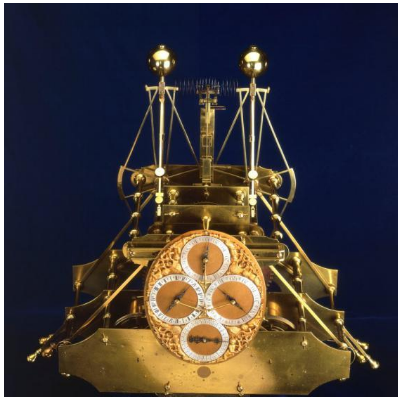
Time standards and time scales in radio navigation systems



References

Presentation of J. Paduch, C. Nowinski, A. Rycielski
A.Weintrit: Jednostki miar wczoraj i dziś. Przegląd systemów miar i wag na lądzie i na morzu

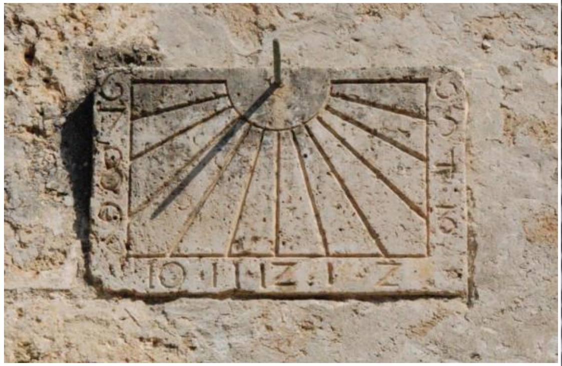
History of Time Measurements

The first instrument used to determine time was the *gnomon*.

This tool was invented by the Chinese approximately in the year 2500 BC, though some sources indicate its use dates back to as early as 4000 BC.

Use of gnomon for time measuring was primarily seen in Chinese, Egyptian, Babylonian societies.

The gnomon is a rod or pole that indicates the time as the shadows direction change.



History of Time Measurements

Around the year 2000 BC, Egyptians introduced portable sundials and other similar instruments; they could conduct measurements based not on the direction of the shadow but rather based on its length.

Alternatively, time was established on the basis of stellar clocks for measuring in the night.

Since then, sundials have undergone a significant evolution. The principal difference seen in modern sundials is that the rod in relation to the card is not vertical, but inclined at an angle depending on the latitude

History of Time Measurements

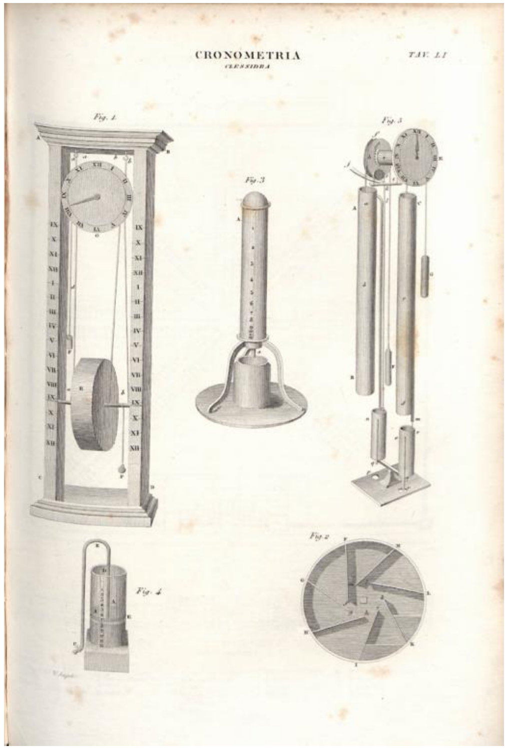
Likely the first instrument that determined time regardless of the time of day was a water clock.

Though the earliest date of the water clock use is not known, their use was seen in Babylon and Egypt from the 1600 BC. However, some sources indicate that water clocks were used in China as early as 4000 BC.

Water clock consisted of a tank with a opening through which the water was running. Accuracy of the clock was not large, because the flow of water depend on the height column of water in a tank.Water clocks remained a prominent tool for time measurements up to 1400 BC.

History of Time Measurements

Sand clock (hour glass) was the instrument operated similarly to the water clock, offering greater precision in measurements because it does not depend on the sand level.



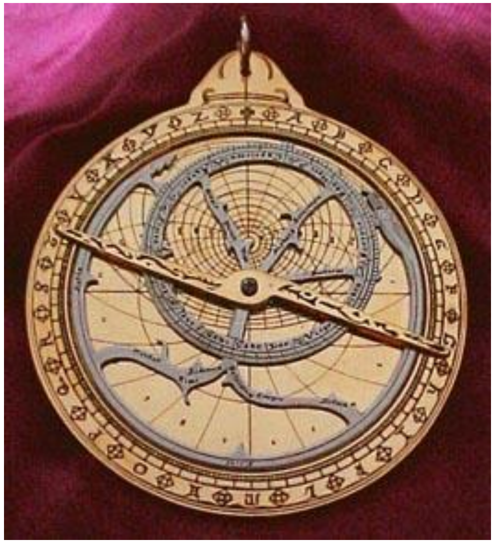
History of Time Measurements

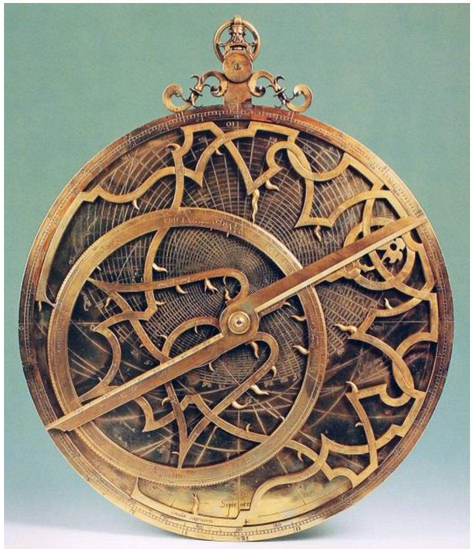
The fire clock was a variation of the 24-hour timekeeping instrument, initially used in China. Initially, the time was measured by a burning candle with hour marks behind other possibility was an oil lamp (the measure of time was the level of oil falling in the tank). Later a flammable powder was used. The period of its burning determined the passage of time. However, like water clocks, they had a relatively low accuracy.

History of Time Measurements

A great scientific and technical achievement of the ancient Greeks was the astrolabe, invented by Hipparchus (180-120 BC). It consisted of several concentric circles of initially wood, later improved with copper, brass, and even silver elements.

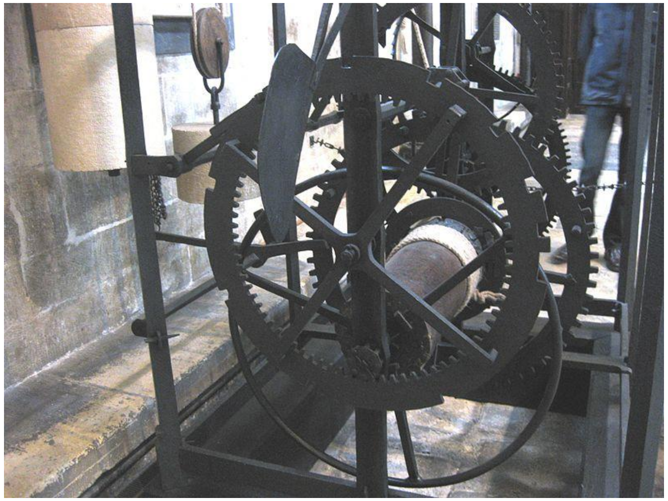
Astrolabe is a model of projections of the sky on a flat surface and shows the position of objects of the sky at a given time or date visible from a given latitude on the surface of the Earth





History of Time Measurements

At the beginning of the fourteenth century new instruments of time measurement appeared - mechanical clocks in which the source of movement was mechanical energy contained in a spring or a weight. The Chinese scientist Liang Lingzan (724r) is regarded as the inventor of the mechanical clock, and according to other sources - Gerbert of Aurillac, a French mathematician and astronomer (from 999, Pope Sylwester II). Still other sources say that the first mechanical clock driven by weight was constructed in the mid-ninth century by the Italian priest Pacificus.



The oldest clocks: the Cathedral of Salisbury (1386) and the Cathedral of Beauvais (1305) are considered to be the oldest working clocks.

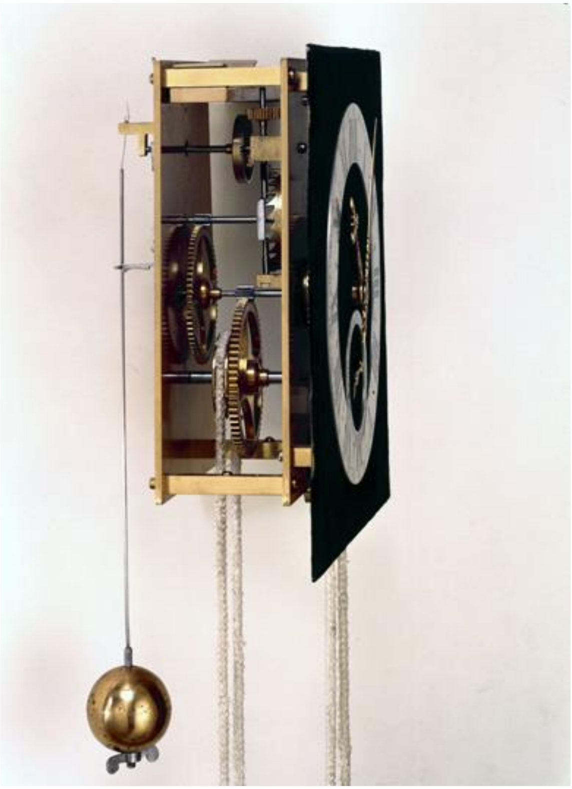
History of Time Measurements

An important development in the area of time measurement was the drive-spring, occurring about a century after the invention of the clock tower. The oldest known clock was made in the year 1435 for Philip the Good, Duke of Burgundy.

„Personal” mechanical clocks that could be carried (for example during the voyage) were developed at the beinnig of the 16th century.

History of Time Measurements

Dutch scientist Christiaan Huyghens (year 1629-1695) is considered to be the inventor of the clock pendulum (1656).



The precision was reduced by:

- small precision of gears,
- fluctuations due to the fact that the pendulum did not hang freely,
- changes of the length of the pendulum caused by the changes of temperature.

History of Time Measurements

The Commissioners for the Discovery of the Longitude at Sea, or more popularly Board of Longitude, British government body formed in 1714 to administer a scheme of prizes intended to encourage innovators to solve the problem of finding longitude at sea.

The Board administered prizes for those who could demonstrate a working device or method. The main longitude prizes were:

- £10,000 for a method that could determine longitude within 60 nautical miles (110 km; 69 mi) (£1,300,000 as of 2016)
- £15,000 for a method that could determine longitude within 40 nautical miles (74 km; 46 mi) (£2,000,000 as of 2016)
- £20,000 for a method that could determine longitude within 30 nautical miles (56 km; 35 mi) (£2,700,000 as of 2016).

The first clock that met working conditions at sea took 5 years to build, and was completed by John Harrison in 1735.

History of Time Measurements

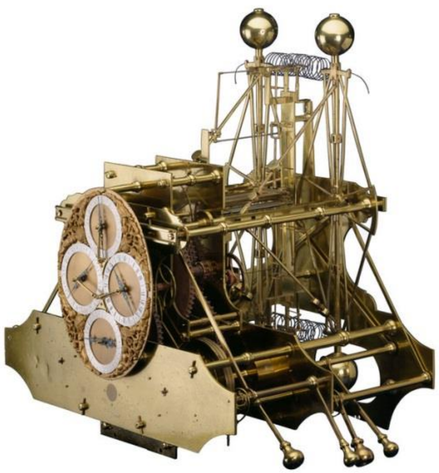
Harrison was first awarded £250 in 1737, in order to improve on his promising H1 sea clock, leading to the construction of H2.

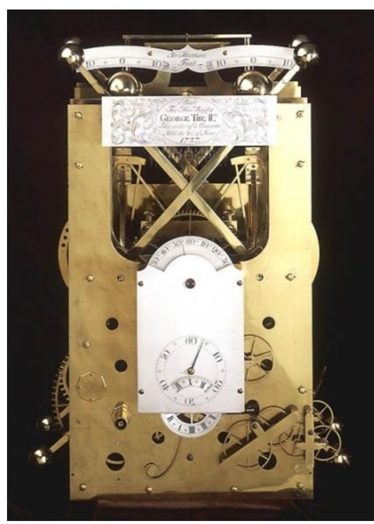
£2,000 was rewarded over the span of 1741–1755 for continued construction and completion of H2 and H3. From 1760 to 1765, Harrison received £2,865 for various expenses related to the construction, ocean trials, and eventual award for the performance of his sea watch H4.

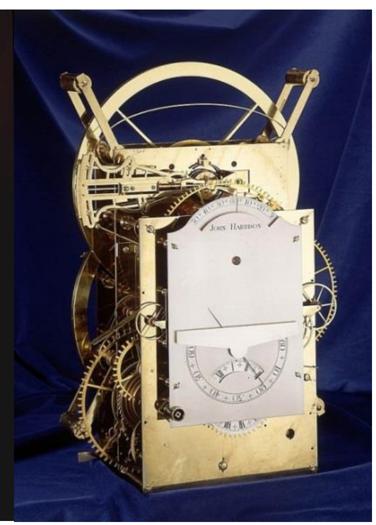
Despite the performance of the H4 exceeding the accuracy requirement of the highest reward possible in the original Longitude Act, Harrison was rewarded £7,500 (that is, £10,000 minus payments he had received in 1762 and 1764) once he had revealed the method of making his device, and was told that he must show that his single machine could be replicated before the final £10,000 could be paid.

History of Time Measurements

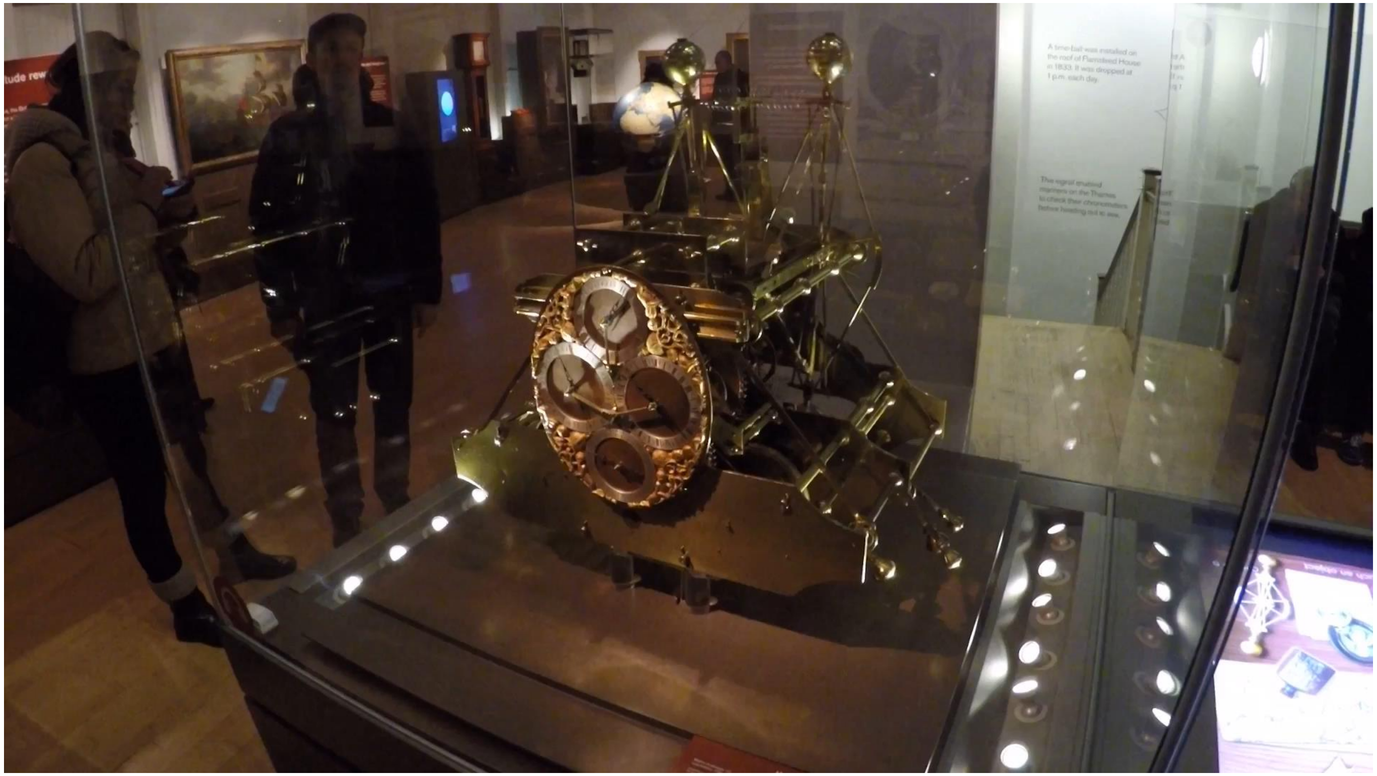
Throughout the course of improvements, the following clocks were developed: H1, H2, H3 (1730-1735) (1737-1759) and H4 (1755-1759).







History of Time Measurements



History of Time Measurements

Today:

Quartz clocks measure time using the oscillating quartz crystal.

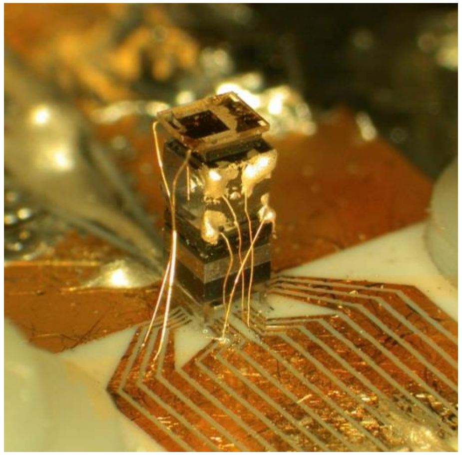
Vibrations of the crystal are counted by digital systems, which indicate the current time on the display of the watch.

Crystal oscillators produces a signal that offers a more accurate reading in comparison to mechanical clocks.

History of Time Measurements

The atomic clock is a type of clock which is based on counting periods of an atomic frequency pattern.

Nowadays, the most accurate atomic clocks are based, for example, on cesium compounds. The accuracy of such clocks reaches 10^-18, which means 1 second during the age of the Universe.



History of Time Measurements

GPS CONSTELLATION STATUS FOR 01/04/2017

Plane	Slot	SVN	PRN	Block-Type	Clock	Outage Date	Nanu-Type	Nanu-Subject
F	1	41	14	IIR	RB			
F	2	55	15	IIR-M	RB			
F	3	68	9	IIF	RB			
F	4	60	23	IIR	RB			
F	5	70	32	IIF	RB			
F	6	43	13	IIR	RB			
C	2	66	27	IIF	RB			
C	3	72	8	IIF	CS			
C	4	53	17	IIR-M	RB			
C	5	59	19	IIR	RB			
B	1	56	16	IIR	RB			
B	2	62	25	IIF	RB			
B	3	44	28	IIR	RB			
B	4	58	12	IIR-M	RB			
B	5	71	26	IIF	RB			
B	6	51	20	IIR	RB			
A	1	65	24	IIF	CS			
A	2	52	31	IIR-M	RB			
A	3	64	30	IIF	RB			
A	4	48	7	IIR-M	RB			

Today: Atomic clocks

In satellite systems like GPS or GLONASS, the source of the actual time is based on an atomic clock. Due to economical reasons, after 2000, cheaper rubidium clocks are increasingly installed on the satellites. Their ten times lower price and four times longer service life are of decisive economic importance.

History of Time Measurements

Today: Pulsar clocks

A pulsar clock is a clock which depends on counting radio pulses emitted by pulsars. The first pulsar clock in the world was installed in St Catherine's Church, Gdańsk, Poland, in 2011. It was the first clock to count the time using a signal source outside the Earth. The pulsar clock consists of a radiotelescope with 16 antennas, which receive signals from six designated pulsars

Time scales

Solar time is a calculation of the passage of time based on the position of the Sun in the sky. The fundamental unit of solar time is the day. Two types of solar time are **apparent solar time (sundial time)** and **mean solar time (clock time).**

The apparent sun is the true sun as seen by an observer on Earth. Apparent solar time or true solar time is based on the apparent motion of the actual Sun. It is based on the apparent solar day, the interval between two successive returns of the Sun to the local meridian. Solar time can be crudely measured by a sundial. The length of a solar day varies through the year, and the accumulated effect produces seasonal deviations of up to 16 minutes from the mean. The effect has two main causes:

- Earth's orbit is an ellipse, not a circle, so the Earth moves faster when it is nearest the Sun (perihelion) and slower when it is farthest from the Sun (aphelion)
- Earth's axial tilt (known as the obliquity of the ecliptic), the Sun's annual motion is along a great circle (the ecliptic) that is tilted to Earth's celestial equator.

Time scales

Length of apparent solar day (1998)	
Date	Duration in mean solar time
February 11	24 hours
March 26	24 hours − 18.1 seconds
May 14	24 hours
June 19	24 hours + 13.1 seconds
July 25/26	24 hours
September 16	24 hours − 21.3 seconds
November 2/3	24 hours
December 22	24 hours + 29.9 seconds

These lengths will change slightly in a few years and significantly in thousands of years.

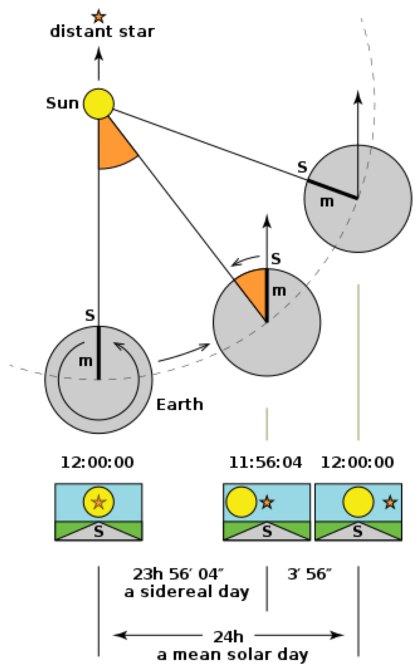
Time scales

Mean solar time is the hour angle of the mean Sun plus 12 hours. This 12 hour offset comes from the decision to make each day start at midnight for civil purposes whereas the hour angle or the mean su n is measured from the zenith (noon).

Currently (2009) this is realized with the UT1 time scale, constructed mathematically from very long baseline interferometry observations of the diurnal motions of radio sources located in other galaxies, and other observations.

Time scales

Sidereal time is a time scale that is based on Earth's rate of rotation measured relative to the fixed stars. More exactly, sidereal time is the angle, measured along the celestial equator, from the observer's meridian to the great circle that passes through the March equinox and both celestial poles, and is usually expressed in hours, minutes, and seconds. A sidereal day is approximately 23 hours, 56 minutes, 4.0905 SI seconds or also (24 hours - 4 minutes + 4 seconds).



Time scales

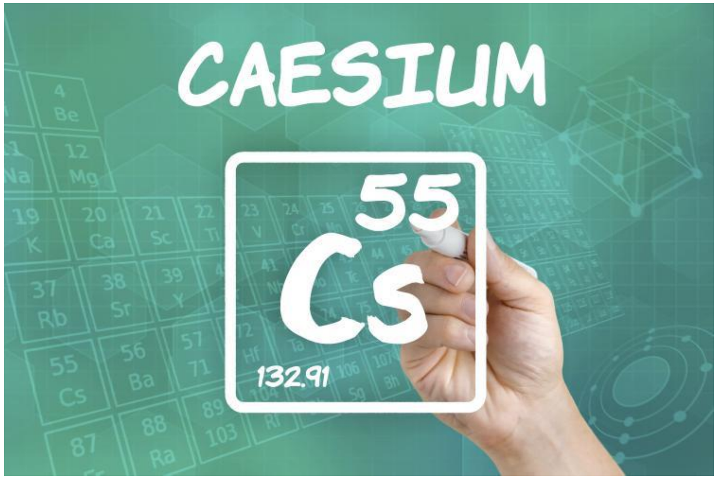
Universal Time (UT) is a time standard based on Earth's rotation. It is a modern continuation of Greenwich Mean Time (GMT), i.e., the mean solar time on the Prime Meridian at Greenwich, England.

In fact, the expression "Universal Time" is ambiguous (when accuracy of better than a few seconds is required), as there are several versions of it, the most commonly used being Coordinated Universal Time (UTC) and UT1. All of these versions of UT, except for UTC, are based on Earth's rotation relative to distant celestial objects (stars and quasars), but with a scaling factor and other adjustments to make them closer to solar time.

UTC is based on International Atomic Time, with leap seconds added to keep it within 0.9 second of UT1

Time scales

International Atomic Time (TAI, from the French name temps atomique international) is a high-precision atomic coordinate time standard based on the notional passage of proper time on Earth's geoid. TAI is a weighted average of the time kept by over 400 atomic clocks in over 50 national laboratories worldwide. The majority of the clocks involved are caesium clocks. The clocks are compared using GPS signals and two-way satellite time and frequency transfer. Due to the signal averaging TAI is an order of magnitude more stable than its best constituent clock.



Time scales

Coordinated Universal Time (abbreviated to UTC) is the primary time standard by which the world regulates clocks and time. It is within about 1 second of mean solar time at 0° longitude, and is not adjusted for daylight saving time. In some countries where English is spoken, the term Greenwich Mean Time (GMT) is often used as a synonym for UTC.

The current version of UTC is based on International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the slowing of the Earth's rotation. Leap seconds are inserted as necessary to keep UTC within 0.9 seconds of the UT1 variant of universal time.

Time scales

A **leap second** is a one-second adjustment that is occasionally applied to civil time Coordinated Universal Time (UTC) to keep it close to the mean solar time at Greenwich, in spite of the Earth's rotation slowdown and irregularities. UTC was introduced on January 1, 1972, initially with a 10 second lag behind International Atomic Time (TAI). Since that date, 27 leap seconds have been inserted, the most recent on December 31, 2016 at 23:59:60 UTC, so in 2018, UTC lags behind TAI by an offset of 37 seconds.

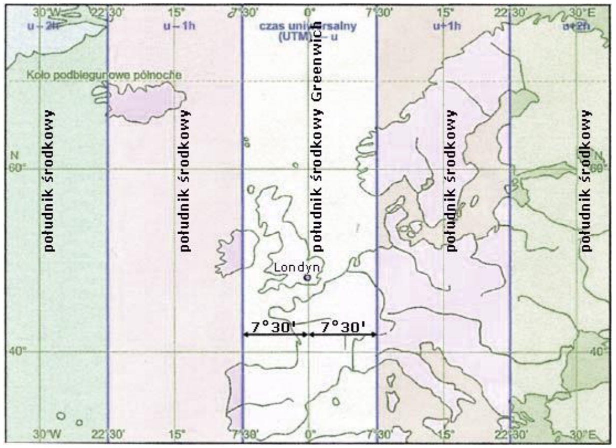
Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	total	
Jun 30	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	11	27
Dec 31	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0		16	

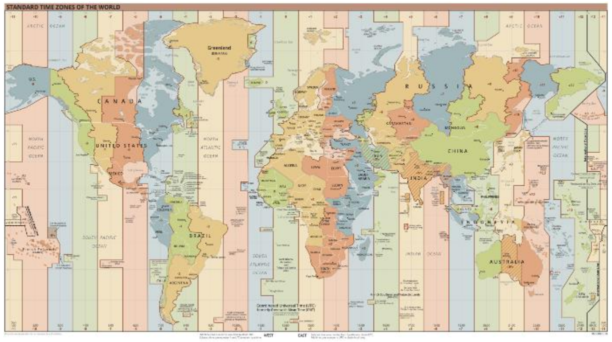
Time scales

Standard time is the synchronization of clocks within a geographical area or region to a single time standard, rather than using solar time or a locally chosen meridian (longitude) to establish a local mean time standard.

Historically, the concept was established during the 19th century to aid weather forecasting and train travel. Applied globally in the 20th century, the geographical areas became extended around evenly spaced meridians into time zones which (usually) centered on them.

The standard time set in each time zone has come to be defined in terms of offsets from Universal Time (UTC). In regions where daylight saving time is used, that time is defined by another offset, from the standard time in its applicable time zones.





THE END

http://www.leapsecond.com/java/gpsclock.htm