SVN 23 – What Happened?

CGSIC
Portland, Oregon, USA
12th – 13th Sept 2016

Prof. Charles Curry BEng, CEng FIET, FRIN
Chronos Technology Ltd
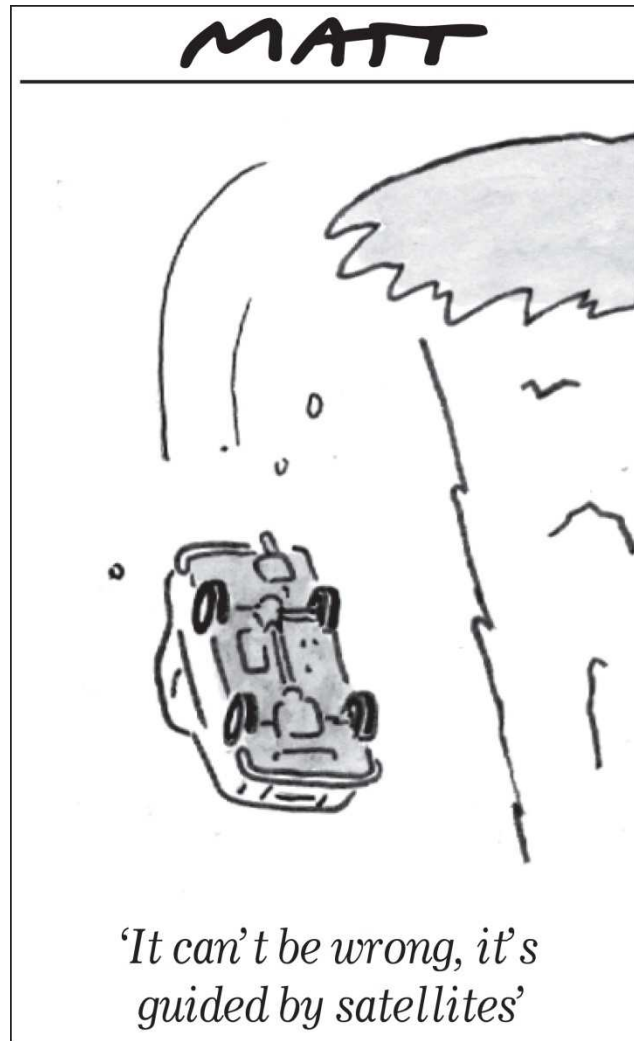
Black Swan Events

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?

'It can't be wrong, it's guided by satellites'

'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

- Graceful retirement….or not!

- A GPS Black Swan – The early stages

- Understanding and Clearing Up

- Impacts on networks and receivers

- 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
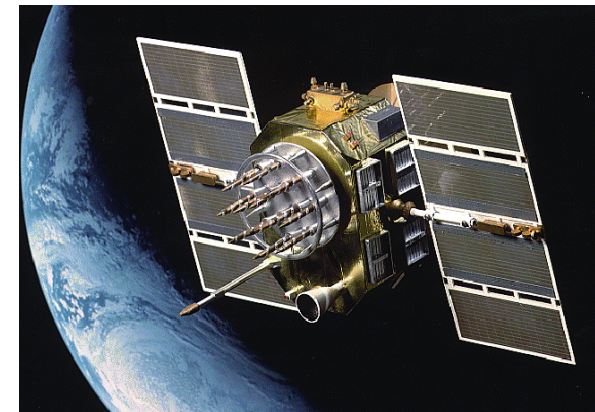
Previous History 0f SVN23

- 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

SVN 23 Timing Anomaly, Satellite Footprint - 1830 to 2120Z
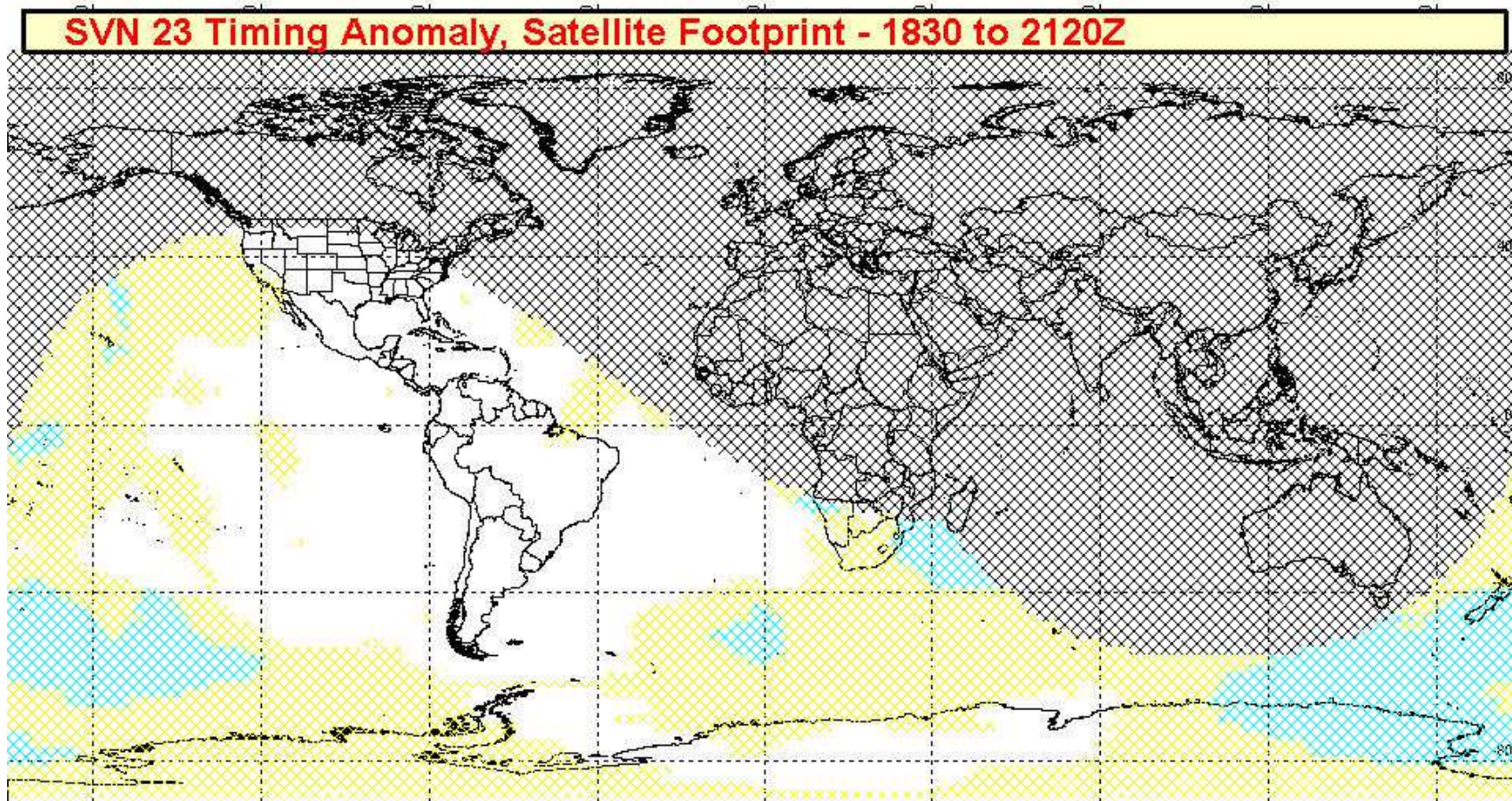
Plot shows progressive failure
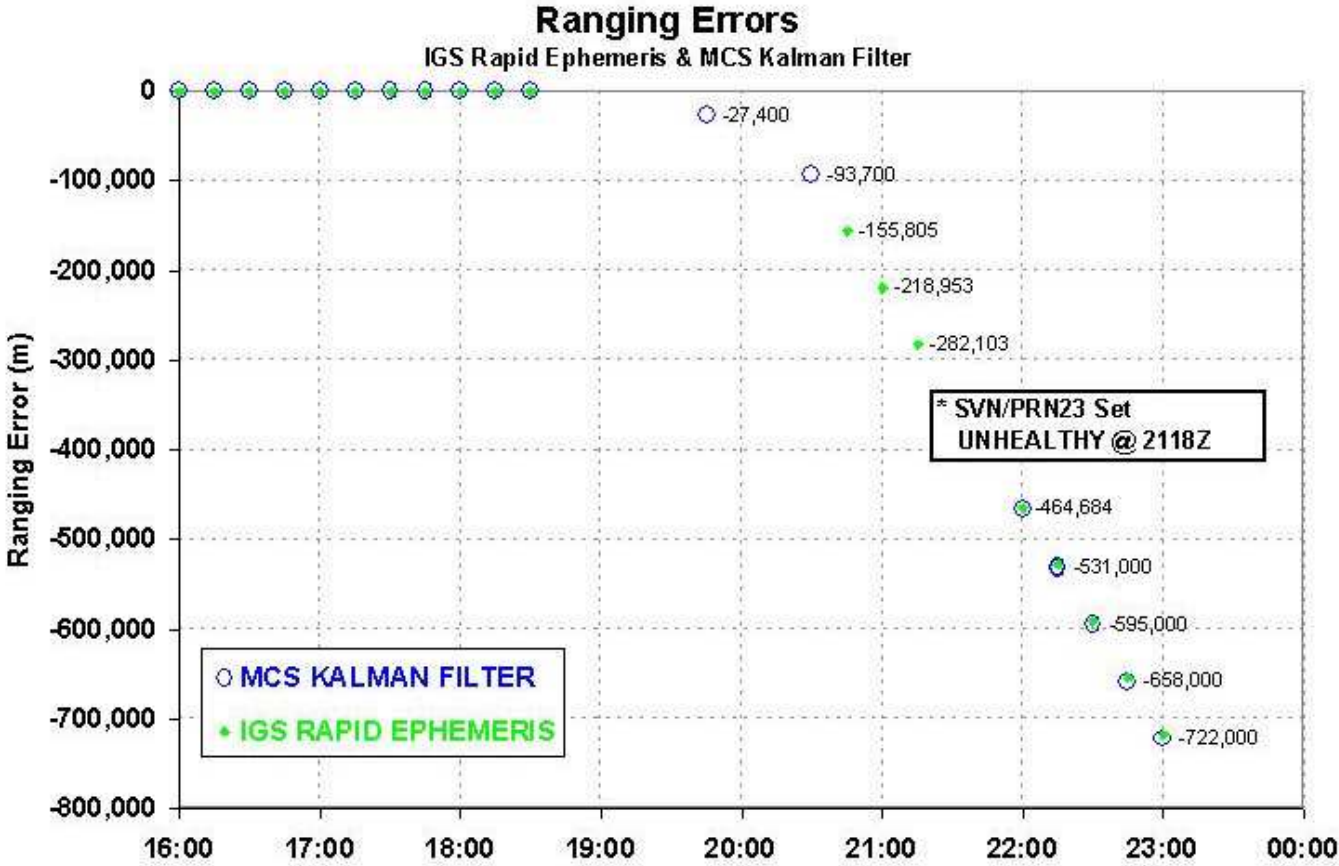
SVN23 - 26th January 2016

- Alarms at a major UK NOC early hours 26th

- Red lights all over – Panic!

- GPS signal into SSU disqualified

- Loads of systems across the country in holdover!

- What was going on?
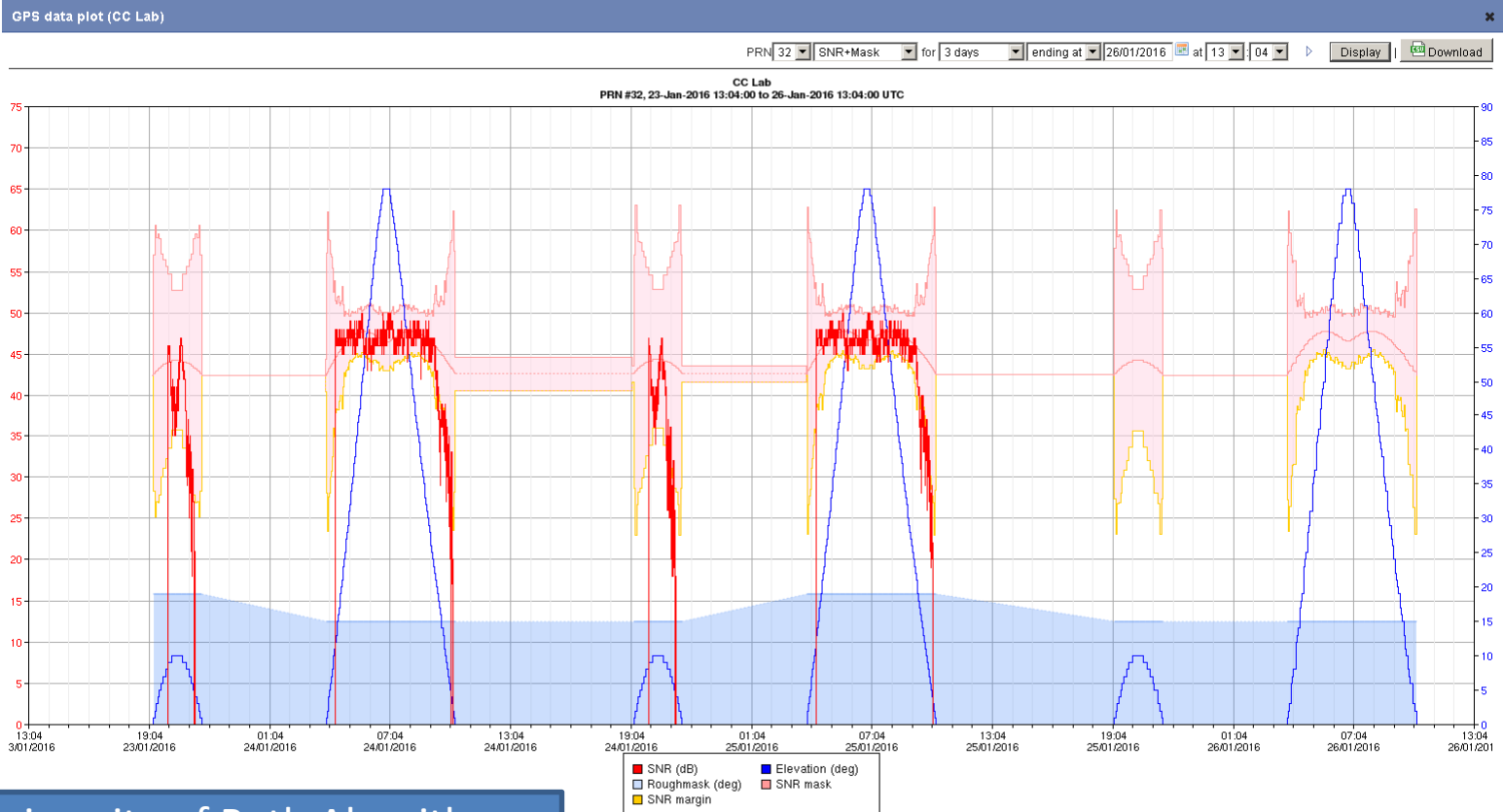
- Now we know…..but then it was OMG!

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)
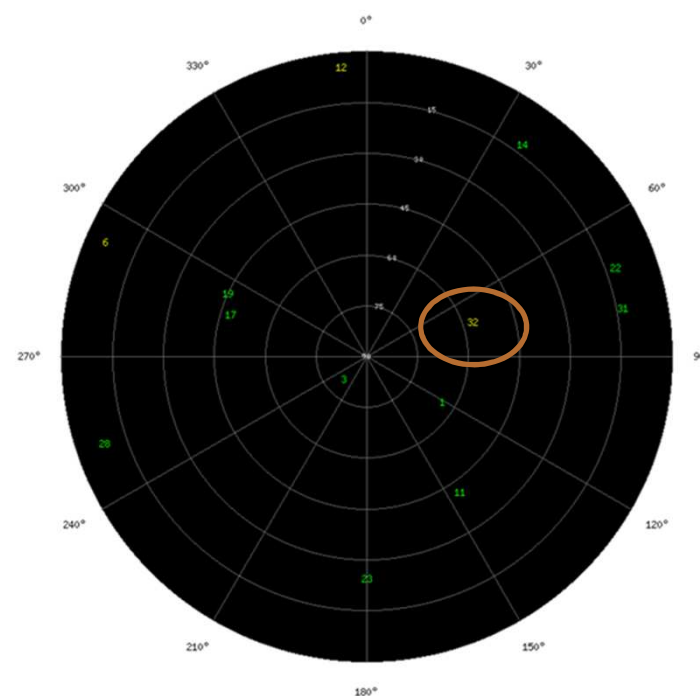
PRN32 Definitely not there!

University of Bath Algorithm
in SENTINEL sensor

Time-Nuts Blog

- http://www.leapsecond.com/time-nuts.htm

- 1st blog - Paul Boven

  - *Tue Jan 26 10:12:41 EST 2016 -13.7µsec jump*

- *Martin Burnicki - Meinberg*

  - *Wed Jan 27 11:49:52 EST 2016*

```
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 *
```

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 27th calls still coming in
- 02:00 UTC 28th last events logged
- 09:00 UTC took 4 hours to clear event log

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 the -13.7µsec
- Some did not. Hmmmm…
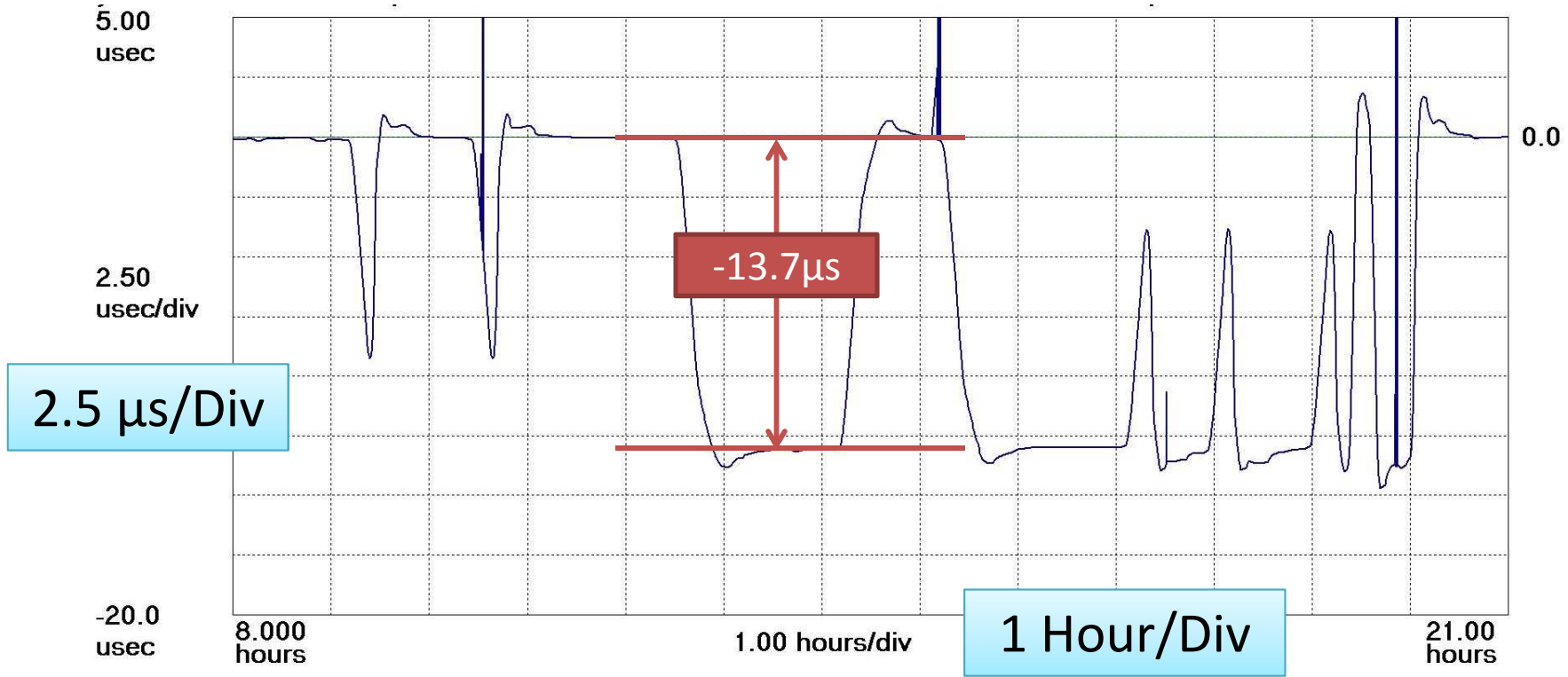- Finally a Statement from USAF
 - But not until the 27th Jan

Analytical Graphics Video

https://dl.dropboxusercontent.com/u/22447827/Videos/GpsBadTiming2DMap.wmv
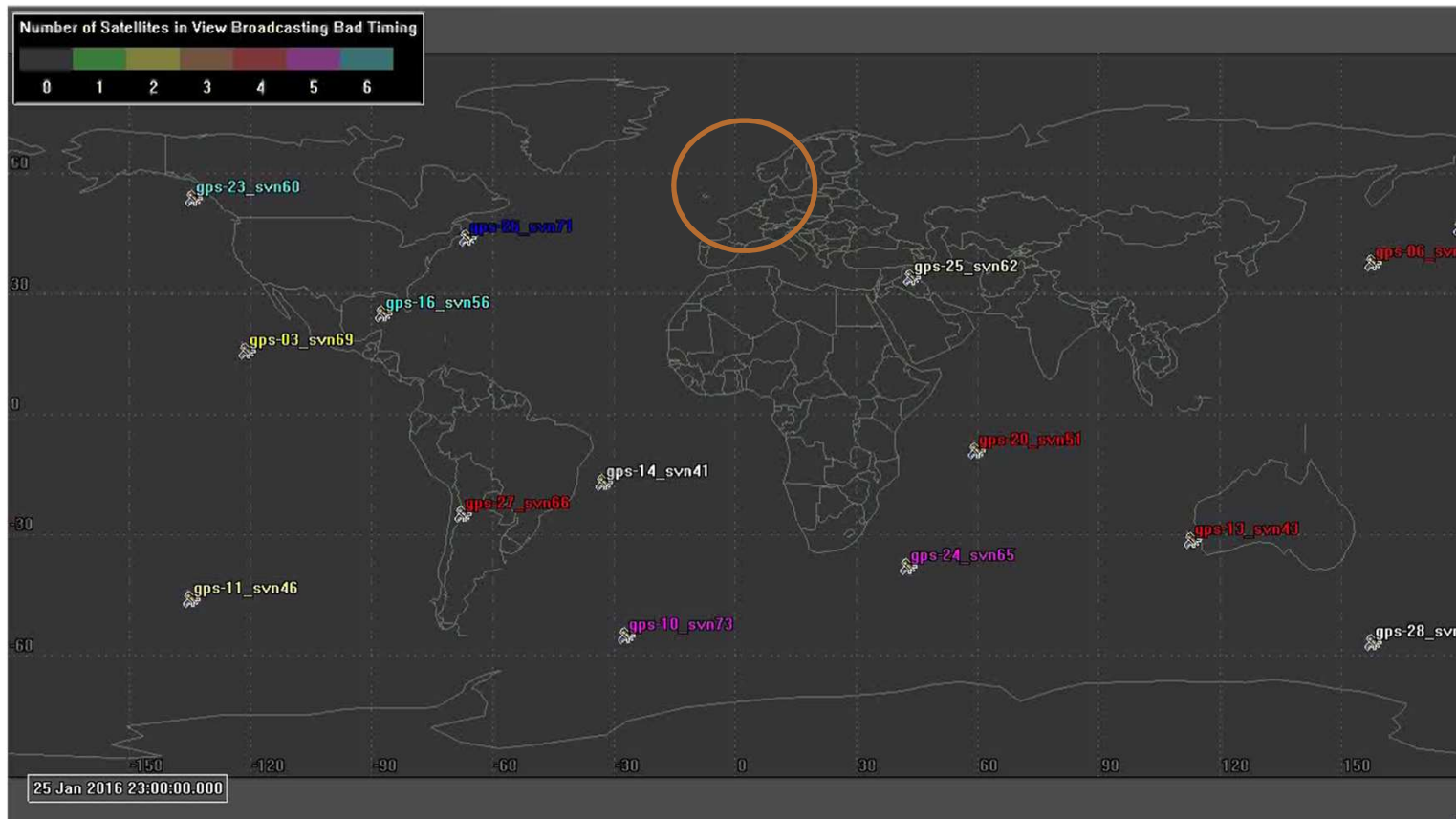
Courtesy Ted Driver at Analytical Graphics via John Lavrakas

Impact and Duration – 26th

2.5 µs/Div

-13.7µs

1 Hour/Div

-13.7 µsec error in UTC word

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
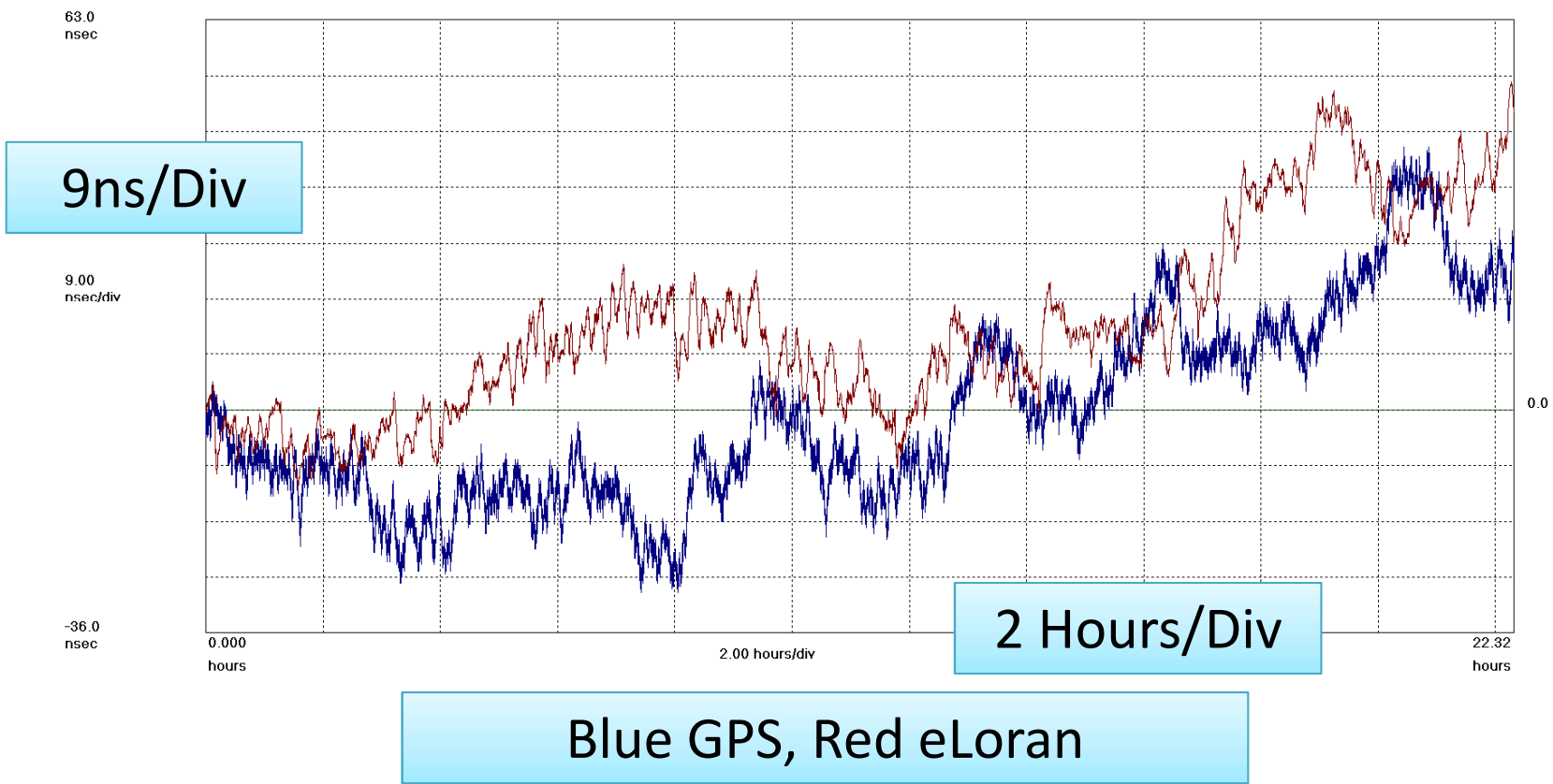
GPS v eLoran

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-0
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; 2016/01/25; 23

200ns/Div

2 Hours/Div
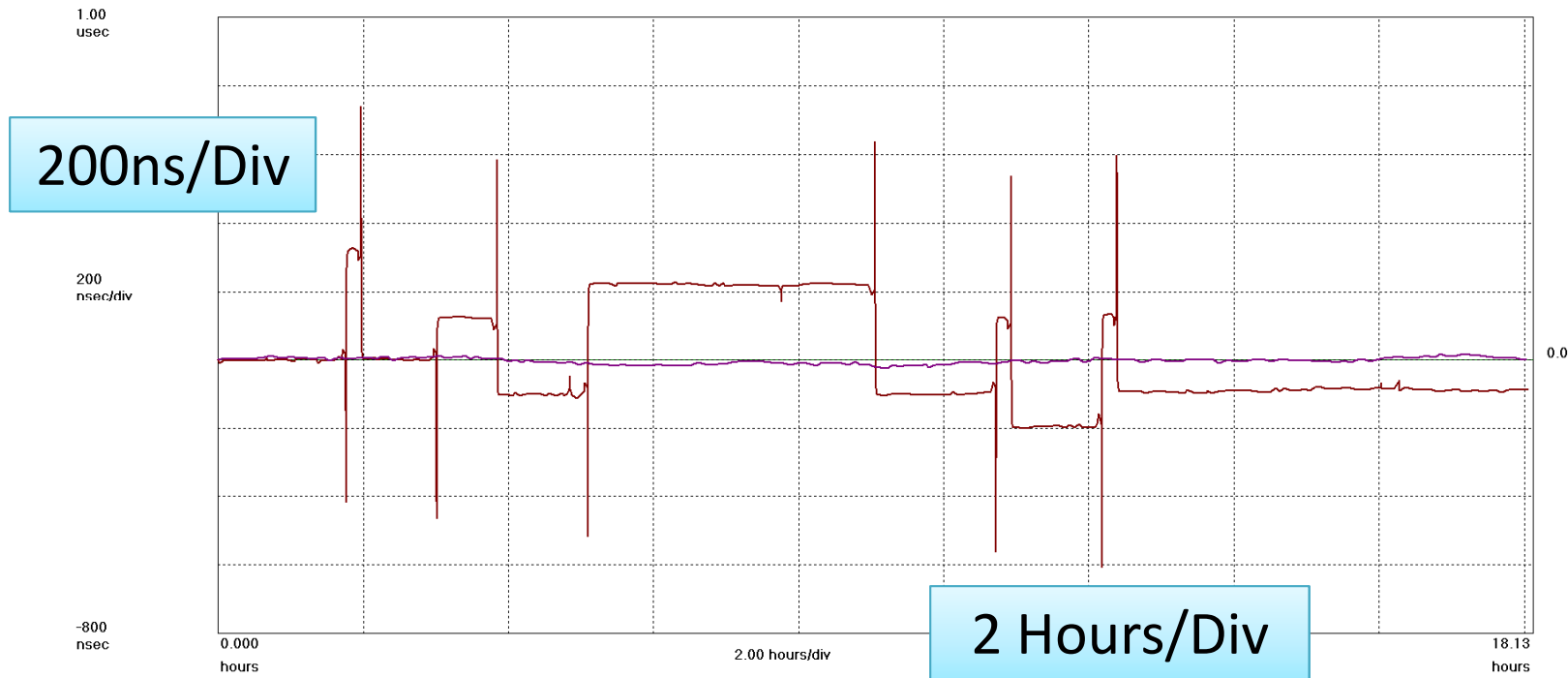
**TRAIM mitigates
No Impact on eLoran**

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

Resilience at the Transmitter level, but not at the UTC source or technology level

Interference

GPS1 GPS2

TX1 TX2

GPS1 GPS2

TX1 TX2

City

City

Not dissimilar to reuse of frequencies in cell clusters. eICIC

Glonass 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/

Why -13.696 μsecs?

- **High Level Explanation - Thanks to Marc Weiss**
- UTC from the GPS system is a linear offset from GPS time (A0)
  - $= A0 + A1(t - t0\_UTC)$
  - t0_UTC = Week Number and a second of the week
- **Reference Week Number determined using the oldest satellite in the fleet**
  - Guess what? They just retired SVN23!
  - But did not take it out of the list estimator!
- System defaulted to the beginning of GPS Time = Jan 5th 1980
  - Multiplying A1 term by 36 years resulted in 13.696 μsecs
- **No system alarms; only calls coming in from users!**
- Took time to work it out - by which time 15 satellites infected
  - Another bug prevented changing the uploads until end of the GPS day
- **Is there a mathematical proof of the -13.696 μsecs?**

Case Study & Further Reading

- **SVN 23 Case Study**

- **RAEng Report on GNSS Vulnerabilities**

- **RAEng Report on Space Weather**

Conclusion

- **SVN23 was a wake-up call for single UTC traceable timing 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

Thankyou
Please visit our Booth at ION

www.chronos.co.uk

www.gpsworld.biz

www.taviga.com

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