DEVELOPMENTS IN THE POSSIBLE REDEFINITION OF UTC

Report of the IAU Working Group on the Definition of Coordinated Universal Time

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1. BACKGROUND

The definition of Coordinated Universal Time (UTC) as a stepped atomic time scale to be maintained close to UT1 following Recommendation 460 of the International Radio Consultative Committee (CCIR) in 1970 was implemented in 1972. The original intent was to accommodate celestial navigation needs. Since 1972 the widespread use of electronic means to navigate has overtaken celestial navigation. This fact, along with increasing dissatisfaction with the possible disruption to modern electronic communications and navigation systems caused by the insertion of a leap second, has called into question the current definition of UTC. An extensive review of the background and issues relating to the leap second can be found in Nelson, *et al.* (2001).

In 1999, the Consultative Committee for Time and Frequency brought to the attention of the ITU-R concerns and issues that had arisen over the disruption caused by inserting Leap Seconds into UTC. In 2000, as the follow-on organization to the CCIR, the ITU-R adopted Question 236/7 "Future of the UTC Timescale" for study and consideration of possible future action. It further required that this Question should be brought to the attention of the International Earth Rotation Service (IERS), now called the International Earth rotation and Reference system Service, and other international organizations.

The issues addressed by this question were:

1. What are the requirements for globally-accepted time scales for use both in navigation/telecommunication systems, and for civil time keeping?

2. What are the present and future requirements for the tolerance limit between UTC and UT1?

3. Does the current leap second procedure satisfy user needs or should an alternative procedure be developed?

The Question stipulated that the results of the requested studies into these issues should be completed by 2006 and included in recommendation(s).

The question, which originated from ITU-R Working Party 7A (WP 7A Time Signals and Frequency Standard Emissions) of Study Group 7 Science Services, considered the question to be of such importance that a Special Rapporteur Group (SRG) was created from WP7A to help stimulate studies by Sector Members and gather information for the Working Party on possible recommendations. The SRG met in December 2000, March 2001, May 2001, December 2001, and March 2002. The general lack of interest both within and outside the timing community prompted the SRG to organize a special colloquium on the subject hosted by the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN) in Torino, Italy in 2003. During this time independent surveys on

the topic were also conducted by the IERS, The International Union of Radio Sciences (URSI), the Communications Research Laboratory of Japan (CRL), and the National Institute of Standards and Technology of the USA (NIST). The SRG presented a summary overview (primarily conclusions) to the CCTF meeting in May 2004 and a summary report at the ITU-R WP 7A meeting in September, 2004. At that meeting the U.S. proposed a recommendation to modify the definition of UTC so that adjustments would be made in the future to keep the difference between UTC and UT1 within one hour.

The International Astronomical Union (IAU) Working Group on the Definition of Coordinated Universal Time was created in compliance with IAU Resolution B2 of the 24th IAU General Assembly. The members were F. Arias, W. Dick, E. Fedoseev, D. Gambis, W. Klepczynski, S. Leschiutta, J. Luck, Z. Malkin, D. Matsakis, P. Pâquet, J. Vondrák, P. Wallace, and S. Ye. D. McCarthy served as Chairman of the Group and as IAU representative to the ITU-R SRG on the Future of UTC.

At the next IAU General Assembly it was decided to extend the lifetime of the Working Group so that they would be in a position to formulate a response to possible recommendations from the ITU-R. The membership was revised at that time, and its new members are F. Arias, W. Dick, D. Gambis, M. Hosokawa, W. Klepczynski, J. Laverty, S. Leschiutta, Z. Malkin, D. Matsakis, R. Nelson, J. Vondrak, P. Wallace, N. Capitaine (ex officio), and D. McCarthy continued as chair. The procedures of the ITU-R are such that any recommendations that are accepted by the ITU-R for possible adoption are provided to Member States and Sector Members for consideration before final adoption by the ITU-R. At that time, the IAU will be requested to comment and the Working Group will submit any response considered necessary through Division 1 to the General Secretary for IAU approval.

2. OPTIONS DISCUSSED

The possible options were identified at the first meeting of the ITU-R SRG and formed the framework of discussions and studies into the future of UTC. These alternatives include:

- Maintain the *status quo*
- Increase the tolerance between UT1 and UTC
- Periodic insertion of leap seconds
- Variable adjustments in frequency
- Redefine the SI second
- Substitute TAI for UTC
- Discontinue any leap seconds in UTC

None of the options beyond the first has received significant acceptance in discussions and surveys to this point. Also discussed was the feasibility of establishing a low-cost, low-precision UT1 service for any applications that need approximate mean solar time. More frequent distribution of this service via the Internet was considered as a possible way to accomplish this and the IERS has indicated they would take steps to implement that service.

3. ISSUES

At the time the ITU-R adopted Question 236/7 it was clear from analyses of Earth rotation that, at some future point, multiple leap seconds per year will be required to maintain the currently defined tolerance between UT1 and UTC. While advances in telecommunications, navigation and related fields are moving toward the increasing need for a single, internationally recognized uniform time scale, no overwhelming consensus has emerged on the issue. This leaves maintaining the status quo until change is essential as the only option rather than actively seeking an alternative in anticipation of that change.

Continuation of the current definition has also led to concerns regarding the timing sequence to be followed during the actual implementation of a leap second. The convention is to number the leap second with the label “60” in the minute in which it has been inserted. Unfortunately current computerized timing systems do not always permit a second to be labeled “60.” In the past, systems circumvented the problem which may have resulted in 2 seconds labeled 59 or even a second without a label. A conventional means to resolve this problem has not been implemented.

A more significant problem is the traditional approach to systems development of generating an internal system time for operations that are producing multiple *de facto* time scales. These “pseudo time scales” could lead to confusion and potentially serious consequences. The cost incurred to have the capability to introduce a leap second when it is needed rather than on a regular schedule is

also a concern. The costs include the extensive testing of hardware and software systems along with the personnel costs for an event that may or may not occur can be considerable. It has led to a variety of equipment with non-standard approaches or no approach at all.

Some members of the astronomical community have expressed great concern over any change to the current system. These concerns are based on the use of existing software that takes advantage of the current definition and uses UTC as a substitute for UT1. Their requirements for precision are such that the current 0.9-second tolerance is adequate, and their software has been designed accordingly. Should the definition of UTC be modified in any way that would permit this tolerance to be exceeded, they anticipate it would create a substantial cost to make non-trivial changes in existing software. Some members of the astrodynamic community have voiced similar concerns regarding legacy software used in the determination of orbital parameters of artificial satellites that again utilizes UTC as a substitute for UT1. It should be noted that in addition to the UT1 service contemplated by the IERS, the Global Positioning System intends to provide routinely the latest values of Earth orientation parameters, including UT1-UTC, in future navigational messages for easy access to the information.

It should be kept in mind that although UT1 is expressed as a time, it is not used practically as a time scale. It is used as an angle relating the rotation angle of the Earth in the celestial reference frame. Knowledge of UT1 is essential in relating the celestial and terrestrial reference systems and is obtained observationally for that purpose. The IERS provides daily values and predictions for up to a year into the future with accuracy much greater than that obtained by assuming that UT1 is equivalent to UTC. It is conceivable that the systems served by legacy software based on the current UTC definition could benefit from using more realistic values for UT1 as opposed to the UTC approximation.

The reference of UTC to UT1 does provide a means of keeping UTC in rough synchronization with the position of the Sun in the sky. Although departures of local solar time from local time based on UTC may differ by hours currently, it is generally agreed that a change in the definition of UTC that would cause the time of day to depart significantly from a solar connection would be unacceptable, but the specification of a “significant departure” is contentious.

4. TORINO COLLOQUIUM

Although there was no overall consensus other than the general agreement that the responsibility for maintaining and disseminating UT1 information should remain solely with the IERS, the findings from the official report of the Torino Colloquium, held in 2003, were the following.

The definition of UTC will undoubtedly need to be changed from the current UTC standard by the dynamics of the Earth at some point in the future. It was suggested that a means of transitioning to a uniform time scale could be accomplished by the creation of another time scale that might be called Temps International (TI) to clearly distinguish it from Universal Time.

If a change were to be made, a date suggested to inaugurate that change could be 2022, the 50th anniversary of the institution of the UTC timescale. This date was influenced by the assumed lifetimes of existing systems that would be expensive to change.

TI could be a continuous atomic time scale, without leap seconds, synchronized with UTC at the time of transition.

5. SPECIAL RAPPORTEUR REPORT

Following the Torino Colloquium and after further discussion, the SRG prepared a summary report outlining a possible transition to a new definition of UTC. The final report of the SRG was submitted to ITU-R Working Party 7A. It contained the following recommendations that were presented at the 16th CCTF meeting, May 2004.

The suggested creation of a new name was not recommended because it could create significant confusion and complications in the process of defining a widely used time scale that has been incorporated throughout the radiocommunications community. A name change alone could cause great confusion and complications in the ITU-R and the multitude of systems needing to implement the new standard.

The radio broadcast of DUT1 information should be discontinued since UT1 is available via IERS. Since there did not appear to be any users or need to do so. The general availability of internet data services for both transmission of correction parameters as well as actual timing information may well satisfy the needs of the astronomical and satellite orbit determination communities.

The redefinition of a new "UTC" is not necessary since the change contemplated was a modification not unlike previous modifications in character though with much larger effects.

Divergence from solar time, a possible issue in "civil" timekeeping is considered to be insignificant as the difference of approximately 1 hour would take until 2600 to accumulate. A step adjustment at that time could maintain approximate agreement for some similar period thereafter. It is very probable that advances in time keeping will lead to other solutions before the first correction is necessary.

The recommended date for change was suggested as not later than 2010.

6. RECOMMENDATION PROPOSED TO ITU-R WP-7A

In order to work toward a final decision on the matter, and because formal proposals must be submitted by sector members, the United States submitted a proposed revision to ITU-R TF.460 in September, 2004. In that proposed recommendation the Operational Rules for the formation of UTC after 0000 UTC December 21, 2007 would be modified so that the difference of UT1 from UTC should not exceed 1 hour. It further proposed that adjustments to the UTC time scale should be made as determined by the IERS to ensure that the time scale remains within the specified tolerances and that the IERS should announce the introduction of an adjustment to the UTC time scale at least five years in advance. At the time of that announcement the IERS should provide directions regarding the details of the implementation of the adjustment. The recommended broadcast of DUT1 would be discontinued upon acceptance of the recommendation. Analysis of historical observations of the Earth's rotation currently indicates that such an adjustment would not be required for at least 500 years.

This Recommendation was not adopted by the Working Party due to the lack of unanimous agreement on any proposed date for implementation. However, it was accepted as a draft ITU document for future discussion, and the Chairman of the SRG was requested to distribute the document for comments.

The ITU-R considered the matter again in November, 2005 and a draft press release that was released prematurely by a member of WP7A is attached as Appendix A. The ITU-R requested sector members to send reports regarding their experiences with the 31 December 2005 leap second to the Special Rapporteur Group to assist them in further discussions. This Working Group drafted the reply for the IAU General Secretary, and a copy is attached as Appendix B.

7. QUESTIONNAIRE

The Working Group completed an internal survey of their opinions relating to the issues. A copy of the questionnaire and a compilation of the results are provided in Appendix C.

8. CURRENT STATUS (AUGUST 2006)

Discussion continues on this subject. It is expected that the issue will be discussed once again at the meeting of ITU-R International Working Party 7A in Geneva, 29 August – 1 September 2006. At that time it is expected that the ITU-R Working Party 7A will request the Special Rapporteur Group to distribute a report to the ITU-R Sector Members along with the current version of the proposed draft amendment. Appendix D is the report of the SRG and Appendix E contains the latest version of the proposed draft U.S. recommendation. It is further expected that comments will be requested from the Sector Members in time for discussion at the September, 2007, meeting of the Working Party.

9. FUTURE

It is expected that the IAU as a sector member will be expected to respond to the ITU-R in the autumn of 2006, after formally receiving the report of the Special Rapporteur Group along with the current version of the proposed draft amendment and a request for comment.

10. RECOMMENDATIONS

Based on the results of the questionnaire and recognizing that the ITU-R is unlikely to prepare a formal ITU-R proposal for consideration by sector members before the autumn of 2007, the Working Group makes the following recommendations.

A. In response to the expected distribution of the ITU-R request in the autumn of 2006, the General Secretary of the IAU in consultation with the President of Division 1 and the Presidents of the Commissions within IAU Division 1, reply noting the following points:

i. There is no strong consensus within the IAU either for or against a proposed change in the definition of UTC.

ii. The IAU requests that a sufficient time be allowed between the adoption of any change in definition and its date of implementation to permit astronomical software to be changed with the least cost and inconvenience. It is suggested that that time be at least five years.

iii. The IAU requests that it be consulted as part of any formal action taken to change the definition of UTC.

B. The current Working Group on the Definition of Coordinated Universal Time be dissolved. A future working group could be formed should the ITU-R prepare a formal ITU-R proposal for acceptance by Sector members.

9. REFERENCES

Nelson, R. A., McCarthy, D. 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," *Metrologia*, **38**, pp. 509-529.

APPENDIX A

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

Document 7A/TEMP/16R1-E
11 November 2005
English only

Working Party 7A

STATEMENT FOR RELEASE TO THE PRESS

THE FUTURE OF COORDINATED UNIVERSAL TIME (UTC) AND THE LEAP SECOND

A working party of the International Telecommunication Union – Radiocommunication Sector (ITU-R) has considered a proposed change to UTC at a meeting in Geneva on 8 -11 November 2005. The proposal is based on studies done by an ITU-R Special Rapporteur Group (SRG) that was established due to some evidence of the difficulties experienced by communication, navigation and other electronic systems caused by leap seconds and the general proliferation of continuous system "time scales".

The proposed change is intended to make UTC a continuous time scale. This would however cause UTC to gradually diverge from UT1, the astronomical time scale based on the irregular rotation of the Earth. At present, leap seconds are added to UTC to limit its divergence from UT1 by no more than 0.9 seconds. The proposal recommends that the maximum difference allowed between UTC and UT1 be increased to one hour (an event predicted to occur only once every several hundred years).

The working party has discussed the proposed change and options, and decided that more time is required to build consensus. In addition, the forthcoming leap second just prior to 01 January 2006 00:00:00 h UTC – the first for seven years – provides an opportunity to further document current problems.

UTC has been adopted as the basis of civil time in most of the world. It is derived from more than 200 atomic clocks operated in some 50 time standards laboratories around the world. The Bureau International des Poids et Mesures (BIPM) is responsible for computing UTC on the basis of data from those laboratories. UT1 is maintained by the International Earth Rotation and Reference Systems Service (IERS) and it is this body that decides when leap second adjustments should be applied. The procedures for maintaining UTC are described by Recommendation ITU-R TF.460-6.

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APPENDIX B

International Astronomical Union
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Email: iau@iap.fr - URL: http://www.iau.org/

Mr. Alexandre Vassiliev
Counsellor for ITU-R SGD/SG3 & (SGD/SG7)
International Telecommunications Union
Radiocommunication Bureau
Place des Nations
CH-1211 Geneva 20
Switzerland

Paris, March 3rd, 2006

Dear Mr. Vassiliev,

In response to the letter of 7 December 2005 from Valery Timofeev, Director of the International Telecommunication Union Radiocommunication Bureau, regarding issues related to the implementation of the leap second on 31 December 2005, the International Astronomical Union (IAU) offers the following observations. These comments address the issues reported in the areas of navigation, communication, dissemination of precise time, and astronomical services.

The IAU is not aware of any significant problems encountered in navigational systems as a result of the leap second implementation in 2005. Sufficient lead time was provided by the announcement of the International Earth Rotation and Reference Systems Service (IERS) to enable system operators to test equipment prior to the event. The GLONASS navigational system was not available for 2.5 minutes beginning 1 minute after the insertion of the leap second, but at this point it is unclear if that outage was related to the leap second.

The IAU is not aware of any reports of significant outages in communications related to the insertion of a leap second on 31 December 2005. CDMA cell phone systems generally operate on a uniform time (GPS Time) free of leap seconds and need only to know the offset between their internal system time and Coordinated Universal Time (UTC) in order to provide time to their customers. Some cell phone companies failed to update to the new value following the leap second causing the wrong time to be displayed, but no outages were noted.

There were, however, reports of problems related to the transmission of precise time as a result of the leap second event. A low frequency radio station apparently indicated the insertion of the leap second in the wrong minute. A significant percentage of time transfer information provided by Network Time Protocol services was also affected. Some systems properly recorded the sequence of seconds, but others recorded two consecutive seconds labeled "59" or two seconds labeled "0." Some may have failed to indicate any label. This situation clearly calls for efforts toward the international standardization of Network Time

protocols. Some GPS receiving equipment designed to provide precise time apparently failed to record time properly at the time of leap second insertion. These receivers operated properly after they were re-started.

There were some issues reported that were related specifically to astronomical operations. At least one radio telescope engaged in very long baseline interferometry observations for the determination of Earth orientation failed to implement the leap second properly, causing a minor problem. Some other observational Earth rotation information was reported incorrectly and the GPS data reported to the International Global Navigation Satellite System Service (IGS) by a regional network was reported incorrectly by one second. Some software used to correlate VLBI observations experienced minor problems because it had not been tested for leap second compliance previously.

These observations represent only the information that has been made available publicly. There may well have been a variety of minor problems that have not been reported, for example with previously untested software.

In summary, the IAU community was not significantly affected adversely by any problems resulting from the insertion of the leap second on 31 December 2005. However, it should be noted that the testing of software and equipment was facilitated by the six-month lead time provided by the IERS notification. Also, it is important to note that a significant investment in personnel time and effort is required to prepare for the insertion of the leap second and to ensure that the actual event does not adversely affect astronomical observations.

The IAU is concerned with possible changes in the definition of UTC and has had a Working Group devoted to the topic since 2000. The Group is preparing a final report for presentation at the IAU General Assembly in August, 2006. I expect that topic will be discussed in depth at that time. The IAU would be happy to share the reports of those discussions with the International Telecommunications Union when they become available.

Sincerely,

Oddbjørn Engvold
IAU General Secretary

Cc.: Mr. Valery Timofeev
Radiocommunication Bureau (BR) Director

APPENDIX C

The following is the Working Group questionnaire

A. The following statements are generally accepted. If you disagree with any one of them, please indicate that fact and explain your reasons.

1. UT1 is a convenient measure of the Earth's rotation angle and is, therefore, convenient for the determination of local hour angles of celestial objects.

2. It is desirable to have civil time be "close" to solar time.

3. It will become necessary in the future to insert more than one leap second per year.

4. Operationally, clocks currently treat the sequence of seconds during the insertion of a leap second ambiguously.

COMMENTS

B. The maximum difference between civil and solar time should not be greater than (seconds, minutes, *etc.*)

C. On a scale of 1 (completely disagree) to 5 (completely agree) please indicate the numerical value that represents your opinion.

1. The current definition of UTC is adequate to meet the needs for practical precision timekeeping for the foreseeable future.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

2. It is important to have a time scale without discontinuities in epoch for use in practical applications.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

3. TAI meets the need to have a time scale without discontinuities in epoch for use in practical applications.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

APPENDIX C

4. The use of TAI as a time scale in addition to UTC should be encouraged in spite of potential public confusion.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

5. The insertion of leap seconds can create significant safety of life concerns.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

6. The insertion of leap seconds can create significant communication outages.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

7. It is important to continue the radio broadcast of DUT1 (the low-precision estimate of UT1-UTC) for navigators.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

8. It is important to make a decision regarding possible changes in the definition of UTC before the implementation of navigational time scales in GALILEO and GPS III.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

9. It is better to put off a decision on possible re-definition of UTC (future of leap seconds) for some period of time.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

If your answer above ≥ 3 please indicate an approximate period of time to delay a decision.

_____ years

10. If any change is made, the name "Coordinated Universal Time" should be retained as the name for the standard worldwide time scale.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

11. The financial cost to revise legacy software to allow for a departure from the current definition of UTC is too high to make such an option worth considering.

Disagree 1 ☐ 2 ☐ 3☐ 4 ☐ 5 ☐ Agree

If your answer > 3 please define prohibitive: _____ dollars

D. If a change were to be made in the definition, what would be an adequate time to allow necessary changes in software to be made?

_____ years

E. OTHER COMMENTS:

Questionnaire Results

Regarding the recent questionnaire, on some issues there was general agreement, but in others there was a wide range of opinions All agreed that UT1 is a convenient measure of the Earth's rotation angle, and is, therefore, convenient, or at least an appropriate starting point, for the determination of local hour angles of celestial objects. With the exception of one member, all felt that it would become necessary in the future to insert more than one leap second per year. The dissenting member feels that this would not happen for "hundreds of years" regardless of the projection of the least-squares fit to the parabolic departure of UT1 from a uniform time scale over the last 2 millennia. With one exception, respondents were either ambivalent or in disagreement with the statement that the current definition of UTC is adequate to meet the needs for practical precision timekeeping for the foreseeable future. When asked what the maximum difference between civil and solar time should be, only one response listed one second. The remaining replies ranged from 2 hours to one minute. Again with one exception all were in complete agreement that it is important to have a time scale without discontinuities in epoch for use in practical applications. One respondent felt strongly that it was important to continue the radio broadcast of DUT1 (the low-precision estimate of UT1-UTC) for navigators. Others strongly disagreed or were ambivalent. With one exception most felt that it was not the case that the financial cost to revise legacy software to allow for a departure from the current definition of UTC is too high to make such an option worth considering. That response estimated the cost of revising the software to be $250M. All agreed that a period of 5 to ten years should be allowed to make the necessary revisions in software.

With the exception of two replies, all agreed that it is desirable to have civil time be "close" to solar time. Those who disagreed pointed out that we commonly deal with civil time that may be more than an hour different from local solar time. One reply strongly disagreed that TAI meets the need to have a time scale without discontinuities in epoch for use in practical applications, and one pointed out that it could be used, but practical concerns about accessibility and dissemination could cause problems. On the same topic there was no agreement on whether the use of TAI as a time

scale in addition to UTC should be encouraged in spite of potential public confusion. Replies ranged from strong agreement to strong disagreement. Similarly there was no agreement of opinions on whether the insertion of leap seconds could create significant safety of life concerns. Again replies ranged from strong agreement to strong disagreement.

Opinions were divergent on the question of the importance of making a decision regarding possible changes in the definition of UTC before the implementation of navigational time scales in GALILEO and GPS III. Regarding this issue, F. Arias pointed out that on 26 March 2004 a letter had been sent by Dr Jorg Hahn (Galieo Project Office, ESA) to the Consultative Committee for Time and Frequency (CCTF) signaling the importance of making any decision about the future of UTC or its new definition before Galileo starts to operate. One respondent thought that a decision could be put off for twenty years and one felt that a delay of five years would be acceptable. All others felt that a decision should be made within three years. There was no overall agreement on the retaining the name "Coordinated Universal Time" as the name for the standard worldwide time scale.

One reply noted that operationally, clocks do currently treat the sequence of seconds during the insertion of a leap second unambiguously. That is, modern clocks do permit the leap second to be labeled unambiguously as second number "60". The rest of the group disagrees.

In comments that were sent with the questionnaire, R. Nelson summarizes the concerns of those who argue for a change in the current definition of UTC:

> "Time is significant for many methods of communication. Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) depend on precise time synchronization. Earth stations for communications satellites typically use GPS signals as their time reference. Computer systems connected via sophisticated networks depend on a common time. Satellites for communication, scientific, and military applications having on-board time registration systems must be calibrated using a single time scale.
>
> "The existence of leap seconds in UTC encourages the adoption of independent scales of time that are uniform. The Global Positioning System uses its own internal time scale (GPS Time) because it cannot tolerate the one-second discontinuities of UTC. Similarly, new systems like Galileo anticipate the adoption of a uniform atomic time scale to avoid time discontinuities.
>
> "When it was introduced in 1972, the concept of leap seconds was a technical advance because it permitted the transmission of both an approximation to UT1 for celestial navigation and the interval of the SI second in the same radio emission. Today UTC is an impediment to the future growth of interconnected timekeeping systems that must be synchronized with great precision."

Z. Malkin hopes, "it's commonly agreed that there is no solution that will satisfy all mankind, and the question is which strategy will meet changing reality. If the IAU ignores the requirements of new technologies, they will make a decision without us, and this can add more chaos in timekeeping! So, I would propose to pay less attention to arguments in favor of one decision or another, but collectively look for a strategy that will mitigate losses inevitable in any case. As an

example already discussed, the IERS could publish TAI-UT1. Another example, also already mentioned is a low-cost UT1 service making use of modern technology, network time protocols, etc."

Regarding possible recommendations for the future, P. Wallace notes, "The simple fact is that, if there really are life-critical existing systems out there that are vulnerable to leap seconds, they were criminally mis-designed. They should have used TAI from the start and should be re-engineered without delay to do so." Malkin would go further suggesting "that UTC as it is defined now (*i.e.* with leap seconds) should be discontinued, and TAI should be used. A UT1 service might be established for users who need true time/Earth position angle." In any event J. Laverty feels that, "If a continuous time scale without steps in epoch is required for some precise timekeeping applications then it should not have steps of any magnitude. Leap hours would be considerably more difficult to implement than leap seconds and if they could be handled without unacceptable consequences then so, arguably, can leap seconds. It is disingenuous to argue that it is so long until the first leap hour would be required that the mechanism can be incorporated into the definition of UTC without consideration of the practical consequences. There are means by which the offset between local civil timescales and UTC could be kept to within one hour without applying steps of any size to UTC." Along those lines of thought, W. Dick suggests that, "Instead of introducing a 'leap hour', civil (zonal) time can be re-defined to keep civil time close to solar time. Thus, UTC will be continuous, and the necessary change can be treated like the introduction of Daylight Saving Time."

Concerns raised about possible changes to the current definition are generally related to concerns about navigation and the cost of updated software. Z. Malkin addressed these issues in his comment:

> "Russian astronomers' experience shows that the problem with software which may fail when |UTC-UT1| becomes greater than 0.9 sec. may be exaggerated. I trust colleagues who pointed out the cost of updating software in case the leap seconds will discontinue, but did somebody count what may be the cost of the interruption of services when the next leap second will be introduced?
>
> "As to celestial navigation, one of the routine operations in navigation is to account for clock offset, and navigators have to know how to do that. So, what is the difference which clock correction will be used? If a navigator used a clock accurate enough to make no correction, I guess he use GNSS, and in such a case he has his position without observations of celestial bodies."

APPENDIX D

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

WP-7A Special Rapporteur Group
1 March 2004

UTC TRANSITION PLAN

1.0 Background

As a result of issues raised by sector members of the ITU-R (International Telecommunication Union - Radiocommunications) and a letter from the Director of the Bureau International des Poids et Mesures (BIPM) to the Secretary General of the ITU, a new question, ITU-R 236/7 (2000) "The Future of the UTC Timescale", was generated by ITU-R Study Group 7 (Science Services) Working Party 7A (Standard Frequency and Time Signal Services). The question considers the future definition and use of Coordinated Universal Time (UTC) in the ITU-R Recommendations. Any *major change to the UTC timescale* as defined in the current recommendations has a potentially significant impact on synchronization of communications networks, navigation systems and time distribution performance. Due to the potential impact of changing the UTC Time Scale and to focus on the issues, Study Group 7, Working Party 7A established a Special Rapporteur Group (SRG) to specifically address the future of the *leap second and related issues*.

The SRG has established liaison with Section Members and related scientific bodies to address the question. Coordination and technical exchange meetings have been held over the past 4 years to gather data on UTC utilization, analyse usage and examine *alternative approaches to reduce or eliminate the operational impact of the leap second*. Meetings were held in conjunction with International Conferences dealing with Time and Frequency as well as special presentations to the Institute of Navigation and the Civil GPS Interface Committee. Several bodies in the international community conducted surveys and information fact-finding that produce mixed results.

2.0 The Question of the Future of the UTC Time Scale

These efforts had not produced clearly defined user group(s) using UTC time information nor a consensual opinion on future utilization. Consequently, the SRG organized a special colloquium on the future of UTC for deliberating and exploring possible recommendations with representative organizations and contributing parties. At the Colloquium, distinguished representatives in the areas of International Timekeeping, Navigation, Earth Rotation, Telecommunications and Internet Timing were invited to make presentation dealing with the subject areas. These areas would be impacted by changes in the UTC Timescale to one degree or another. Contributed presentations were invited to express additional viewpoints.

The results of the special colloquium were as follows:

1. Analyses of deceleration of the earth's rotation lead to the ultimate prediction of multiple leap seconds per annum to maintain the currently defined tolerance between UT1 and UTC.
2. The astronomical community has great concerns over any change to the current system. These concerns stem from the use of software using UTC as the readily available source of UT1 and this software has been incorporated into instrument pointing systems and other equipment controlling software that has become too old to be readily modified or changed. Similarly, the astrodynamic community concerned with the determination of orbital parameters of artificial satellites and other celestial bodies utilise the UTC for the same purpose.

3. It was generally agreed that at some point the definition of UTC would need to be modified due to changes in the earth's rotation rate. There was no overwhelming consensus on whether the status quo should be maintained until a change was necessary or an alternative should be actively pursued in anticipation of a future change.
4. Advances in telecommunications, navigation and related fields are moving toward the need for a single internationally recognized time scale to regulate and provide uniformity to these systems. The global nature of these systems providing omnipresent precise service are requiring increasingly precise T&F coordination and are becoming integrated international services.
5. Developing telecommunication and navigation systems could produce the need for even more T & F precision systems. Their international service requiring universal synchronization and increased bandwidth. The traditional model of generating internal system time scales for system operation could produce. de facto multiple global time scales. This multiplicity of "pseudo time scales" could lead to confusion and potentially disastrous consequences.
6. The special case of the international computer network, the so-called "Internet", which is facilitated by the international telecommunication network, requires global syntonization. Currently, GPS with it's capability for providing precise T&F for synchronization has been adopted into an ad hoc global plieschronous system. This use in the telecommunication network would be described as a feature of the physical layer. Consequently, intra-system syntonization has not been recognized within the application layers evolving internet protocols.

Several alternative proposals have been put forward concerning the Leap Second and were discussed at the special colloquium. One proposed alternative seemed to be preferred if a change were to be made. The essence of this proposal is:

1. That any change slowly evolve from the current UTC Standard by transition to a uniform timescale, perhaps to be called *Temps International* (TI).
2. A suggested date for inaugurating any change would be 2022, the 50th anniversary of the UTC timescale. The date suggested is influenced by the lifetimes of existing systems that would be expensive to change.
3. TI should be a continuous atomic time scale, without Leap Seconds, that is synchronized with UTC at the time of transition.
4. Responsibility for disseminating UT1 information should remain solely with the IERS.

2.0 Proposed Transition

The results of the special colloquium and prior activities of the SRG have been considered in the following recommendations.

1. Creation of another time scale, namely **International Time (TI)**, for an evolutionary introduction will add significant complications in the process of defining a new time scale. A name change alone could cause great confusion and complications in the ITU-R process and systems attempting to implement the new standards. Creation of a new name is not recommended. Of the defined time scales typically given in the literature, in fact only UTC is maintained and distributed for international timekeeping purposes.
2. The necessity of broadcasting DUT1 was largely unsupported. Most users apparently needing UT1 appeared to use UTC directly as an approximation UT1. Broadcast of DUT1

should be discontinued. Availability of UT1 for the purposes of orbit determination software and astronomical instruments could by achieved through publication via IERS Website and BIPM Circular T. The IERS is responsible for determining earth rotation parameters and has accepted responsibility for UT1 and its dissemination.

3. Redefinition of a new "**UTC**" is not necessary. The current definition may be adjusted to produce a broadcast time scale that capitalizes on the current organizational and systems support structure. This would achieve a long-term continuous time scale supported by timing centers coordinating their real-time realizations.

4. Divergence from solar time producing an increasing error that may be an issue in "civil" timekeeping purposes was estimated as a few seconds over three years. An error of approximately 1 hour would result in the year 2600. Subsequent step adjustment could maintain approximate agreement or advances in time keeping may lead to other solutions in the future. (E.F. Arias, B. Guinot, T.J. Quinn, "Rotation of the Earth and Time scales", Bureau International des Poids et Mesures, *Proceedings of ITU-R Special Rapporteur Group Colloquium on the UTC Time Scale*, Torino (Italy), 28 – 29 May 2003.)

5. The adoption of these recommendations will need to be considered within the formal ITU-R procedures. Consequently, submission and adoption of proposed changes to the ITU-R will determine the actual date for adoption. In consideration of that process the recommended date is suggested as 2010.

3.0 Conclusion

Report planned actions at CCTF.

Report Transition Plan to ITU-R SG 7

Revise ITU-R for circulation to Sector Members

Formal Recommendation submitted under Usual Procedures

U.S. submits proposed to submit revision to ITU-R Recommendation

5.0 Bibliography

BIPM letter to the Secretary General of the ITU

ITU-R Question on the Future of the UTC Time Scale

APPENDIX E

DOCUMENTS
RADIOCOMMUNICATIONS
STUDY GROUPS
PERIOD 2004-2006

USWP-7A/1
1 JULY 2004
ORIGINAL: ENGLISH

UNITED STATES OF AMERICA

PROPOSED REVISED RECOMMENDATION ITU-R TF.460-6*

Standard-frequency and time-signal emissions

(Question ITU-R 102/7)

(1970-1974-1978-1982-1986-1997-2002)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference, Geneva, 1979, allocated the frequencies 20 kHz ± 0.05 kHz, 2.5 MHz ± 5 kHz (2.5 MHz ± 2 kHz in Region 1), 5 MHz ± 5 kHz, 10 MHz ± 5 kHz, 15 MHz ± 10 kHz, 20 MHz ± 10 kHz and 25 MHz ± 10 kHz to the standard-frequency and time-signal service;

b) that additional standard frequencies and time signals are emitted in other frequency bands;

c) the provisions of Article 26 of the Radio Regulations;

d) the continuing need for close cooperation between Radiocommunication Study Group 7 and the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the General Conference of Weights and Measures (CGPM), the Bureau International des Poids et Mesures (BIPM), the International Earth rotation and Reference system Service (IERS) and the concerned Unions of the International Council of Scientific Unions (ICSU);

e) the desirability of maintaining worldwide coordination of standard-frequency and time-signal emissions;

f) the need to disseminate standard frequencies and time signals in conformity with the second as defined by the 13th General Conference of Weights and Measures (1967);

g) the desirability of maintaining a relationship between a uniform time scale (UTC) and the time defined by the rotation of the Earth (UT1);

h) that the complexity of the variability of the Earht's rotation currently limits the accuracy with which the difference between the two types of time scales can be predicted to a few tenths of a second one year in advance;

i) that the International Earth rotation and Reference system Service provides updated data relating the two time scales daily to users;

Supprimé : Rotation

Supprimé : the continuing need to make universal time (UT) immediately available to an uncertainty of one-tenth of a second,

Supprimé : (IERS)

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* This Recommendation should be brought to the attention of the IMO, the ICAO, the CGPM, the BIPM, the IERS, the International Union of Geodesy and Geophysics (IUGG), the International Union of Radio Science (URSI) and the International Astronomical Union (IAU).

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recommends

1 that all standard-frequency and time-signal emissions conform as closely as possible to coordinated universal time (UTC) (as defined in the Annex); that the transmission of time signals should not deviate from UTC by more than 1 microsecond; that standard frequencies should not deviate by more than 1 part in 10^{11} and that the time signals emitted from each transmitting station should bear a known relation to the phase of the carrier;

2 that the IERS provide convenient access to values of UT1-UTC so that users have access to UT1;

3 that, if necessary, adjustments in the epoch of UTC be made following the guidance given in the Annex.

Supprimé : see

Supprimé : 1

Supprimé : transition

Supprimé : the

Supprimé : ms

Supprimé : the

Supprimé : 10

Supprimé : fo

Supprimé : standard-frequency and time-signal emissions, and other time-signal emissions intended for scientific applications (with the possible exception of those dedicated to special systems) should contain information on UT1 – UTC and TAI – UTC (see Annex 1);

Supprimé : .

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ANNEX

Supprimé : 1

Time scales

A Universal time (UT1)

Supprimé : ¶

UT1 is the time scale determined from astronomical observations of the rotation of the Earth with respect to the International Celestial Reference System. A technical description and the concepts involved are available in the publications of the IERS (Frankfurt am Main, Germany).

Supprimé : Universal time (UT) is the general designation of time scales based on the rotation of the Earth.¶
In applications in which an imprecision of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of UT which should be used:¶
UT0 . is the mean solar time of the prime meridian obtained from direct astronomical observation;¶
UT1 . is UT0 corrected for the effects of small movements of the Earth relative to the axis of rotation (polar variation); ¶
UT2 . is UT1 corrected for the effects of a small seasonal fluctuation in the rate of rotation of the Earth; ¶
UT1 . is used in this Recommendation, since it corresponds directly with the angular position of the Earth around its axis of diurnal rotation.¶
Concise definitions of the above terms and the concepts involved are available in the publications of the IERS (Paris, France).

B International atomic time (TAI)

The international reference scale of atomic time (TAI), based on the second (SI), as realized on the rotating geoid, is formed by the BIPM on the basis of clock data supplied by cooperating establishments. It is in the form of a continuous scale, e.g. in days, hours, minutes and seconds from the origin 1 January 1958 (adopted by the CGPM 1971).

C Coordinated universal time (UTC)

UTC is the time-scale maintained by the BIPM, with assistance from the IERS, which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with TAI but differs from it by an integer number of seconds. The UTC time scale is in proximate agreement with UT1. The value of the difference UT1-UTC, either observed or predicted, is disseminated by the IERS. It may be regarded as a correction to be added to UTC to obtain UT1.

Supprimé : The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap-seconds) to ensure approximate agreement with UT1.¶
D . DUT1

Operational Rules
(prior to 0000 UTC, December 21, 2007)

DUT1

The value of the predicted difference UT1 – UTC, as disseminated with the time signals is denoted DUT1; thus DUT1 ≈ UT1 – UTC. DUT1 may be regarded as a correction to be added to UTC to obtain a better approximation to UT1.
The values of DUT1 are given by the IERS in multiples of 0.1 s.

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Supprimé : The following operational rules apply:

1 Tolerances

Supprimé : 1

1.1 The magnitude of DUT1 should not exceed 0.8 s.
1.2 The departure of UTC from UT1 should not exceed ±0.9 s (see Note 1).
1.3 The deviation of (UTC plus DUT1) should not exceed ±0.1 s.

NOTE 1 – The difference between the maximum value of DUT1 and the maximum departure of UTC from UT1 represents the allowable deviation of (UTC + DUT1) from UT1 and is a safeguard for the IERS against unpredictable changes in the rate of rotation of the Earth.

2 Leap-seconds

2.1 A positive or negative leap-second should be the last second of a UTC month, but first preference should be given to the end of December and June, and second preference to the end of March and September.
2.2 A positive leap-second begins at 23h 59m 60s and ends at 0h 0m 0s of the first day of the following month. In the case of a negative leap-second, 23h 59m 58s will be followed one second later by 0h 0m 0s of the first day of the following month (see Annex).

Supprimé : 3

2.3 The IERS should decide upon and announce the introduction of a leap-second, such an announcement to be made at least eight weeks in advance.

3 Value of DUT1

3.1 The IERS is requested to decide upon the value of DUT1 and its date of introduction and to circulate this information one month in advance. In exceptional cases of sudden change in the rate of rotation of the Earth, the IERS may issue a correction not later than two weeks in advance of the date of its introduction.
3.2 Administrations and organizations should use the IERS value of DUT1 for standard-frequency and time-signal emissions, and are requested to circulate the information as widely as possible in periodicals, bulletins, etc.
3.3 Where DUT1 is disseminated by code, the code should be in accordance with the following principles (except § 3.4 below):

– the magnitude of DUT1 is specified by the number of emphasized second markers and the sign of DUT1 is specified by the position of the emphasized second markers with respect to the minute marker. The absence of emphasized markers indicates DUT1 = 0;

– the coded information should be emitted after each identified minute if this is compatible with the format of the emission. Alternatively the coded information should be emitted, as an absolute minimum, after each of the first five identified minutes in each hour.

Full details of the code are given in the Annex .

Supprimé : 2

3.4 DUT1 information primarily designed for, and used with, automatic decoding equipment may follow a different code but should be emitted after each identified minute if this is compatible with the format of the emission. Alternatively, the coded information should be emitted, as an absolute minimum, after each of the first five identified minutes in each hour.

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3.5 Other information which may be emitted in that part of the time-signal emission designated in § 3.3 and 3.4 for coded information on DUT1 should be of a sufficiently different format that it will not be confused with DUT1.

3.6 In addition, UT1 – UTC may be given to the same or higher precision by other means, for example, by messages associated with maritime bulletins, weather forecasts, etc.; announcements of forthcoming leap-seconds may also be made by these methods.

3.7 The IERS is requested to continue to publish, in arrears, definitive values of the differences UT1 – UTC and UT2 – UTC.

Supprimé : E . DTAI¶
The value of the difference TAI – UTC, as disseminated with time signals, shall be denoted DTAI. DTAI = TAI – UTC may be regarded as a correction to be added to UTC to obtain TAI.¶
The TAI – UTC values are published in the BIPM Circular T. The IERS should announce the value of DTAI in integer multiples of one second in the same announcement as the introduction of a leap-second (see § D.2).

Supprimé : ANNEX 2

Code for the transmission of DUT1

A positive value of DUT1 will be indicated by emphasizing a number, *n*, of consecutive second markers following the minute marker from second marker one to second marker, *n*, inclusive; *n* being an integer from 1 to 8 inclusive.

$$\text{DUT1} = (n \times 0.1)\ \text{s}$$

A negative value of DUT1 will be indicated by emphasizing a number, *m*, of consecutive second markers following the minute marker from second marker nine to second marker (8 + *m*) inclusive, *m* being an integer from 1 to 8 inclusive.

$$\text{DUT1} = -(m \times 0.1)\ \text{s}$$

A zero value of DUT1 will be indicated by the absence of emphasized second markers.
The appropriate second markers may be emphasized, for example, by lengthening, doubling, splitting or tone modulation of the normal second markers.
Examples:

FIGURE 1

DUT1 = + 0.5 s

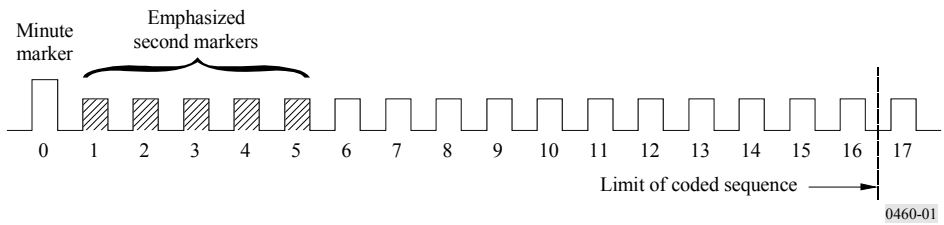

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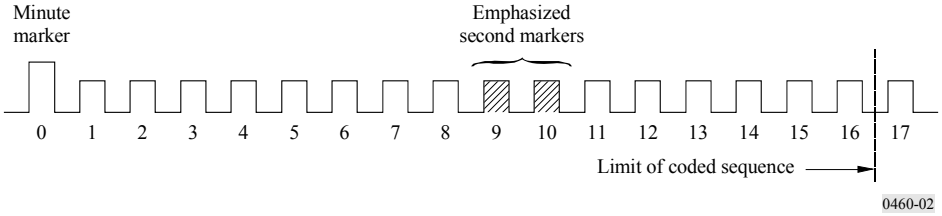
FIGURE 2

DUT1 = – 0.2 s



Supprimé : ANNEX 3

Dating of events in the vicinity of a leap-second

The dating of events in the vicinity of a leap-second shall be effected in the manner indicated in the following Figures:

FIGURE 3

Positive leap-second

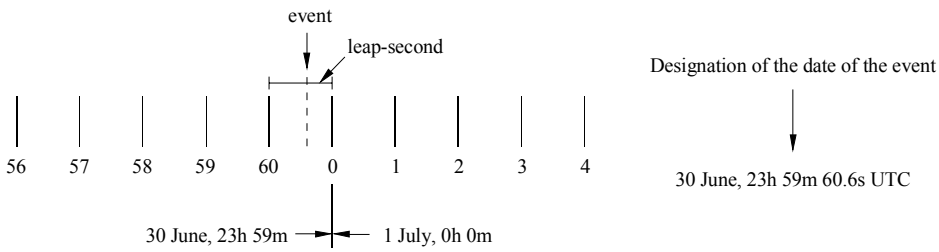
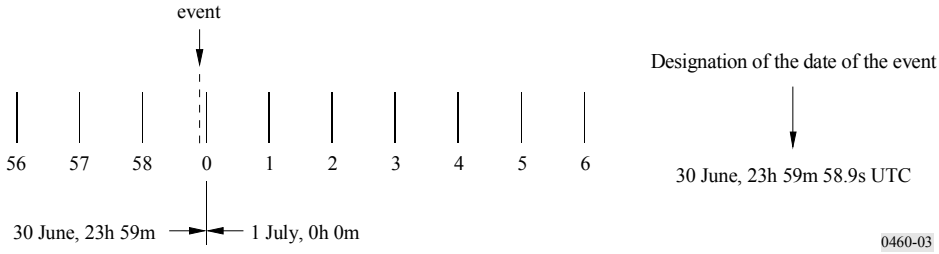


FIGURE 4

Negative leap-second



APPENDIX E

Operational Rules
(after 0000 UTC December 21, 2007

1. Tolerance

The difference of UT1 from UTC should not exceed ±1h.

2. Adjustments to UTC

2.1 Adjustments to the UTC time scale should be made as determined by the IERS to ensure that the time scale remains within the specified tolerances.

2.2 The IERS should announce the introduction of an adjustment to the UTC time scale as least five years in advance. At the time of the announcement the IERS should provide directions regarding the details of the implementation of the adjustment.

2.3 All operational rules and nomenclature prior to 0000 UTC December 21, 2007 given above no longer apply.

Note: Analysis of historical observations of the Earth's rotation currently indicates that such an adjustment would no be required for at least 500 years.

Mise en forme : Puces et numéros

Mise en forme : Puces et numéros