

SVN 23 – What Happened? (aka ‘UTC Anomaly Event’)



ITSF

Prague, Czech Republic

1st – 3rd November 2016

Charles Curry BEng, CEng, FIET, FRIN

Chronos Technology Ltd

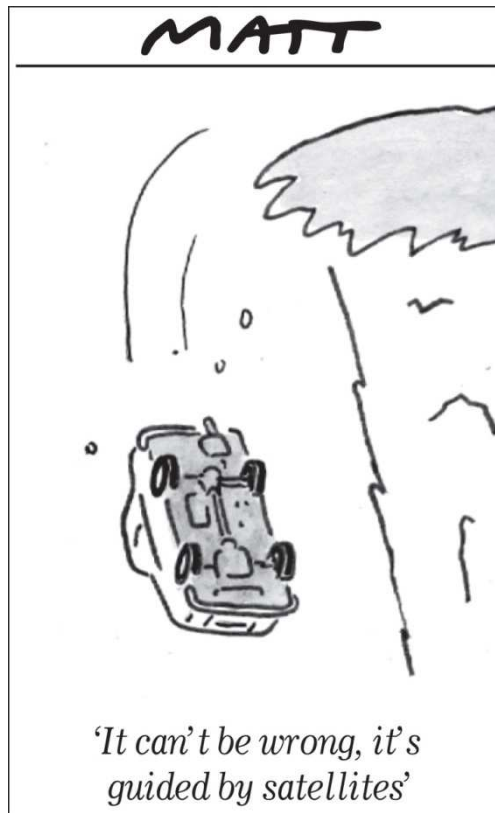
Black Swan Events



Nassim Nicholas Taleb
2007 “The Black Swan”

- **Surprise** to the **observer**
- **Significant impact**
- With **hindsight** – could have been **predicted**.
- **Not necessarily a surprise to all**

What can possibly go wrong?



'Matt Cartoon, The Daily Telegraph © Telegraph Media Group Limited'

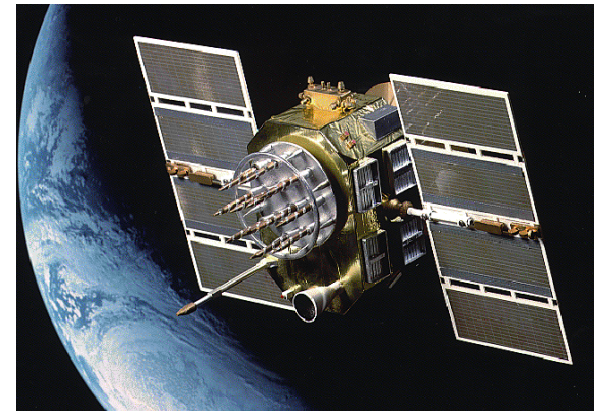
<http://www.telegraph.co.uk/news/matt/>

Presentation Contents

- SVN-23 PRN-32 – A Classic Bird – but not a Black Swan!
- Previous History
- A GPS Black Swan – The early stages
- Understanding and Clearing Up
- Impacts on networks and receivers
- Mathematical derivation of the UTC anomaly
- Similar Events & Conclusions

SVN-23 – A Classic Bird!

- What car were you driving in 1990?
- Launched Nov 1990, Cape Canaveral
- 1st of the Block IIA's
- USA-66
- Satellite Vehicle Number 23
- Originally PRN23
- Decommissioned Feb 2004
- Set Useable Feb 2008 – PRN32

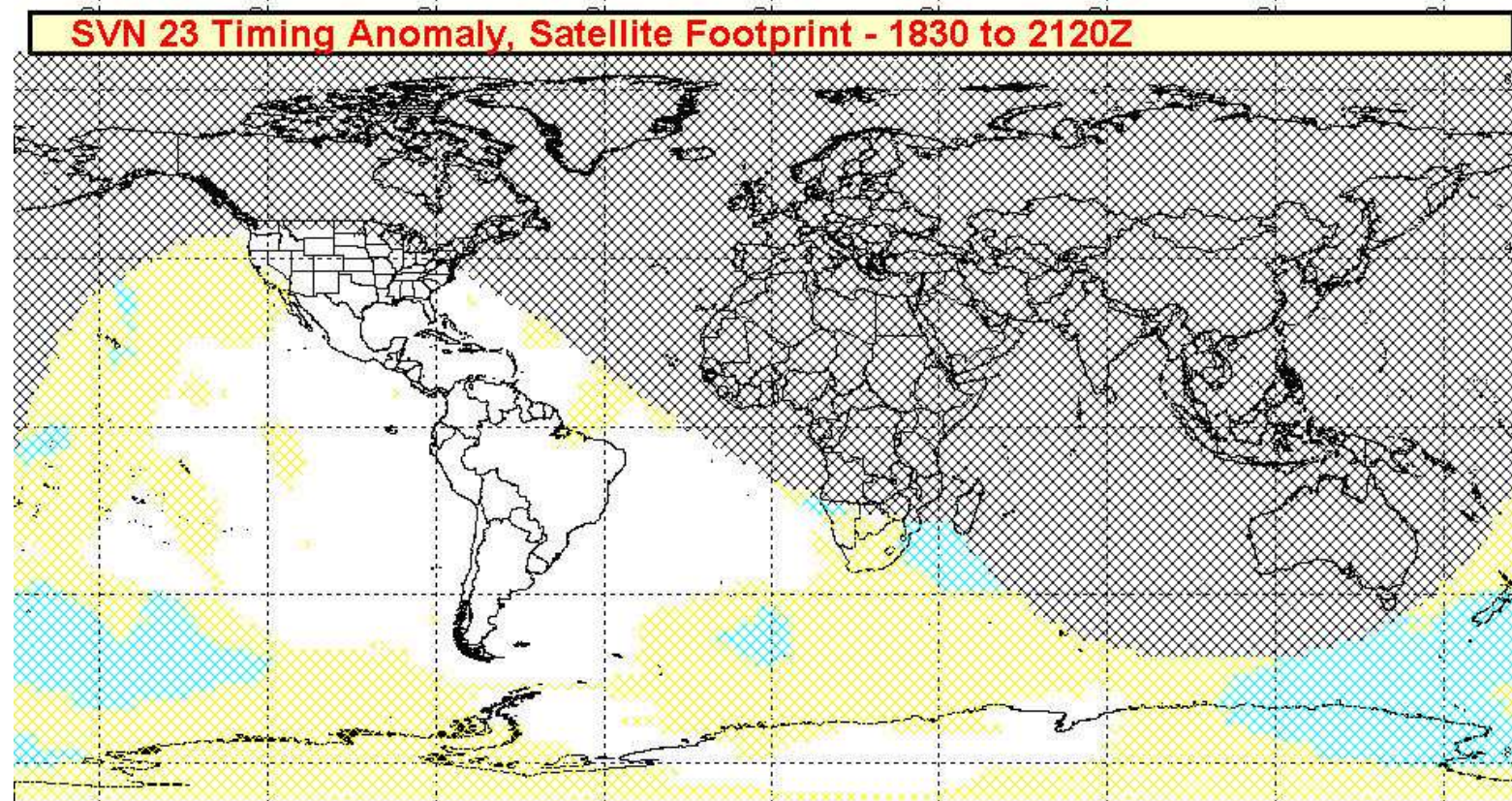


Previous History Of SVN23

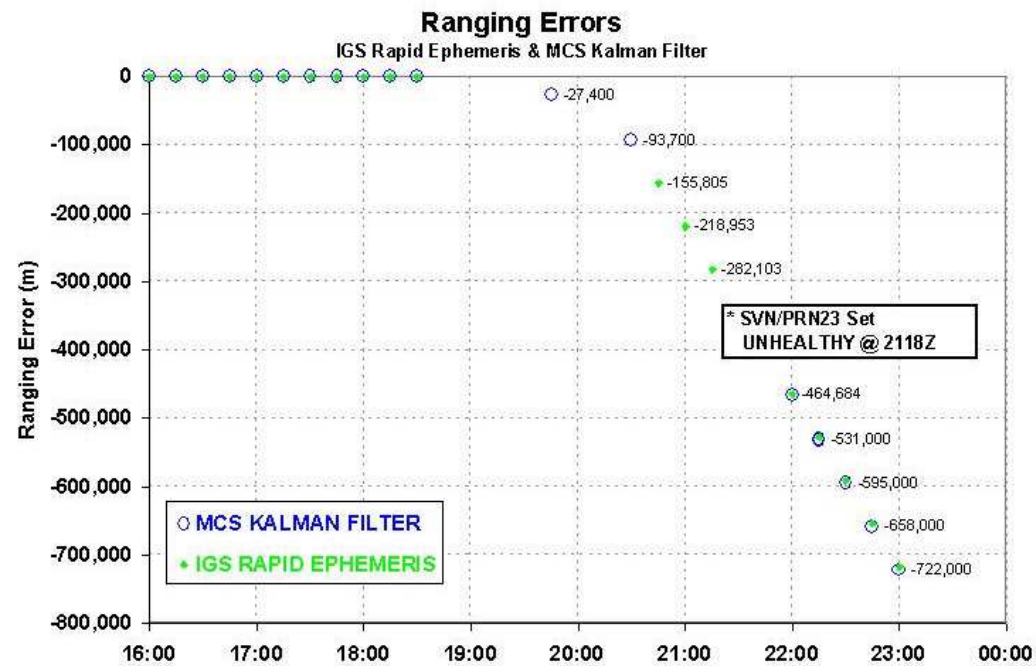
- 1st January 2004 – Remember?
- PRN23 Atomic Clock failure
- Major GPS failure in BT network
- NANU2004001
- Returned to service using another clock January 20th NANU2004008
- Retired Feb 2004
- Reactivated Feb2008 at PRN32

Thanks to Wikipedia and NANU Archives at NAVCEN

Affected Area



Plot shows progressive failure



Plot Courtesy of Boeing

SVN23 - 26th January 2016



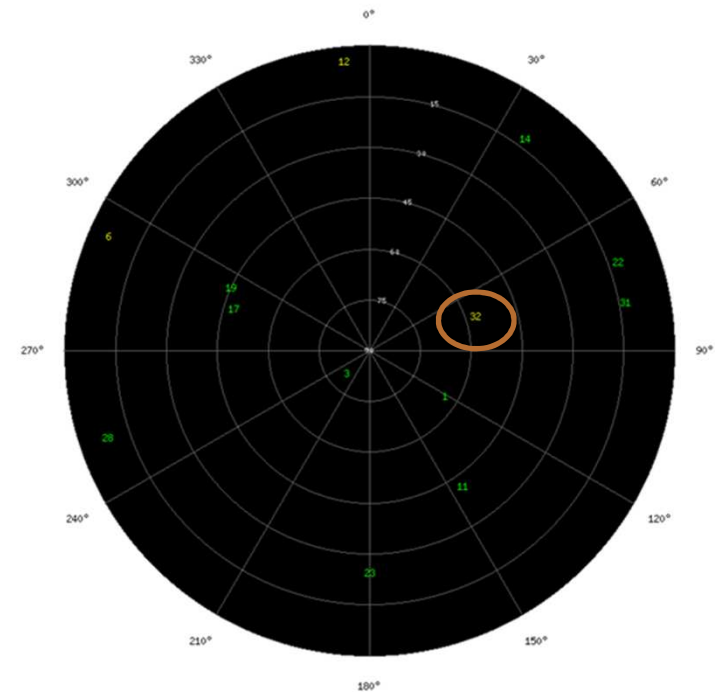
- Alarms at a major UK NOC early hours 26th
- Red lights all over – Panic!
- GPS signal into SSU disqualified
- Loads of system across the country in holdover!
- What was going on?
- Now we know.....but then it was OMG!

Where was PRN32?

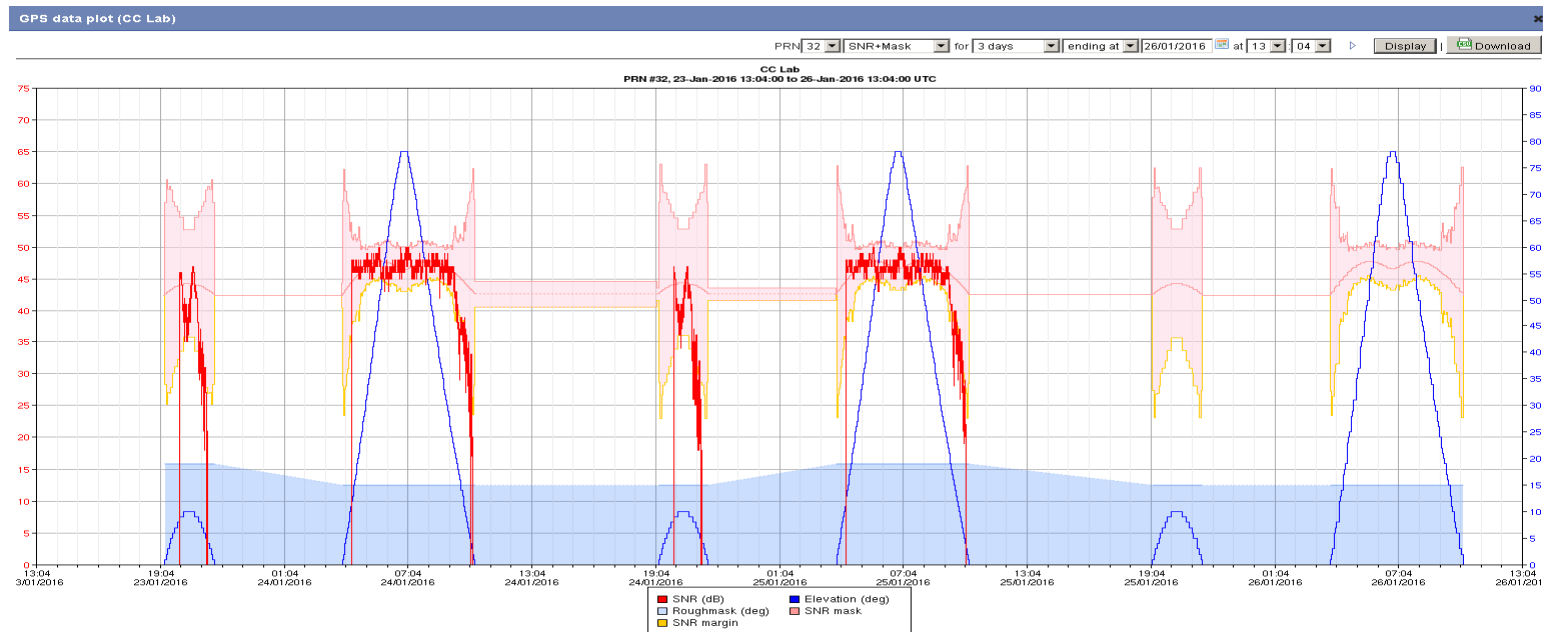


- Someone said PRN32 had disappeared!
- Not been watching NANU's
 - Retired from Service NANU 2016008 25th Jan
- Sky plot at 7:51 UTC 26th

GPS sky view (sw200135 - 2016-01-26 07:51:59)



PRN32 Definitely not there!



University of Bath algorithm in the Chronos SENTINEL GPS Interference monitoring system

Chronos Support Team – 26th



- 00:21 UTC 1st alarm message logged @ CTL
- 02:00 UTC 1st call to CTL Support Manager
 - Clearly a major GPS problem!
- 07:49 UTC NAVCEN report “problem”
- 08:00 UTC other customers calling in
- 09:30 UTC proactive call around
- 13:10 UTC NAVCEN “resolve” problem
- 14:00 UTC phone contact with NAVCEN
- 09:00 UTC Weds 27th calls still coming in
- 02:00 UTC Thurs 28th last events logged
- Friday 29th – finally cleared all event logs



Event Summary

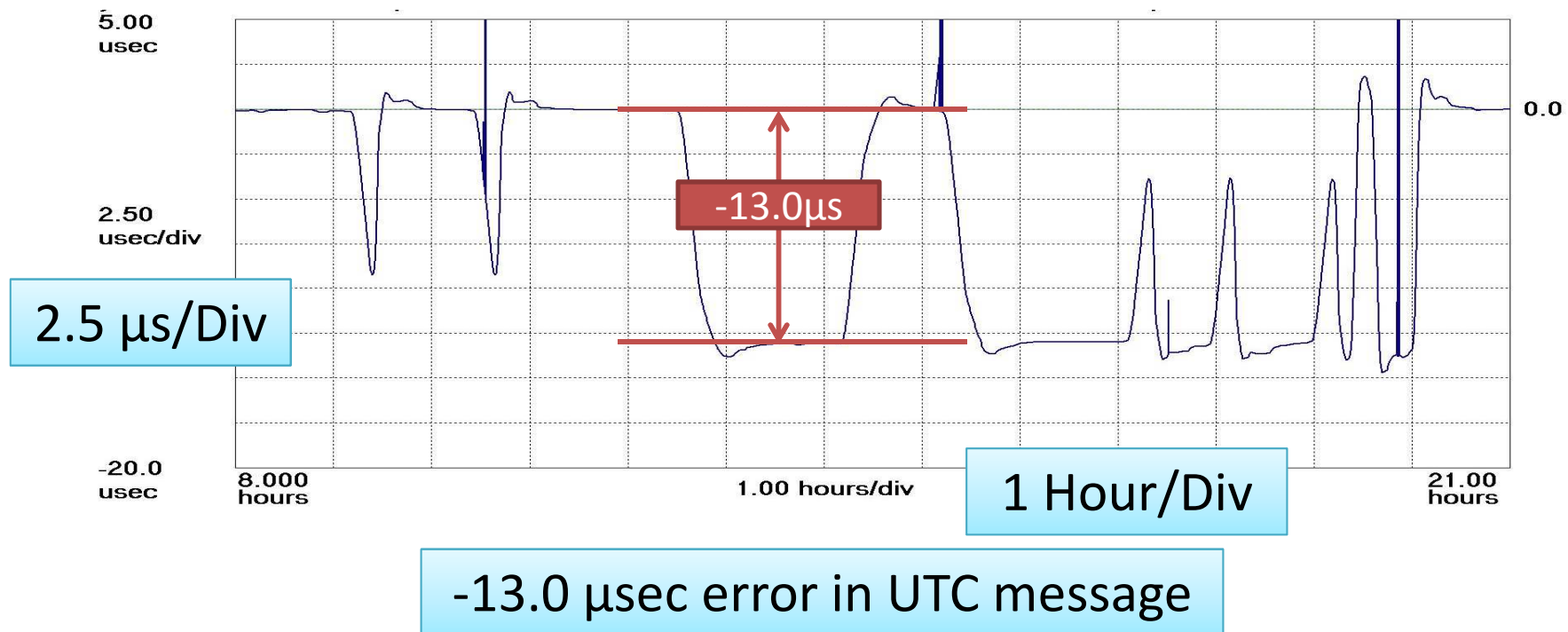


	Network Type	Region	Qty GPS Elements	Notes
Customer A	Fixed Line	UK	Large	Generated nearly 2000 alarms and standing condition events throughout duration
Customer B	Transport Comms	UK	Small	Customer in panic mode as systems in holdover
Customer C	Fixed Line	Global	Large	Nearly 2500 alarms generated during event. Roughly 40 elements entered holdover due to lack of backup inputs.
Customer D	Fixed Line	UK	Small	Element in holdover
Customer E	Transport Comms	UK	Small	TimeSource only systems. Caused local switches to go into free run.
Customer F	Mobile	UK	Medium	No adverse impact. All systems have backup network feeds and Rb clocks
Customer G	Private Network	UK	Small	System backed up by Caesium
Customer H	Mobile	UK	Medium	Difficult to determine number of affected elements but majority of elements have backup sync feeds taken from another Telecom operator.
Customer I	Fixed Line	Sweden	Medium	Affected all SSU 2000 units
Customer J	Mobile	UK	Medium	Some TimeSource inputs reporting high MTIE and MTIE alarms on SSU2000
Customer K	Mobile	UK	Medium	All SSU2000 disqualified GPS inputs. Systems reverted to line timing traceable to another carrier

Impacts on Receivers

- Some receivers impacted, some not
- Not all receivers of the same design impacted
- Did not impact navigation (RTK) receivers
- TRAIM had some mitigating effect
- Some receivers showed a $-13.0\mu\text{sec}$
- Some did not. Hmmmm...
- Finally a Statement from USAF
 - But not until the 27th Jan

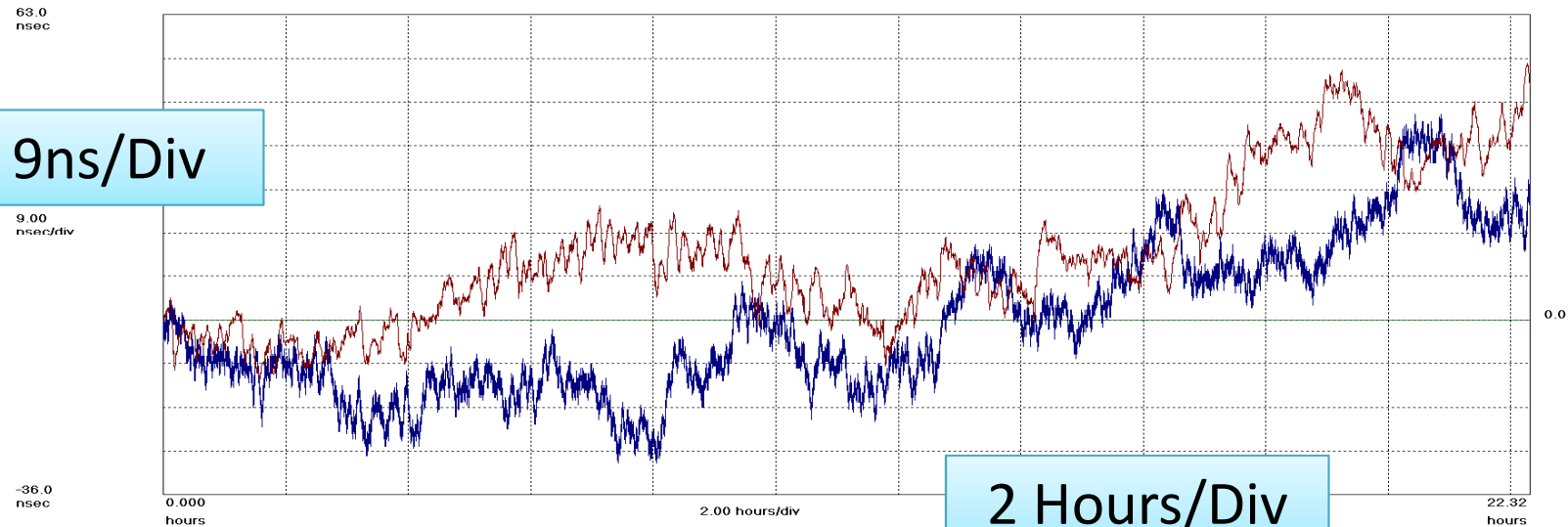
Impact and Duration – 26th



Some GPS Rx Not Impacted



Microsemi TimeMonitor Analyzer
Phase deviation in units of time: Fs=999.2 mHz; Fo=1.0000000 Hz; 2016/01/26; 18:15:44
1 (blue): HP 53132A; Test: 1355; A: CCLab; B: PRS45A; GPS 1pps; Samples: 80289; Gate: 1 s; Ref ch2: 10.00 MHz; TI/Time Data Only; TI 1->2: 53131A sn 13743; 2016/01/26; 18:15:44
2 (red): HP 53132A; Test: 1354; A: CCLab; B: PRS45A; eLoran E 1pps; Samples: 80289; Gate: 1 s; Ref ch2: 10.00 MHz; TI/Time Data Only; TI 1->2: 53132A sn 3944; 2016/01/26; 18:15:44



9ns/Div

2 Hours/Div

Blue GPS, Red eLoran

GPS v eLoran

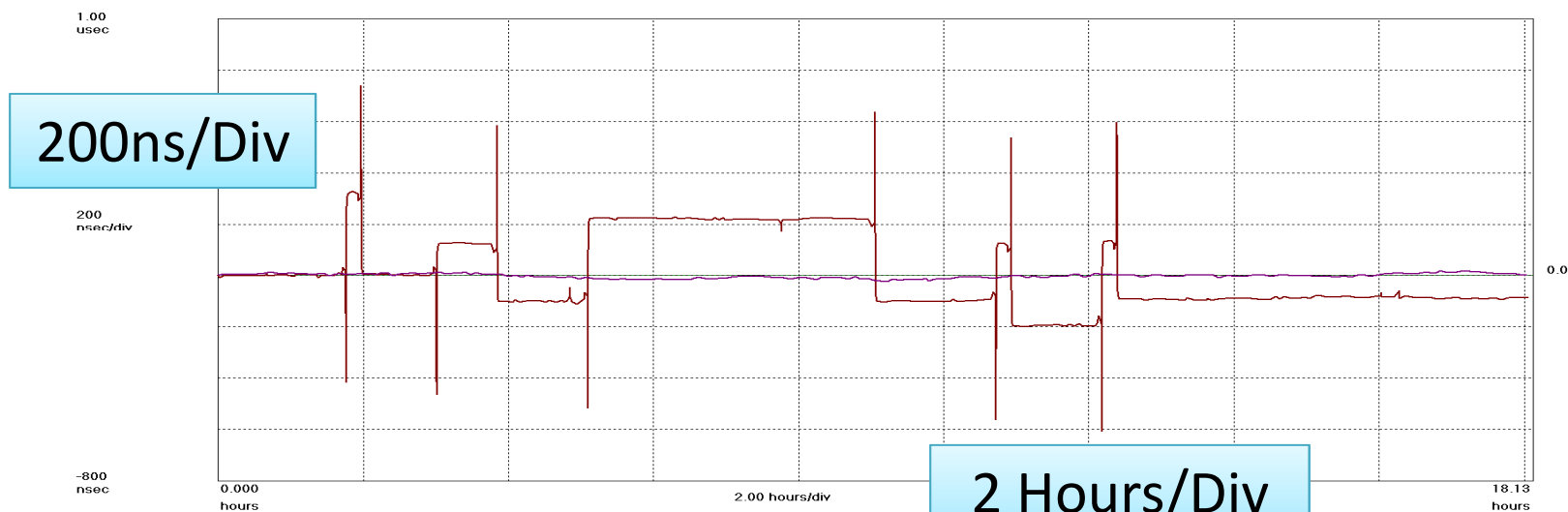


Microsemi TimeMonitor Analyzer

Phase deviation in units of time: Fs=996.0 MHz; Fo=1.0000000 Hz; 2016/01/26; 00:00:28

2 (red): Agilent 53220A; Test: 755; A: CsWatch; B: PRS45A; GPS 1pps; Samples: 65001; Gate: 1 s; Start: 25600; Stop: 90600; Total Points: 148483; Ref ch2: 10.00 MHz; TI/Time Data Only; TI 1->2: 172.31.2.55; A-53230A-C

3 (magenta): HP 53132A; Test: 1346; A: CCLab; B: PRS45A; eLoran E 1pps; Samples: 65071; Gate: 1 s; Start: 286000; Total Points: 351070; Ref ch2: 10.00 MHz; TI/Time Data Only; TI 1->2: 53132A sn 3944; 2016/01/26; 2;



TRAIM mitigates
No Impact on eLoran

USAF Statement – 27th Jan 2016



The [official USAF press release](#) stated:

“On 26 January [2016] 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.

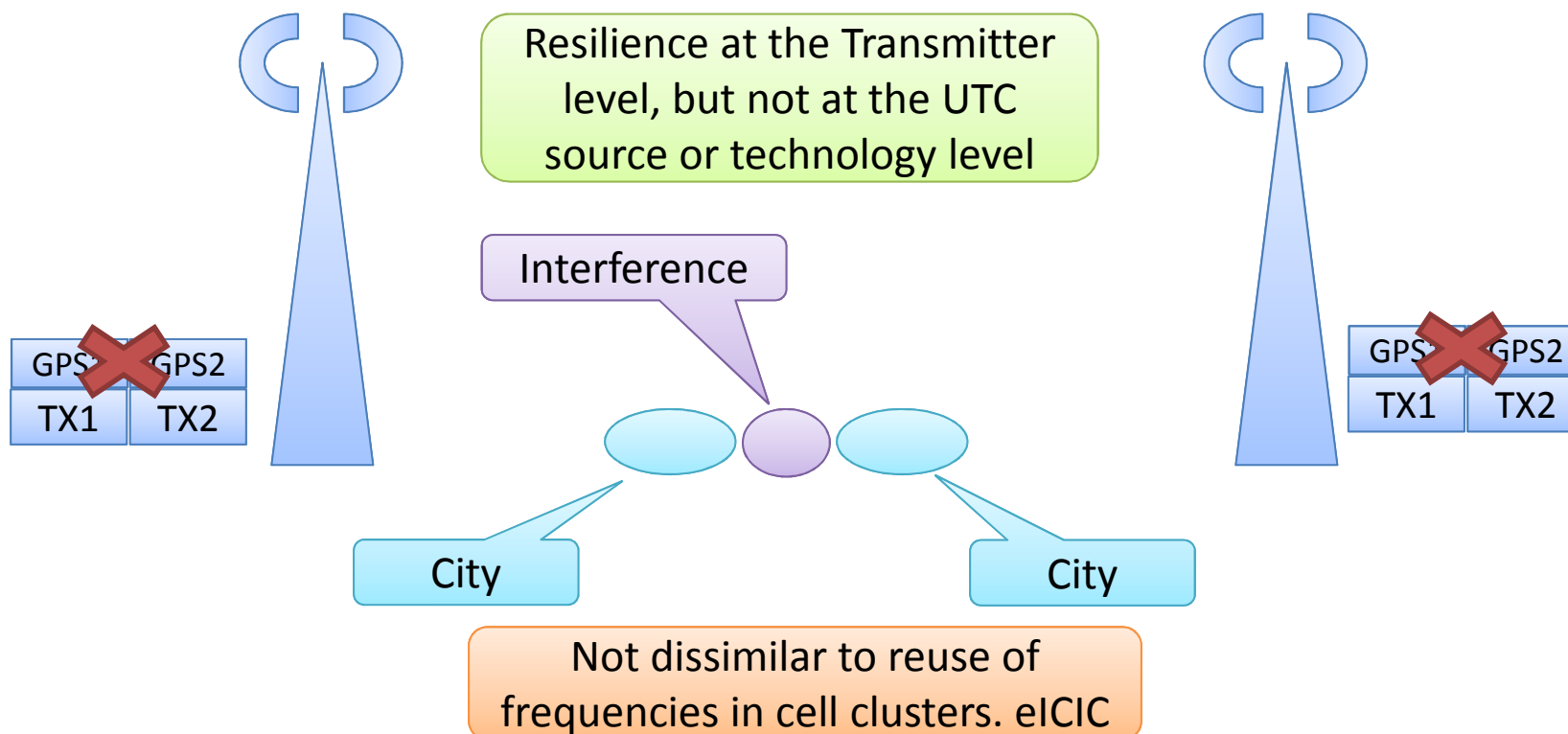
The issue was resolved at 6:10 a.m. MST, however global users may have experienced GPS timing issues for several hours. U.S. Strategic Command’s Commercial Integration Cell, operating out of the Joint Space Operations Center, effectively served as the portal to determine the scope of commercial user impacts. Additionally, the Joint Space Operations Center at Vandenberg AFB has not received any reports of issues with GPS-aided munitions, and has determined that the timing error is not attributable to any type of outside interference such as jamming or spoofing. Operator procedures were modified to preclude a repeat of this issue until the ground system software is corrected, and the 50th Space Wing will conduct an Operational Review Board to review procedures and impacts on users. Commercial and Civil users who experienced impacts can contact the U.S. Coast Guard Navigation Center at 001 703 313 5900.”

Press Coverage

- **“GPS Glitch Caused Outages, Fuelled Arguments for Backup” – 29th Jan 2016**
 - <http://www.insidegnss.com/node/4831>
- **“UK radio disturbance caused by satellite network bug” - 2nd Feb 2016**
 - <http://www.bbc.co.uk/news/technology-35463347>
- **“Lights out for Space Vehicle Number 23: UK smacked when US sat threw GPS out of whack” - 3rd Feb 2016**
 - http://www.theregister.co.uk/2016/02/03/decommissioned_satellite_software_knocks_out_gps/



Impact on DAB SFN

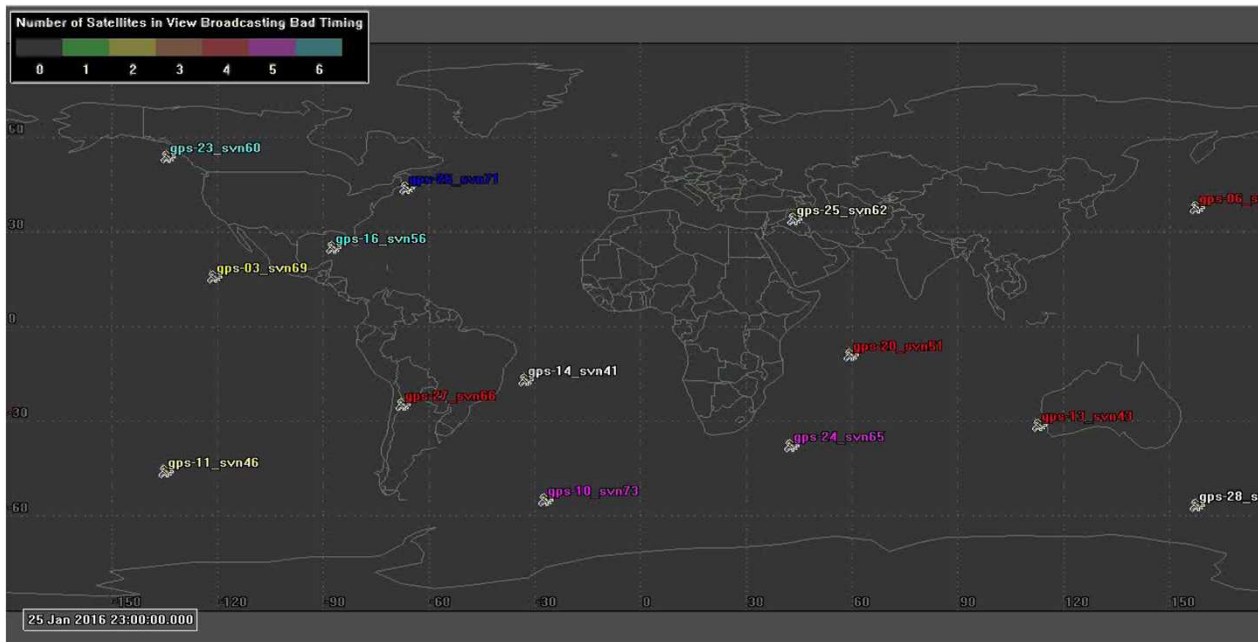


Early Leads on the UTC Anomaly

- <http://www.leapsecond.com/time-nuts.htm>
- 1st blog - Paul Boven
 - *Tue Jan 26 10:12:41 EST 2016 -13.7μs jump*
- Martin Burnicki - Meinberg
 - *Wed Jan 27 11:49:52 EST 2016*
 - *Confirmed that the A_0 term had moved -13.696*
- Refers to UTC time in IS-GPS-200H
 - $\Delta t_{UTC} = \Delta t_{LS} + A_0 + A_1(t_E - t_{ot} + 604800(WN - WN_t))$
 - Seconds
- Early lead from Marc Weiss indicated a week number issue
 - Related to the SVN23 retirement event
- Origin of the -13.0 μs remained an elusive computation!

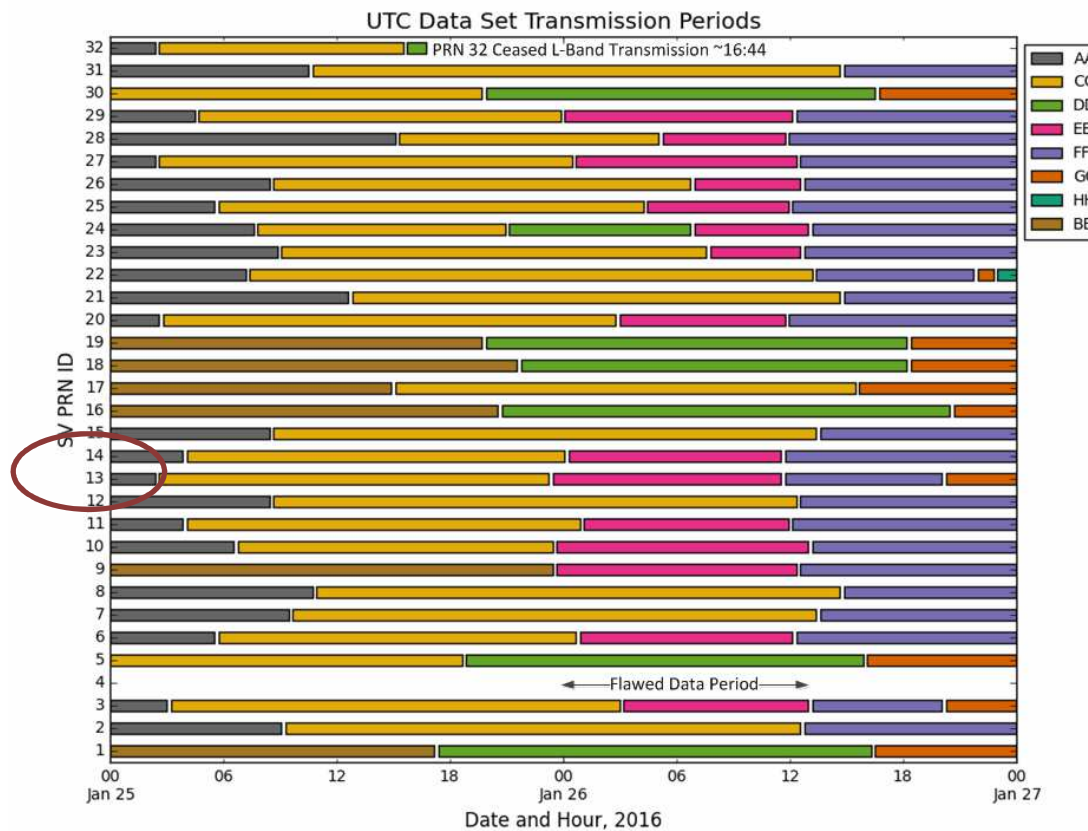
sv	sfw7	sfw8	wnt tot	a0 bits	a0[us]
09	0x3FFFF1B3	0x23800017	--> 00 000000:	0xFFFFC68E	-13.696 *
07	0x3FFFFFEA	0x3FD3967B	--> 89 319488:	0xFFFFFFFF	-0.001
02	0x3FFFFFD5	0x3FD39644	--> 89 319488:	0xFFFFFFFF	-0.001
06	0x3FFFF18C	0x23800028	--> 00 000000:	0xFFFFC68E	-13.696 *
23	0x3FFFF18C	0x23800028	--> 00 000000:	0xFFFFC68E	-13.696 *
30	0x00000000	0x00139664	--> 89 319488:	0x00000000	+0.000
05	0x0000003F	0x0013965B	--> 89 319488:	0x00000000	+0.000
16	0x00000000	0x00139664	--> 89 319488:	0x00000000	+0.000
26	0x3FFFF18C	0x23800028	--> 00 000000:	0xFFFFC68E	-13.696 *

Analytical Graphics Video



Courtesy Ted Driver at
Analytical Graphics via
John Lavrakas

<https://dl.dropboxusercontent.com/u/22447827/Videos/GpsBadTiming2DMap.wmv>

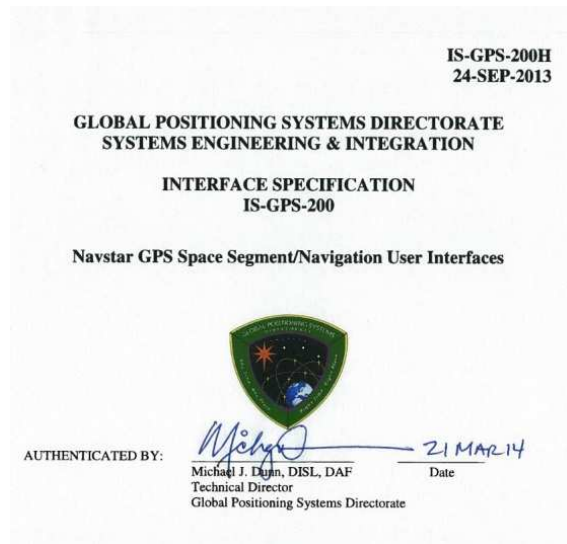


ION 2016 Portland OR GPS Receiver Impact from the UTC Offset (UTC0) Anomaly of 25-26 January 2016

*Karl Kovach, Philip J. Mendicki,
The Aerospace Corporation; Ed
Powers, US Naval Observatory;
Brent Renfro, ARL, The
University of Texas at Austin*

**EE Dataset Value of Δt_{UTC} was
-13.025 μs
Shown pink and impacted 15
satellites**

Calculating the UTC Offset



$$\Delta t_{UTC} = \Delta t_{LS} + A_0 + A_1(t_E - t_{ot} + 604800(WN - WN_t)), \text{ seconds}$$

Where:

Δt_{LS} = current leap second

t_E = GPS receiver's estimate of current GPS TOW

t_{ot} = reference time for UTC data secs in week

604800 = number of seconds in a week

WN = current full GPS week number

WN_t = UTC reference week number

Page 123 - Section 20.3.3.5.2.4
Coordinated Universal Time (UTC)

Let's use real data

Values are taken from the navigation message from SVN43/PRN13 (one of the first satellites to be impacted) for times before the event (23:13) and during (23:26)

$$\Delta t_{UTC} = \Delta t_{LS} + A_0 + A_1(t_E - t_{ot} + 604800(WN - WN_t))$$

Date	Time	$\Delta t_{UTC} \mu s$	Δt_{LS}	A_0	A_1	t_E	t_{ot}	WN	WN_t
25 Jan	23:13	-0.002	17s	-9.93132e-10	5.33e-15	170034	319488	89	89
25 Jan	23:27	-13.025	17s	-1.3696e-05	1.24e-14	170874	0	89	0

Data and method courtesy John Lavrakas

So What Happened?

- A Satellite retirement event triggered the anomaly
 - The SVN23 retirement in particular, but we should not blame SVN23!
- Previous retirements had gone OK...So?
 - So (I) assume procedure not followed or operator error
 - NAVCEN and 2SOPS understandably coy about this
 - A software bug was triggered by zeroing out the satellite's database values **before** removing the satellite from the database
 - In every other case prior, the satellite was **removed first**, and so we never saw the problem
- Not looking for scapegoats
 - GPS is an incredible machine
 - The guys that fly and fix GPS are an incredible team

...and why not all receivers?

- Mitigation due to RAIM effects
- Did not need new ephemeris during event?
 - or collected from a 'good' satellite
- Recognition of flawed UTCO data e.g. outside 'fit interval'
 - squelch GPS, ignore, mark GPS unhealthy
- Ideal topic for further research and testing!

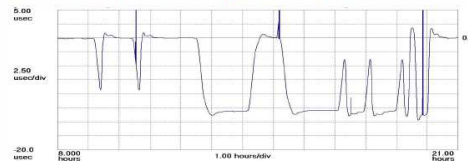
Case Study & Further Reading



GPS Anomaly Event - 26 January 2016



GPS Satellite Vehicle Number (SVN) 23 launched in 1990 was retired from service in January 2016. It had occupied Pseudo-Random Noise (PRN) sequence 32 since 2008. According to NAVAIR 2016008 it was marked unusable at 15:36 UTC on 25th January and decommissioned at 22:00 UTC later that same day. Unfortunately (for reasons not yet fully known) the UTC signal on some satellites was off by 13 microseconds. This Case Study charts the activity undertaken by the Chronos support team during and after this unprecedented GPS anomaly event. For some with long memories this is not the first time that SVN23 has caused a problem. The last time was 1st January 2004. The trace below shows how the anomaly event impacted one particular GPS timing receiver over an extended period during the day.



The official USAF press release stated:

"On 26 January [2016] 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. U.S. Strategic Command's Commercial Integration Cell, operating out of the Joint Space Operations Center, effectively served as the portal to determine the scope of commercial user impacts. Additionally, the Joint Space Operations Center at Vandenberg AFB has not received any reports of issues with GPS-aided munitions, and has determined that the timing error is not attributable to any type of outside interference such as jamming or spoofing. Operator procedures were modified to preclude a repeat of this issue until the ground system software is corrected, and the 50th Space Wing will conduct an Operational Review Board to review procedures and impacts on users. Commercial and Civil users who experienced impacts can contact the U.S. Coast Guard Navigation Center at 001 703 313 5900."

You can also log your experience [here](#)

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- [SVN 23 Case Study](#)
- [RAEng Report on GNSS Vulnerabilities](#)
- [RAEng Report on Space Weather](#)

CASE STUDY

Glomass in 2014



- Glonass 1st April 2014
 - All satellites broadcast corrupt data for 11 hours
 - Massive positional errors
- Glonass 14th April 2014
 - 8 satellites set unhealthy for 30 minutes
- Press Coverage
 - <http://gpsworld.com/the-system-glonass-fumbles-forward/>
 - <http://gpsworld.com/the-system-glonass-in-april-what-went-wrong/>



Conclusion

- SVN23 was a wake-up call for single UTC traceability solutions
- A true Black Swan!
- Ignore mitigation options at your peril
 - Network backup – PTP, SyncE
 - Another GNSS
 - Another off-air UTC Traceable PNT e.g. eLoran
- Preferably 3 dissimilar sources of UTC over 3 dissimilar technological routes





Thankyou

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