



Why Leap Seconds are Difficult for a Vendor

- ▶ Inconsistencies in notification date
 - GPS < 6 months
 - NTP needs 24 hours
 - IRIG IEEE-1344 2 – 64 seconds
 - Manual input IERS sends out Bulletin C ~ 6 months in advance
- ▶ Inconsistencies in data presentation
 - GPS leap-second current, leap second pending, effective date
 - NTP Effective date and sign
 - IRIG sign
 - Manual Effective date and sign
- ▶ Leap-second sources added to instrument code sequentially
- ▶ Customer desires for prioritization may be inconsistent
 - Is GNSS primary (which GNSS in the future)?
 - Is the user primary?
- ▶ Serving NTP using an IRIG reference needs manual leap second entry
- ▶ Approach is to rewrite software to a standard leap-second centric view

- ▶ Leap-second information is an ephemeral resource
- ▶ Instrument software using leap seconds developed over decades by multiple developers
- ▶ A software engineer working on instrument code today may add innocuous functionality having no obvious connection with leap seconds (or even timing) and introduces a leap second bug
 - Function produces an event that needs to be logged
 - Logging calls the time stamper
 - The time stamper translates TAI to UTC using leap seconds
 - The function may block if valid information is not available
- ▶ Leap-second test scenarios don't identify code dependencies that later show up in unusual circumstances
- ▶ The problem is being addressed by instrumenting code to identify calls from leap-second aware and leap-second unaware functions
 - Warnings and errors are produced and logged for unaware function calls

- ▶ Use of GPS almanac before checksum computed
 - Takes up to 26 minutes to get full almanac with validity checking
 - Potential to use invalid data
 - Different engines output leap-second information after varying intervals
- ▶ Instruments are forced to gather information from multiple, possibly incorrect, or out of date information
- ▶ Use of leap-second file to supplement time source
- ▶ Leap-second files are out of date when an instrument sits on the shelf for 6 months (and less in the future)
- ▶ Leap-second information may appear out of date due to ICD-GPS-200 implementation errors in GPS engines
- ▶ These are all issues of the ephemeral nature of leap-second information and the difficulty of dealing with it

- ▶ ICD-GP-S200 misinterpretations by engine manufacturers cause incorrect GPS week downloads
 - Novatel, M12 and other Motorola designs
 - These engines periodically transmit incorrect effectivity dates
 - Failure to pass validity checking in instrument code leads to unexpected behavior

- ▶ First 48 hours of the year
 - GPS satellites are uploaded sequentially, some transmitting out of date information
 - No problem for a device that transitioned through the leap second
 - Instruments that start shortly after a leap-second opportunity must make a best guess whether to use leap second current or pending
 - This guess is made with the knowledge that the effectivity date might be wrong due to the ICD-GPS-200 problem
 - Leap-second files are used to aid startup, but easily get out of date and may be corrupted

Incorrect Vendor Assumptions Based on Reverse Engineering



- ▶ That the leap second is effective at the next quarterly opportunity
 - GPS CONOPS had always conformed
 - It did not appear necessary to use the effectivity date
 - Some instruments executed a leap second early due to GPS announcement of the leap second prior to Sept 30 2008
- ▶ That GPS would advance the current leap second after the leap second and **move the effectivity date to the future**
 - GPS CONOPS had always conformed
 - Validity testing of the leap-second information depended on the consistency and currency of the leap-second date
 - Last year, GPS started to leave the effectivity date equal to the last implementation date
 - On June 29 last year, some instruments invalidated GPS broadcast leap-second information due to age and did not update the leap-second file
 - Restarts following that date led to failures due to the lack of an current leap second file.

- ▶ Turn on **in** the first ~2 days following a leap second opportunity (December 31 and June 30)
 - Expired leap-second file
 - Leap second future = leap second current + 1
 - Effectivity date not the next opportunity
 - Can't tell if effectivity date is correct or if the effectivity date has been corrupted by ICD-GPS-200 misinterpretation
 - Can't tell if the SV providing the leap-second information hasn't been uploaded
- ▶ The possibility of mistakes can't be avoided
 - Guess that the satellite has not been uploaded
 - Use the leap-second future value to set the instrument time
 - This is wrong if the information represents a future scheduled leap second

- ▶ Turn on **after** ~2 days following a leap-second opportunity
 - Expired leap-second file
 - Leap second future = leap second current + 1
 - Effectivity date not the next opportunity
 - Can't tell if effectivity date is correct or if the effectivity date has been corrupted by ICD-GPS-200 misinterpretation
 - Can't tell if the SV providing the leap-second information hasn't been uploaded
 - We assume that the effectivity date is corrupt
- ▶ The possibility of mistakes can't be avoided
 - Guess and use leap second current to set the instrument time
 - Schedule a leap second at the next opportunity
 - This is wrong if the satellite has not been uploaded
- ▶ The use of 2 days is arbitrary and is not guaranteed

- ▶ Problems with vendors simply not understanding how to implement leap seconds are principally a thing of the past
- ▶ Current leap-second issues primarily result from
 - Legacy code that was not designed for leap seconds from the ground up
 - Un-testable leap second issues due to unsuspected leap-second dependencies
 - Errors in legacy GNSS engines
 - Ambiguities resulting from operational difficulties that prevent timely GNSS satellite uploads
- ▶ Modern instruments are designed around leap-seconds from the start
- ▶ Most leap-second problems will go away as legacy hardware, firmware, and software are updated
- ▶ But, it will still take quite a long time...