Coordinated Universal Time

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World map of current time zones

Coordinated Universal Time (French: *Temps universel coordonné*), 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;[1] it does not observe daylight saving time. For most purposes, UTC is considered interchangeable with Greenwich Mean Time (GMT), but GMT is no longer precisely defined by the scientific community.

The first Coordinated Universal Time was informally adopted on 1 January 1960.[2]

The system was adjusted several times, including a brief period where time coordination radio signals broadcast both UTC and "Stepped Atomic Time (SAT)" until a new UTC was adopted in 1970 and implemented in 1972. This change also adopted leap seconds to simplify future adjustments. This CCIR Recommendation 460 "stated that (a) carrier frequencies and time intervals should be maintained constant and should correspond to the definition of the SI second; (b) step adjustments, when necessary, should be exactly 1 s to maintain approximate agreement with Universal Time (UT); and (c) standard signals should contain information on the difference between UTC and UT."[2]

A number of proposals have been made to replace UTC with a new system that would eliminate leap seconds, and the decision to remove them altogether has been tabled until 2023.[3]

The current version of UTC is defined by International Telecommunications Union Recommendation (ITU-R TF.460-6), *Standard-frequency and time-signal emissions*[4] and is based on International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the slowing of Earth's rotation.[5]

Leap seconds are inserted as necessary to keep UTC within 0.9 seconds of universal time, UT1.[6] See the "Current number of leap seconds" section for the number of leap seconds inserted to date.

Contents

Etymology

The official abbreviation for Coordinated Universal Time is *UTC*. This abbreviation arose from a desire by the International Telecommunication Union and the International Astronomical Union to use the same abbreviation in all languages. English speakers originally proposed *CUT* (for "coordinated universal time"), while French speakers proposed *TUC* (for "temps universel coordonné"). The compromise that emerged was *UTC*,[7] which conforms to the pattern for the abbreviations of the variants of Universal Time (UT0, UT1, UT2, UT1R, etc.).[8]

Uses

Time zones around the world are expressed using positive or negative offsets from UTC, as in the list of time zones by UTC offset.

The westernmost time zone uses UTC−12, being twelve hours behind UTC; the easternmost time zone, theoretically, uses UTC+12, being twelve hours ahead of UTC. In 1995, the island nation of Kiribati moved those of its atolls in the Line Islands from UTC-10 to UTC+14 so that Kiribati would all be on the same day.

UTC is used in many internet and World Wide Web standards. The Network Time Protocol, designed to synchronise the clocks of computers over the internet, encodes times using the UTC system.[9] Computer servers, online services and other entities that rely on having a universally accepted time use UTC as it is more specific than GMT. If only limited precision is needed, clients can obtain the current UTC from a number of official internet UTC servers. For sub-microsecond precision, clients can obtain the time from satellite signals.

UTC is also the time standard used in aviation,[10] e.g., for flight plans and air traffic control clearances. Weather forecasts and maps all use UTC to avoid confusion about time zones and daylight saving time. The International Space Station also uses UTC as a time standard.

Amateur radio operators often schedule their radio contacts in UTC, because transmissions on some frequencies can be picked up by many time zones.[11]

UTC is also used in digital tachographs used on large goods vehicles (LGV) under EU and AETR rules.

Mechanism

UTC divides time into days, hours, minutes and seconds. Days are conventionally identified using the Gregorian calendar, but Julian day numbers can also be used. Each day contains 24 hours and each hour contains 60 minutes. The number of seconds in a minute is usually 60, but with an occasional leap second, it may be 61 or 59 instead.[12] Thus, in the UTC time scale, the second and all smaller time units (millisecond, microsecond, etc.) are of constant duration, but the minute and all larger time units (hour, day, week, etc.) are of variable duration. Decisions to introduce a leap second are announced at least six months in advance in "Bulletin C" produced by the International Earth Rotation and Reference Systems Service.[13][14] The leap seconds cannot be predicted far in advance due to the unpredictable rate of rotation of the Earth.[15]

Nearly all UTC days contain exactly 86,400 SI seconds with exactly 60 seconds in each minute. However, because the mean solar day is slightly longer than 86,400 SI seconds, occasionally the last minute of a UTC day is adjusted to have 61 seconds. The extra second is called a leap second. It accounts for the grand total of the extra length (about 2 milliseconds each) of all the mean solar days since the previous leap second. The last minute of a UTC day is permitted to contain 59 seconds to cover the remote possibility of the Earth rotating faster, but that has not yet been necessary. The irregular day lengths mean that fractional Julian days do not work properly with UTC.

Since 1972, UTC is calculated by subtracting the accumulated leap seconds from International Atomic Time (TAI), which is a coordinate time scale tracking notional proper time on the rotating surface of the Earth (the geoid). In order to maintain a close approximation to UT1 (equivalent to GMT), UTC occasionally has discontinuities where it changes from one linear function of TAI to another. These discontinuities take the form of leap seconds implemented by a UTC day of irregular length. Discontinuities in UTC have occurred only at the end of June or December, although there is provision for them to happen at the end of March and September as well as a second preference.[16][17] The International Earth Rotation and Reference Systems Service (IERS) tracks and publishes the difference between UTC and Universal Time, DUT1 = UT1 − UTC, and introduces discontinuities into UTC to keep DUT1 in the interval (−0.9 s, +0.9 s).

As with TAI, UTC is only known with the highest precision in retrospect. Users who require an approximation in real time must obtain it from a time laboratory, which disseminates an approximation using techniques such as GPS or radio time signals. Such approximations are designated UTC(*k*), where *k* is an abbreviation for the time laboratory.[18] The time of events may be provisionally recorded against one of these approximations; later corrections may be applied using the International Bureau of Weights and Measures (BIPM) monthly publication of tables of differences between canonical TAI/UTC and TAI(*k*)/UTC(*k*) as estimated in real time by participating laboratories.[19] (See the article on International Atomic Time for details.)

Because of time dilation, a standard clock not on the geoid, or in rapid motion, will not maintain synchronicity with UTC. Therefore, telemetry from clocks with a known relation to the geoid is used to provide UTC when required, on locations such as those of spacecraft.

It is not possible to compute the exact time interval elapsed between two UTC timestamps without consulting a table that describes how many leap seconds occurred during that interval. By extension, it is not possible to compute the duration of a time interval that ends in the future and may encompass an unknown number of leap seconds (for example, the number of TAI seconds between "now" and 2099-12-31 23:59:59). Therefore, many scientific applications that require precise measurement of long (multi-year) intervals use TAI instead. TAI is also commonly used by systems that cannot handle leap seconds. GPS time always remains exactly 19 seconds behind TAI (neither system is affected by the leap seconds introduced in UTC).

For most common and legal-trade purposes, the fractional second difference between UTC and UT (GMT) is inconsequentially small. Greenwich Mean Time is the legal standard in Britain during the winter, and this notation is familiar to and used by the population.[20]

Time zones

Time zones are usually defined as differing from UTC by an integer number of hours,[21] although the laws of each jurisdiction would have to be consulted if sub-second accuracy was required. Several jurisdictions have established time zones that differ by an integer number of half-hours or quarter-hours from UT1 or UTC.

Current civil time in a particular time zone can be determined by adding or subtracting the number of hours and minutes specified by the UTC offset, which ranges from UTC−12:00 in the west to UTC+14:00 in the east (see List of UTC time offsets).

The time zone using UTC is sometimes denoted UTC±00:00 or by the letter *Z*—a reference to the equivalent nautical time zone (GMT), which has been denoted by a *Z* since about 1950. Time zones were identified by successive letters of the alphabet and the Greenwich time zone was marked by a *Z* as it was the point of origin. The letter also refers to the "zone description" of zero hours, which has been used since 1920 (see time zone history). Since the NATO phonetic alphabet word for *Z* is "Zulu", UTC is sometimes known as "Zulu time". This is especially true in aviation, where "Zulu" is the universal standard.[22] This ensures all pilots regardless of location are using the same 24-hour clock, thus avoiding confusion when flying between time zones.[23] See the list of military time zones for letters used in addition to *Z* in qualifying time zones other than Greenwich.

On electronic devices that only allow the current time zone to be configured using maps or city names, UTC can be selected indirectly by selecting Reykjavík, Iceland, which is always on UTC and does not use daylight saving time.[24]

Daylight saving time

UTC does not change with a change of seasons, but local time or civil time may change if a time zone jurisdiction observes daylight saving time (summer time). For example, local time on the east coast of the United States is five hours behind UTC during winter, but four hours behind while daylight saving is observed there.[25]

History

At the 1884 International Meridian Conference held in Washington, D.C., the local mean solar time at the Royal Observatory, Greenwich in England was chosen to define the Universal day, counted from 0 hours at mean midnight. This agreed with civil Greenwich Mean Time (GMT), used on the island of Great Britain since 1847. In contrast, astronomical GMT began at mean noon, 12 hours *after* mean midnight of the same date until 1 January 1925, whereas nautical GMT began at mean noon, 12 hours *before* mean midnight of the same date, at least until 1805 in the Royal Navy, but persisted much later elsewhere because it was mentioned at the 1884 conference. In 1884, the Greenwich Meridian was used for two-thirds of all charts and maps as their Prime Meridian.[26] In 1928, the term Universal Time (UT) was introduced by the International Astronomical Union to refer to GMT, with the day starting at midnight.[27] Until the 1950s, broadcast time signals were based on UT, and hence on the rotation of the Earth.

In 1955, the caesium atomic clock was invented. This provided a form of timekeeping that was both more stable and more convenient than astronomical observations. In 1956, the U.S. National Bureau of Standards and U.S. Naval Observatory started to develop atomic frequency time scales; by 1959, these time scales were used in generating the WWV time signals, named for the shortwave radio station that broadcasts them. In 1960, the U.S. Naval Observatory, the Royal Greenwich Observatory, and the UK National Physical Laboratory coordinated their radio broadcasts so time steps and frequency changes were coordinated, and the resulting time scale was informally referred to as "Coordinated Universal Time".[28]

In a controversial decision, the frequency of the signals was initially set to match the rate of UT, but then kept at the same frequency by the use of atomic clocks and deliberately allowed to drift away from UT. When the divergence grew significantly, the signal was phase shifted (stepped) by 20 ms to bring it back into agreement with UT. Twenty-nine such steps were used before 1960.[29]

In 1958, data was published linking the frequency for the caesium transition, newly established, with the ephemeris second. The ephemeris second is the duration of time that, when used as the independent variable in the laws of motion that govern the movement of the planets and moons in the solar system, cause the laws of motion to accurately predict the observed positions of solar system bodies. Within the limits of observing accuracy, ephemeris seconds are of constant length, as are atomic seconds. This publication allowed a value to be chosen for the length of the atomic second that would work properly with the celestial laws of motion.[30]

In 1961, the Bureau International de l'Heure began coordinating the UTC process internationally (but the name Coordinated Universal Time was not formally adopted by the International Astronomical Union until 1967).[31][32] Time steps occurred every few months thereafter, and frequency changes at the end of each year. The jumps increased in size to 100 ms. This UTC was intended to permit a very close approximation to UT2.[28]

In 1967, the SI second was redefined in terms of the frequency supplied by a caesium atomic clock. The length of second so defined was practically equal to the second of ephemeris time.[33] This was the frequency that had been provisionally used in TAI since 1958. It was soon recognised that having two types of second with different lengths, namely the UTC second and the SI second used in TAI, was a bad idea. It was thought that it would be better for time signals to maintain a consistent frequency, and that that frequency should match the SI second. Thus it would be necessary to rely on time steps alone to maintain the approximation of UT. This was tried experimentally in a service known as "Stepped Atomic Time" (SAT), which ticked at the same rate as TAI and used jumps of 200 ms to stay synchronised with UT2.[34]

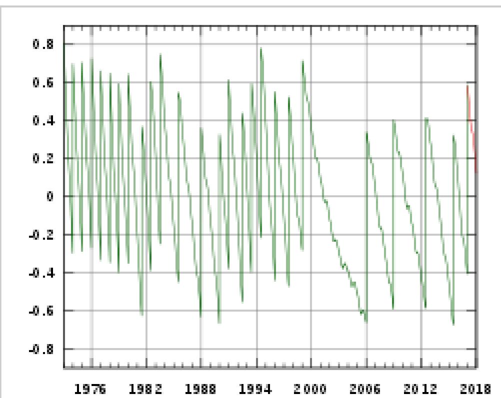
There was also dissatisfaction with the frequent jumps in UTC (and SAT). In 1968, Louis Essen, the inventor of the caesium atomic clock, and G. M. R. Winkler both independently proposed that steps should be of 1 s only.[35] This system was eventually approved, along with the idea of maintaining the UTC second equal to the TAI second. At the end of 1971, there was a final irregular jump of exactly

0.107758 TAI seconds, so that 1 January 1972 00:00:00 UTC was 1 January 1972 00:00:10 TAI exactly, making the difference between UTC and TAI an integer number of seconds. At the same time, the tick rate of UTC was changed to exactly match TAI. UTC also started to track UT1 rather than UT2. Some time signals started to broadcast the DUT1 correction (UT1 − UTC) for applications requiring a closer approximation of UT1 than UTC now provided.[36][37]

Current number of leap seconds

The first leap second occurred on 30 June 1972. Since then, leap seconds have occurred on average about once every 19 months, always on 30 June or 31 December. As of January 2017, there have been 27 leap seconds in total, all positive, putting UTC 37 seconds behind TAI.[38]

Rationale



Graph showing the difference DUT1 between UT1 and UTC (in seconds). Vertical segments correspond to leap seconds.

Earth's rotational speed is very slowly decreasing because of tidal deceleration; this increases the length of the mean solar day. The length of the SI second was calibrated on the basis of the second of ephemeris time[30][33] and can now be seen to have a relationship with the mean solar day observed between 1750 and 1892, analysed by Simon Newcomb. As a result, the SI second is close to 1/86400 of a mean solar day in the mid-19th century.[39] In earlier centuries, the mean solar day was shorter than 86,400 SI seconds, and in more recent centuries it is longer than 86,400 seconds. Near the end of the 20th century, the length of the mean solar day (also known simply as "length of day" or "LOD") was approximately 86,400.0013 s.[40] For this reason, UT is now "slower" than TAI by the difference (or "excess" LOD) of 1.3 ms/day.

The excess of the LOD over the nominal 86,400 s accumulates over time, causing the UTC day, initially synchronised with the mean sun, to become desynchronised and run ahead of it. Near the end of the 20th century, with the LOD at 1.3 ms above the nominal value, UTC ran faster than UT by 1.3 ms per day, getting a second ahead roughly every 800 days. Thus, leap seconds were inserted at approximately this interval, retarding UTC to keep it synchronised in the long term.[41] The actual rotational period varies on unpredictable factors such as tectonic motion and has to be observed, rather than computed.

Just as adding a leap day every four years does not mean the year is getting longer by one day every four years, the insertion of a leap second every 800 days does not indicate that the mean solar day is getting longer by a second every 800 days. It will take about 50,000 years for a mean solar day to lengthen by one second (at a rate of 2 ms/cy, where cy means century). This rate fluctuates within the range of 1.7–2.3 ms/cy. While the rate due to tidal friction alone is about 2.3 ms/cy, the uplift of Canada and Scandinavia by several metres since the last Ice Age has temporarily reduced this to 1.7 ms/cy over the last 2,700 years.[42] The correct reason for leap seconds, then, is not the current difference between actual and nominal LOD, but rather the *accumulation* of this difference over a period of time: Near the end of the 20th century, this difference was about 1/800 of a second per day; therefore, after about 800 days, it accumulated to 1 second (and a leap second was then added).

In the graph of DUT1 above, the excess of LOD above the nominal 86,400 s corresponds to the downward slope of the graph between vertical segments. (The slope became shallower in the 2000s (decade), because of a slight acceleration of Earth's crust temporarily shortening the day.) Vertical position on the graph corresponds to the accumulation of this difference over time, and the vertical segments correspond to leap seconds introduced to match this accumulated difference. Leap seconds are timed to keep DUT1 within the vertical range depicted by this graph. The frequency of leap seconds therefore corresponds to the slope of the diagonal graph segments, and thus to the excess LOD.

Future

As the Earth's rotation continues to slow, positive leap seconds will be required more frequently. The long-term rate of change of LOD is approximately +1.7 ms per century. At the end of the 21st century, LOD will be roughly 86,400.004 s, requiring leap seconds every 250 days. Over several centuries, the frequency of leap seconds will become problematic.

Some time in the 22nd century, two leap seconds will be required every year. The current use of only the leap second opportunities in June and December will be insufficient, and the March and September options will have to be used. In the 25th century, four leap seconds will be required every year, so the current quarterly options will be insufficient. Thereafter there will need to be the possibility of leap seconds at the end of any month. In about two thousand years, even that will be insufficient, and there will have to be leap seconds that are not at the end of a month.[43] In a few tens of thousands of years (the timing is uncertain), LOD will exceed 86,401 s, causing UTC to require more than one leap second per day.

In April 2001, Rob Seaman of the National Optical Astronomy Observatory proposed that leap seconds be allowed to be added monthly rather than twice yearly.[44]

There is a proposal to redefine UTC and abolish leap seconds, such that sundials would slowly get further out of sync with civil time.[45] The resulting gradual shift of the sun's movements relative to civil time is analogous to the shift of seasons relative to the yearly calendar that results from the calendar year not precisely matching the tropical year length. This would be a major practical change in civil timekeeping, but would take effect slowly over several centuries. UTC (and TAI) would be more and more ahead of UT; it would coincide with local mean time along a meridian drifting slowly eastward (reaching Paris and beyond).[46] Thus, the time system would lose its fixed connection to the geographic coordinates based on the IERS meridian. The difference between UTC and UT could reach 0.5 hour after the year 2600 and 6.5 hours around 4600.[43]

ITU-R Study Group 7 and Working Party 7A were unable to reach consensus on whether to advance the proposal to the 2012 Radiocommunications Assembly; the chairman of Study Group 7 elected to advance the question to the 2012 Radiocommunications Assembly (20 January 2012),[47] but consideration of the proposal was postponed by the ITU until the World Radio Conference in 2015, convening on 2 November.[48]

The possibility of suppressing the leap second was considered in November 2015 at the World Radiocommunication Conference (WRC-15), which is the international regulatory body which defines Coordinated Universal Time.[49] No decision to suppress leap seconds was reached; the issue will be studied further and reconsidered in 2023.[50]

See also

- Ephemeris time
- IERS Reference Meridian

- ISO 8601
- List of UTC timing centers
- Mars Time Coordinated (MTC)
- Terrestrial Time
- World Radiocommunication Conference

References

Notes

1. Guinot 2011, p. S181.
2. "COORDINATED UNIVERSAL TIME (UTC) (CCTF/09-32)" (http://www.bipm.org/cc/CCTF/Allowed/18/CCTF_09-32_noteUTC.pdf) (PDF). *Bureau International des Poids et Mesures*. p. 3. Retrieved 30 October 2016.
3. "Coordinated Universal Time (UTC) to retain "leap second"" (http://www.itu.int/net/pressoffice/press_releases/2015/53.aspx). *www.itu.int*. Retrieved 2017-07-12.
4. ITU Radiocommunication Assembly 2002.
5. Time Service Dept. 2016.
6. National Institute of Standards and Technology 2012.
7. National Institute of Standards and Technology 2011.
8. IAU resolutions 1976.
9. How NTP Works 2011.
10. Aviation Time 2006.
11. Horzepa 2010.
12. ITU Radiocommunication Assembly 2002, p. 3.
13. International Earth Rotation and Reference Systems Service 2011.
14. McCarthy & Seidelmann 2009, p. 229.
15. McCarthy & Seidelmann 2009, chapter 4.
16. History of TAI-UTC c. 2009.
17. McCarthy & Seidelmann 2009, pp. 217, 227–231.
18. McCarthy & Seidelmann 2009, p. 209.
19. Time n.d.
20. Langley 1999.
21. Seidelmann 1992, p. 7.
22. Military & Civilian Time Designations n.d.
23. Williams 2005.
24. Iceland 2011.
25. Standard time 2010.
26. Howse 1997, pp. 133–137.
27. McCarthy & Seidelmann 2009, pp. 10–11.
28. McCarthy & Seidelmann 2009, pp. 226–227.
29. Arias, Guinot & Quinn 2003.

30. Markowitz et al. 1958.
31. Nelson & McCarthy 2005, p. 15.
32. Nelson et al. 2001, p. 515.
33. Markowitz 1988.
34. McCarthy & Seidelmann 2009, p. 227.
35. Essen 1968, pp. 161–5.
36. Seidelmann 1992, pp. 85–87.
37. Nelson, Lombardi & Okayama 2005, p. 46.
38. Bulletin C 2016.
39. McCarthy & Seidelmann 2009, p. 87.
40. McCarthy & Seidelmann 2009, p. 54.
41. McCarthy & Seidelmann 2009, p. 230. (Average for period from 1 January 1991 through 1 January 2009. Average varies considerably depending on what period is chosen).
42. Stephenson & Morrison 1995.
43. Allen 2011a.
44. Seaman, Rob (9 April 2001). "Upgrade, don't degrade" (https://web.archive.org/web/20130602095155/http://iraf.noao.edu/~seaman/leap/leapsec.txt). Archived from the original (http://iraf.noao.edu/~seaman/leap/leapsec.txt) on 2 June 2013. Retrieved 10 September 2015.
45. Allen 2011b.
46. Irvine 2008.
47. Seidelmann & Seago 2011, p. S190.
48. Leap decision postponed 2012.
49. "ITU World Radiocommunication Conference set for Geneva, 2–27 November 2015" (http://www.itu.int/net/pressoffice/press_releases/2015/Advisory-08.aspx). International Telecommunications Union. 2015. Retrieved 3 November 2015.
50. "Coordinated Universal Time (UTC) to retain 'leap second' " (https://www.itu.int/net/pressoffice/press_releases/2015/53.aspx). International Telecommunications Union. 19 November 2015. Retrieved 19 November 2015.

Bibliography

- Allan, David W.; Ashby, Neil; Hodge, Clifford C. (1997). *The Science of Timekeeping*. Hewlett-Packard. Application note.
- Allen, Steve (2011a). "UTC is doomed" (http://www.ucolick.org/~sla/leapsecs/utcdoomed). Retrieved 18 July 2011.
- Allen, Steve (2011b). "UTC might be redefined without Leap Seconds" (http://www.ucolick.org/~sla/leapsecs/). Retrieved 18 July 2011.
- Arias, E. F.; Guinot, B.; Quinn, T. J. (29 May 2003). *Rotation of the Earth and Time scales* (http://www.ucolick.org/~sla/leapsecs/torino/arias_3.pdf) (PDF). ITU-R Special Rapporteur Group Colloquium on the UTC Time Scale.
- "Aviation Time" (http://www.aopa.org/path/time.html). *AOPA's Path to Aviation*. Aircraft Owners and Pilots Association. 2006. Retrieved 17 July 2011.

- "Bulletin C" (http://hpiers.obspm.fr/iers/bul/bulc/bulletinc.dat). International Earth Rotation and Reference Systems Service. 6 July 2016.
- Essen, L. (1968). "Time Scales" (http://www.leapsecond.com/history/1968-Metrologia-v4-n4-Essen.pdf) (PDF). *Metrologica*. **4** (4): 161–5. Bibcode:1968Metro...4..161E (http://adsabs.harvard.edu/abs/1968Metro...4..161E). doi:10.1088/0026-1394/4/4/003 (https://doi.org/10.1088%2F0026-1394%2F4%2F4%2F003). Retrieved 18 October 2008.
- Finkleman, David; Allen, Steve; Seago, John; Seaman, Rob; Seidelmann, P. Kenneth (2011). "The Future of Time: UTC and the Leap Second". *American Scientist*. **99** (July–August 2011): 312. arXiv:1106.3141v1 (https://arxiv.org/abs/1106.3141v1). doi:10.1511/2011.91.1 (https://doi.org/10.1511%2F2011.91.1).
- Guinot, Bernard (August 2011). "Solar time, legal time, time in use". *Metrologica*. **48** (4): S181–185. Bibcode:2011Metro..48S.181G (http://adsabs.harvard.edu/abs/2011Metro..48S.181G). doi:10.1088/0026-1394/48/4/S08 (https://doi.org/10.1088%2F0026-1394%2F48%2F4%2FS08).
- "History of TAI-UTC" (ftp://maia.usno.navy.mil/ser7/tai-utc.dat). Time Service Dept., U.S. Naval Observatory. c. 2009. Retrieved 4 January 2009.
- Horzepa, Stan (17 September 2010). "Surfin': Time for Ham Radio" (http://www.arrl.org/news/surfin-time-for-ham-radio). American Radio Relay League. Retrieved 24 October 2011.
- Howse, Derek (1997). *Greenwich Time and the Longitude*. London: Philip Wilson. ISBN 0-85667-468-0.
- "How NTP Works" (http://www.eecis.udel.edu/~mills/ntp/html/warp.html). *NTP: The Network Time Protocol*. 28 July 2011. See heading "NTP Timescale and Data Formats".
- "IAU resolutions adopted at the XVIth General Assembly, Grenoble, France, 1976" (http://www.iau.org/static/resolutions/IAU1976_French.pdf) (PDF). 1976. Resolution no. 3 by Commissions 4 (Ephemerides/Ephémérides) and 31 (Time/L'Heure) (near the end of the document) "recommend that the following notations be used in all languages", UT0(i), UT1(i), UT2(i), UTC, UTC(i), UT, where (i) is institution "i".
- "Iceland" (http://wwp.greenwichmeantime.com/time-zone/europe/iceland/). 2011.
- International Bureau of Weights and Measures (10 October 2011). "Circular T" (ftp://ftp2.bipm.org/pub/tai/publication/cirt.285) (285).
- International Earth Rotation and Reference Systems Service (19 July 2011). "IERS Bulletins" (http://www.iers.org/IERS/EN/Publications/Bulletins/bulletins.html).
- Irvine, Chris (18 December 2008). "Scientists propose 'leap hour' to fix time system" (http://www.telegraph.co.uk/science/science-news/3817096/Scientists-propose-leap-hour-to-fix-time-system.html). *The Telegraph*.
- ITU Radiocommunication Assembly (2002). "Standard-frequency and time-signal emissions" (http://www.itu.int/dms_pubrec/itu-r/rec/tf/R-REC-TF.460-6-200202-I!!PDF-E.pdf) (PDF). International Telecommunications Union. Retrieved 2 August 2011.
- Langley, Richard B. (20 January 1999). "A Few Facts Concerning GMT, UT, and the RGO" (http://www.apparent-wind.com/gmt-explained.html). Retrieved 17 July 2011.
- "Leap second decision is postponed" (http://www.bbc.co.uk/news/science-environment-16625614). BBC News. 19 January 2012.

- McCarthy, Dennis D. (July 1991). "Astronomical Time" (http://www.cl.cam.ac.uk/~mgk25/volatile/astronomical-time.pdf) (PDF). *Proc. IEEE*. **79** (7): 915–920. doi:10.1109/5.84967 (https://doi.org/10.1109%2F5.84967).
- McCarthy, Dennis D.; Seidelmann, P. Kenneth (2009). *TIME From Earth Rotation to Atomic Physics*. Weinheim: Wiley VCH. ISBN 978-3-527-40780-4.
- Markowitz, W.; Hall, R.; Essen, L.; Parry, J. (August 1958). "Frequency of caesium in terms of Ephemeris Time" (http://www.leapsecond.com/history/1958-PhysRev-v1-n3-Markowitz-Hall-Essen-Parry.pdf) (PDF). *Physical Review Letters*. **1** (3): 105–7. Bibcode:1958PhRvL...1..105M (http://adsabs.harvard.edu/abs/1958PhRvL...1..105M). doi:10.1103/PhysRevLett.1.105 (https://doi.org/10.1103%2FPhysRevLett.1.105). Retrieved 18 October 2008.
- Markowitz, Wm. (1988). "Comparisons of ET (Solar), ET (Lunar), UT and TDT". In Babcock, A. K.; Wilkins, G. A. *The Earth's Rotation and Reference Frames for Geodesy and Geophysics: Proceedings of the 128th Symposium of the International Astronomical Union, held in Coolfont, West Virginia, U.S.A., 20–24 October 1986*. Dordrecht: Kluwer Academic Publishers. pp. 413–418. Bibcode:1988IAUS..128..413M (http://adsabs.harvard.edu/abs/1988IAUS..128..413M).
- "Military & Civilian Time Designations" (http://wwp.greenwichmeantime.com/info/timezone.htm). wwp.
- National Institute of Standards and Technology (18 January 2011). "Frequently asked questions (FAQ)" (https://www.nist.gov/pml/div688/utcnist.cfm#cut). Retrieved 17 July 2011.
- National Institute of Standards and Technology (19 March 2012). "Frequently asked questions (FAQ)" (https://www.nist.gov/pml/div688/leapseconds.cfm#often).
- Nelson, G.K.; Lombardi, M.A.; Okayama, D.T. (2005). "NIST Time and Frequency Radio Stations: WWV, WWVH, and WWVB" (https://www.nist.gov/calibrations/upload/sp250-67.pdf) (PDF). National Institute of Standards and Technology. (Special Publication 250-67). Archived (https://web.archive.org/web/20080626003023/http://ts.nist.gov/MeasurementServices/Calibrations/upload/SP250-67.pdf) (PDF) from the original on 26 June 2008.
- Nelson, Robert A.; McCarthy, Dennis D. (13 September 2005). *Coordinated Universal Time (UTC) and the Future of the Leap Second* (https://web.archive.org/web/20110429231210/http://www.navcen.uscg.gov/pdf/cgsicMeetings/45/29a%20UTCLeapSecond.ppt). Civil GPS Interface Committee. United States Coast Guard. Archived from the original (http://www.navcen.uscg.gov/pdf/cgsicMeetings/45/29a%20UTCLeapSecond.ppt) on 29 April 2011.
- Nelson, Robert A.; McCarthy, Dennis D.; Malys, S.; Levine, J.; Guinot, B.; Fliegel, H. F.; Beard, R. L.; Bartholomew, T. R. (2001). "The leap second: its history and possible future" (http://www.cl.cam.ac.uk/~mgk25/time/metrologia-leapsecond.pdf) (PDF). *Metrologia*. **38** (6): 509–529. Bibcode:2001Metro..38..509N (http://adsabs.harvard.edu/abs/2001Metro..38..509N). doi:10.1088/0026-1394/38/6/6 (https://doi.org/10.1088%2F0026-1394%2F38%2F6%2F6).

- Seidelmann, P. Kenneth; Seago, John H. (August 2011). "Time scales, their users, and leap seconds" (http://www.agi.com/resources/user-resources/downloads/white-paper.aspx?id=158). *Metrologia*. **48** (4): S186–S194. Bibcode:2011Metro..48S.186S (http://adsabs.harvard.edu/abs/2011Metro..48S.186S). doi:10.1088/0026-1394/48/4/S09 (https://doi.org/10.1088%2F0026-1394%2F48%2F4%2FS09).
- Seaman, Rob (2003). "A Proposal to Upgrade UTC" (http://iraf.noao.edu/~seaman/leap/). Retrieved 18 July 2011.
- Seidelmann, P.K. (1992). *Explanatory Supplement to the Astronomical Almanac*. Sausalito, CA: University Science Books.
- Stephenson, F. R.; Morrison, L. V. (1995). "Long-term fluctuations in the Earth's rotation: 700 BC to AD 1990". *Philosophical Transactions of the Royal Society A*. **351** (1695): 165–202. Bibcode:1995RSPTA.351..165S (http://adsabs.harvard.edu/abs/1995RSPTA.351..165S). doi:10.1098/rsta.1995.0028 (https://doi.org/10.1098%2Frsta.1995.0028).
- "Standard time" (https://www.law.cornell.edu/uscode/html/uscode15/usc_sup_01_15_10_6_20_IX.html). *U.S. Code*. Legal Information Institute. 2010. Title 15, Chapter 6, Subchapter IX.
- "TF.460-4: Standard-frequency and time-signal emissions" (http://www.cl.cam.ac.uk/~mgk25/volatile/ITU-R-TF.460-4.pdf) (PDF). International Telecommunication Union. 1986. Annex I.
- "Time" (http://www.bipm.org/en/scientific/tai/). International Bureau of Weights and Measures. n.d. Retrieved 22 May 2013.
- Time Service Dept. (2016). "Leap Seconds" (http://tycho.usno.navy.mil/leapsec.html). United States Naval Observatory. Retrieved 4 June 2017.
- United States Naval Observatory. "Universal Time" (http://aa.usno.navy.mil/faq/docs/UT.php). Retrieved 10 October 2013.
- "Universal Time" (http://www.oxforddictionaries.com/us/definition/american_english/Universal-Time). *Oxford Dictionaries: British and World English*. Oxford University Press. Retrieved 6 August 2014.
- Williams, Jack (17 May 2005). "Understanding and using Zulu time" (http://www.usatoday.com/weather/zulu.htm). *USA Today*. Retrieved 25 February 2007.

External links

- *Current* UTC time (https://www.worldtimeserver.com/current_time_in_UTC.aspx)
- Definition of Coordinated Universal Time in German law–ZeitG §1 (3) (http://www.cl.cam.ac.uk/~mgk25/time/zeitgesetz.en.html)
- International Earth Rotation Service; list of differences between TAI and UTC from 1961 to present (http://hpiers.obspm.fr/eop-pc/earthor/utc/TAI-UTC_tab.html)

- U.S. Naval Observatory: Systems of Time (http://www.usno.navy.mil/USNO/time/master-clock/systems-of-time)
- W3C Specification about UTC Date and Time (http://www.w3.org/TR/NOTE-datetime) and IETF Internet standard RFC 3339, based on ISO 8601
- Standard of time definition: UTC, GPS, LORAN and TAI (http://www.ipses.com/prod/timing/UTC-GPS.php?language=en)
- What is in a name? On the term Coordinated Universal Time (https://itunews.itu.int/En/4271-What-is-in-a-nameBROn-the-term-Coordinated-Universal-Time.note.aspx)

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