GNSS System Outages and Their Effect on Timing

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

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Outline

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- **GPS Anomaly**
  - GPS segment error January 2016
- **Galileo Anomaly**
  - Galileo outage July 2019
- **Mitigating GNSS anomalies**

Introduction

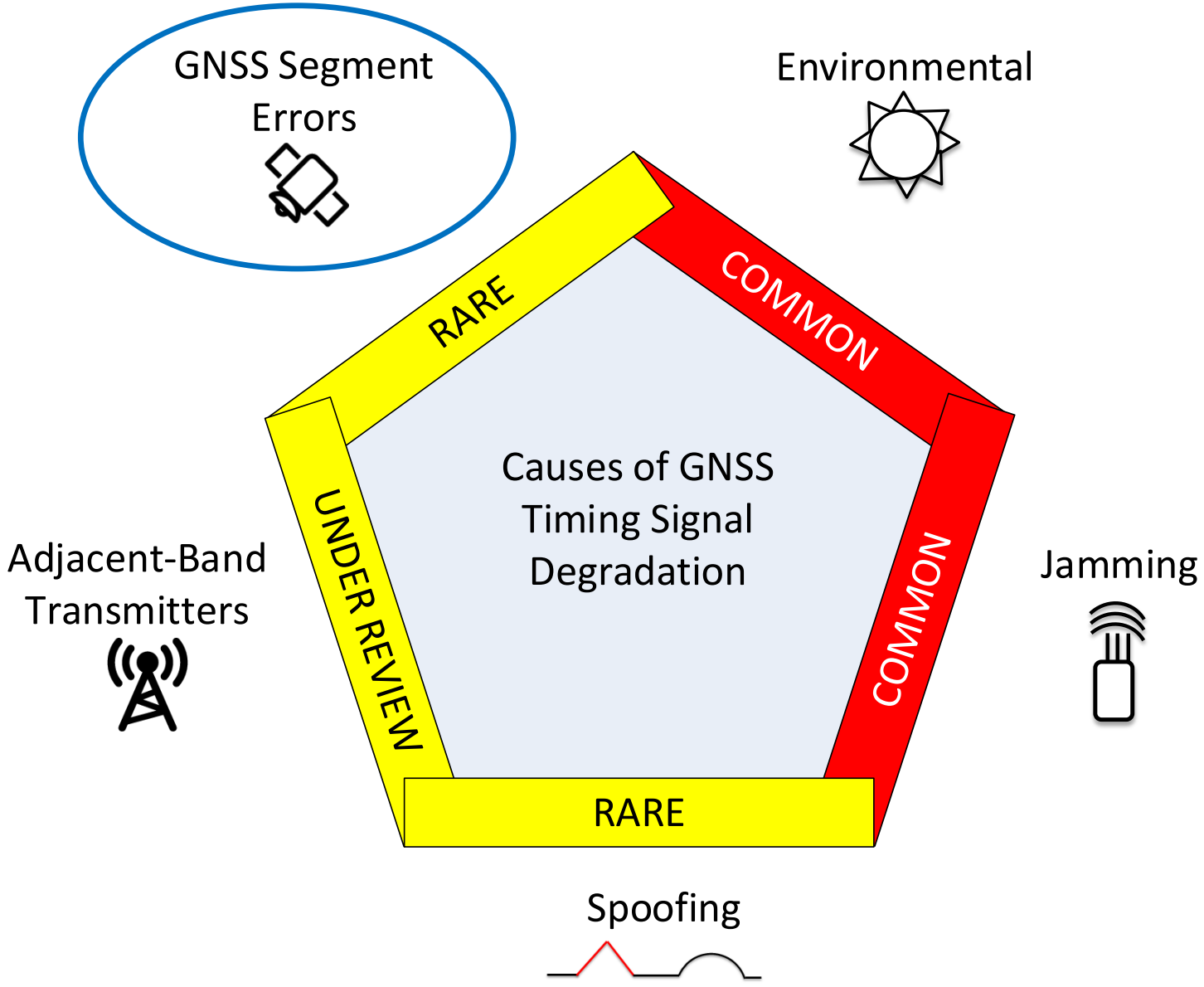
- **GNSS systems serve as the principal source of accurate time for critical infrastructure**
  - Telecommuncations
  - Energy sector
  - Financial industry

- **In January 2016, the GPS system experienced an anomaly lasting a day**

- **In July 2019 the Galileo system experienced an outage lasting one week**

- **In April 2014 the GLONASS system experienced a systemwide failure for 10 hours followed by eight satellites malfunctioning for 30 minutes two weeks later.**

GNSS Vulnerabilities



GPS Anomaly

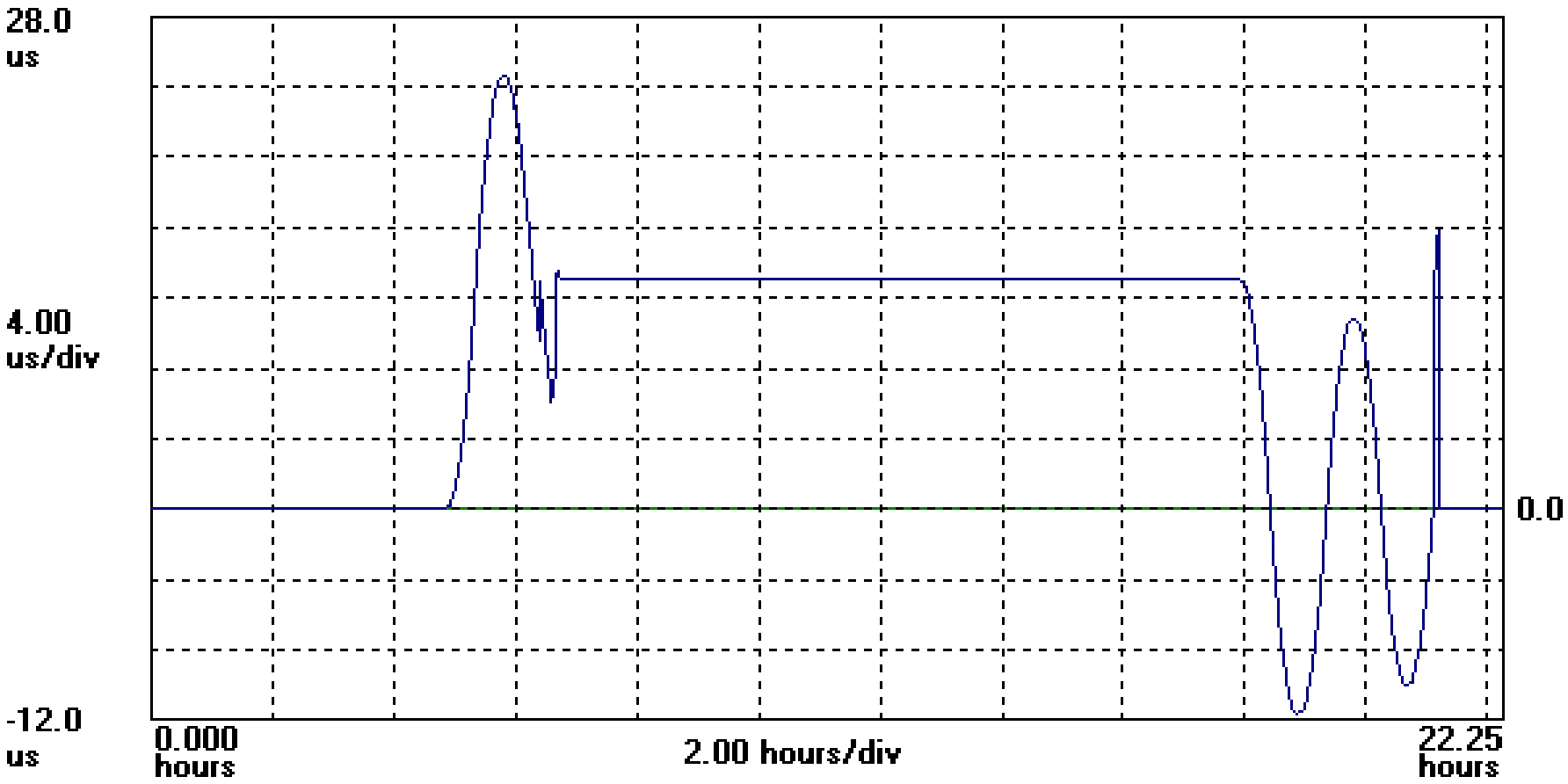
- On January 26, 2016 an issue with the GPS data upload system resulted in incorrect data being transmitted from the satellites on the commercial L1 band signal used by civilian GPS receivers worldwide.

- 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 software 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 issue was resolved at 6:10 a.m. MST, however global users may have experienced GPS timing issues for several hours.

GPS Anomaly

January 2016 GPS Segment Error:

13 µs UTC offset error



Plot showing how the anomaly event impacted one GPS timing receiver

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Galileo Anomaly

- **In July 2019, the Galileo system experienced an system outage lasting nearly one week. During the outage, navigation and timing information was not available.**

European
Global Navigation
Satellite Systems
Agency

- **Galileo, the EU's satellite navigation system, is currently affected by a technical incident related to its ground infrastructure. The incident has led to a temporary interruption of the Galileo initial navigation and timing services, with the exception of the Galileo Search and Rescue (SAR) service. Experts are working to restore the situation as soon as possible. An Anomaly Review Board has been immediately set up to analyse the exact root cause and to implement recovery actions.**

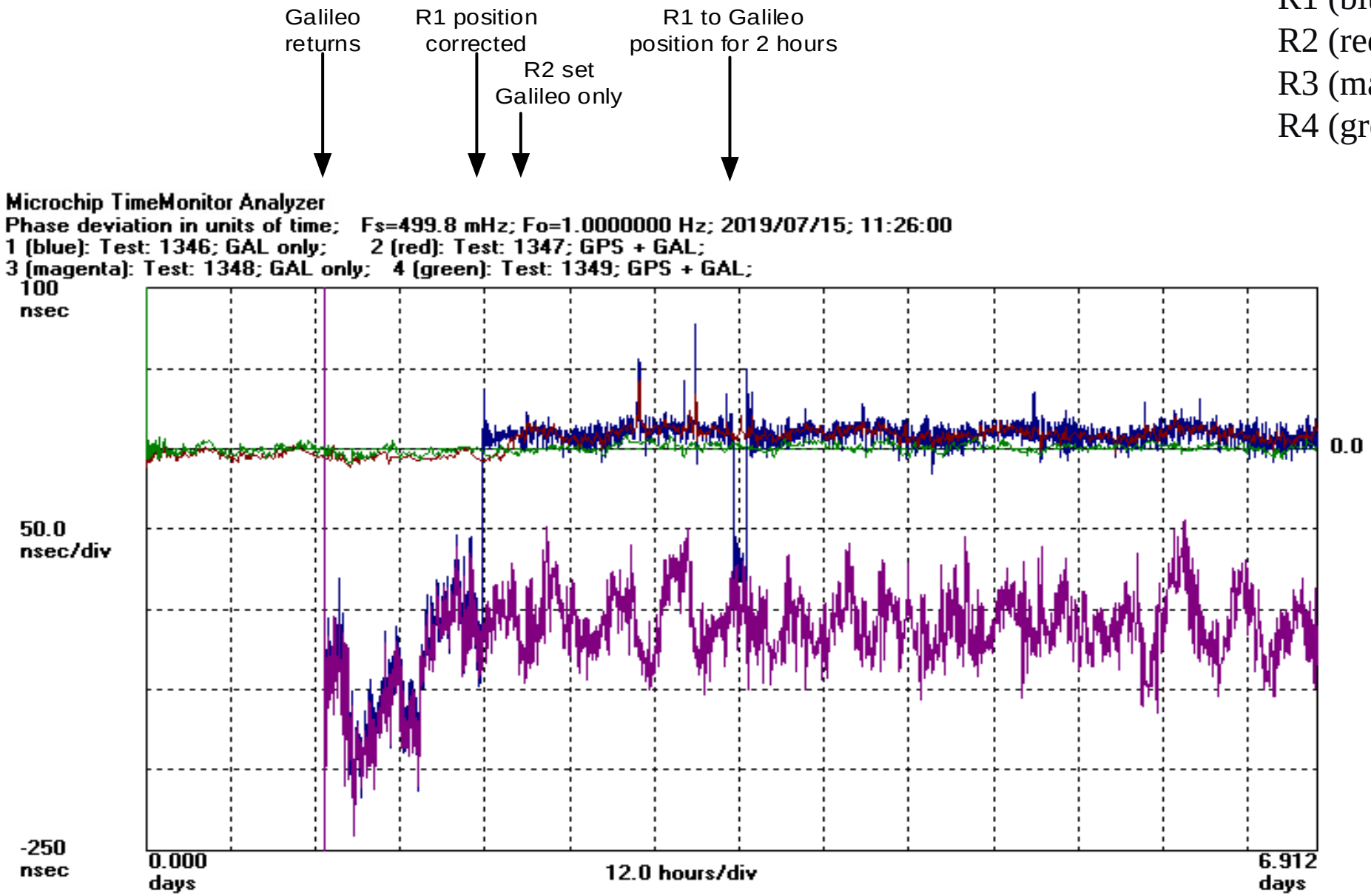
- **The "Initial Services" of the Galileo satellite system were successfully restored on July 19, according to the German Aerospace Centre. Since July 11, Europe's satellite navigation system had been partially unavailable to users due to a technical incident in ground-based infrastructure. The European Global Navigation Satellite Systems Agency (GSA) in Prague informed its customers of the initial failure. During the period of non-service the GSA had warned that there was a "degradation on all Galileo satellites" and that "the signals may not be available nor meet the minimum performance levels" promised by Galileo. Customers who nevertheless continued to use devices that calculated their position using Galileo satellites would do so at their "own risk."**

Galileo Anomaly

- The week-long Galileo system outage afforded an opportunity to study the behavior of the Galileo system as it came back online.
- Four GNSS timing receivers were studied, two set to Galileo only, and two set to GPS+Galileo. The Galileo units ran unlocked until Galileo returned and the Galileo/GPS units ran normally as would be expected since GPS was available.
- This led to an interesting discovery which is detailed the slides that follow.

When Galileo returned after the outage, the survey position was inaccurate which affected time accuracy and stability.

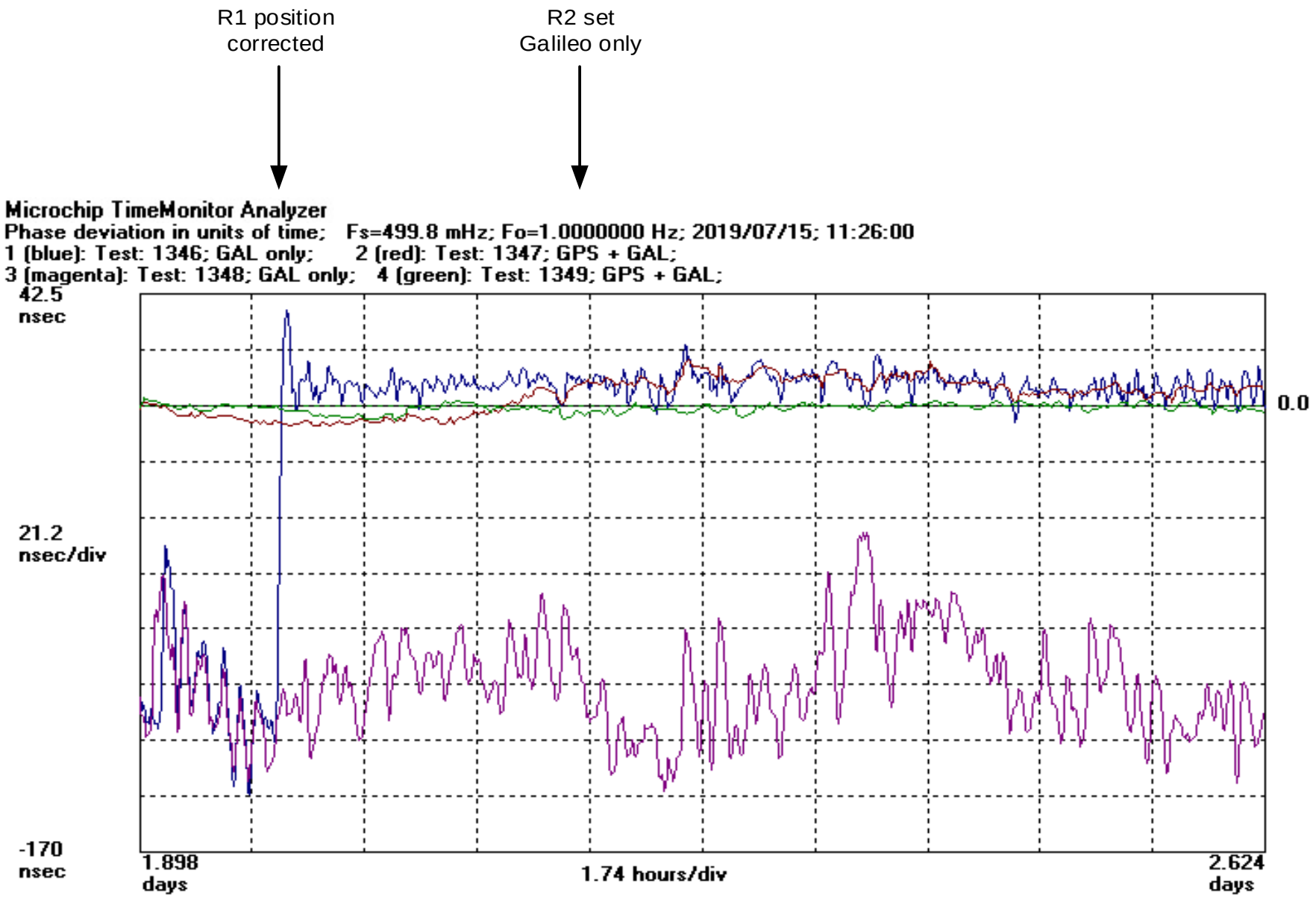
Galileo Anomaly



R1 (blue) Galileo only
R2 (red) GPS + Galileo
R3 (magenta) Galileo only
R4 (green) GPS + Galileo

The Galileo-only timing receivers (R1 & R3), at the point when Galileo first returned, show a bias and excessive wander compared to the other two receivers (R2 & R4).

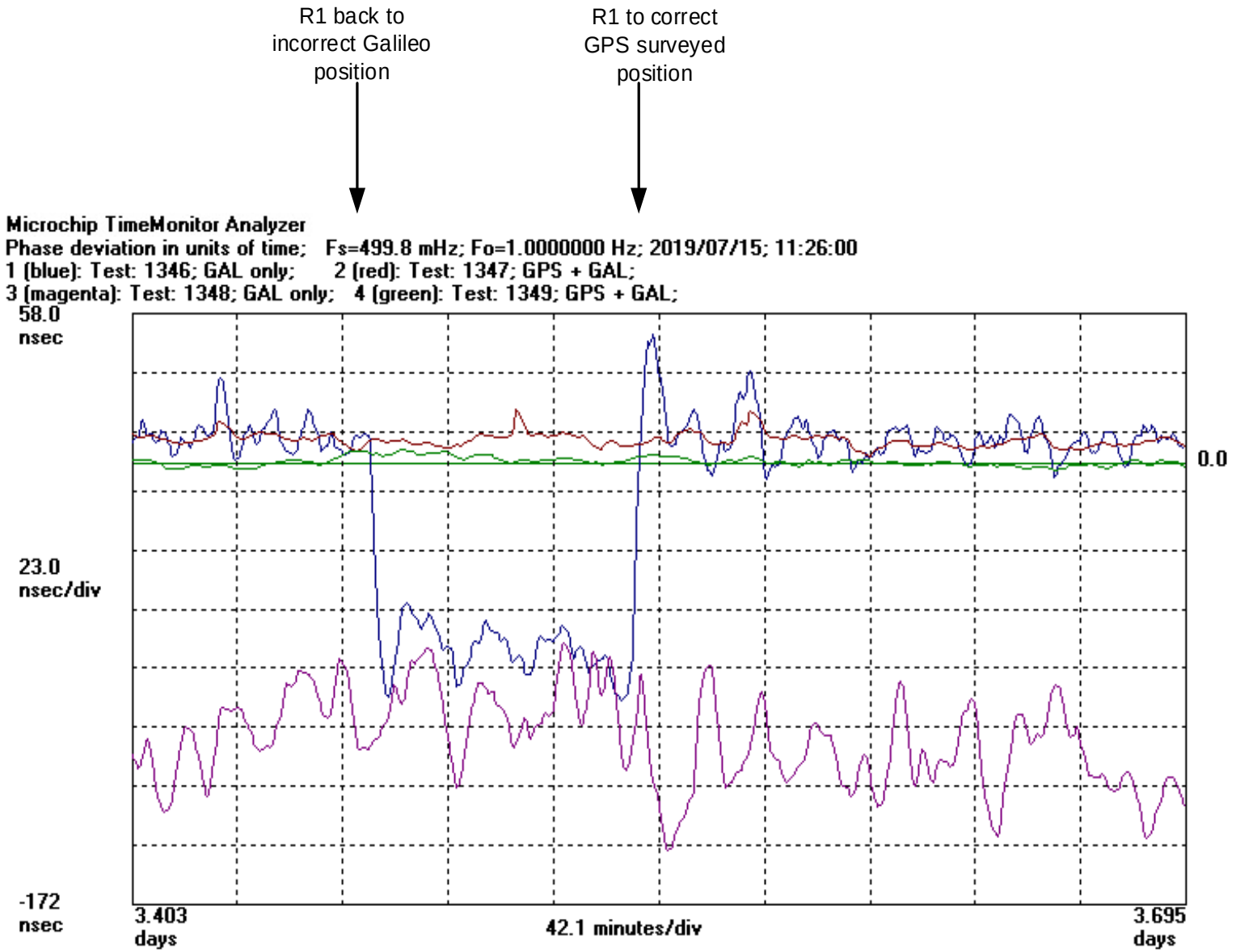
Galileo Anomaly



R1 (blue) Galileo only
R2 (red) GPS + Galileo
R3 (magenta) Galileo only
R4 (green) GPS + Galileo

A careful look at the position coordinates for the two Galileo-only receivers showed that an incorrect Galileo survey position was responsible for the bias and wander. This was further corroborated by manually setting one of the two Galileo-only receivers to the correct position. When this is done, the bias and excessive wander are eliminated. Setting one of the GPS+Galileo receivers, which already had the correct position, showed an even closer match.

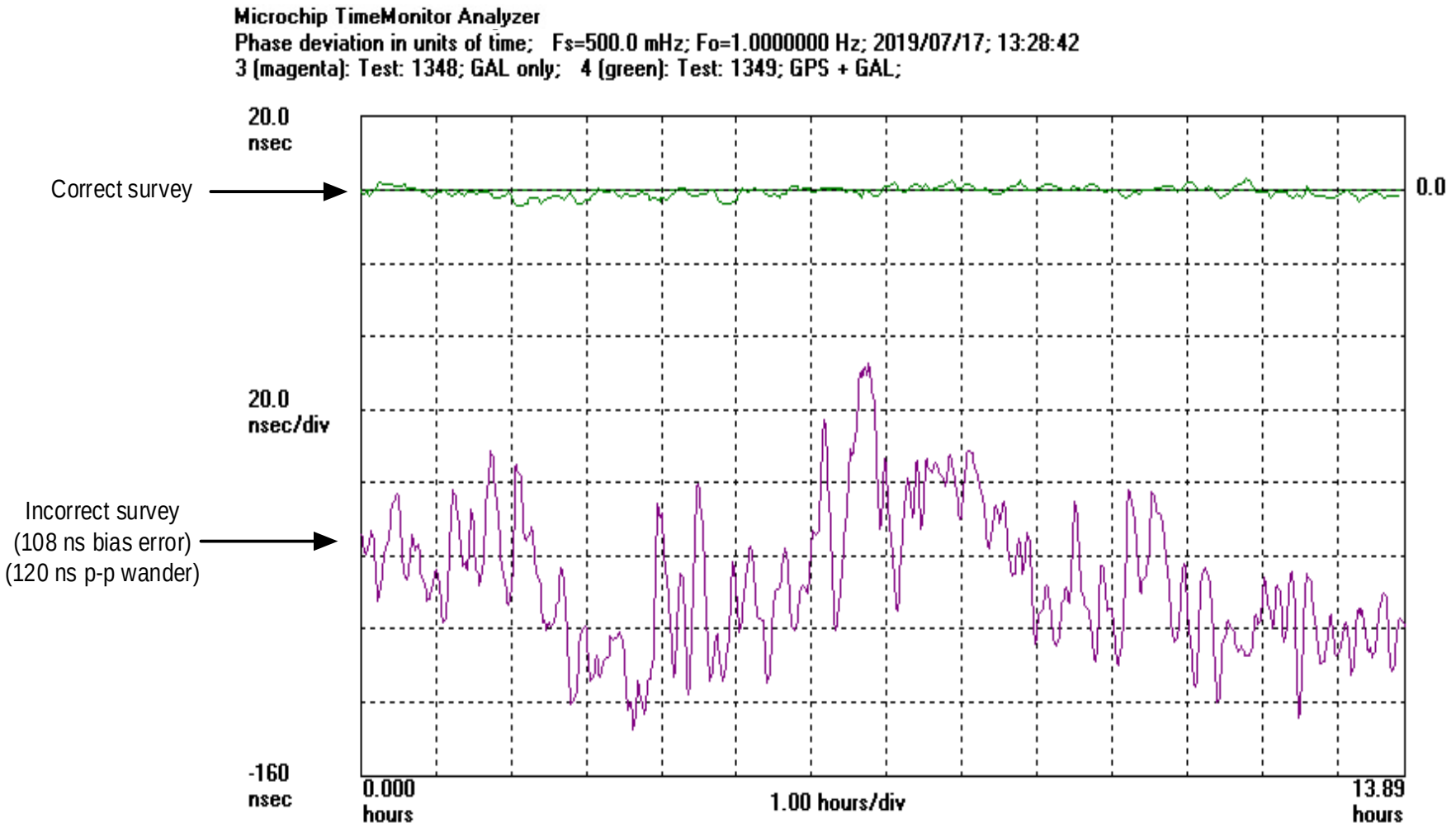
Galileo Anomaly



R1 (blue) Galileo only
R2 (red) GPS + Galileo
R3 (magenta) Galileo only
R4 (green) GPS + Galileo

This plot shows the Galileo-only satellite revert to bias and wander when the position is set back to the incorrect Galileo position. When after two hours it is returned to the correct position, the bias and wander disappear again.

Galileo Anomaly



R1 (blue) Galileo only
R2 (red) GPS + Galileo
R3 (magenta) Galileo only
R4 (green) GPS + Galileo

This plot contrasts the bias and wander between a correctly surveyed receiver and incorrectly surveyed receiver. The former shows undetectable bias with a few nanoseconds peak-to-peak wander, while the latter shows 108 ns bias and 120 ns p-p wander.

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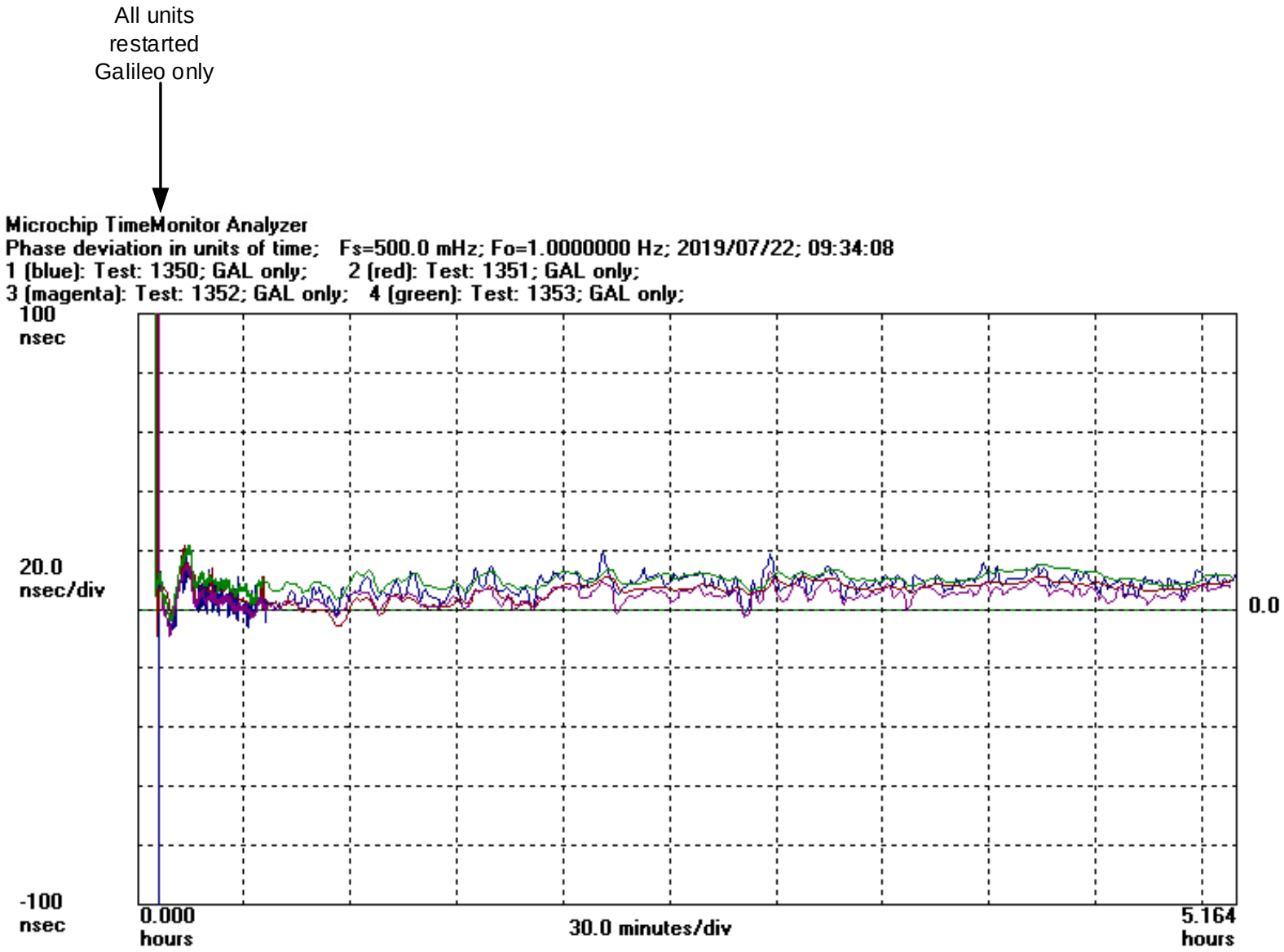
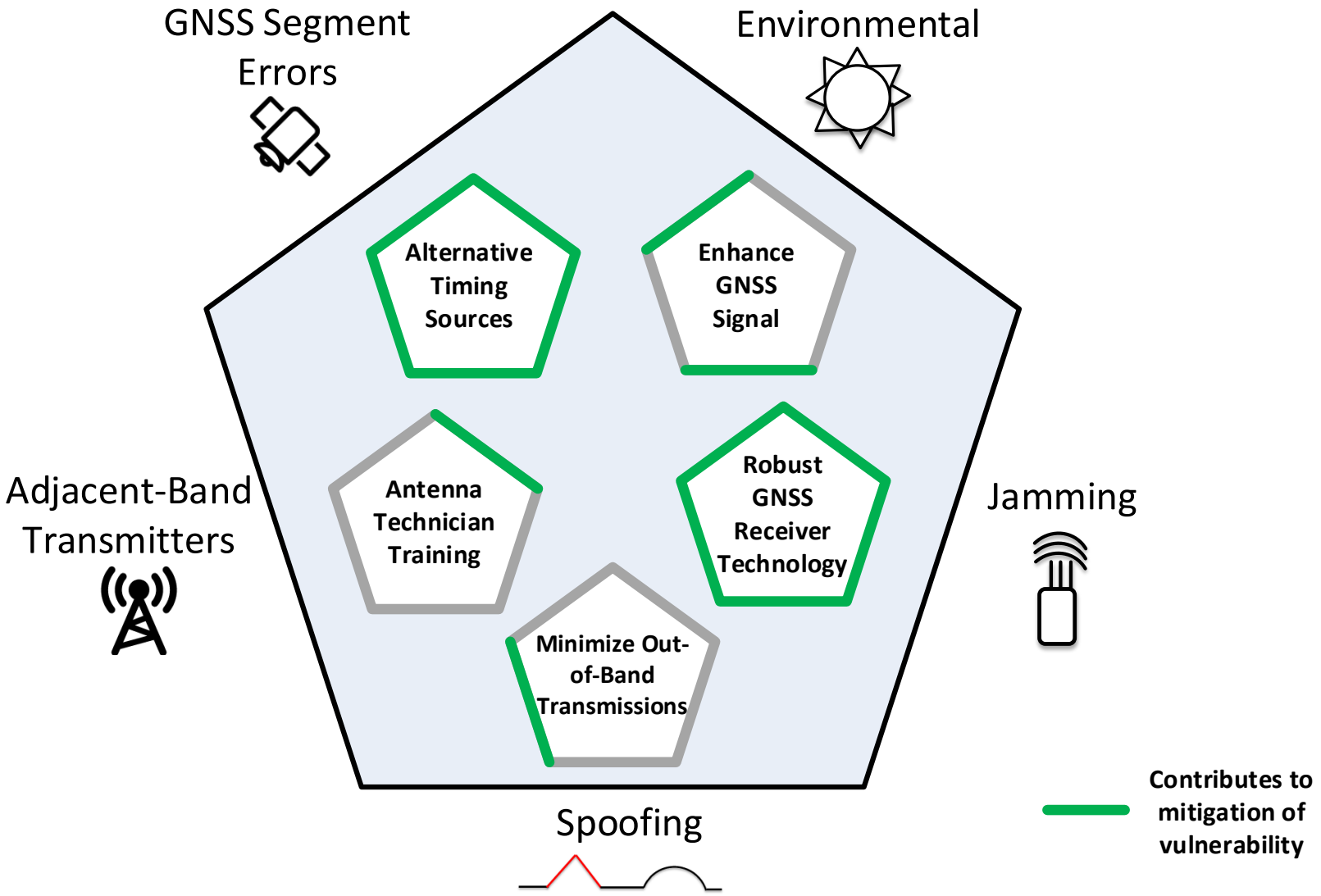
Galileo Anomaly



R1 (blue) Galileo only
R2 (red) Galileo only
R3 (magenta) Galileo only
R4 (green) Galileo only

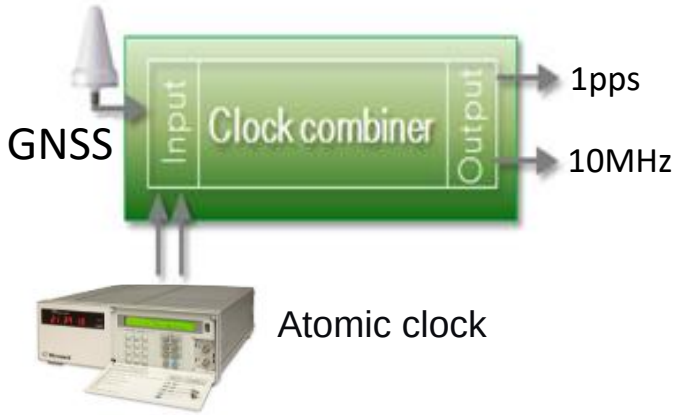
After several days, all four receivers were restarted as Galileo-only. All surveyed to the correct position, and showed consistent and accurate time with minimal wander.

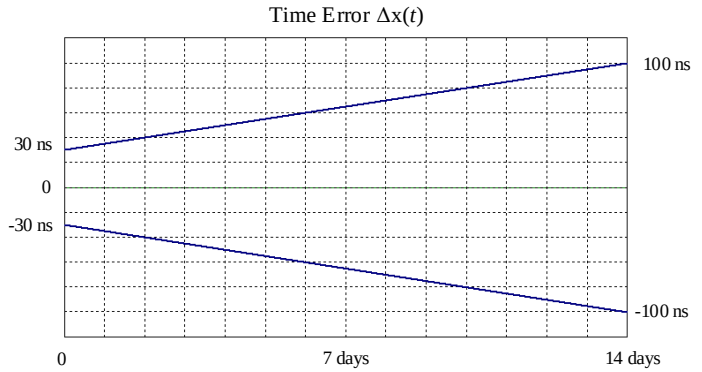
Mitigation of GNSS Vulnerabilities



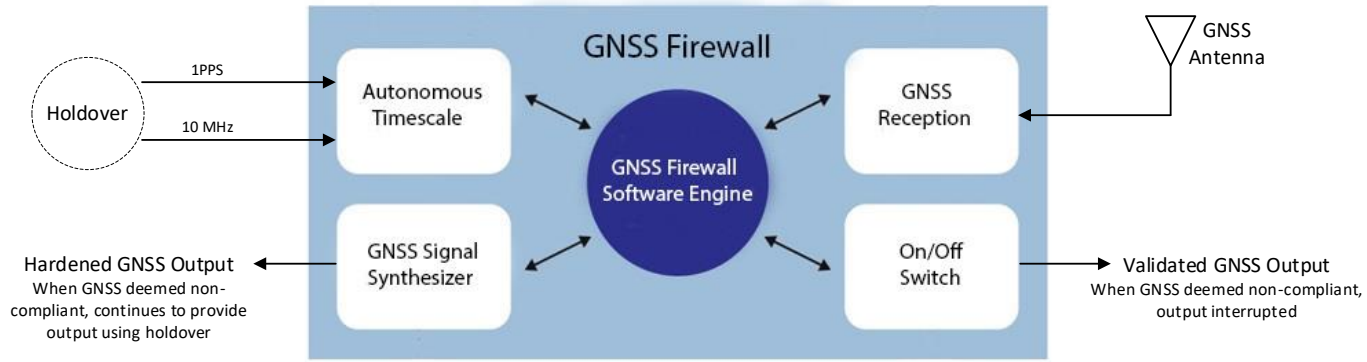
Mitigation of GNSS Vulnerabilities

ePRTC

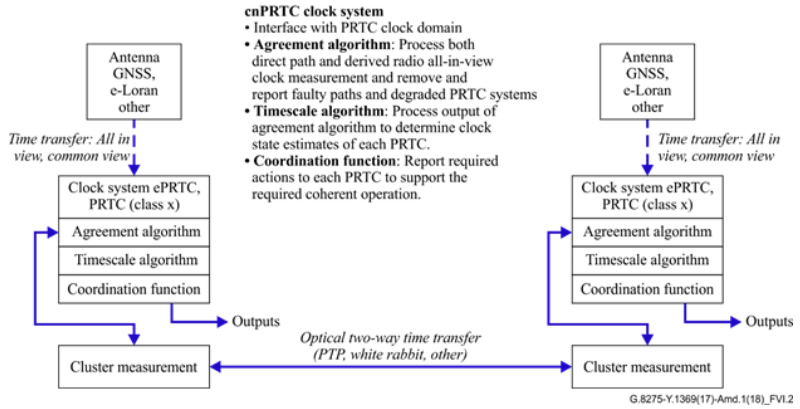


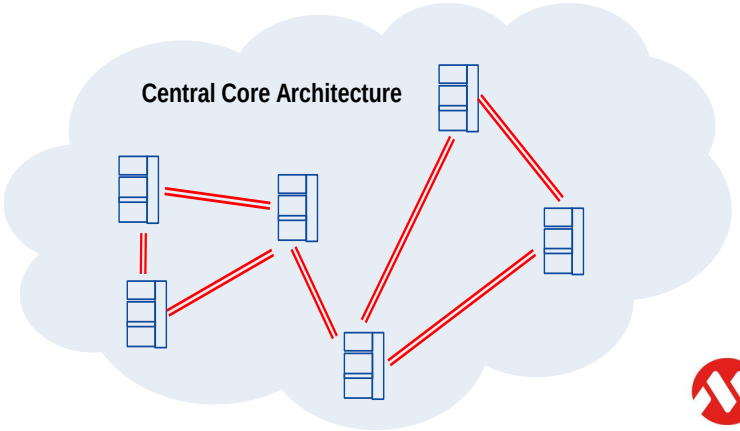


GNSS firewall



cnPRTC





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Summary

- All GNSS systems can experience anomalies, and these anomalies can have an effect on timing receivers.
- These anomalies include jamming, spoofing, adjacent band interference, environmental interference, and GNSS segment errors, the focus of this presentation.
- GNSS segment errors recounted in this presentation included those within the Glonass, GPS, and Galileo systems.
- These range from system malfunctions lasting hours to system outages lasting days.
- Timing systems such as the ePRTC (enhanced primary reference time clock) combining GNSS with an autonomous atomic primary reference clock, the GNSS firewall, and the cnPRTC (coherent network primary reference time clock) provide mechanisms for mitigating these vulnerabilities.

Thank you

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