VIAVI Solutions

Whitepaper

Legacy Navigation: Evaluating GPS Receiver Vulnerabilities in the Week Rollover Scenario

With the world increasingly relying on Global Positioning System (GPS) technologies for Position, Navigation, and Timing (PNT) applications, the awareness regarding legacy receivers' capabilities to properly handle the GPS Week Number Roll Over (WNRO) event has significantly increased.

"Legacy GPS receivers" refers to those receivers reliant on the original L1 band signals broadcasted by the Global Positioning System (GPS) at a frequency of 1575.42 MHz. These signals consist of two codes, one being Coarse Acquisition (C/A) signals, which are freely available for public use, and Precision (P) code, which allows for higher accuracy positioning, but is restricted for use by the U.S. military. The broadcast signals hold navigation messages containing information such as satellite ephemeris, position, and time of broadcast, which allow receivers to calculate their position using a technique known as trilateration.

In the PNT world, the GPS Week Rollover phenomenon characterizes the event that causes GPS receivers to internally reset their week count upon reaching 1024 weeks, or approximately 19.64 years. This is a consequence of the fact that GPS counts the number of weeks using a 10-bit parameter present in the navigation message.

Recognizing the importance of testing legacy GPS receivers carries a high significance given the omnipresent integration of GPS raw data dependent systems present across multiple industries[1], especially in mission critical scenarios where precision is of vital importance and any uncertainty or failure is deemed unacceptable. Such an event was recorded in 2017 in York County, PA, United States, when part of the national emergency service (911) suffered disruptions for over 14 days due to the embedded GPS receivers rolling back to December 14, 1977[2]. Multiple occurrences of mass disruptions have also been reported in the automotive manufacturing industry, exemplified by Honda's reported failures in 2022[3], making their navigation systems unreliable due to the absence of a remedy for the receiver models that were embedded in certain product lines.

Moreover, it is worth noting that depending on the nature of the use case, the impact of losing GPS communications varies drastically. For instance, remotely controlled systems situated in challenging environments (such as Antarctica) might experience prolonged outages lasting months[4], depending on the reliability of the maintenance programs, as well as on developing a fix for the issue. A more comprehensive analysis of historical events and study cases is provided in the upcoming sections of this work.

The importance of ensuring stable and reliable GPS communications is also emphasized by the potential global economic impact. Recent research estimates that in the scenario of a 30-day widespread GPS outage, the global economy would suffer losses worth up to $30.3 billion[5] . While the scenario remains improbable, it is worth noting that any sort of disruption in terms of GPS connectivity would directly influence the financial landscape of operators and their clientele.

The aim of this paper is to analyze the root cause and impact of GPS Week Number Rollover, identify legacy receivers that are considered susceptible to failure in this scenario, as well as to develop a complete testing methodology that could provide the required reassurance in future events.

GPS Week Rollover: Historical Events

To this point, two major occurrences of the event have impacted the world. The first rollover took place on the 22nd of August 1999 at 00:00 UTC time, with the most recent happening on the 7th of April 2019 at the same UTC time. Both the United States Department of Homeland Security and the International Civil Aviation Organization have publicly communicated advisories and alerts regarding the possible consequences.

It is worth noting that the date when the WNRO event will next occur is directly proportional to the initial release date of the receiver's firmware. As stated above, the internal week count of legacy GPS L1 receivers is stored in a 10-bit parameter, which is offset by a hard coded date in the firmware. As the count increases over time and a newer firmware version is released with an updated initial week number, the ability of the receiver to handle WNRO events for the next 19.64 years is extended.

Forecasting the exact timing of the incident is considered challenging, as demonstrated not only by end-users themselves[4], but also by major legacy GPS receiver manufacturers[1,6,7,8]. Tables 1 and 2 provide a concise overview depicting some of the most popular receivers that have encountered operational failures within the recent years and lacked a viable solution for mitigating this issue.

A more detailed list of Furuno legacy receivers that have experienced loss of GPS connectivity[8] is presented by the table in appendix 1.

Table 1: Trimble WNRO Failing Receivers[5]

Manufacturer	Part Number	Description	Remedy	Cutoff date
Trimble	53110-05	Mini T (with FW 1.16)	N/A	20th Dec. 2025
Trimble	53110-15	Mini T custom (with FW 1.16)	N/A	20th Dec. 2025
Trimble	53110-05	Mini T (with FW 1.18)	N/A	25th Aug. 2029
Trimble	53110-15	Mini T custom (with FW 1.18)	N/A	25th Aug. 2029
Trimble	53110-45	Mini T (with FW 1.20)	N/A	22nd Dec. 2029
Trimble	53110-55	Mini T custom (with FW 1.20)	N/A	22nd Dec. 2029

Table 2: Furuno WNRO Failing Receivers[7]

Manufacturer	Part Number	GPS Core	Remedy	Cutoff date
Furuno	GP-80	GN-8096C/D : 4850264 GN-8097C/D : 4850296	N/A	2nd Jan. 2022
Furuno	GP-90	GN-8096C/D : 4850264 GN-8097(/D : 4850296	N/A	2nd Jan. 2022
Furuno	GP-150	GN-8096C/D : 4850264 GN-8097C/D : 4850296	FW Upg.	2nd Jan. 2022
Furuno	GP-1640	GN-8096C/D : 4850264 GN-8097C/D : 4850296	N/A	2nd Jan. 2022
Furuno	GP-1650	GN-8096C/D : 4850264 GN-8097C/ D : 4850296	N/A	2nd Jan. 2022
Furuno	GP-1850	GN-8096C/D : 4850264 GN-8097C/ D : 4850296	N/A	2nd Jan. 2022
Furuno	GP-7000	GN-8096C/D : 4850264 GN-8097C/D: 4850296	N/A	2nd Jan. 2022
Furuno	GP-3500	GN-8096C/D : 4850264 GN-8097C/D : 4850296	FW Upg.	2nd Jan. 2022
Furuno	GP-70 Mk2	GB-97 (GN-8098) : 4850311	N/A	2nd Jan. 2022
Furuno	GP-188	GB-97 (GN-8098) : 4850311	N/A	2nd Jan. 2022
Furuno	GP-280/380/680	GB-97 (GN-80981 : 4850311	N/A	2nd Jan. 2022

Preventive Measures and Solutions – How to test your GPS receiver for WNRO?

A GPS simulator shall be used to test the GPS receiver's behavior at future dates, including known WNRO events. This will allow testing of GPS dependent systems against known scenarios and validating their reliability.

VIAVI Solutions Inc. proposes the following testing procedure, that has been validated against two legacy GPS L1 receivers, and namely: the VIAVI FireFly-1A receiver, which utilizes a u-blox 6 GPS receiver module, and Furuno's GP-37 receiver. The devices have been selected to demonstrate WNRO testing on commonly available GPS L1 receivers considering the worldwide presence of both u-blox and Furuno. GPS signals have been fed into the receivers with the help of the VIAVI CLAW GPS Simulator, an 18-channel GPS Full-Constellation Simulator. The testing methodology is highlighted by Figure 1.

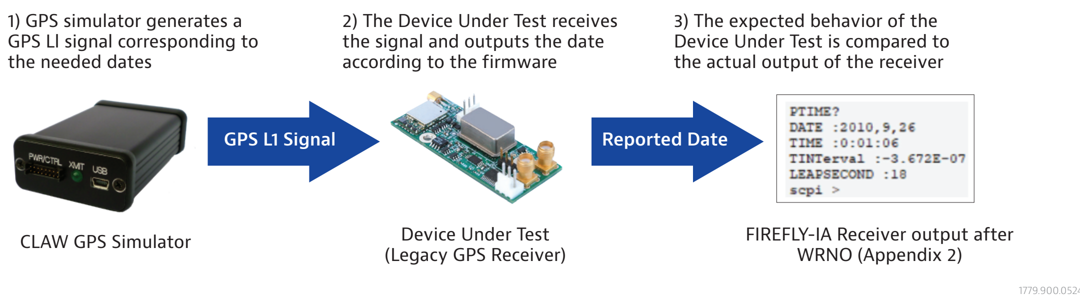


Figure 1: Testing Methodology

Failure when WNRO occurs is identified by receivers failing to lock to the simulated GPS signal or by misreporting the date being simulated. Identification of GPS receiver's specific rollover dates followed a similar process. First, an arbitrary date is selected for simulation that will cause the device under test (DUT) to experience WNRO failure. This date should typically be within a 20 year range from the date of the receiver's purchase or most recent firmware update. Once a date of WNRO failure has been identified, a binary search is performed over a range 20 years prior to find the exact date WNRO failure occurs. Table 3 summarizes the results of the tests. Appendices 2 and 3 offer a visual representation of the simulations that have been performed.

Table 3: WNRO Date Identification Results

GPS Receiver	Firmware Version	Initial Build Date (Firmware)	GPS Simulated Date (MM/DD/YYYY)	Displayed Date (MM/DD/YYYY)	Failure Mode
VIAVI Firefly-1A	3.17	09/26/2010	05/11/2030	9/26/2010	Receiver misreports date as firmware's initial build date
Furuno GP-37[7]	N/A	01/04/2001	06/19/2021	11/01/2001	Receiver misreports date as firmware's initial build date

Government Rules and Regulations

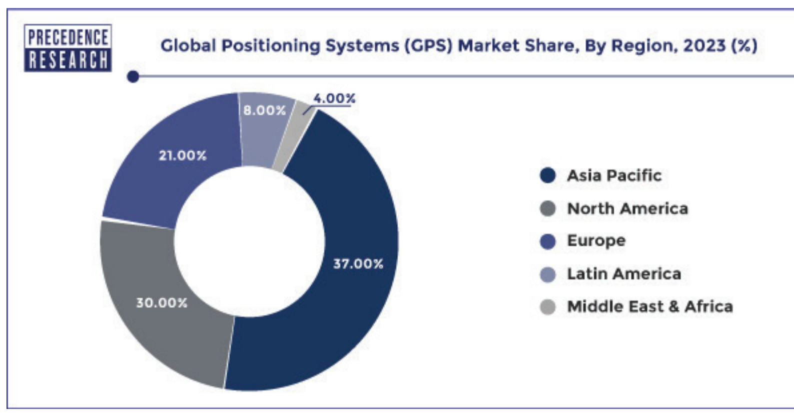
The U.S. Government defined the original specification for the 10-bit segment of the broadcasted week number in ICD-GPS-200C, a document which describes how to interface with the GPS program. The potential effects of rollover have not gone unnoticed by governmental organizations.

The U.S. Naval Observatory describes information about the event and emphasizes the duty of the user to be responsible for corrective actions. To combat the issue, GPS receiver manufacturers implemented software solutions[10]. Recognizing the potential threat of a lack in PNT resiliency, the U.S. government issued executive order 13905 on February 12, 2020. Section 4 of the order describes the implementation as a "PNT profile"[11]. This term is used to define standards and guidelines for requirements of PNT technologies. In response to this order, NIST (The National Institute of Standards and Technology) detailed an instruction "DS-6," a subcategory under data security which mandates firmware and software to consider interoperability issues in systems with regards to leap second and GPS week rollover testing well in advance of those events occurring[12].

Market Trends and Long-term Technical Strategies for Resilience

The importance of ensuring resilience in GPS dependent systems is further emphasized by the rapid growth of the field. Recent market research expects the global market size to reach $417B by 2033[12], with the largest share projected to be seen in North America and Europe (combined) due to the constant development of GPS dependent sectors, such as defense, autonomous driving, and smart agriculture[13]. An additional emerging market segment is represented by the development of smart cities, which is fueling the demand of trustworthy positioning, navigation, and timing solutions, a demand which is expected to be met through the integration of AI and machine learning.

In response to the need for resiliency of the growing market for GPS, the CNAV (Civil Navigation), L5, L2C, and L1C signals have been developed. They are modernized messages that are more flexible than legacy civil signals. One of the key features of the updated signals is their use of a 13-bit week number message to prevent future week rollover events.



Conclusion

The presented work aims to mitigate possible disruptions in response to the limited capabilities of legacy GPS receivers by developing and presenting a comprehensive testing methodology for the WNRO event scenario. Either by ensuring that the embedded GPS receiver is immune to such events, or by being able to determine the time when the roll over might occur, operational continuity is achieved in all sectors deemed as reliant on precise positioning, navigation, or timing data.

The demonstrated testing methodology enables organizations to fortify their PNT infrastructure and develop a proactive approach to managing WNRO events.

While a comprehensive testing plan against the GPS WNRO issue has been developed and presented in this work, continued research is essential for developing fault proof GPS dependent systems that allow organizations across various operating fields to be immune to any scenario when GPS signals become unavailable.

By Christopher Sadiq, Nabeel Al-Khattab, Rareș Stanciu

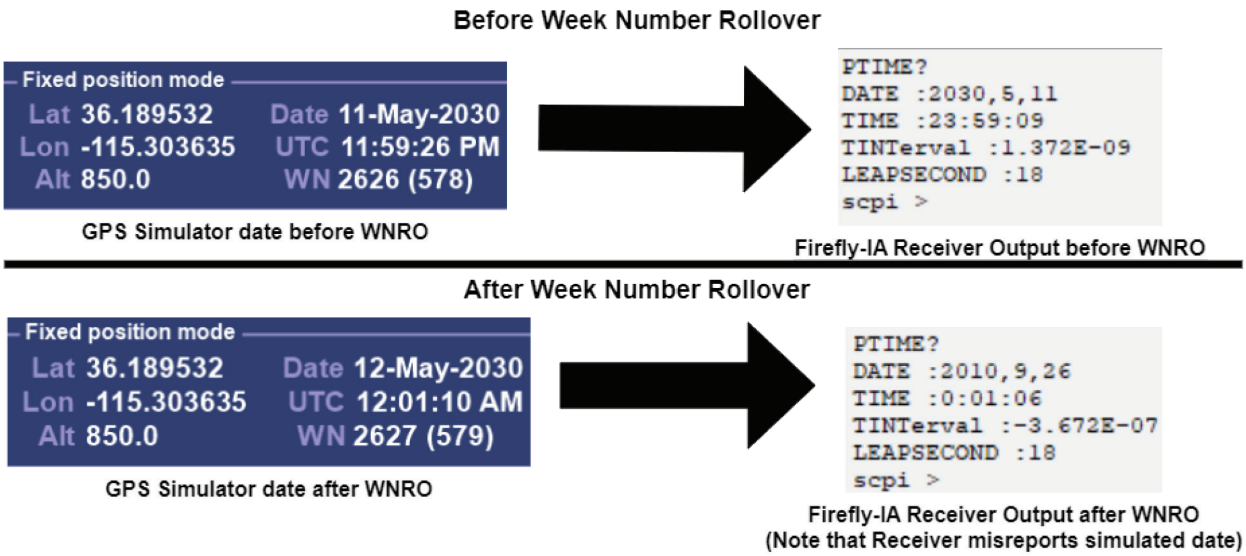
Appendix

Appendix 1: Furuno GPS receivers/ GPS dependent products affected by the week number rollover issue[8]

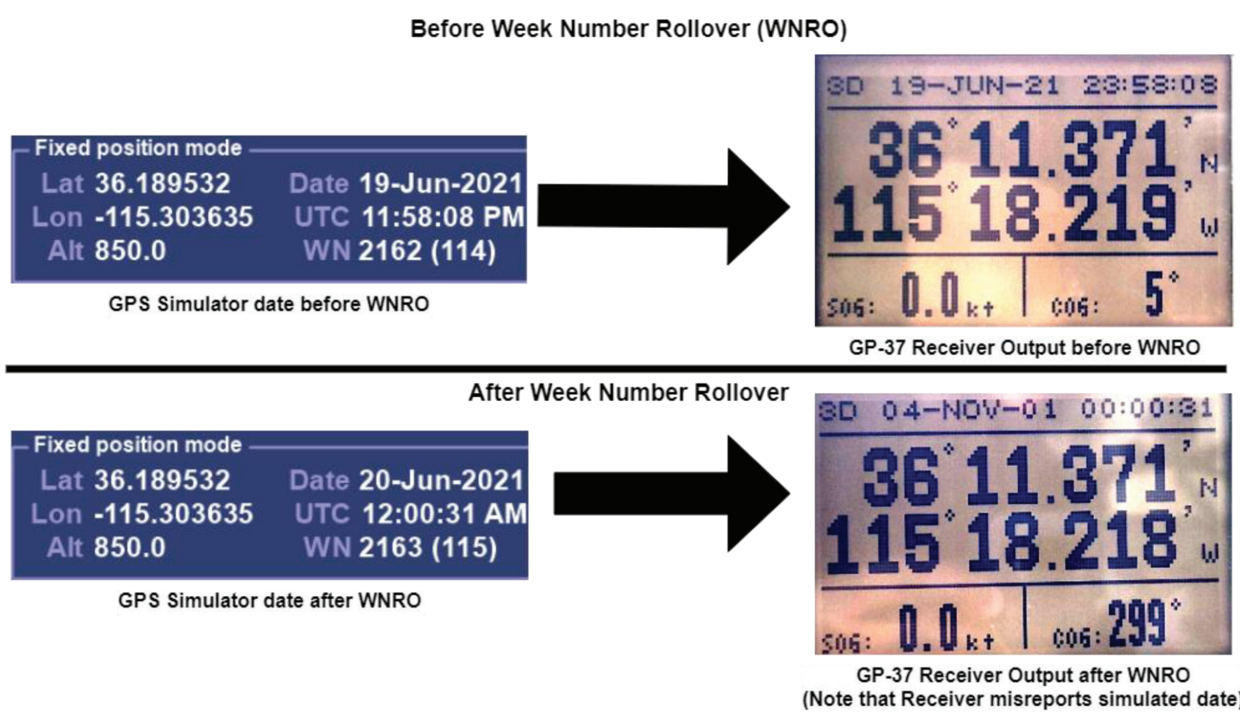
Type	Model
GPS Navigator	GP-80
	GP-90
	GP-90 Dual*
	GP-150
	GP-150 Dual*
	GP-70MK2
	GP-500MK2
	GP-32
	GP-33* (Serial 6412-894) or earlier
DGPS Navigator	GP-37
GPS Receiver	GP-320B
	GP-330B (Serial 445-7001) or earlier
GPS/Plotter	GP-1640
	GP-188
	GP-280
	GP-380
	GP-680
	GP-8000
	GP-8000MK2
GPS/Plotter/Sounder	GP-1650W
	GP-1850W
	GP-7000
	GP-3500*
	GP-1800
	GP-1800MK2
	GP-3000
	GP-3050
	GP-3100
	GP-3100MK2
	GP-3300

* Firmware releases have been published by the manufacturer to mitigate the failure. All other receivers are known to not have a remedy and replacements have been advised.

Appendix 2: WRNO Simulation Results for VIAVI FIREFLY-IA



Appendix 3: WRNO Simulation Results for FURUNO GP-37



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13 Global Positioning Systems (GPS) Market (By Application: Road, Aviation, Marine, Location Based Services, Surveying & Mapping, Others; By Deployment: Standalone tracker, Portable Navigation Devices, Automotive Telematics Systems, Consumer Devices, Others) - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2024-2033 Accessed: Apr.10,2024. [Online]. Available: https://www.precedenceresearch.com/global-positioningsystems-market

VIAVI Solutions

Contact Us +1 800 835 2352
avcomm.sales@viavisolutions.com

To reach the VIAVI office nearest you, visit viavisolutions.com/contact.

gpsvulnerable-wp-avi-nse-ae
30194157 900 0624