CGSIC Subcommittee on Time and CCDS Group of Experts on GPS Standardization

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BIOGRAPHIES

Dr W. Lewandowski is a physicist in the Time Section of the Bureau International des Poids et Mesures (BIPM) and participates in the establishment and diffusion of the TAI and the UTC international time scales. His research interest is in the use of space techniques for time transfer, especially in the use of GPS. Since 1988, he has participated in the work of the Civil GPS Service Interface Committee.

Dr C. Thomas is a principal physicist in the Bureau International des Poids et Mesures, where she became Head of the Time Section after Prof. Guinot's retirement on 1st October 1990. She is then responsible for the establishment and diffusion of the TAI and the UTC international time scales. Her research interest is the use of GPS for time transfer and also the elaboration of time scale algorithms.

D. W. Allan is a senior scientist in the Time and Frequency Division in the National Institute of Standards and Technology, and leader of the group who generates the NIST atomic time scales. In 1984 he received the I. I. Rabi award " for his contribution to the measurement and characterization of precision time and frequency sources". Mr Allan is a member of the Scientific Research Society of America, Sigma Xi, the International Radio Consultative Committee (CCIR), the International Radio Scientific Union (URSI) and the International Astronomical Union (IAU).

ABSTRACT

The use of Global Positioning System (GPS) for worldwide comparisons of atomic clocks has been significantly improved during the last few years. Initially the GPS time transfers were realized with an accuracy of several tens of nanoseconds. Recent studies have shown that time transfer between continents can be realized with an accuracy of a few nanoseconds. Further progress is expected but, for many aspects, this requires coordinated action between timing centers as well as standardization of the receivers and processing of data. The introduction of Selective Availability (SA) also calls for coordination and standardization. Two bodies are concerned with these matters: *CGSIC Subcommittee on Time* and *CCDS Group of Experts on GPS Standardization*. This paper

describes these bodies and reports on their respective roles.

INTRODUCTION

In recent years the GPS (see list of Acronyms at the end of the paper) worldwide time transfer by C/A code receivers in common-view mode [1] has seen significant progress in both precision and accuracy [2]. The accuracy of GPS time links within the continents is approaching 1 ns on an operational basis. Over long distances, between the continents, the accuracy of operational links is still between 10 and 20 ns. Some recent studies however have shown that when using an ultra accurate homogeneous reference frame for antenna coordinates, two frequency measurements rather than a model to account for ionospheric delay and post-processed precise ephemerides instead of broadcast ones, these links can be realized with an accuracy of a few ns [3]. But this is not the end for possibilities of GPS. The accuracy of GPS time transfer could reach the subnanosecond level, as ultra precise post-processed GPS ephemerides of uncertainties of 10 cm are likely to be available in the future.

But when approaching 1 ns accuracy other problems arise. These are mainly due to the lack of standardization in receiver software and some hardware problems. Receivers from different manufacturers may, for example, differ in their:

- model of troposphere,
- processing of raw data,
- start time of track,
- time scales used to monitor tracks,
- updating of constants used for the computation of ephemerides and antenna coordinates,
- locking of broadcast ephemerides during a 13-min track, and
- input frequency to the receiver.

A separate consideration is that some of these problems must also be resolved in order to remove the effects of SA degradation of GPS signals.

It appears that extensive international coordination and standardization is required if further progress is to be made in GPS time transfer and a shield is to be devised against the effects of SA. Two bodies now address these issues:

The *Subcommittee on Time of the Civil GPS Service Interface Committee (CGSIC)*, which is mainly a forum exchanging information between military and civilian elements and cannot undertake formal actions;

The *Group of Experts on GPS Standardization of the CCDS (Comité Consultatif pour la Définition de la Seconde) Working Group on TAI*, which can undertake formal actions by issuing recommendations on standards.

This paper describes these bodies and reports on their respective roles.

HISTORICAL BACKGROUND

CGSIC Subcommittee on Time

In 1986 the US Air Force (USAF) announces that it will not have the necessary resources to distribute information on GPS to civil users when the system is fully operational. For this reason the USAF concludes a contract with the Applied Research Laboratory, University of Texas, to study the problem of GPS data access to civil users. As a consequence of this study the creation of a Civil GPS Service is suggested. This Service will have the administrative responsibility to provide information to civil users through a GPS Information Center. In December 1986 a Steering Committee for the Civil GPS Service is created under the chairmanship of the Department of Defense. The membership comprises 10 military and 8 civilians. In May 1987 the Secretary of Defense asks the Department of Transportation to take responsibility for the Civil GPS Service. The membership is progressively enlarged. In July 1988 the BIPM and the NIST are invited to join the Steering Committee. At present about 100 people are involved in the work of the Committee. They represent the US Army, US civil governmental organizations, universities, private companies, international organizations, and foreign representatives. The chairmanship is assumed by the DoT and the US Coast Guard. In January 1991 the name of the Committee changes to the Civil GPS Service Interface Committee (CGSIC). The full Committee meets three times a year. The Committee has 5 subcommittees which deal with:

- timing;
- surveying and positioning;
- reference stations;
- international cooperation; and
- real time carrier phase.

Basically the Committee provides opportunities to exchange information between military and civilians and provides a forum to promote civil applications of GPS.

The subcommittee on time is chaired by D. W. Allan of the NIST and co-chaired by the BIPM. Its charter is shown in the Appendix.

CCDS Group of Experts on GPS Standardization

As a series of different receiver problems were progressively revealed, several attempts were made to resolve them separately. But this approach was only partially successful. It became clear to the international timing community that a global approach is required which would establish common GPS standards to be adopted by receiver designers and users. Different possible solutions were considered. Finally it has been decided that a group charged with establishment of the standards should operate within the structure of the Comité Consultatif pour la Définition de la Seconde (CCDS). The main reason for this was that the CCDS can make recommendations which are submitted to the approbation of the Comité International des Poids et Mesures (CIPM).

The *CCDS Group of Experts on GPS Standardization* is now being set up. It will operate under the auspices of the permanent CCDS Working Group on TAI. D. W. Allan of the NIST has been appointed chairman of this group. The BIPM is in charge of the secretariat. The nucleus of membership is as follows:

- experts from time laboratories,
- experts from GPS receiver makers,
- an expert in space geodesy,
- members of the Time Section of the BIPM.

It is intended that in the early fall of 1991 the Group will send out its first information letter containing a proposal for the new format of GPS time data. The first formal meeting of the Group will be held during the December 1991 PTTI meeting in Pasadena, California.

GPS TIME-TRANSFER PROBLEMS

In this section we give several examples of problems encountered during GPS time transfer. We report briefly on progress already accomplished, and underline residual difficulties which may be resolved through the work of the *CGSIC Subcommittee on Time* and the *CCDS Group of Experts on GPS Standardization*. The list below exemplifies the problems but does not attempt to be exhaustive.

Homogenization of antenna coordinates

Errors of antenna coordinates were one of the largest terms in the global error budgets of GPS time links [2]. These errors were first reduced for continental links (see Fig. 1) [4,5]. Then in 1990 a global homogenization of coordinates was realized in one of the most accurate reference frames, the ITRF (IERS Terrestrial Reference Frame). Some of the time laboratories already have coordinates expressed in ITRF with uncertainties as low as 10 cm.

The *CGSIC Subcommittee on Time* was a forum which helped to organize geodetic links between time laboratories and the nearest ITRF sites. For example, the geodetic link between USNO and the Maryland VLBI Point was realized by NGS.

The *CCDS Group of Experts on GPS Standardization* will consider general problems relating to the choice of global reference frames. They may also deal with problems relating to the introduction of the coordinates into receivers. At present most receivers require the introduction of coordinates in geographical form (latitude, longitude, and height). This can be a source of error if constants and reference ellipsoids are not standardized. Introduction of coordinates in cartesian form (x,y,z) is likely to be recommended.

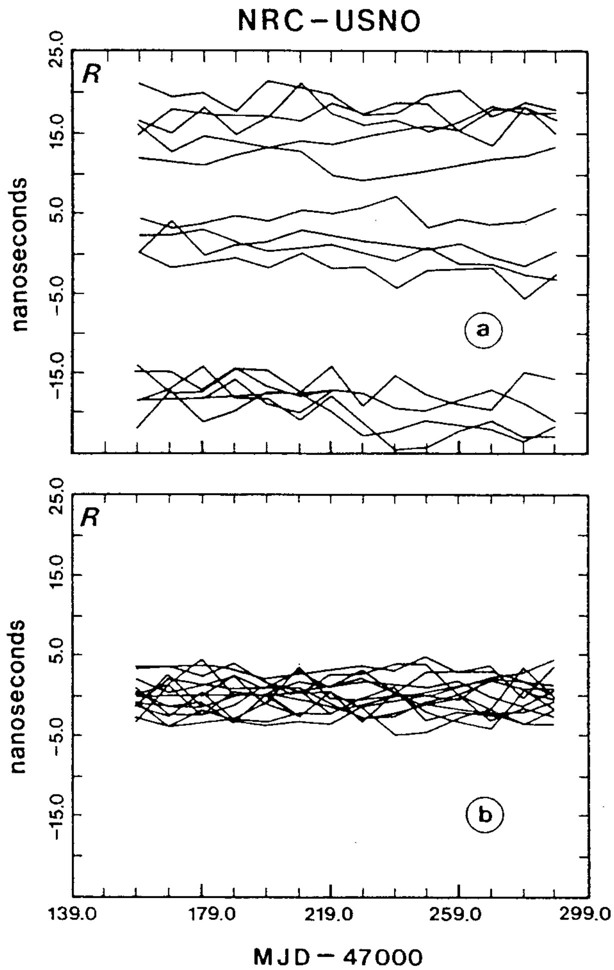

Figure 1 - *Residuals (R) with respect to the mean of UTC(NRC)-UTC(USNO), as given by individual tracks.*

(a)- before coordinate corrections,
(b)- with differential coordinate corrections derived by BIPM from time comparisons (dx = 9.47m, dy = -2.96m, dz = 4.05m)

Use of precise ephemerides.

Several studies have shown improvements in time transfer brought about by the use of precise ephemerides (see Fig. 2) [3,6,7]. The uncertainty of broadcast ephemerides ranges from about 7 m to 30 m, and those of the DMA post-processed precise ephemerides range from 2 m to 3 m. The JPL has announced that in the near future post-processed, ultra precise ephemerides of the uncertainty of about 10 cm may be expected. The use of post-processed precise ephemerides also appears to be the most efficient way to overcome the degradation of broadcast ephemerides by SA [8].

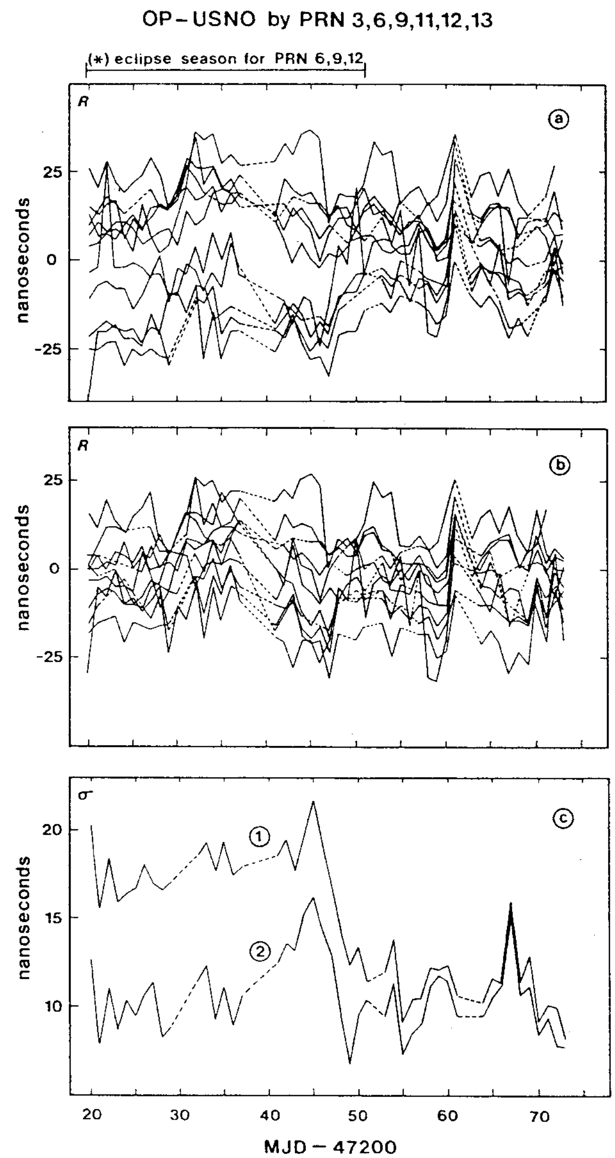

Figure 2 - *Residuals (R) with respect to the mean of UTC(OP)-UTC(USNO) as given by individual tracks (March-April 1988).*

(a)- with broadcast ephemerides,
(b)- with precise ephemerides,
(c) 1- standard deviations of residuals of (a),
2- standard deviations of residuals of (b).

The *CGSIC Subcommittee on Time* provides the most recent updates of information on progress in the computation of precise ephemerides and on the availability of these ephemerides.

A particular problem the *CCDS Group of Experts on GPS Standardization* will have to consider is the locking of broadcast ephemerides during each 13 min tracking session. This is necessary for the use of precise ephemerides [6]. The choice of the reference frame for ephemerides, and updating of the constants in the receiver software is a matter for consideration.

Receiver hardware

A recent study [9] has shown one particular GPS time receiver type being sensitive to external temperature. This sensitivity has been shown to depend on the length of antenna cables. With a 100 m antenna cable the peak to peak deviations reached 20 ns.

The *CGSIC Subcommittee on Time*, using its large forum of scientists and manufacturers, could help in spreading information of this sort and so promote improvements.

The *CCDS Group of Experts on GPS Standardization* will also deal with hardware standards such as the frequency transported through antenna cables, the length of antenna cables, internal receiver delays ...

Selective Availability

According to the information currently available to civil users through the meetings of CGSIC, the degradation brought about by Selective Availability consists of

- a phase jitter of the satellite clock, the effect of which can be completely removed by a strict common-view,
- a changeable bias in the broadcast ephemerides.

Several tests and applications of SA were carefully studied by the timing community. The 1990 implementation of SA (March 25 - August 10, 1990) consisted only of clock jitter (see Fig. 3) [10]. Figure 4 illustrates how the effect of SA clock degradation can be removed by a strict common-view measurement. The most recent implementation of SA at the beginning of July 1991 also included the degradation of broadcast ephemerides.

The role of the *CGSIC Subcommittee on Time* is to provide the international timing community with the most recent information on SA and to promote the needs of this community during general meetings of the CGSIC.

The *CCDS Group of Experts on GPS Standardization* may be expected to promote the realization of strict common-views (synchronization within 1 s). This implies adopting a common time scale for monitoring tracks. Some receivers use UTC for this purpose, some use GPS time and some use both time scales. Another important improvement is the adoption of common procedures for sampling and smoothing raw data. The international tracking schedule for common-view time transfer issued by the BIPM is likely to be recommended by the committee as well as use of post-processed precise ephemerides to overcome the effects of SA.

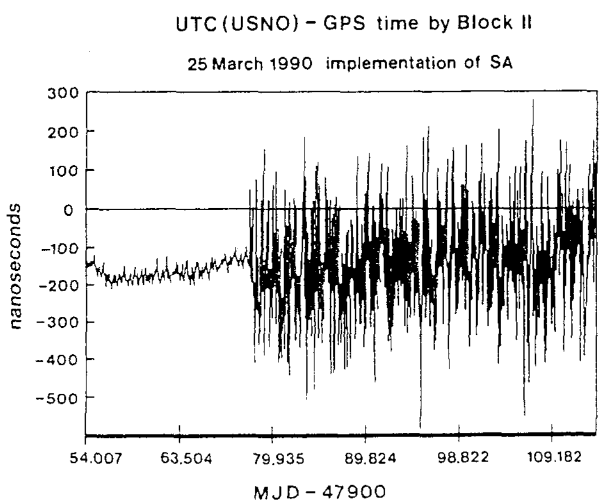

Figure 3 - *Implementation of SA on Block II satellites on the 25th of March 1990.*

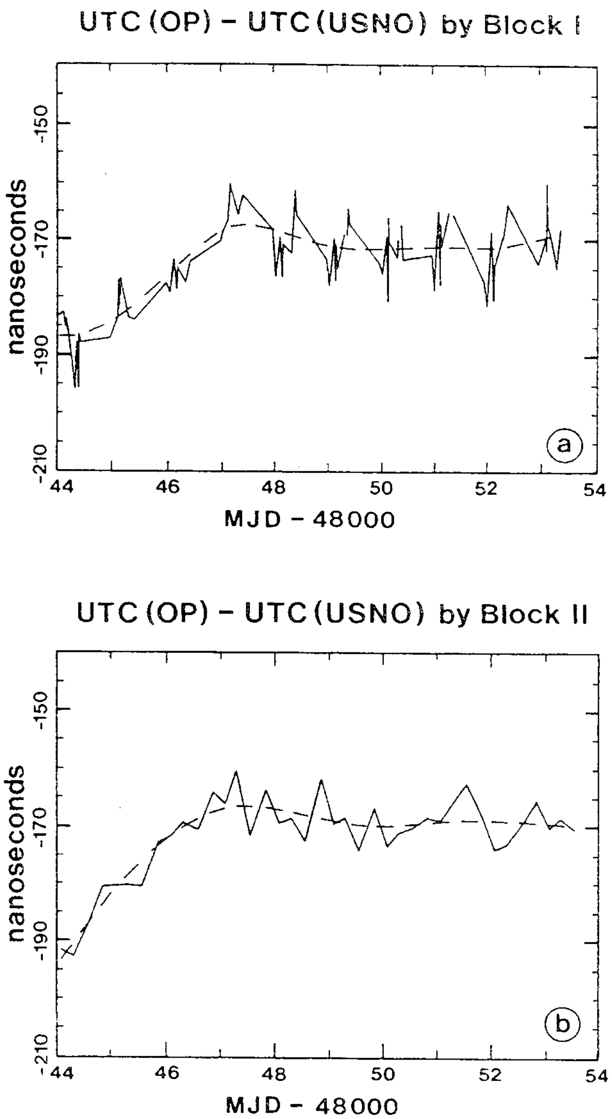

Figure 4 - *Values of UTC(OP)-UTC(USNO) as obtained in common view mode by satellites of (a) Block I (SA off) and (b) Block II (SA on).*

CONCLUSION

Accuracy of a few nanoseconds in worldwide GPS time transfer is now possible. Further improvements are feasible through international coordination and standardization of receivers and data processing. Joint action is required to overcome the SA degradation of GPS signals.

To achieve these goals, the committees described in this paper are both indispensable and complementary. The *CGSIC Subcommittee on Time*, although not having the ability to take formal action, provides valuable information and promotes the needs of the timing community. The *CCDS Group of Experts on GPS Standardization* establishes standards and takes formal measures to implement them.

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LIST OF ACRONYMS AND ABBREVIATIONS

BIPM	Bureau International des Poids et Mesures.
C/A	Coarse/Acquisition Code.
CCDS	Comité Consultatif pour la Définition de la Seconde.
CIPM	Comité International des Poids et Mesures.
CGPM	Conférence Générale des Poids et Mesures.
CGSIC	Civil GPS Service Interface Committee.
DoD	Department of Defense.
DoT	Department of Transportation.
DMA	Defense Mapping Agency.
GPS	Global Positioning System.
GPSIC	GPS Information Center.
IERS	International Earth Rotation Service.
ITRF	IERS Terrestrial Reference Frame.
JPL	Jet Propulsion Laboratory.
MJD	Modified Julian Date.
NGS	National Geodetic Survey.
NRC	National Research Council.
NIST	National Institute of Standards and Technology.
OP	Observatoire de Paris.
SA	Selective Availability of GPS.
TAI	International Atomic Time.
USAF	US Air Force.
USNO	US Naval Observatory.
UTC	Coordinated Universal Time.

Appendix

CHARTER OF THE SUBCOMMITTEE ON TIME OF THE CIVIL GPS SERVICE INTERFACE COMMITTEE

Objectives

1. To determine the requirements and needs of the civilian timing community for GPS information.

2. To determine the sources of GPS timing information.

3. To determine the methods by which GPS timing data will be disseminated.

Terms of Reference

1. The types of civil users to be represented by this subcommittee are those involved in national and international timing centers, use time for the synchronization and syntonization of systems, and require time for distinguishing events recorded by data acquisition systems.

2. The GPS timing information to be released and distributed by the GPSIC will follow the policies as set forth in the GPS Security Classification Guidelines.

3. The methods to be used for distributing GPS timing data can include all forms of communication, varying from conventional mail/telephone services to computer-to-computer links. For sophisticated data communication techniques, individual standards and protocols are to be indentified for compatibility with US systems.

Coordination and Reporting

1. The work of this subcommittee will be coordinated with that of the other subcommittees.

2. The work of this subcommittee will be reported to the CGSIC at its regular meetings.