items such as aspirin, allergy, stomach, cold, flu, and other medicines.

11. Communications: Consider your telecom, computer, internet, and other communications needs. A cellular phone on a different carrier than the regular phone is a prudent idea. A portable computer and plenty of batteries may cover your computer needs if used sparingly. A walkie-talkie, short wave or ham radio may be useful.

12. Transportation: Some people claim that there will be problems with post 1981 cars. General Motors, Ford, and others claim that their cars will not experience Y2K failures. Prudence would dictate alternative modes of transportation in case there are auto or mass transit problems. Depending on the area, bicycles, skis, snowmobile, or skates may

provide possible alternatives. Definitely have a FULL TANK OF GAS in whatever car or fuel powered alternative you use by Dec 30 at the latest and be prepared to use it sparingly, since a bulk commodity like gasoline is at the end of a long inventory chain.

13. For loved ones that you care for, perhaps you should all congregate together if you can't get back and forth or if some of them have need of support. Consider if you need to go to work or if you can take a vacation and just take care of the home front.

14. Security: Depending on your own situation, a whistle, air horn, or cell phone may be sufficient for your needs. Consider that some electronic security systems may not work and that the police may not be able to get to you as rapidly as normally. A good review of your situation is the first step. Sensible planning and practice in security matters is a must. If you decide to have a firearm or other weapon, learn how to use, store, and care for it. If you are NOT mentally, emotionally, and physically prepared to use these items properly, do not have them. In the long run, the best policy is to be a good neighbor and work with your community to watch out for each other. Security is an issue however, since most people will be keeping a larger supply of cash on hand than usual while others may have nothing.

15. By now, you should have copies of important records and receipts for bills on paper where you can get them if needed for mortgage, insurance, utilities, banks, credit cards, etc. A recent credit bureau report is a good idea. I firmly believe that having enough cash on hand to meet your needs for two weeks is a minimum. The cash on hand should include lots of small bills and change. Larger amounts so you have enough for bigger bills could be stored with travelers checks or already made out money orders.

Hopefully these precautions will be just a dress rehearsal exercise and nothing more!

REFERENCES

Jesperson, J. and Hanson, D., (Editors), Proceedings of the IEEE-Special Issue on Time and Frequency,
Volume 79, Number 7, IEEE Publishing Services, Piscataway, NJ, July 1991

Seidelmann, P. Kenneth, (Editor) Explanatory Supplement To The Astronomical Almanac, University Science Books, Mill Valley, California, 1992

(Letter of Promulgation), Global Positioning System (GPS) Standard Positioning Service (SPS) Signal Specification, Department of Defense, Washington, DC, December 1993

"Leap Seconds", http://tycho.usno.navy.mil/leapsec.html

"FFIEC Home Page", http://www.ffiec.gov/y2k

"Testing Personal Computers for Year 2000 Compatibility", http://www.bog.frb.fed.us/y2k/pctesting.htm

"Y 2 Care About Y2K: Checklist", http://www.consumer.gov/y2k/index.html

"Microsoft Outlines a Three-Step Approach to Help Consumers Tackle the Y2K Problem", http://www.microsoft.com/presspass/features/1999/06-01y2k.htm

"General Motors Year 2000 Readiness Disclosure", April 9, 1999, http://www.gm.com/about/info/news/y2k/question.html

"Ford Motor Company's Y2K SEC Filing", http://www2.ford.com/display.asp?story=435