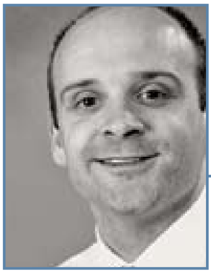
GNSS Solutions: Reference Systems, UTC Leap Second, and L2C Receivers ?

GNSS is a rapidly evolving and expanding field. New applications are being conceived seemingly daily, and old techniques are being continually revitalized by innovative research. As GNSS permeates our lives, however, it becomes ever more difficult to track recent developments and to remain up to speed on all of its many facets. With great pleasure, therefore, we introduce this regular column, GNSS Solutions, conceived as a means of providing "solutions" to GNSS-related topics.

GNSS Solutions is structured in a question-and-answer format. All answers are provided by GNSS experts, thus ensuring the very best information is always presented to readers. In addition to striving to address germane topics in the field of GNSS, we invite readers to ask their own questions and comments by contacting the column editors, Professor Gérard Lachapelle and Dr. Mark Petovello, Department of Geomatics Engineering, University of Calgary.



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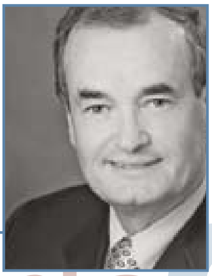

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Will the new L2C signals be able to be tracked by existing L2-capable (civilian) receivers?

The new civil signals being broadcast on the GPS L2 frequency from the latest GPS Block IIR-M and IIF satellites are significantly different from the existing P/Y codes modulated on the same frequency by the older Block II GPS satellites. The existing P (or the encrypted P/Y) signal is a 10.023 Mbps (million bits per second) binary code that is seven days in length. In other words, the P/Y code symbol pattern repeats every week. The new L2C signal is a 1.023Mbps signal that is composed of two sub-codes time-multiplexed together. Figure 1. shows the frequency spectrum of these two signals centered on the L2 central frequency of 1227.6MHz.

The first of the L2C sub-codes, the L2 civil-moderate (L2C-M), is 20 milliseconds in length generated at 511.5 kbps. The second, the L2 civil-long (L2-C-L), is 1.5 seconds in length generated at the same chipping rate of 511.5 kbps. These two codes are then time-multiplexed together as shown in Figure 2. The C codes are modulated onto the quadrature (Q) component of the RF output signal 90 degrees out of phase of the in-phase (I) signal where the P/Y code is modulated.

The switch alternates between the C-M and C-L codes at a 1.023 MHz rate. The switch times are synchronous with the generation of the C-L and CM codes. The resulting output code is half the C-M symbol followed by half the

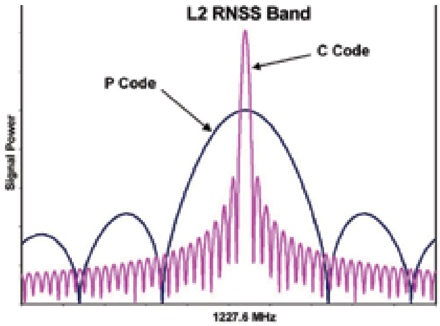

FIGURE 1. Frequency spectrum of L2 C and P codes

C-L symbol every two microseconds (μs). The L2C-M code also carries the satellite broadcast data, including time of day and orbital parameters, and so forth. The L2C-L does not contain broadcast data, which makes it ideal for very narrow band tracking and suitable for E911 indoor positioning.

Older receivers designed to track the L1 P/Y signal have local P- or P/Y-code generators used to correlate and synchronize to the signal received by the antenna of the GPS receiver. Civilian receivers must use complicated "semi-codeless" techniques to track the P/Y signal due to the encryption applied to the signal. These semi-codeless techniques result in a large amount of signal strength loss compared with tracking the pure P code or the new C-M and C-L codes.

The P- or P/Y-code generator cannot be used to track the new C-M or C-L codes. They do not generate the same codes, and the codes they do generate are not at the correct rate in symbols per second. So, unless the older receivers were configured with Field Programmable loGic Arrays (FPGAs) that could be reprogrammed to support the new codes and interleaving strategy, then these receivers will not be capable of tracking these new signals. That said, FPGA-based receivers are not normally found in commercial products due to their increased cost and power usage.

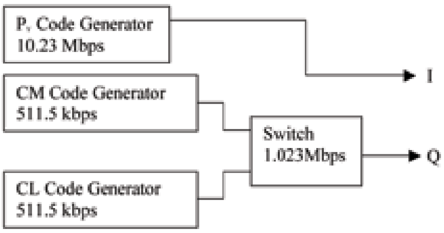

FIGURE 2. Block diagram showing how these signals are generated in the satellite

The time multiplexing of the L2 signal between the C-M and C-L codes adds an additional complication to the receiving equipment design. **Figure 3.** is a block diagram of a typical GNSS signal-processing channel.

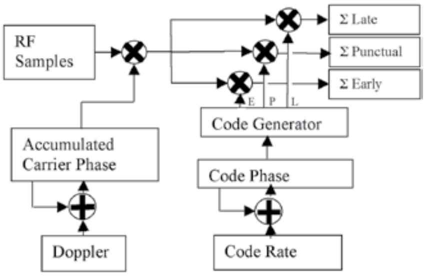

FIGURE 3. Typical receiver hardware to track GNSS PRN codes

The code generators required to track C-M and C-L are significantly different than those required to generate the P/Y code. First, and fundamentally, because of the different family of codes, the shift register configuration of the P/Y code is significantly different from that of the C-M/C-L. The second difference is due to the time-interleaving of the C-M and C-L symbols. The code generator for the C-M and C-L must create a three-state output, -1, 0 and +1. In contrast, to configure the P code, the output code is a continuous stream of +/- 1 values.

The output spacing time delay between the Early, Punctual and Late signals are typically fixed at half the broadcast bit size. For P code this spacing would be 50 nanoseconds. **Figure 4** shows how the resulting code tracking discriminator output (the difference between the accumulated Early and Late correlation values) would look like. To track the C-M code, the code generator needs to output +1/-1 in phase with the respective C-M code and then output a 0 during the time interval when the C-L code is being broadcast. The resulting generated symbol size is approximately 1 μs, which is half the original bit size of 2 μs (= 1/511.5 kbps). Failure to generate this three-state code will result in a 300 m tracking uncertainty zone as shown in **Figure 5**. This uncertainty zone effectively means that the discriminator is insensitive to local code errors of +/- half of a chip, thus negatively affecting measurement accuracy. This design "twist" would not have been anticipated with older receivers and even if they had a general-purpose code generator (for example., using FPGAs) they would still have problems tracking these new codes.

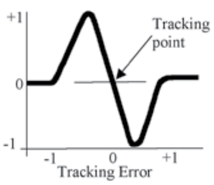

FIGURE 4. E-L discriminator output with proper chip size match

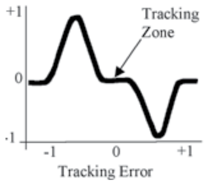

FIGURE 5. E-L discriminator output with improper chip size match

One item to keep in mind, however, is that the P/Y signal will continue to be supported. The older receivers will still be capable of tracking and collecting pseudorange and carrier phase measurements from the new modernized satellites. The owners of older hardware will continue to enjoy the current level of performance that they see today. However, they will not see the many advantages that the new signals provide, such as higher signal strength, lower cross correlation, and improved support for high sensitivity indoor applications.

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The GPS Operations Center has released the following Notice Advisory to Navstar Users (NANU) on L2C broadcasts:

GENERAL MESSAGE TO ALL GPS USERS

On 16 Dec 05 at approximately 2330z L2-Band Civil Signal (L2C) will be turned on. The following conditions of use apply:

a. The Air Force shall not guarantee the availability or quality of L2C signals until Initial Operational Capability (IOC).

b. Users are cautioned that the new signal is under development and may be used for a variety of test applications until achievement of IOC. Prior to IOC, signal availability and quality of the L2C signal may be subject to change without prior notice. Therefore, any use of the L2C signal prior to being declared operational is at the user's own risk.

Please contact the NAVCEN (703-313-5900) or the GPSOC (DSN 560-2541/ Comm 719-567-2541) if you encounter problems.

Why was a leap second introduced to Coordinated Universal Time (UTC) on December 31, 2005?

On December 31, 2005, the International Bureau of Weights and Measures (BIPM) inserted a leap second into Coordinated Universal Time (UTC) in order to comply with the internationally accepted definition of UTC. The International Earth Rotation and Reference System Service (IERS) is responsible for making the decision to insert a leap second into UTC based on astronomical observations of the Earth's rotation with respect to distant quasars made using very long baseline radio interferometry techniques. This definition follows Recommendation ITU-R TF.460-5 of the International Telecommunications Union Radiocommunications Sector (ITU-R), which specifies that the difference between UTC and the astronomically observed version of Universal Time called UT1 does not exceed 0.9 seconds. It further recommends that the preferred time to insert the leap second is at 23h 59m 59s UTC on either 31 December or 30 June.

This definition has been in place since its first implementation in 1972 in accordance with a recommendation of the ITU-R predecessor organization, the International Radio Consultative Committee (CCIR). **Figure 1** displays the history of the UT1-UTC difference since 1992.

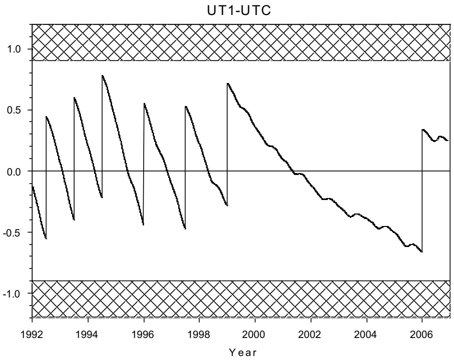

FIGURE 1. Observations of UT1-UTC since 1992. The hatched area represents the tolerance limits defined by the ITU-R recommendation. Data past 24 November 2005 are predicted.

Source: IERS Rapid Service and Prediction on Center at U.S. Naval Observatory.

The current definition of UTC specifies that the second of UTC be constant in length and, consequently independent of the Earth's rotation. The rotational speed of the Earth is observed to vary, however, and if we want to keep the time scale in common use for everyday purposes synchronized with the Earth's rotation, an adjustment must be made in UTC. This is the leap second.

In 1967 the international definition of the second specified in terms of an atomic energy level in the cesium atom was made effectively equivalent to an astronomical second based on a mean solar day of 86,400 seconds in about 1820. Over the past 1,000 years, the Earth's rotation has been slowing at an average rate of 1.4 milliseconds per day per century, so that the day is now about 2.5 milliseconds longer than it was in 1820. A difference of 2.5 milliseconds per day amounts to about 1 second per year, and this is the reason for the insertion of leap seconds. Superimposed on this very slowly increasing difference are shorter-term variations in the length of the day. Periods between leap seconds are not, therefore, constant.

Figure 2 presents a plot of the time difference ΔT between a uniform scale such as time based on the Earth's annual motion about the Sun (Terrestrial Dynamical Time) or atomic time (Terrestrial Time) and the variable, astronomically based time scale such as UT1 since 1650. It shows that the linear increase in the length of the day results in a parabolic difference in time between a uniform and non-uniform time scale.

Scientific research has identified three types of variation in the Earth's rotation: a steady deceleration, random fluctuations, and periodic changes. In addition to the astronomical evidence for the steady deceleration seen in the parabolic nature of the data in Figure 2, evidence for a long-term deceleration in the Earth's rotation, extending over millions of years can also be seen in coral fossils that exhibit both daily and annual growth rings. The evidence suggests that the rate of deceleration has been substantially the same. Besides a steady decrease, the Earth's rotation is subject to frequent small changes that are apparently random. A periodic seasonal variation caused principally by meteorological effects also occurs.

The ITU-R is currently discussing possible changes in the definition of UTC that could lead to dropping leap seconds in the future. However, the group has not reached agreement on a new definition and intends to seek a broad consensus internationally before taking any action.

Editors' Note: The GPS Interface Specification (IS) defines how the offset between GPS time and UTC is communicated using the GPS navigation message. Basically, since GPS time is continuous, the offset between GPS time and UTC is updated to account for the leap second. Furthermore, because the navigation message

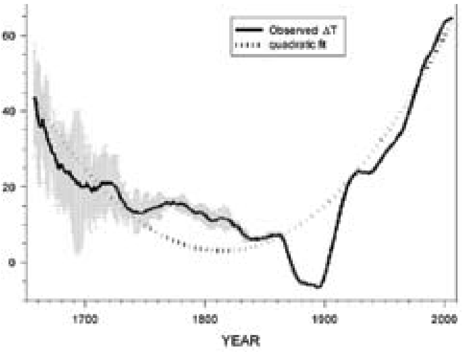

FIGURE 2. Observations of ΔT since 1650. The error bars show the statistical errors of the astronomical observations.

Source: McCarthy, D.D. & Babcock, A.K. 1986, "The Length of the Day Since 1656," Phys. Earth Planet. Inter., 44, 281–292 and IERS Rapid Service and Prediction Center at U. Naval Observatory.

also contains information about upcoming (or recently past) leap seconds there should be no delay in accounting for the leap second within the receiver, assuming it is compliant with the latest GPS Interface Specification (IS). The latest version is IS-GPS-200D and can be downloaded from: http://www.navcen.uscg.gov/gps/geninfo/IS-GPS-200D.pdf

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Will GPS and Galileo have the same or interoperable reference systems?

The short answer to this question is 'YES', in that both Galileo and GPS shall use as a basis for their reference system definitions, those used by the International Terrestrial Reference System (ITRS).

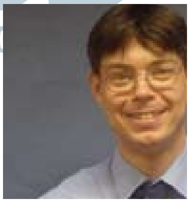
However, this unfortunately does not end the issue because, whilst the definition of the reference systems is the same for both GNSS systems, their realizations into reference frames shall take place individually for Galileo and GPS in order to guarantee system independence. By making two such realizations, which result in the creation of the Galileo Terrestrial Reference Frame (GTRF) for Galileo and the World Geodetic System 1984 (WGS-84) for GPS, some small discrepancies shall be introduced between them, and this cannot be avoided. If one looks, however, at the requirements for Galileo, it can be seen that the difference between the GTRF and the latest realization of the ITRS shall be kept to within three centimetres (2 sigma). Although I am not aware of an equivalent requirement for WGS-84, if we look at the differences that currently exist between this frame and the ITRF, they also are in the order of two to three centimeters.

As such, one can expect that, assuming the situation as described above is maintained, on average the difference at any point on the Earth between the GTRF and WGS-84 shall be in the order of two to three centimeters. (No reason at all exists to doubt that this will be the situation, as the EU/US agreement on GNSS, signed June 2004, states that "the parties agree to realise their geodetic coordinate reference frames as closely as possible to the International Terrestrial Reference System.")

For almost all users of GNSS, who use code-based observables to derive their position, this will neither be an issue nor indeed noticeable, as such inconsistencies are well within the noise of resultant positioning accuracies of a few metres. Indeed, even for users of carrier-based techniques that deliver decimetric or centimetric levels of positioning accuracy over local/regional areas, no problem is likely to arise as a result of these minor differences in reference frames because most such techniques use relative positioning, which has the effect of differencing out such errors.

Therefore, only high precision geodetic users are likely to encounter any reference system discrepancies, and I am sure that these groups shall quickly develop models and techniques to account for such differences. Indeed, I hope that any inconvenience to them shall be more than offset by the addition of data from some 40 globally distributed (in some of the world's most remote locations) and uniform Galileo Sensor Stations, upon which the GTRF shall be based, as an input to the international geosciences community.

Finally I would like to mention the Galileo Geodetic Service Provider (GGSP), which is an organisation created within the Galileo program and made up of Germany's GeoForschungsZentrum (GFZ) and Bundesamt fur Kartographie und Geodasie (BKG), the European Space Agency's European Space Operations Centre (ESOC), Switzerland's Astronomical Institute University of Berne (AIUB), France's Institut Geographique National (IGN), National Resources of Canada (NRCan) and Wuhan University of China. GGSP's role is to ensure not only that the GTRF meets its performance targets with respect to ITRF, but also that the geodetic community is fully involved throughout its definition, implementation, and maintenance in order to ensure that the GTRF becomes as precise, useful, and accessible a reference frame as possible for all interested users.



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