TransNav
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 11
Number 2
June 2017

DOI: 10.12716/1001.11.02.01

The Concept of Time in Navigation

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ABSTRACT: The article discusses the concept of time in navigation, especially in marine navigation, as well as selected time measures, among others: Greenwich Mean Time (GMT), Universal Time Coordinated (UTC), International Atomic Time TAI (Temps Atomique International), GPST (Global Positioning System Time) eLoran Time and interrelation between these measures. Understanding how time is involved in navigation, and using it, is one of the navigator's most important duties. Nowadays we have satellite navigation to help us know where we are. These satellites contain several very precise and accurate clocks, because time and location are completely and totally inter-related in satellite navigation. There is growing interest internationally concerning the vulnerability Global Navigation Satellite Systems (GNSS) to natural and man-made interference, plus the jamming and spoofing of their transmissions. These vulnerabilities have led to a demand for sources of resilient PNT (Positioning, Navigation and Timing) [16], including a robust means of distributing precise time nationally and internationally.

1 INTRODUCTION

Time is the indefinite continued progress of existence and events that occur in apparently irreversible succession from the past through the present to the future [9]. Time is a component quantity of various measurements used to sequence events, to compare the duration of events or the intervals between them, and to quantify rates of change of quantities in material reality or in the conscious experience. Time is often referred to as the fourth dimension, along with the three spatial dimensions [2].

The history of the origins of time measurement is very distant and closely associated with the development of astronomical research. The count of time is of great importance in everyday life and has also played an important role in navigation [14].

In the 20s and 30s of the twentieth century, that is, during the initial period of the maritime radionavigation, the problem of time knowledge did not really matter to the user, as the position was measured by the only one radiolocation device, i.e. radio direction finder (RDF), where measured parameter was angle. The situation has radically changed with the emergence of new methods, based on distance measurements or distance differences, and when there was a need to synchronize broadcast time transmissions. If in classical navigation and astronavigation the accuracy of 0.5 s, even 1 s both measurement and knowledge of time was sufficient, unfortunately in radionavigation became unacceptable. The problem of creating one, common to all, time scales, became of particular importance at the launch of new terrestrial radionavigation systems and satellite navigation systems covering the entire surface of the Earth.

For several years now, especially in long-term measurements of radio frequency and time signals have been used mainly the radio signals emitted by navigation systems. This is possible because navigational systems are based on the measurement of the delay of radio signals emitted by several remote transmitting stations, and the nature of the operation of these systems indicates that all stations must emit synchronous signals based on one common time scale. These valuable properties of signals emitted by navigation systems have made them used to measure the frequency and time of signals used in synchronous telecommunication systems. Some operators also use these signals to directly control the clock of telecommunication devices.

The first global radionavigation system was the Omega system, which has long since been decommissioned [12]. The practical application for synchronization of telecommunication networks has found the Loran-C system, whose some individual chains are still interwoven with some marine areas. However, the widespread use of navigation system signals for the synchronization of telecommunications networks has only brought the GPS system.

2 CONCEPT OF TIME

Time is the physical size, characterizing events by the order in which they occur. Usually, time is used in three completely different meanings [14]:

- as the **moment** (point of duration) at which the event took place; in practice, this means that the exact date of the selected time point is given, e.g. when the position of the ship is determined; in satellite systems this refers, for example, to the time the satellite transmits the signal;
- as a period or **interval** between two border events, e.g. time between two observed positions; in satellite systems, this refers, for example, to the time of propagation of the signal on the route from satellite (the moment of sending the signal) to the terrestrial user (the time of signal reception by receiver);
- as a **duration** or continuance, a measure of the length of the past time, such as watch duration, duration of counting, star life; in satellite systems, this refers, for example, to the effective life time of an orbiting satellite.

Time as a duration means the past, present, and future of all existence. Time as an interval covers the period between two events. As a point in duration, time means the precise instance, second, minute, hour, day, month, and year as determined by a clock or calendar.

The basic unit of time is the second (s). Over the past several decades, the definition of a second has changed several times as units of time, and new time scales have been established. These changes were due to the introduction of ever more accurate time patterns, from mechanical through quartz to atomic, and in the not so distant future also hydrogen.

3 UNDERSTANDING TIME IN NAVIGATION

Time understand as a point in duration can use many different reference points. When we talk about local time, noon for our location is quite different from noon to someone in Australia or America. If we want to reference time to some common point so that everyone in the world knows what that time is, then we must all agree on the point. Greenwich Mean Time (GMT) is the primary time used for official events and is measured at the zero meridian in Greenwich, which has been agreed upon by all nations of the world more than hundred years ago. Time and longitude are so intertwined in navigation that it is difficult to discuss of one without understanding the other. But before we get into this relationship, let go first to cover some history in the search for time, its measurement, and the inventions used to measure it [11],[15].

For most of history, ordinary people did not have access to any kind of time-measuring device, other than to glance at the sky on a sunny day and see where the sun was. For them, time as we understand it today did not really exist. The measurement of time began with the invention of sundials in ancient Babylon and Egypt about 16th century BC. The need for a way to measure time independently of the sun eventually gave rise to various devices, such as sandglasses, waterclocks, and glowing candles. Sandglasses and waterclocks utilized the flow of sand and water to measure time, while candles used their decreased height. All three provided a metaphor for time as something that flows continuously, and thus began to shape the way we usually think of time [11].

Though their accuracy was not great, these devices provided a way to measure time without the need for the sun to be visible. Each of these time-measuring devices carried markings designed to give sundial time. In addition to a lack of accuracy, sandglasses, waterclocks, and candles had to be reset frequently. It did not collide with great discoveries; Bartolomeo Dias, Christopher Columbus and Vasco da Gama had to use hourglasses to measure time.

After the discovery of the laws of the pendulum, a more accurate clock was invented that could not only count the hours, but eventually minutes and seconds. The idea of measuring time by splitting it into equal, discrete intervals and counting them was at odds with the concept of time as something that flows. The division of a day into 24 equal hours, of each hour into 60 minutes, and of each minute into 60 seconds are all human inventions required by the need for a more accurate measurement of time [15].

Despite the various improvements, most early clocks were highly unreliable. However, this was of little consequence, since they could be checked and adjusted regularly by reference to the sun. Thus, despite the technology and the mechanical nature of the time clocks produced, time was still ultimately dependent on the sun.

By the middle of the seventeenth century, pendulum clocks that were accurate to within 10 seconds per day were being manufactured. This was far more precise than the sundial. But, for the vast majority of the world's population, the sun would continue to provide the principal means of telling the local time. However, the definitive time was provided by a clock. From then on, clocks were used to set and calibrate sundials, rather than the other way around as previously had been the case [11].

Of course, any system that used the sundial as a primary reference point was using local time. To bring order to this temporal chaos, regional time zones started to develop. By the late nineteenth century, many countries had adopted uniform time systems within their borders but there was hardly any coordination between nations. In particular, there was the fundamental issue of where to locate the base line for measuring longitude.

Time and navigation are inextricably linked together. For example, if some people lived on one of the Pacific Islands, they learned about the currents in the sea and the stars in the sky. With the stars in the sky they could figure out where they were when sailing from one island to another. There is plenty of available information on the early methods of navigation, even ancient. In the Middle Ages there was a great desire to improve navigation and there was a great push to advance the technology between 1500-1800 as we realized that if we knew what time it was we could determine our longitude. We also shifted from using the quadrant and astrolabe to the sextant. It was in the 1700s that John Harrison invented the marine chronometer, a long-sought timekeeping device to solve the problem of establishing one's East/West position (longitude) at sea. This is really important because if your clock is off that means your longitude will be off too.

The establishment of a worldwide system to measure longitude brought with it a notion of worldwide time. Since there are 24 hours in a day and 360 degrees in a circle, each 15 degrees of longitude represented one hour. Thus, by wrapping a 360-degree longitudinal grid around the earth, the planet was divided into 24 time zones, each one hour different from its neighbours.

Though largely hidden from our view, the fine-grained notion of time in use today, based on the movement of pulsars and measured by the tiny quantum energy states of the atom, quite literally affects the very fabric of our daily lives and the way we view ourselves and the world we live in. We live by the clock, and in many ways we are slaves to the clock. The use of Greenwich Mean Time for celestial navigation is required since all the Nautical Almanac tables are referenced to GMT and it is the official time for all maritime navigation. Accurate time is very important to celestial because any clock errors will throw the fix off by many miles.

4 DEFINITION OF TIME UNIT

Any recurrent physical phenomenon can be used to determine the time unit pattern. Initially, the second was related to the rotation of the Earth. In 1832, Charles F. Gauss defined a second as 1/86400 part of the mean solar day, i.e. the period between the lower culmination of the mean Sun. This approach remained until 1956. From this definition it was evident that the time unit was derived from the rotation of the Earth around its axis, which was then considered to be even. Improving the accuracy of clocks, especially after introducing of William H. Short and the quartz clocks, in the 1920s and 1930s enabled the first to detect and then measure the annual changes in the rotation of the Earth. In order to eliminate these irregularities in 1956, the definition of a second was changed, referring now to the period of Earth's circulation around the Sun, more precisely to the tropical year in 1900 (the year of the tropics, the time between successive passages of the Sun through the point of Aries, where celestial equator crosses the ecliptic, and also the cycle of repetition of the seasons). Because of the earlier Simon Newcomb's theory of the motion of Earth it was apparent that the tropical year was 31556925,9747... seconds, the new definition said that the second is 1/31556925,9747 part of the tropical year. In 1960, such a definition entered the SI, although not for long [14],[15].

In the meantime, works at the National Bureau of Standards (USA) have shown that it is possible to phase-conjugate a quartz oscillator to the resonant frequency of a quantum transition in certain molecules or atoms. In such a process, strong quartz oscillations are tuned into the feedback loop so that they are accurate replicas of the weak quantum signal. Soon the frequency standard based on atomic cesium - prototype of modern atomic clocks was made. The precision of this type of device, surpassing several orders of magnitude, the conventional quartz oscillator, finally led to a second re-definition: the SI second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom (1967).

This SI second, referred to atomic time, was later verified to be in agreement, within 1 part in 10^{10}, with the second of ephemeris time as determined from lunar observations. Nevertheless, this SI second was already, when adopted, a little shorter than the then-current value of the second of mean solar time

Where did such number of periods in this definition come from? The first cesium frequency bands had the accuracy of one part per 10^9 - 10^{10}, while the universal time seconds, even after smoothing seasonal fluctuations and Earth-bound (UT2) fluctuations, could have varied at several levels in 10^8 over a decade. It was necessary to determine the frequency of cesium transition with a better unit, ephemeris seconds. Between 1955 and 1958, special observations of the Moon were made (the ephemeris time is best determined on this object), receiving at the frequency of 9192631770 ± 20 Hz. The inaccuracy of this result is mainly due to the error of ephemeris. Further follow-up to 1967 confirmed this result. To this day, the compatibility of ephemeris seconds with atomic seconds is satisfactory, although the future will settle for how long.

We can guess that the already mentioned atomic time is the scale by which the atomic second is discussed here. In fact, time signals distributed by radio and available on a daily basis are synchronized to atomic frequency patterns. There are many such patterns, and each one works independently of each other. Consequently, there is a need to continually compare their practices and develop a certain average scale; it is the Temps Atomique International, or TAI. In this situation, it will be very important how long is the TAI second. It turns out that since 1987 (previously, it was different), the TAI second is systematically longer than the definite SI second from the sea level. In 1995, the difference was specifically one part for 10^{14}. Who cared about such a small deviation? However, there are more serious reasons for efforts to improve this scale. They provide the pulsars - fast-rotating neutron stars. It seems very likely that some of the millisecond pulsars rotate more stable than the best atomic scales in averaging periods of the order of a year or more. At such intervals, the instability of atomic patterns may therefore limit the accuracy of certain parameters obtained from observation [14].

Good example of the use of atomic clocks is provided by the Global Positioning System. GPS depends on a network of 24 satellites orbiting the earth. Each satellite continually beams down a signal giving its position and the mean-time determined by the four atomic clocks it carries on board. By picking up and comparing the time signals from three satellites, a ground receiver can compute its latitude and longitude with an accuracy of a few meters with selective availability turned off. The clocks on the satellites have to be extremely accurate. The determination of the position of the ground receiver depends on the tiny intervals of time it takes an electromagnetic signal to travel from each of the satellites to the receiver. Since the signal travels at 186,000 miles per second, a timing error of one-billionth of a second will produce a position error of about one foot. The onboard clocks are accurate to one second in 30,000 years [11].

5 TIME SCALES

The most important observation of covering the stars by the Moon is the moment in time when the phenomenon occurred. An observer should have access to a time service, that is, a clock operating according to a certain scale. Time information was obtained over the ages from different sources, including shuttle clocks. For marine users, these timers, however, were not useful due to rolling and pitching. The situation changed radically only in 1759 when English watchmaker John Harrison "Longitude" replaced the pendulum with a metal spring and constructed the first mechanical chronometer. Until the appearance on the market the first receivers of the satellite Transit system, the chronometers were the main sources of time information on sea-based vessels.

In order to establish a time scale, you should not only measure, calibrate, but also determine the beginning of the time scale. Earth's rotation is associated with three time scales: star time, mean solar time, and the most known universal time UT, based on averaged over a year of Earth rotation.

The most famous international time scales include the following scales:

- UT - Universal Time - is counted from 0 hours at midnight, with unit of duration the mean solar day, defined to be as uniform as possible despite variations in the rotation of the Earth;
- UT1 is the principal form of Universal Time; while conceptually it is mean solar time at 0° longitude, precise measurements of the Sun are difficult; hence, it is computed from observations of distant quasars using long baseline interferometry, laser ranging of the Moon and artificial satellites, as well as the determination of GPS satellite orbits; UT1 is the same everywhere on Earth, and is proportional to the rotation angle of the Earth with respect to distant quasars, specifically, the International Celestial Reference Frame (ICRF), neglecting some small adjustments; the observations allow the determination of a measure of the Earth's angle with respect to the ICRF, called the Earth Rotation Angle (ERA, which serves as a modern replacement for Greenwich Mean Sidereal Time); UT1 is computed by correcting UT0 for the effect of polar motion on the longitude of the observing site; it varies from uniformity because of the irregularities in the Earth's rotation;
- UT0 - is the rotational time of a particular place of observation; local approximation of universal time without taking into account polar motion; it is observed as the diurnal motion of stars or extraterrestrial radio sources., and also from ranging observations of the Moon and artificial Earth satellites. The location of the observatory is considered to have fixed coordinates in a terrestrial reference frame (such as the International Terrestrial Reference Frame) but the position of the rotational axis of the Earth wanders over the surface of the Earth; the difference between UT0 and UT1 is on the order of a few tens of milliseconds; the designation UT0 is no longer in common use;
- UTC (GMT) - Coordinated Universal Time; it differs from TAI by an integral number of seconds; it is the international standard on which civil time is based; it ticks SI seconds, in step with TAI; it usually has 86,400 SI seconds per day but is kept within 0.9 seconds of UT1 by the introduction of one-second steps to UTC, the "leap second"; as of 2017, these leaps have always been positive (the days which contained a leap second were 86,401 seconds long); whenever a level of accuracy better than one second is not required, UTC can be used as an approximation of UT1; the difference between UT1 and UTC is known as DUT1;
- TAI is the International Atomic Time scale, a statistical timescale based on a large number of atomic clocks; the unit of this time is SI second;
- TDT (Terrestrial Dynamical Time) or TT (Terrestrial Time) - Earth dynamic time, used for observation from the surface of the Earth; with unit of duration 86400 SI seconds on the geoid, is the independent argument of apparent geocentric ephemerides. TDT = TAI + 32.184 seconds;
- TDB (Barycentric Dynamical Time) - Barycentric dynamic time, used for ephemeris related to the solar barycentric system; is the independent argument of ephemerides and dynamical theories that are referred to the solar system barycentre; TDB varies from TT only by periodic variations;
- GMT (Greenwich Mean Time) is the mean solar time at the Royal Observatory in Greenwich, London. GMT was formerly used as the

international civil time standard, now superseded in that function by Coordinated Universal Time (UTC). Today GMT is considered equivalent to UTC for UK civil purposes (but this is not formalised) and for navigation is considered equivalent to UT1 (the modern form of mean solar time at 0° longitude); these two meanings can differ by up to 0.9 s. Consequently, the term GMT should not be used for precise purposes;

- GAST (Greenwich Apparent Sideral Time) - associated with the true equinox date; is Greenwich Mean Sidereal Time (GMST) corrected for the shift in the position of the vernal equinox due to nutation. Nutation is the mathematically predictable change in the direction of the earth's axis of rotation due to changing external torques from the sun, moon and planets. The smoothly varying part of the change in the earth's orientation (precession) is already accounted for in GMST. The right ascension component of nutation is called the "equation of the equinoxes";
- GMST (Greenwich Mean Sideral Time) - average time of the star for the Greenwich meridian; it is the measure of the earth's rotation with respect to distant celestial objects; linked to the average equinox for a given date. Compare this to UT1, which is the rotation of the earth with respect to the mean position of the sun. One sidereal second is approximately 365.25/366.25 of a UT1 second. In other words, there is one more day in a sidereal year than in a solar year.

Currently, GMT can be considered as a general equivalent of universal time UT. The ephemeris time ET, which today only has historical significance, is associated with the Kepler movement, or central gravity-based movement. Ephemeris time ET was a dynamic scale used in the period 1960-1983. Later it was replaced by the TDT and TDB scales. The difference between earthly and barycentric dynamic time scale is due to the change of gravitational potential along the Earth's orbit.

After the introduction of atomic time models into the market in the 1960s, a new term emerged - atomic time, the unit of which is the atomic second. The beginning of the atomic time scale was set at 1 January 1958 00h 00m 00s UT2. At this time the time in both scales was identical. Since then there have been two time scales, one based on rotational motion of the Earth, and the other on atomic patterns. Earth's rotation is associated with day and night phenomena that are associated with the biological cycle of all living organisms living there. Therefore, on the one hand, it was necessary to measure time with increasing accuracy, and on the other hand to continue using universal time. Due to the fact that one second in atomic time is shorter by about $2.6 \cdot 10^{-8}$ s, the number of past atomic seconds increases faster than the universal ones. That means that after a year the atomic scale reading will be about 0.82 s larger than the universal scale. For this reason, a compromise solution was needed that would take into account both the advantages of atomic patterns and the changes in rotation and circulation of the Earth. This solution has introduced a new time scale called Coordinated Universal Time - Universal Time Coordinated (UTC).

Coordinated Universal Time UTC - standard time based on TAI taking into account the irregular rotation of the Earth and coordinated with solar time. To ensure that the mean Sun over a year passes over Greenwich meridian at 12:00 UTC, with an accuracy of not less than 0.9 s, from time to time to UTC is added so-called transient second. This operation is carried out by IERS (International Earth Rotation Service). Coordinated Universal Time is expressed using a 24-hour clock and uses the Gregorian calendar. It is used in air and maritime navigation, where it is known under the military name Zulu time ("Zulu" in the phonetic alphabet corresponds to the letter "z", which denotes the Greenwich meridian 0).

In October 1971, the atomic scale of TAI (International Atomic Time) was introduced officially, based on atomic patterns in which the unit is said SI second. The difference between TAI and UT1 on the beginning of selected years is shown in Table 1. The difference is growing steadily, exceeding the 34 seconds in 2010 and 37 seconds in 2017.

Table 1. Difference between TAI and UT1 on 1st Jan. in selected years

Year	TAI - UT1 [s]
1558	0
1968	6,1
1978	16,4
1988	23,6
1998	30,8
2003	32,3

Earth's spin is not uniform. Quasi-periodic changes as well as age decline are observed. Because of this, time scales based on Earth's rotation are changing relative to atomic time and dynamic scales. Delta T is the difference between Terrestrial Time (TT) and Universal Time (UT1) i.e.

Delta T = TT – UT1.

It is a measure of the difference between a time scale based on the rotation of the Earth (UT1) and an idealised uniform timescale at the surface of the Earth (TT). TT is realised in practice by TAI, International Atomic Time, where TT (TDT) = TAI + 32.184 seconds. In order to predict the circumstances of an event on the surface of the Earth such as a solar eclipse, a prediction of Delta T must be made for that instant of TT.

Delta T = TDT – UT

The value of Delta T changes quite irregularly and is difficult to predict. The length of the day varies throughout the year by 0.002 seconds. The speed of rotation of the Earth is highest in July and August and the smallest in March.

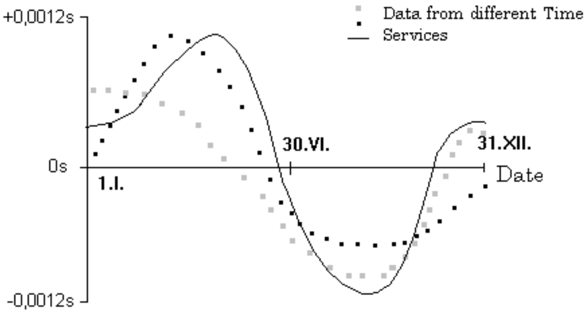


Figure 1. Annual irregularities in vortex movement [1]

Tidal forces in the Earth-Moon system cause energy dissipation and synchronization of the Moon's spin motion relative to its orbital motion. The speed of rotation of the Earth also depends on tidal forces. For example, the difference T in 1999 was about 64 s (Fig.2).

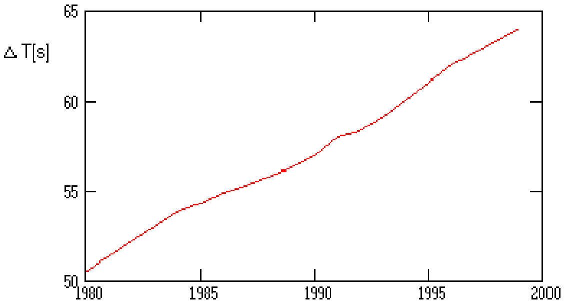


Figure 2. Irregularities in vortex movement in recent years (based on data from The Astronomical Almanac [1])

The diagram (Fig.3) displays the values of Delta T for the telescopic era (1620 to the present) as tabulated on pages K8 and K9 of the current edition of The Astronomical Almanac [1]. Data are given for the beginning of each year. A simple parabolic function used to estimate Delta T is also plotted for comparison purposes. It takes the form Delta T = – 20 + 32·T^2 [8], where T is the number of centuries since 1820. This function is based on the assumption that the length of the mean solar day has been increasing by about 1.7 milliseconds per century.

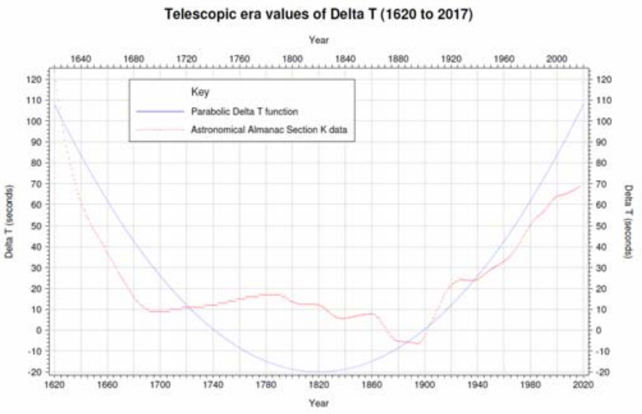


Figure 3. Telescopic era values of Delta T (1620 to 2017) [1],[8]

The diagram (Fig. 4) shows the values of Delta T derived from Bulletin B of the IERS. Two sets of predictions are also provided for comparison purposes. The daily Delta T data and predictions are plotted for the interval 2000 to 2050 from MICA v2.2.2. The predictions derived from the IERS Sub-bureau for Rapid Service and Predictions are also plotted for the period 2006 April 1 to 2027 October 1 along with their uncertainties (vertical error bars). The current trend of observed Delta T data lies between the two sets of predictions. This diagram illustrates the problem faced by almanac producers when trying to estimate suitable values of Delta T for future almanacs.

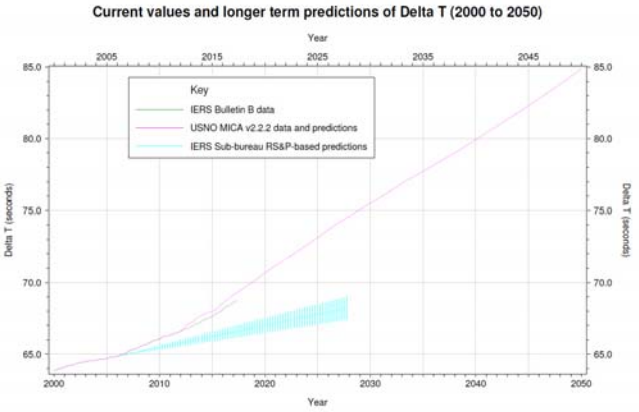


Figure 4. Current values and longer term predictions of Delta T (2000 to 2050) [1]

6 GPS TIME (GPST)

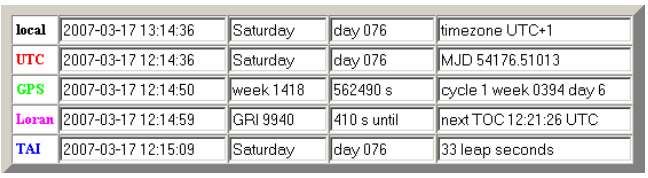
Over the last twenty years, the Global Positioning System (GPS) has become the primary tool for national and international atomic clocks. This technique gives ten times better accuracy than using the Loran-C navigation system (also used for most time station services in many Western countries). This is why for the first time the best world frequency standards can be compared in a way that is accurate to their accuracy. So far, atomic clock technology has always been ahead of time. Time accuracy of GPS satellites is 10-20 ns (1 ns = 10^{-9} s) at intercontinental distances and 2-3 ns within one continent. With average averaging of 10 days, the difference in pattern frequencies is measured at one part level at 10^{14}. There are further studies counting on achieving clock accuracy of 0.3 ns or better.

GPS is a satellite navigation system based on measurements of distances to satellites. Atomic clocks (cesium or rubidium). It allows you to instantly and continuously determine position and time anywhere in the world.

Nearly all of the time service labs are equipped with well-performing, fully automated GPS receivers. The system has its own time, the so-called GPST (GPS Time). GPS time is a continuous scale (GPS time counting started midnight from 5 to 6 January 1980 00h 00m 00s UTC) synchronized to one microsecond accuracy with UTC (USNO) time, i.e., UTC time in the United States Naval Observatory (in turn this implementation differs from UTC in general less than 1 ms). As far as GPS is concerned, no leap seconds are introduced, so far (first half of 2017), the difference between UTC has risen to 18 seconds (GPST - UTC);

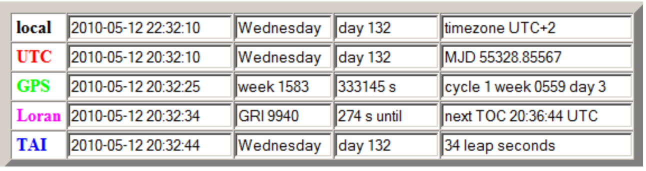
the TAI - GPST difference is approximately 19 seconds. GPS satellite signals carry encoded information about the current satellite clock correction relative to GPS time and UTC (USNO) time with accuracy 100 ns.

Table 2. Difference between local time LT, UTC, GPS time, Loran time and TAI: for 17-03-2007 at 12:14:36 UTC [6]



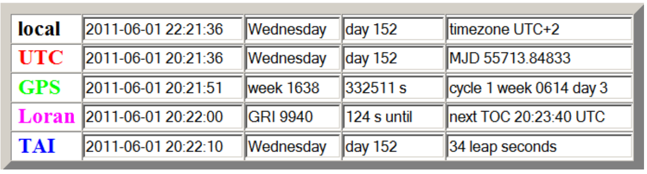
local	2007-03-17 13:14:36	Saturday	day 076	timezone UTC+1
UTC	2007-03-17 12:14:36	Saturday	day 076	MJD 54176.51013
GPS	2007-03-17 12:14:50	week 1418	562490 s	cycle 1 week 0394 day 6
Loran	2007-03-17 12:14:59	GRI 9940	410 s until	next TOC 12:21:26 UTC
TAI	2007-03-17 12:15:09	Saturday	day 076	33 leap seconds

for 12-12-2010 at 20:32:10 UTC



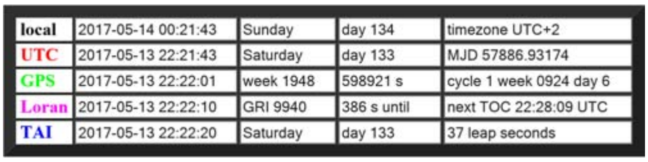
local	2010-05-12 22:32:10	Wednesday	day 132	timezone UTC+2
UTC	2010-05-12 20:32:10	Wednesday	day 132	MJD 55328.85567
GPS	2010-05-12 20:32:25	week 1583	333145 s	cycle 1 week 0559 day 3
Loran	2010-05-12 20:32:34	GRI 9940	274 s until	next TOC 20:36:44 UTC
TAI	2010-05-12 20:32:44	Wednesday	day 132	34 leap seconds

for 01-06-2011 at 20:21:36 UTC



local	2011-06-01 22:21:36	Wednesday	day 152	timezone UTC+2
UTC	2011-06-01 20:21:36	Wednesday	day 152	MJD 55713.84833
GPS	2011-06-01 20:21:51	week 1638	332511 s	cycle 1 week 0614 day 3
Loran	2011-06-01 20:22:00	GRI 9940	124 s until	next TOC 20:23:40 UTC
TAI	2011-06-01 20:22:10	Wednesday	day 152	34 leap seconds

for 13-05-2017 at 22:21:43 UTC



local	2017-05-14 00:21:43	Sunday	day 134	timezone UTC+2
UTC	2017-05-13 22:21:43	Saturday	day 133	MJD 57886.93174
GPS	2017-05-13 22:22:01	week 1948	598921 s	cycle 1 week 0924 day 6
Loran	2017-05-13 22:22:10	GRI 9940	386 s until	next TOC 22:28:09 UTC
TAI	2017-05-13 22:22:20	Saturday	day 133	37 leap seconds

7 PRACTICAL USE OF THE TIME SCALES

Which of the many time scales should we use in practice? It depends on the situation, on our needs, abilities and on specific applications. A sailor, an amateur of astronavigation for observation, should, in principle, have sufficient time in the Baltic Sea region, CET or EET (Central or Eastern European Time), obtained by synchronizing the local clock to the radio time signals of one of the many stations. When compiling observations, it should convert this time into a universal time coordinated UTC by subtracting 1 or 2 hours from the time zone. Sun observers should have the ability to calculate the real sun time, because it governs the position of the sun relative to the horizon; e.g. at 12:00 o'clock that time, the sun is on the local meridian, i.e. in the highest point on the horizon. Real time is obtained from the universal by adding the longitude of the place (λ, positively East of Greenwich) and adding the time equation (read from the astronomical almanac). If we are interested in the accuracy of one second, then we do not have to worry about the differences between UTC, UT0, UT1 and UT2 identifying them with just universal time, UT [14].

Professional astronomers may need rotational time, so they should convert UTC to UT1 by adding appropriate corrections (called DUT1 and dUT1 with accuracy of 0.1 and 0.02 s respectively) also read from radio signals: UT1 = UTC + DUT1 + dUT1.

To set up a telescope for a particular star, we need a local real star time. We can calculate it for a specific time UT from the Greenwich Mean Sidereal Time (GMST), adding a correction to the score (it is also read from the almanac) adding the longitude of the observation location:

$$ST = GMST + (nutation) + \lambda.$$

In the opposite case, we want to know when the selected object is in a certain position relative to the horizon. We must then know or calculate its angle in this place. If the object culminates, then we know immediately that its q is 0h (12h). In other situations, it is generally necessary to use simple spherical trigonometric formulas. From an hour angle, we get instant local star time: LST = a + q, and hence the Greenwich Apparent Sidereal Time GAST = ST - λ. From this result, we will subtract the time to get Greenwich Mean Sidereal Time GMST. Now to convert the Greenwich time GMST to UT, we need to calculate or look up the almanac and read the GMST0, i.e. the Greenwich Mean Sidereal Time at midnight UT in Greenwich. If GMST0 is numerically larger than GMST, it means that the last one is for the next star daily, so for continuity it should be returned (add to GMST) one day, i.e. 24 hours. We now safely calculate the final:

$$UT = (GMST - GMST0) \cdot 0.997269566329,$$

always receiving a non-negative value less than 24h. If the UT falls less than 4 minutes, then our object probably (if there is no significant motion in the right angle) will again appear on the same hour angle (24 hours after the star, i.e. after 23h 56m 04.09s of mean solar time).

We should use time as uniformly as possible in the observation results. On very long stretches, the best approximation is the ephemeris time we get from universal time by adding the DT parameter (we read it from the tables or, for dates before 1620, we calculate according to one of the analytical expressions available in the literature). Dates are expressed in ephemeris Julian days (JED), i.e. we use a simple algorithm to calculate the JED for the calendar year, month and day, but the UT time is replaced by the calculated ET hour. The measure of the distance of two events in time is the difference of the respective Julian days: JED2- JED1.

Since 1955 there is also an equivalent ephemeris nuclear scale, but more accurate than the ET scale related to TAI we have from January 1, 1961 (since 1972 they are full seconds time differences TAI - UTC). By moving from ET to TAI, however, remember that these scales are shifted in relation to each other by 32,184 seconds. Even more uniform is the TT scale in BIPM (Bureau International des Poids et Mesures) implementation. Unfortunately, it is only available since 1976. TT scales can be treated exactly the same as ET, because they are intended as continuators of it.

Complete information on the UTC scale and its related problems can be found in, inter alia, Vol. 2, Admiralty List of Radio Signals in the chapter titled Radio Time Signals [13].

Since the early 1990s, all radio signals are UTC. Also, the broadcasting of terrestrial broadcasting systems and satellite navigation systems is directly or indirectly related to UTC.

7.1 *Astronomical Times Definitions*

Several important time scales still follow the rotation of the earth, most notably civil and sidereal time, but of these are now derived from atomic time through a combination of earth rotation theory and actual measurements of the earth's rotation and orientation.

GMST (Greenwich Mean Sidereal Time) - Sidereal time is the measure of the earth's rotation with respect to distant celestial objects. Compare this to UT1, which is the rotation of the earth with respect to the mean position of the sun. One sidereal second is approximately 365.25/366.25 of a UT1 second. In other words, there is one more day in a sidereal year than in a solar year.

By convention, the reference points for Greenwich Sidereal Time are the Greenwich Meridian and the vernal equinox (the intersection of the planes of the earth's equator and the earth's orbit, the ecliptic). The Greenwich sidereal day begins when the vernal equinox is on the Greenwich Meridian. Greenwich Mean Sidereal Time (GMST) is the hour angle of the average position of the vernal equinox, neglecting short term motions of the equinox due to nutation.

It might seem strange that UT1, a solar time, is determined by measuring the earth's rotation with respect to distant celestial objects, and GMST, a sidereal time, is derived from it. This oddity is mainly due our choice of solar time in defining the atomic time second. Hence, small variations of the earth's rotation are more easily published as (UT1 - Atomic Time) differences. In practice, of course, some form of sidereal time is involved in measuring UT1.

GAST (Greenwich Apparent Sidereal Time) - Greenwich Apparent Sidereal Time (GAST) is Greenwich Mean Sidereal Time (GMST) corrected for the shift in the position of the vernal equinox due to nutation. Nutation is the mathematically predictable change in the direction of the earth's axis of rotation due to changing external torques from the sun, Moon and planets. The smoothly varying part of the change in the earth's orientation (precession) is already accounted for in GMST. The right ascension component of nutation is called the "equation of the equinoxes" [5].

GAST = GMST + (equation of the equinoxes)

LMST (Local Mean Sidereal Time) - Local Mean Sidereal time is GMST plus the observer's longitude measured positive to the East of Greenwich. This is the time commonly displayed on an observatory's sidereal clock. LMST = GMST + (observer's East longitude)

LST (Local Sidereal Time) - The definition of Local Sidereal Time given in the glossary of the Explanatory Supplement to the Astronomical Almanac is "the local hour angle of a catalog equinox." This fits the common text book definition

Hour Angle = LST - Right Ascension

In practice, LST is used more loosely to mean either LMST or "Local Apparent Sidereal Time" = GAST + (observer's East longitude). The operational definition probably varies from one observatory to the next.

7.2 *TAI, UTC and Leap Seconds*

The global reference for time is International Atomic Time (TAI), a time scale calculated at the BIPM, using data from some 400 atomic clocks in over 70 national laboratories. The BIPM organizes clock comparisons for the determination of TAI through an international network of time links. Corrections to local national timing laboratory clocks are generally applied monthly or weekly and typically will be a few nanoseconds (ns).

TAI long-term stability is set by weighting participating clocks. The scale unit of TAI is kept as close as possible to the SI second by using data from those national laboratories which maintain the best primary standards. These will generally be Hydrogen Masers or high performance Cesium standards.

UTC is identical to TAI except that from time to time a leap second is added to ensure that, when averaged over a year, the Sun crosses the Greenwich meridian at noon UTC to within 0.9 s. The dates of application of the leap second are decided by the International Earth Rotation Service (IERS) [3].

7.3 *PNT (Positioning, Navigation and Timing)*

Global Navigation Satellite Systems (GNSS) provide positioning, navigation, and timing information. These satellite systems are augmented by ground stations which can be used as reference points to increase the accuracy of information derived from the satellite signals.

All three: positioning (determining location), navigation (finding your way from one to another), and timing (supplying highly accurate time to synchronize complex systems) are used together with map data and other information (weather or traffic data, for instance) in modern navigation systems [16].

We need a broad range of smart, low-cost, high-performance GPS/GNSS timing clock and test products for next generation navigational systems. It should be well suited for some of the following applications:

- GPS/GNSS timing for mobile vehicle locations,
- navigational timing measurement & analysis instruments,
- ground pseudo GPS timing systems,
- guidance & telemetry reference clocks,
- radar & sensor timing systems,
- submarine navigational timing systems,

– high-performance clock stability analysers.

7.4 *Enhanced Loran as a National Time Standard*

Enhanced Loran eLoran is an internationally standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It is the latest in the long-standing and proven series of low-frequency, Long-Range Navigation (Loran) systems, one that takes full advantage of 21st century technology [3].

eLoran meets the accuracy, availability, integrity, stability and continuity performance requirements for aviation non-precision instrument approaches, maritime port and harbour entrance and approach manoeuvres, land-mobile vehicle navigation, and location-based services, and is a precise source of time and frequency for applications such as telecommunications. It is an independent, dissimilar, complement to Global Navigation Satellite Systems. It allows GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.

What is important, eLoran meets a set of worldwide standards and operates wholly independently of GPS, Glonass, Galileo, BeiDou or any future GNSS. Each user's eLoran receiver will be operable in all regions where an eLoran service is provided. eLoran receivers work automatically, with minimal user input. eLoran transmissions are synchronized to an identifiable, publicly-certified, source of Co-ordinated Universal Time (UTC) by a method wholly independent of GNSS. This allows the eLoran Service Provider to operate on a time scale that is synchronized with, but operates independently of, GNSS time scales. Synchronizing to a common time source will also allow receivers to employ a mixture of eLoran and satellite signals [4].

The principal difference between eLoran and traditional Loran-C is the addition of a data channel on the transmitted signal [3]. This conveys application-specific corrections, warnings, and signal integrity information to the user's receiver. It is this data channel that allows eLoran to meet the very demanding requirements of landing aircraft using non-precision instrument approaches and bringing ships safely into harbour in low-visibility conditions. eLoran is also capable of providing the exceedingly precise time and frequency references needed by the telecommunications systems that carry voice and internet communications.

Each country that contributes to Universal Coordinated Time (UTC) operates a national time standard that is independent of GNSS. Its technology will generally be based on a Hydrogen Maser. This will be adjusted using monthly corrections supplied by the BIPM in France [4].

Low-frequency eLoran is now emerging as the preferred advanced source of positioning, navigation and timing (PNT) signals alternative or complementary to global navigation satellite systems (GNSS). eLoran is globally-standardized and does not share the vulnerability of GNSS to incidental or deliberate jamming, intentional spoofing, radio-frequency interference or space weather events.

A number of countries are actively reconsidering their dependence on GNSS across multiple critical infrastructure applications and some are planning the implementation of eLoran transmitter networks. Within this context falls the question of how to deliver their national time service to those clients who have come to recognize their own vulnerability to the disruption of GNSS. The paper [4] discusses the concept of delivering such national time services by means of eLoran signals. It was proposed the use of eLoran to disseminate precise time, timing and phase traceable to UTC for both indoor and outdoor applications. Continuous accuracies of better than 100 ns with respect to UTC are being achieved in current proof-of-concept and technology-readiness trials. The paper [4] proposes and illustrates a method of establishing national time standard services using eLoran. These would be traceable to sovereign national UTC. They would be of great benefit to a wide range of users, notably telecommunications providers and financial sector organisations for whom precise time synchronisation will be required by future services. These organisations are also becoming concerned about their dependence on GNSS timing, given its vulnerability to jamming and interference and the complexity and expense of deploying it, especially when required indoors.

The paper [4] explores the ability of eLoran to distribute UTC traceable time to applications in GNSS-denied environments, including indoors. It sets the foundation for further research into the application and dissemination of UTC using eLoran signals in geographical regions where they are available. Research into this topic has been conducted by Chronos Technology in collaboration with UrsaNav [3]. This has shown that UTC-traceable time of an accuracy better than 100 ns and with a quality comparable to that provided by GPS can be received even indoors at ranges of more than 800 km (500 miles) from eLoran transmitting stations. This new time service meets the latest ITU performance standards in respect of telecommunications phase stability.

8 THE BENEFITS AND RISKS OF USING TELECOMMUNICATION SIGNALS IN NAVIGATION SYSTEMS

Until advances in the late twentieth century, navigation depended on the ability to measure latitude and longitude. Latitude can be determined through celestial navigation; the measurement of longitude requires accurate knowledge of time. This need was a major motivation for the development of accurate mechanical clocks, including marine chronometers. While satellite navigation systems such as the Global Positioning System (GPS) require unprecedentedly accurate knowledge of time, this is supplied by equipment on the satellites; vessels no longer need timekeeping equipment.

The basic requirement for proper operation of the GPS system is to maintain a uniform time scale within it, and this property is used for telecommunications. Most stationary GPS receivers have the ability to output a one-second signal (1 pps) closely related to the GPS time scale.

The benefits of using GPS and in the future Galileo (possibly also Glonass) are significant. Mass-produced non-military GPS receivers are cheap, which is conducive to a wide range of GPS capabilities [14].

GPS signals allow you to reproduce with exactly equal accuracy the unambiguously expressed seconds pulses representing the GPS time scale in almost the entire globe. A one-second signal can be used as a reference time signal and as a reference frequency signal.

Standard time signals are used to maintain accurate time uniformity in different areas of the economy, such as [14]:

- telecommunications (charging, identification of places of failure),
- telematics, ITS, ICT (data flow control),
- power engineering (charging, synchronization of power generators),
- banking (transaction date, time stamps),
- state administration (documentation of events - police, rescue services, customs),
- transport (trains, buses, ships, aircraft),
- road transport (tolls, tolls, synchronized traffic lights).

1 pps signal is used as the reference frequency signal mainly for synchronizing telecommunication networks and to stabilize radio frequencies where the needs exceed the standard level. Use of GPS signals can be done in two ways.

In the first, passive, 1 pps signal acts as a reference frequency when measuring the clock frequencies produced by telecommunication clocks and possibly initiating alerts in case of anomaly. In the second mode, the active 1 pps signal is used to generate clock signals in telecommunication devices controlled automatically and corrected based on GPS signals. In this case, mediation of the quartz or rubidium generator affected by the digital phase loop is required.

In the first solution the use of a GPS signal allows the placement of two instead of three cesium clocks in that clock, which at a substantial price and for several years only implies the importance of the pattern. Economic benefits. Despite the reduction in the number of cesium patterns, it will be possible to indicate which of the two cesium patterns have been damaged or that the GPS receiver has been damaged (disassembled). In addition, with the use of uncomplicated measuring instruments, data can be obtained for manual correction of the frequency of particular cesium standards to approximate the coherence requirements of clock signals with UTC time scale.

The second solution applies to automatically controlling and correcting frequencies in lower clock hierarchically. These are SSU clocks for transit and local nodes (a solution especially used on the American continent), and even digital or cellular base stations. Some operators under normal operating conditions do not use GPS signals, but this capability is used in emergency situations. Generally this allows the use of lower class quartz or rubidium generators and thus lower their price.

In telecommunications applications, the difference between the UTC time scale and the GPS time scale is omitted. So using the GPS signals allows you to play all the quality nodes with the UTC time scale in all nodes of the telecommunications network, which is an undoubted advantage of the solution. The disadvantages of the solution include the dependence of the correct operation of the operator network from the access to GPS signals, which the operator has no influence.

Precise time signal can be the basis of effective and common encryption methods, including in areas such as finance, banking, insurance, electronic document certification, etc.

Telecommunication providers should ask: what would happen to existing networks if GPS were no longer available? This discussion has shown that Loran can provide telecommunication providers with a redundant synchronization source to GPS that satisfies some technical requirements. Legacy Loran has historically demonstrated the ability to easily meet the frequency performance requirements of a PRS in a wired telephone network and the basic requirements of the wireless CDMA (Code Division Multiple Access) network. eLoran adds the timing capabilities that allow it to better meet the time synchronization requirements of CDMA and to potentially support future networks with sub-microsecond synchronization requirements. With its large coverage area and its high level of performance, eLoran can provide telecommunications providers with the synchronization redundancy they need to keep their networks fully operational in the absence of GPS.

9 CONCLUSIONS

There are a lot of time definitions. Time is the indefinite continued progress of existence and events that occur in apparently irreversible succession from the past through the present to the future. Time is a component quantity of various measurements used to sequence events, to compare the duration of events or the intervals between them, and to quantify rates of change of quantities in material reality or in the conscious experience. Time is often referred to as the fourth dimension, along with the three spatial dimensions [7],[10],[17].

In this paper, the Author presents the ability of using eLoran as a national time standard and proposes further research to assess spatial and temporal variations in the reception of UTC traceable time distributed by using eLoran. It proposes this new means of disseminating national sovereign UTC for use at times and in places where GNSS is denied. It will serve critical infrastructure applications, notably telecommunications networks and financial services, in which sub-microsecond UTC-traceable time is essential to the continuity of operations. In particular it will serve these applications without the need for expensive roof mounted GNSS antenna deployments or managing complex fibre connectivity.

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