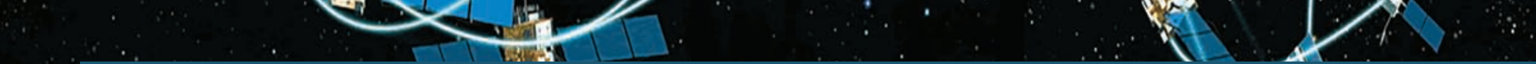


Reliable Time from GNSS Signals

ANDREAS BAUCH
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT, BRAUNSCHWEIG, GERMANY

PETER WHIBBERLEY
NATIONAL PHYSICAL LABORATORY, TEDDINGTON, UK

Precise time is crucial to a great variety of economic activities around the world. Communication systems, electric power grids, and financial networks all rely on precision timing for synchronization and operational efficiency. Here, the authors will show how the time obtained from GNSS satellite signals is related to the international time scale, UTC, and explain how GNSS receivers can be used to ensure that they are operating correctly, as reliable and traceable sources of time.

Precise timing is essential for the functioning of any global navigation satellite system (GNSS). GNSS themselves are part of national critical infrastructures in key sectors of the economy such as electricity distribution, telecommunications, and all modes of transport, which require accurate and reliable time to operate effectively. In all of these sectors, the time information required can be obtained from GNSS signals, underpinned by the international infrastructure for time and frequency metrology. In this article, we will describe this global metrology system for timekeeping, explain how it underpins the time information provided by GNSS, and introduce the important concept of traceability in measurement.

According to the U.S. Government's official GPS website: <URL: http://www.gps.gov/applications/timing/, access 2016-11-03> *"In addition to longitude, latitude, and altitude, the Global Positioning System (GPS) provides a critical fourth dimension – time. Each GPS satellite contains multiple atomic clocks that contribute very precise time data to the GPS signals. GPS receivers decode these signals, effectively synchronizing each receiver to the atomic clocks. This enables users to determine the time to within 100 billionths of a second (100 nanoseconds), without the cost of owning and operating atomic clocks."* The term "time" is used with at least two connotations: *time interval* and *time of day*. In many countries, laws or decrees prescribe the use of certain units such as the *second* of the International System of units (or SI) for time interval and its inverse, the *hertz*, for frequency.

In official use, a link to the national time standards maintained in National Metrology Institutes (NMIs) – such as the National Physical Laboratory (NPL) in the United Kingdom and Physikalisch-Technische Bundesanstalt (PTB) in Germany – is essential if measurements are being made with any claim to accuracy. Many countries have a "time law" that prescribes adherence to a certain time scale as the legal time, and often the NMI, or sometimes another institute, is entrusted explicitly with its dissemination. In practice, the common global time scale, Coordinated Universal Time (UTC), provides the underlying reference in all countries, with the appropriate time zone and summer time offsets applied.

From a purely technical point of view, GNSS signals are capable of providing the required time information. All GNSS system time scales are based on the international reference time scale, Coordinated Universal Time (UTC). There are two types of offsets between these system time scales and UTC. Integer second offsets exist because leap seconds have been introduced in UTC, but not in GPS time, Galileo System Time (GST), or BeiDou time. In addition, at the nanosecond level, "small" offsets exist. But when it comes to court, questions may be asked such as "Who told the satellite clock what time-of-day it is?" Or "Are the time-of-day *and* the time unit provided by GNSS traceable to UTC?" Traceability is a key concept in metrology, and requires an *unbroken chain of comparisons or calibrations between a measurement result and a reference standard, with measurement uncertainty assigned to each step.* The words in italics are close to the definition of the term in the International Vocabulary of Metrology (known by its French abbreviation, VIM), and apply just as much to a measurement of time based on received GNSS satellite signals as to any other measurement procedure.

In the next section, we will explain in brief the operation of the international metrology system and the realization of UTC to which the national realizations and thus legal times adhere. A section on dissemination of GNSS times follows, including some detail about the "time"-related quantities included. Finally, we discuss options for the validation of GNSS time signals so that their use can be compliant with legal prescrip-

tions and brief y touch upon the issue of liability.

The BIPM and Time Scales

The International Bureau of Weights and Measures (BIPM) is the intergovernmental organization which organizes and supports the joint work of Member State signatories of the Metre Convention on matters related to metrology and measurement standards. The BIPM, which is located in Paris, France, is overseen by the International Committee for Weights and Measures (CIPM), made up of 18 elected representatives from the NMIs. The CIPM also has a number of Consultative Committees that provide more detailed guidance and coordination of specific areas of metrology, including the Consultative Committee for Time and Frequency (CCTF). Overall supervision and strategy formulation is provided by the General Conference on Weights and Measures (CGPM), formed by delegates from the 58 Member States who meet every four years.

The BIPM has the particular task to generate and disseminate the international reference time scale UTC, which is carried out by its Time Department. UTC is a post-processed time scale; it is the result of worldwide cooperation of 78 institutes (as of March 2017), mainly NMIs, but also including some astronomical observatories and research centers that operate high-quality atomic

Tabulating Time-Related Data from Galileo and GPS Navigation Messages

Here, we describe the time-related data from the navigation messages of Galileo and GPS, which are almost identical in format and content.

Space Clock Offset from System Time

The correction between the individual space vehicle clock and GNSS system time at a given time is calculated from the transmitted parameters, here shown for Galileo in Table 1 (European GNSS [Galileo] Open Service Signal In Space Interface Control Document, OD SIS ICD, European Union (2010), listed in Additional Resources [IB1]). The corresponding definition for GPS is given in §20.3.3.3.1.8 and the associated Table 20-1 in Global Positioning Systems Directorate Systems Engineering & Integration, Interface Specification IS-GPS-200H, listed in Additional Resources [IB2].

Week Numbering and Time of Week

GPS week number zero (0) started at midnight UTC(USNO) Jan. 5, 1980 /morning of Jan. 6, 1980, according to 6.2.4 adapted from specifications described in [IB2]. The Galileo week zero corresponds to GPS week 1024, which af er week roll-over was reported as week zero. The GST start epoch was 00:00 UTC Sunday, Aug. 22, 1999. At that epoch, GST was ahead of UTC by 13 seconds. As 12 bits are reserved for the week number, roll over occurs only af er about 78 years. Table 2 lists the parameters, as reported in Table 63 of [IB1].

Offset Between System Time and UTC

Both GPS and Galileo provide parameters to estimate time in UTC from the system time for a given epoch. The parameters comprise the integer seconds offset due to the leap seconds in UTC, and offset and rate coefficients for the accurate prediction of the difference (at ns-level). They are listed in Table 3, based on §20.3.3.5.2.4 of [IB2] and Table 69 of [IB1]. As previously stated, offset from UTC means from UTC(USNO) in the case of GPS and from a prediction of UTC, based on UTCE, in the case of Galileo. We can see from Figure 1 that – at least for the period covered – the differences are marginal, but not zero and not identical. Tables 2 and 3 represent the means of accurately determining "time-of-day" in UTC via GNSS signals.

Offset Between System Times

In support of interoperability, GPS and Galileo report the predicted time offset between the two system times, termed GGTO, in the navigation message. This is covered by §5.1.8 of [IB1] and §30.3.3.8 in [IB2], respectively. In the sign convention of [IB2] the quantity GGTO is equal to Galileo System Time (GST) minus GPS time. GNSS receivers that generate data files according to the Receiver Independent Exchange Format RINEX version 3.01 and higher report these quantities. As an example, see the header of a navigation file (Figure 3 in the main text) retrieved from a GNSS timing receiver, operated at PTB. The file was generated on day 310 of year 2016, day 6 of GPS week 1921 *(WN)*, which starts with second 518400 *(TOW)*. Quantities of interest here are shown in the red lines. GPGA represents GGTO as just defined, although the wording on the sign can be a bit ambiguous.

Parameter	Designation	Bits	Units
t_{0C}	Clock correction data reference, Time of Week	14	Multiples of 60 s
a_{f0}	SV clock bias correction coef cient	31	Multiples of 2^{-34} s
a_{f1}	SV clock drift correction coef cient	21	Multiples of 2^{-46} s/s
a_{f2}	SV clock drift rate correction coef cient	6	Multiples of 2^{-59} s/s^2

Table 1. Galileo SV clock correction parameters, adapted from [IB1].

Parameter	Designation	Bits	Unit
WN	Week Number	12	weeks
TOW	Time of Week	20	seconds

Table 2. GST parameters, adapted from [IB1].

Parameter	Designation	Bits	Unit
A_0	Constant term of polynomial	32	2^{-30} s
A_1	First order term of polynomial	24	2^{-50} s
Δt_{LS}	Leap second count before leap second adjustment	8	s
t_{ot}	UTC data reference time of week	8	3600 s
WN_{ot}	UTC data reference week number	8	Week
WN_{LSF}	Week number of leap second adjustment	8	Week
DN	Day number at the end of which a leap second is introduced	3	Day
ΔtLSF	Leap second count after leap second adjustment	8	S

Table 3. Parameters of the GST to UTC conversion, adapted from [IB1].

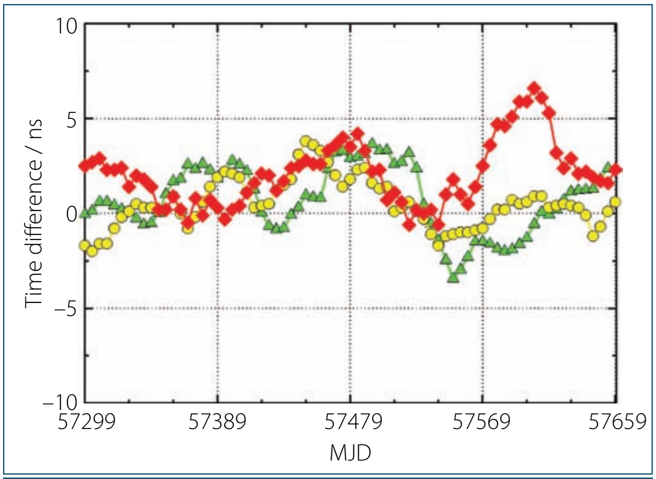


FIGURE 1 Reference time scales for GPS (yellow), GLONASS (red) and Galileo (green) in comparison with UTC during one year, ending at Modified Julian Day (MJD) 57659, September, 28 2016.

FIGURE 2 Regional Metrology Organizations Worldwide, © BIPM

clocks and time transfer equipment, which we will collectively refer to as timing centers. Clock and time transfer data are regularly reported to the BIPM, which calculates UTC early in each calendar month from data covering the previous month. The results of the processing are published in the *BIPM Circular T*. UTC is thus a "paper" time scale and is physically represented (only) by the realizations of UTC, known as UTC*(k)* time scales, maintained by the 78 timing centers. UTC provides the reference for all precise time and frequency measurements and transmissions worldwide, including the GNSS system time scales, as will be explained below.

Each monthly Circular T reports the time differences UTC – UTC*(k)* at 5-day intervals, with specified uncertainties. As an example, illustrating the accuracy achieved today and the significance for GNSS, the differences from UTC over one year of three time scales that serve as references for GNSS system times are depicted in **Figure 1**. UTC(USNO) is realized at the United States Naval Observatory, Washington D.C., and serves as the time reference for GPS. UTC(SU) is realized at the Russian Institute VNIIFTRI, Mendeleevo, Moscow Region, and serves as the time reference for GLONASS. UTCE is the average of five UTC*(k)* time scales realized at European timing institutes, and serves as the time reference for Galileo.

It is important to note that many, though not all, of the institutes maintaining UTC*(k)* time scales are NMIs that are signatories of the Mutual Recognition Arrangement (MRA) established by the CIPM. The MRA provides a framework for NMIs to demonstrate the equivalence of their measurement standards and services. Thus, traceability to UTC can in theory be obtained equivalently from any of the NMIs that are signatories of the CIPM MRA. However, there is a stumbling block: USNO is not an NMI and thus did not sign the MRA, so it is not able to demonstrate formal traceability to UTC through its UTC(USNO) time scale based on its internal measurement capabilities. The other institutes involved are NMIs and are covered by the MRA. Further measures are therefore needed to obtain traceability to UTC in the strict sense by receiving GPS signals.

Metrology worldwide is coordinated through the regional metrology organizations (RMOs), with memberships based on the NMIs of the countries represented. There are currently six RMOs, as shown in **Figure 2**. The European Association of National Metrology Institutes, known as EURAMET, is the RMO that covers Europe. It coordinates the cooperative activities of NMIs in Europe in fields such as metrology research, traceability of measurements to the SI units, international recognition of national measurement standards, and certification of the Calibration and Measurement Capabilities (CMCs) of its members. The work of EURAMET is organized in 12 Technical Committees (TC), of which one deals with Time and Frequency (TC-TF). The EURAMET website lists the institutes participating in TC-TF, which are the institutes responsible for time and frequency in each country, and the current contact persons <URL: http://www.euramet.org/technical-committees/tc-tf/>.

A study of the legal time regulations and practices across Europe was published by the EURAMET TC-TF in 2011, and is available for download from the EURAMET website <URL: https://www.euramet.org/publications-media-centre/documents/>. It revealed wide variations in the procedures adopted by different countries. For example, just over half of the 34 countries participating in the survey have their legal time defined in legislation, but in varying levels of detail. In 11 of those countries the NMI is responsible for realizing legal time, but dissemination of legal time is an NMI responsibility in 20 countries. In all countries, however, UTC is in practice the underlying reference time scale, with the appropriate time zone and daylight saving time offsets applied.

GNSS Time Scales and How they are Disseminated

The primary purpose of any GNSS is to serve as a positioning and navigation system. But each system relies on accurate timing, and pseudorange measurements made by a receiver are combined with the data reported in the GNSS navigation message to provide among other parameters, time to users that require it. Details of signal properties and the on-board configurations of the satellites in the existing GNSS are well documented and explained further in textbooks on GNSS, including in the handbook published by the International Telecommunication Union (2010) listed in Additional Resources near the end of this article. The navigation messages include the almanac, orbit parameters, and parameters that relate the individual satellite clock time to the underlying GNSS system time. Details of the data format are given in the sidebar "Tabulating Time-Related Data from Galileo and GPS Navigation Messages." As explained in the context of Figure 1, the system times are steered towards realizations of UTC, except for the integer second offsets that result from different choices of origin and system time scales (other than that of GLONASS) not applying leap second adjustments.

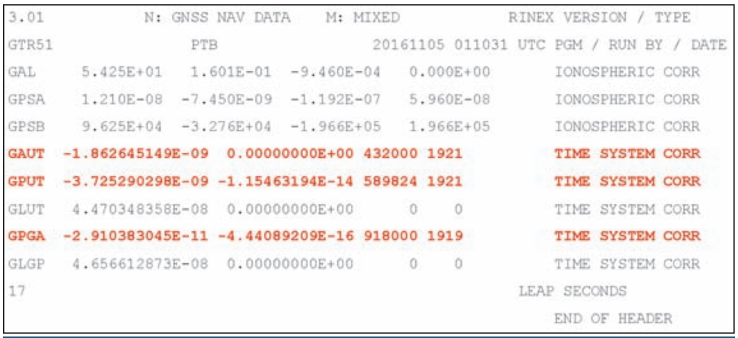
Using GNSS Signals as a Source of UTC

Two distinct types of GNSS timing receiver have been developed. The more sophisticated "scientific" receivers, sometimes called time transfer receivers, determine the pseudorange of each satellite in view with respect to signals from a local reference clock connected to the receiver, and use the information contained in the navigation message to provide output data in the form of local reference clock minus GNSS time. Recommendations on a common data file format and a standard formula and parameters for data evaluation were developed jointly by the BIPM and the CCTF. For wider use, in particular for positioning and navigation, the "Receiver Independent Exchange" format, RINEX, was developed as part of the work of the International GNSS Service (IGS).

For this article, the more relevant receivers are those designed to discipline the frequency of their inbuilt quartz oscillator (or rubidium atomic frequency standard) to GNSS time and to deliver standard frequency (typically 10 megahertz) and a one-pulse-per-second (1 PPS) output signals representing the GNSS time. A GPS-only device like this is often called a GPS-disciplined oscillator (GPSDO), and is widely used in calibration laboratories, industry, and wherever accurate frequency is required.

Another class of instruments outputs the time-of-day information, converted from the navigation message, either in a clock display, in standard electrical time codes such as IRIG, or by acting as a Network Time Protocol (NTP) server for time dissemination in networks. We will consider the use of these devices in the next section.

The EURAMET TC-TF has prepared a technical guide for calibration laboratories that use GPSDOs as their source of frequency or time traceability to UTC, which was published in 2016, and is available for download (see Additional Resources). The guide discusses in detail the requirements that a calibration laboratory should meet in order to claim formal traceability to UTC when using a GPSDO. The considerable variations in regulations across Europe created some complications, but there was agreement on a range of core requirements. In particular, calibration of the GPSDO is recommended if low uncertainties



```
3.01           N: GNSS NAV DATA    M: MIXED            RINEX VERSION / TYPE
GTR51                  PTB                20161105 011031 UTC PGM / RUN BY / DATE
GAL      5.425E+01   1.601E-01  -9.460E-04   0.000E+00       IONOSPHERIC CORR
GPSA     1.210E-08  -7.450E-09  -1.192E-07   5.960E-08       IONOSPHERIC CORR
GPSB     9.625E+04  -3.276E+04  -1.966E+05   1.966E+05       IONOSPHERIC CORR
GAUT  -1.862645149E-09  0.00000000E+00 432000 1921          TIME SYSTEM CORR
GPUT  -3.725290298E-09 -1.15463194E-14 589824 1921          TIME SYSTEM CORR
GLUT   4.470348358E-08  0.00000000E+00      0    0          TIME SYSTEM CORR
GPGA  -2.910383045E-11 -4.44089209E-16 918000 1919          TIME SYSTEM CORR
GLGP   4.656612873E-08  0.00000000E+00      0    0          TIME SYSTEM CORR
17                                                     LEAP SECONDS
                                                            END OF HEADER
```

FIGURE 3 B1 RINEX 3.01 navigation file header from day 310 of year 2016 from a GNSS receiver operated at PTB

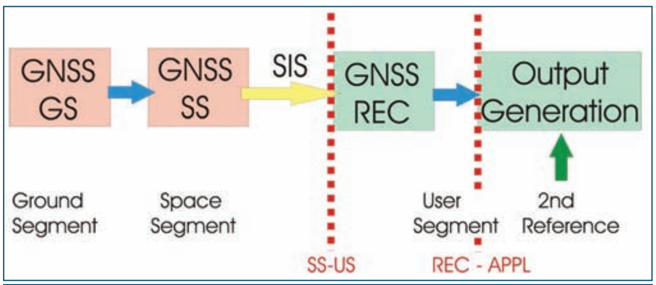


FIGURE 4 Flow of information and signals between a GNSS Ground Segment (GS) and Space Segment (SS), through the Signals in Space (SIS) to the Receiver (REC) and the final output of the application (APPL).

are claimed (better than 1 microsecond for time, or 1 part in 10^{11} for frequency), and a method is needed to verify correct operation when the GPSDO is in use, for example by monitoring its internal control parameters or by comparing it with a second, independent, standard.

Validation of GNSS-Based Timing

Figure 4 sketches the steps from GNSS signal generation in the GNSS Ground Segment (GS), through the Space Segment (SS), to the user application. Inside the perimeter of GNSS operations, there are certainly numerous cross-checks to verify the properties of the GNSS system time and the parameters of the navigation message. Each of the GNSS operators has established a public web portal with information about anomalies, signal outages etc. In the case of Galileo, the European GNSS Service Centre <https://www.gsc-europa.eu/> provides "Notice Advisories to Galileo Users" (NAGUs). But these do not represent a satellite-by-satellite publicly available verification of signal content, or a means to establish traceability of measurements based on GNSS signals to national or international standards.

The situation at the boundary line between the space and user segments (SS-US in Figure 4) has become a hot topic: how to protect against spoofing, and how to verify or authenticate the signals arriving at the receiver? The subject was recently treated in depth in *Inside GNSS* in an article by Gianluca Caparra *et alia* (2016) listed in Additional Resources.

In some GNSS markets, including civil aviation and the maritime sector, certification has become common practice or even mandatory. The certification covers the receiver performance, assuming well-defined properties of the received signal at the SS-US border (such as carrier-to-noise density ratio, level of multipath, and interfering signals in neighboring frequency bands). This topic was addressed in *Inside GNSS* in an article by Jules McNeff (2012) listed in Additional Resources. One kind of certification employs a certified signal simulator as a source of signals to be fed directly to the receiver. This, of course, covers only part of the problem. A full certification test would have to take into account the antenna, including its environmental conditions and the antenna cable.

In the timing community, such formal procedures are rare. The 78 laboratories worldwide operate around 200 GNSS timing receivers from at least five different, commercially independent manufacturers. There is therefore some variety of both hardware (front-end, signal processing etc.) and the proprietary software to provide data outputs, enabling confidence in their performance to be built up through cross-comparisons. This network of receivers can be considered as a verification mechanism for the timing properties of GNSS signals. The GNSS monitoring bulletins published free of charge by several NMIs, including NPL and PTB, provide a readily available means of confirming that the broadcast GNSS timing signals were correct. The bulletins support the demonstration of traceability between measurements made using the space signals, for example when using a GPSDO, and the UTC*(k)* time scale of the issuing NMI.

To be more specific, we can consider the situation in PTB. Up to eight GNSS receivers from four different manufacturers have been operated during recent years, and their observations are compared daily. Standard daily observation files in the formats described in the paper by Pascale Defraigne and Gérard Petit, (2015) and listed in Additional Resources, and – as far as possible — in RINEX format are publicly available for the previous day at <ftp://ftp.ptb.de/pub/time/GNSS/> in various folders. These files provide a direct reference to UTC(PTB) for the experienced user. For the public, a weekly Time Service Bulletin (TSB) is published at ftp://ftp.ptb.de/pub/time/bulletin/. Users in Germany who seek to obtain traceability to German legal time from GNSS signals are advised to take note of the contents of the TSB, or are guided to perform data analysis by following standard procedures to obtain evidence of the performance of their local equipment. Near-real-time services that also verify the full data content of the navigation message (see again the sidebar on page 39) are not yet available, but such services are possible to set up using the real-time services provided by the IGS.

Dissemination of GNSS Time Across Networks

Time distribution in Local Area Networks using the Network Time Protocol (NTP) or the Precision Time Protocol (PTP) has become well established, and a wide variety of equipment is on the market to serve the needs. For security reasons, the servers used are often not connected to the internet. Instead of obtaining time via NTP from public servers, the time-of-day information included in the GNSS SIS is translated into the NTP or PTP messages. The line labelled REC-APPL in Figure 4 indicates that the transmission of time information from a receiver into an application is another process whose correctness needs to be assessed carefully to verify traceability. One option, implemented in some equipment, is to cross-check the time-of-day information from the GNSS signals against the time signals received through a second reference, which would typically be a dedicated standard frequency and time broadcast service, such as DCF77 in Germany and MSF in the U.K.

Within Europe, new regulations draf ed by the financial services regulator, the European Securities and Markets Authority (ESMA), specify that beginning January 3, 2018, all automated trades are timestamped to UTC with an uncertainty no greater than 100 microseconds. Af er consultation, ESMA has concluded that GPS and other GNSS services can be used as the time source provided that measures are put in place to demonstrate traceability and that the receiver is working correctly. Exchanges and trading venues must therefore modify or upgrade their timing infrastructure to provide evidence of UTC traceability at all times when trading is taking place, even if they are already distributing time through their networks from a GNSS source.

With such regulations in place in finance, and similar timing requirements appearing in other areas such as smart-grids and the efficient use of renewable energy, the question of the liability of GNSS operators in the event of users incurring significant costs as a result of errors in the signals received at the SS-US interface (see **Figure 3**) has become quite topical. Although we are not qualified to answer legal questions, our understanding is that the so-called Interface Control Documents (ICDs), cited in the sidebar for the cases of GPS and Galileo, are the primary references in any controversy. If the signals generated in the Space Segment comply with the specifications in the ICDs, the operator of the GNSS has done its job well.

Many readers will remember the "GPS Ground System Anomaly" reported by the U.S. Air Force on Jan 27, 2016. In its official press release it stated: "On 26 January at 12:49 a.m. MST, the 2nd Space Operations Squadron at the 50th Space Wing, Schriever Air Force Base, Colo., verified users were experiencing GPS timing issues. Further investigation revealed an issue in the Global Positioning System ground sof ware which only affected the time on legacy L-band signals. This change occurred when the oldest vehicle, SVN 23, was removed from the constellation. While the core navigation systems were working normally, the coordinated universal time timing signal was off by 13 microseconds which exceeded the design specifications." The publicly available information, derived from the detailed analysis of the event provided from the proceedings of ION GNSS+ 2016 and listed in Additional Resources, indicates that the parameters A0 and WN_{OT} (see Table 3) were transmitted incorrectly by an increasing number of satellites for several hours. However, the ICD states that such data should be regarded as *invalid* if WN_{OT} is so different from the current epoch (here more than two years).

If any user application was affected by this anomaly – it affected only timing users, not positioning services – the software routines evaluating the SIS messages were not sufficiently following the underlying ICD. It therefore appears unlikely that the GNSS operator could be held liable for any losses incurred in this or similar cases, although it will not be possible to make any definitive statements until a claim has been tested in a court of law.

A Look Ahead at Liability

To conclude this section, we try to analyze the aspect of liability from our (non-expert) point of view. Should a future event cause real loss or damage to users of GNSS time applications, the legal treatment of claims would be faced with enormous complexities. While the stakeholders involved would likely undertake all necessary investigations for identifying the root cause of the event, affected users would also have to provide proof of underlying fault. As users will lack the necessary insights into the complex chain underlying GNSS time applications, provision of such proof may be very difficult. The detailed legal background was reported in an earlier contribution in this "GNSS & the Law" column (see Additional Resources). According to this analysis, no contractual liability could be evoked if the root cause lies in the performance of one of the GNSS systems. Non-contractual liability is limited due to the doctrine of sovereign immunity and applicable national laws on state liability. Both the U.S. and Russian governments traditionally deny any legal responsibility for the performance of GPS or GLONASS system and signal performance, and China also has not made any commitments in this respect.

Regarding Galileo, the European Union (EU) as the owner of the system and the European GNSS Agency (GSA) as the user services provider, theoretically bear non-contractual liability under Article 340 of the Treaty on the Functioning of the European Union (TFEU). However, compensation is to be made "in accordance with the general principles common to the laws of the Member States", which leaves a significant level of uncertainty. Furthermore, the European Commission has recently published so-called Service Definition Documents for the Open Service and Search and Rescue initial services. Both documents contain terms and conditions for the use of these services, including a rather far-reaching disclaimer of liability. The EU and the other entities involved do not offer any warranty regarding service availability, continuity, accuracy, integrity, reliability and fitness for purpose. They shall not be held liable for any damages resulting from the use of the service, other than in accordance with Article 340 TFEU. Even for Galileo, affected users will be faced with significant legal and factual barriers to receiving compensation.

On the international level, there are no specific legal instruments governing liability for GNSS signals and services.

For more than 15 years, the matter has been discussed within the International Maritime Organisation (IMO), the International Civil Aviation Organization (ICAO) and the International Institute for the Unification of Private Law (UNIDROIT). However, all these efforts have not resulted in any common position or the development of any proposal for a legal instrument. Overall, users will therefore have enormous difficulties in receiving compensation for their loss or damage arising from malfunctioning of GNSS time services.

Conclusion

Precise time is crucial to a great variety of economic activities around the world. Communication systems, electric power grids, and financial networks all rely on accurate and reliable timing for synchronization and operational efficiency. The free availability of GPS time has enabled cost savings for companies that depend on precise time and has led to significant advances in capability.

Companies worldwide use GPS to time-stamp business transactions, providing a consistent and accurate way to maintain records and ensure their traceability. Major financial institutions use GPS to obtain precise time for setting the internal clocks used to timestamp financial transactions. Large and small businesses are turning to automated systems that can track, update, and manage multiple transactions made by a global network of customers, and these require the accurate timing information available through GPS and from other GNSS in the near future.

We have shown in this article how the time obtained from GNSS satellite signals is related to the international time scale, UTC, and explained how GNSS receivers can be used, with some care to ensure that they are operating correctly, as reliable and traceable sources of time.

Manufacturers

The GNSS timing receiver described in this article and operated at PTB was a MESIT model GTR51 from **MESIT defence, s.r.o.,** Uherské Hradiště, Czech Republic.

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Authors

Andreas Bauch has a diploma in physics. He joined Phyikalisch-Technische Bundesanstalt, Braunschweig, Germany (PTB) as a PhD student, being initially engaged in studies on frequency shifting ef ects in caesium atomic clocks. He got his PhD (Dr. rer. nat.) from Johannes-Gutenberg University, Mainz, Germany. Since then he has been always involved in time and frequency metrology, focused at first on the development and operation of atomic clocks, later more and more on time comparison techniques (GNSS, TWSTFT). He became responsible for PTB's Time Unit Laboratory in 1991. Today he is Head of PTB's Time Dissemination Working Group and as such has the management responsibility for the operation of PTB's time dissemination services. He has served as delegate to the Consultative Committee for Time and Frequency (CCTF) and to Study Group 7 of the International Telecommunication Union. Between 2009 and 2013 he chaired the EURAMET Technical Committee for Time and Frequency. Since 2009 he is member of ESA's GNSS Science Advisory Committee which he chaired between 2012 and 2015. He has authored and co-authored more than 100 papers in refereed journals and conference proceedings.

Peter Whibberley is a Senior Research Scientist in the Time and Frequency group at the National Physical Laboratory (NPL), the UK's national measurement institute. After graduating from Oxford University, UK, Peter worked on far infrared and millimeter wavelength measurement at NPL until moving to Time and Frequency in 1990. For 10 years he was part of a small team that constructed a prototype caesium fountain primary frequency standard at NPL. Since then Peter has acted as lead scientist for the Time activities at NPL, including operation of the national time scale UTC(NPL), the satellite-based time transfer links to other national timing centres, and the time dissemination services. Peter participates in a number of international committees, including Study Group 7 of the International Telecommunication Union, and has been elected to take over as Chair of the Technical Committee for Time and Frequency within EURAMET, the European Association of NMIs, in May 2017.

Ingo Baumann is co-founder and partner of BHO Legal in Cologne, Germany, a boutique law f rm for European high technology projects mainly in the space sector. Ingo studied law at the Universities of Muenster and Cologne. His doctoral thesis, written at the Institute for Air and Space Law in Cologne, examined the international and European law of satellite communications. Baumann worked several years for the German Aerospace Centre (DLR), including as head of the DLR Galileo Project Of ce and CEO of the DLR operating company for the German Galileo Control Center. IG