The Impact of the GPS UTC Anomaly Event of 26 January 2016 on the Global Timing Community

Prof Charles Curry, BEng, CEng, FIET, FRIN *Chronos Technology Ltd*

BIOGRAPHY

Charles Curry is a Chartered Engineer, a Fellow of the Institution of Engineering and Technology (IET), the Royal Institute of Navigation (RIN); and founder & Managing Director of Chronos Technology Ltd. Charles graduated in Electronics from Liverpool University in 1973, and started his career at GEC Hirst Research Centre working on silicon MOS boundary research, progressing to Racal Instruments where he was responsible for sales of test equipment including specialist frequency and time products such as Loran C and Caesium standards. Later with GSE Rentals Charles was involved with some of the first civil GPS and laptop PC deployments into the North Sea offshore oil exploration industry during the early 1980s.

He founded Chronos in 1986, a leading global system integrator, service solutions provider and manufacturer for synchronisation, timing, GNSS and GPS jamming, detection products based in the UK. Chronos has supplied and installed many thousands of GPS & Timing systems worldwide for mobile and fixed line telecom operators. The Chronos Synchronisation MasterClass has been delivered to more than a 1000 delegates across the globe.

Charles founded the International Timing Sync Forum (ITSF) in 2001 and chairs the ITSF Steering Group. He is also a member of the Workshop on Synchronization in the USA Telecommunications Systems (WSTS) Steering Group which meets annually. Charles is also a member of the Industry Advisory Boards for the Universities of Liverpool and Bath, Electrical and Electronics Faculties.

In 2012 Charles was awarded Honorary Professorships from the University of Bath, Faculty of Engineering & Design, Department of Electronic & Electrical Engineering and the University of Liverpool, Department of Electrical Engineering & Electronics.

ABSTRACT

On 26th January 2016 alarms started to occur on GPS timing receivers around the globe. These kicked off at 2am in the morning in the UK. What had happened, what was going wrong?

This presentation will tell the story as experienced by the Chronos support team, who over a 4 day period dealt with nearly 5000 alarm events from many different GPS timing receivers installed around the world. It will examine whether the alarms were service affecting or was the equipment switching to a resilient fall-back status.

This event was not without precedent. The last time such an event happened to the GPS transmission was 1st January 2004 and coincidentally SVN23 was to blame then. A major network event happened to Glonass on April 1st 2014. These qualify as "Black Swan Events" first proposed by Nassim Nicholas Taleb in his 2001 book, "Fooled by Randomness".

This was a unique event with unique impact across the globe. Chronos supports many 1000s of GPS based timing receivers for over 100 clients in over 50 countries. With this view of GPS based timing around the globe, Chronos was in a position to watch the vent unfold. This paper not only tells the story of the evolution of the event, but also reviews more recent work to understand what caused the event and how it manifested itself.

INTRODUCTION

On 26th January 2016 alarms started to occur on GPS timing receivers around the globe. These kicked off at 2am in the morning in the UK. This presentation will tell the story as experienced by the Chronos support team, who over a 4 day period dealt with nearly 5000 alarm events from many different GPS timing receivers installed around the world. It will examine whether the alarms were service affecting or was the equipment switching to a resilient fall-back status.

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 NANU 2016008 it was marked unusable at 15:36 UTC on 25th January and decommissioned at 22:00 UTC later that same day. Unfortunately, the UTC signal on some satellites was off by 13 microseconds. This White Paper charts the activity undertaken by the Chronos support team during and after this unprecedented GPS anomaly event.

IMPACT ON GPS TIMING RECEIVERS

This UTC anomaly event impacted GPS timing receivers in a number of different ways. The traces below show how the anomaly event impacted three different GPS timing receivers over an extended period during the 26th January 2016.

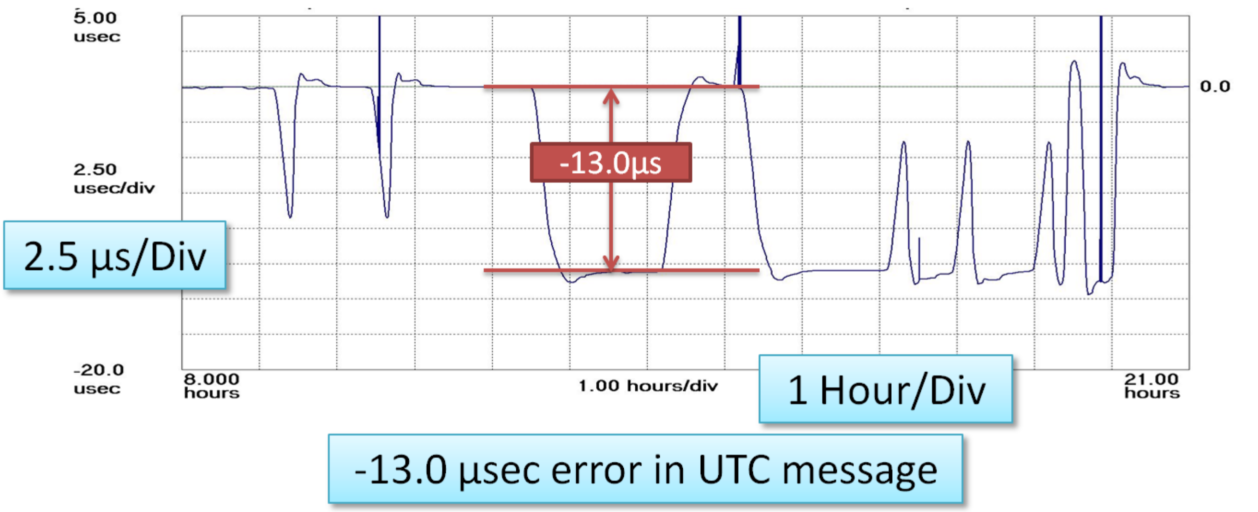

Figure 1: Trace showing full 13 µsec impact of Anomaly Event on one GPS Timing Receiver

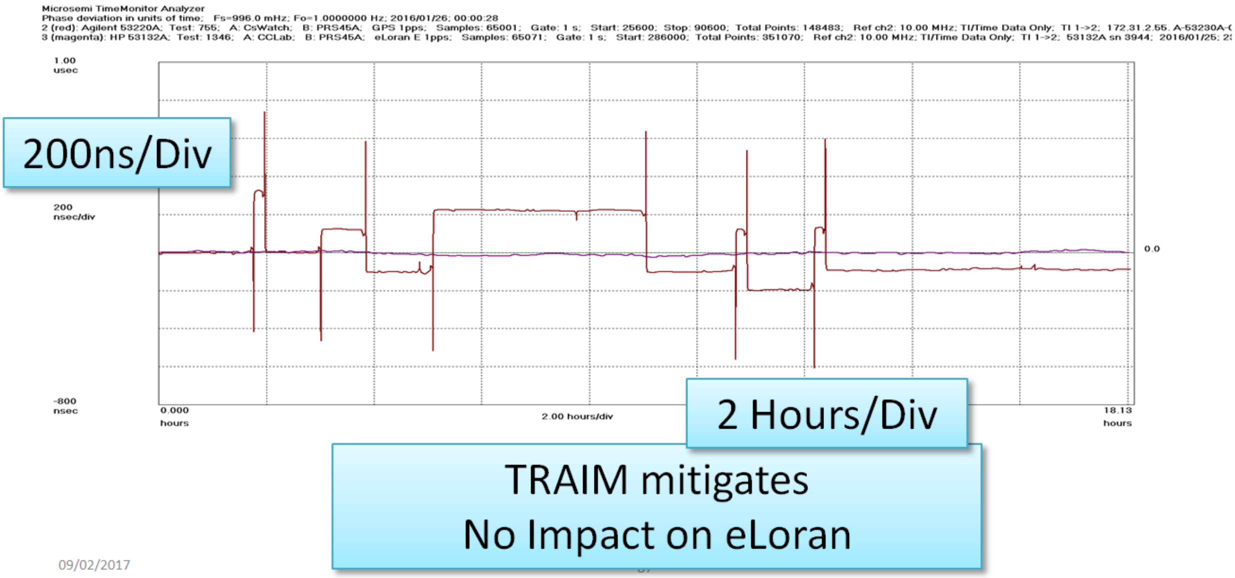

Figure 2: TRAIM Mitigates impact. No Impact on eLoran

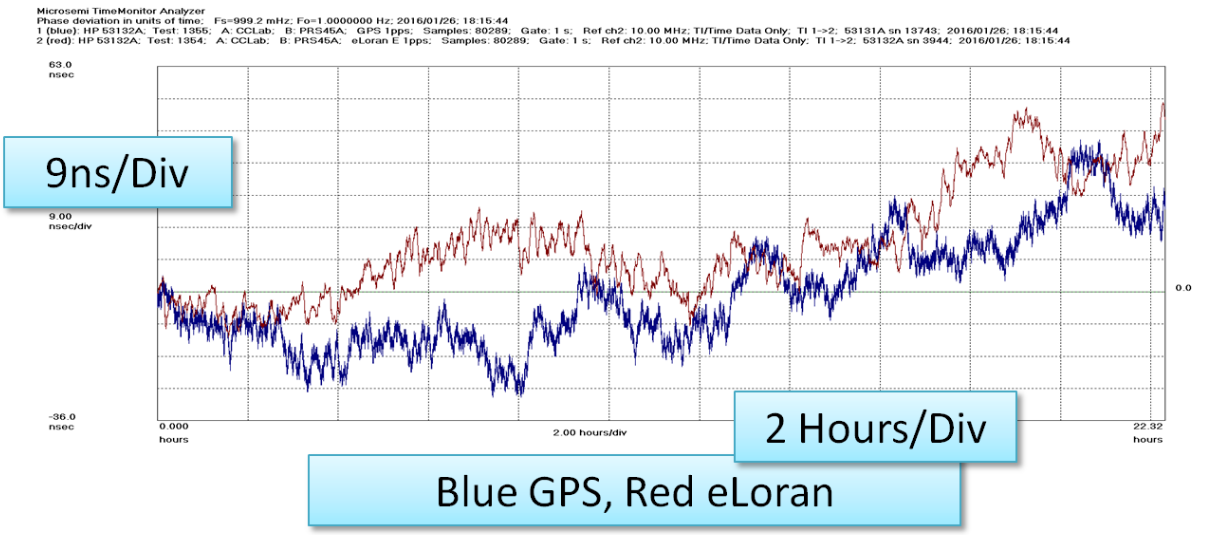

Figure 3: GPS Receiver not impacted

LACK OF CONSISTENCY

There was no consistency with the impacts on different receivers. During the event, some receivers were impacted, some were not. Not all receivers of the same design were impacted. It did not impact navigation (RTK) receivers. There was evidence that TRAIM had some mitigating effect. Some receivers showed a -13.0µsec offset, some did not. Some receivers rejected the GPS conditioning signal which put the Rb or OCXO oscillators into holdover.

Interestingly, during 2016 the eLoran signal from Anthorn was using 5071A Cs steered to UTC with a specially designed GPS receiver. There was no adverse impact to the eLoran timing signal during the UTC anomaly event

Some conclusions from this include mitigation due to RAIM effects. Some receivers were not impacted because they did not need new ephemeris during the event or as only fifteen satellites were impacted they collected ephemeris from a 'good' satellite. On one early GPS receiver – the HP55300 from 1996, mitigation may also have been due to recognition of flawed UTCO data e.g. outside 'fit interval' where the receiver squelched the GPS, and marked GPS as unhealthy – although this has not been proven.

CHRONOS SUPPORT DESK

The Chronos Support Desk was kept very busy. This section explains the unfolding Story of the SVN 23 Event 2016

Chronos operates a 24x7x365 support desk for nearly 100 timing equipment users in over 50 countries around the globe. The first call into the Chronos support team came at 02:00 UTC from a panicked engineer from Customer A who had been called out of bed by their Network Operations Centre (NOC) reporting alarms at a handful of Microsemi (Symmetricom) SSU2000s. These were disqualifying GPS inputs due to the Maximum Time Interval Error (MTIE) metric being outside of set limits. The customer's engineer was concerned as three sites had gone into holdover since (at those sites) no backup inputs had been assigned. At this stage it appeared that the GPS error had cleared and the Chronos Support Manager was able to force the units out of holdover. However the scale of the problem escalated as these sites went back into holdover along with dozens of other sites suffering GPS based timing issues. It was apparent at this point that there was something amiss with the GPS constellation itself and a fault report was logged at USCG NAVCEN website at the second attempt on the 26th at 12:00 UTC and phone contact was made with NAVCEN at 14:00 UTC.

Over the next 12 hours the GPS anomaly affected approximately two thirds of the NetSync 55300 GPS Timing Units and SSU2000 estate belonging to the customer. The impact was different on the two systems. The 55300 would squelch the GPS feed into the 55400 SSU and would not be available for approximately 100 minutes, whereas the SSU2000 would disqualify the GPS input due to the MTIE threshold being breached for more than 100 seconds. The MTIE values were showing an error of 13 microseconds across all the affected SSU2000s. At the time reports were coming in from industry sources that only some satellites were reporting the error. Reliable sources now confirm that 15 satellites were affected. This would explain why the problem appeared sporadic and in some instances was not equipment affecting, in others the problem re-occurred. Most of the errors were concentrated on systems from the UK Midlands down to the South East.

The Chronos Support team worked with the customer to maintain a level of alarms low enough to avoid the situation escalating into a "Serious incident" before normal working hours. During the whole course of the event more than 2000 alarms and report messages were dealt with.

At 08:00 UTC the Chronos support team received a call from Customer B operating a London transportation network communications system, reporting two SSU2000s in holdover. This had escalated internally and was causing major concern. Hourly updates were requested until the issue was resolved.

A proactive period of customer network assessment and damage limitation then took place. By 09:30 UTC all customers with whom Chronos had support contracts with remote access had been checked and relevant customer teams alerted to the issue and the effect it was having on their network.

All customers were instructed how to clear down the MTIE alarms thereby re-qualifying the GPS input once the events had stopped occurring.

During the proactive period a major global network belonging to Customer C was reporting 300 alarms at the time of logging in. The majority of their sites had been seriously impacted and were in holdover due to a lack of secondary backup synchronisation feeds. The Chronos support team started work to remotely recover the systems from holdover however most sites re-entered holdover due to the on-going nature of the problem and at this stage further remedial work was abandoned. Due to alarm escalation settings these alarms became Major / Critical after 24 hours. Rubidium backup ensured that there was little risk of traffic impairments assuming that the situation could be resolved.

At 15:00 UTC Customer D who had decided in the past not to renew their support contract, and therefore had not been proactively called, contacted the Chronos support desk to ask why their SSU was in holdover.

By 19:49 UTC an official USAF press release was published:

“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.”

The Chronos Support desk received notification from USCG NAVCEN at 16:00 UTC on 27th to confirm that the issue had been identified and resolved. However, it was clear that the issue was not yet fully resolved as although the frequency of events slowed down by 14:00 on the 27th there was some evidence of events up to the early hours of the 28th. Customer A’s network was fairly alarm free by now due to the constant clearing down of events throughout the morning.

Work started getting Customer C’s global network alarm free on the morning of the 28th which by then had generated nearly 2500 alarms and took about 4 hours to clear.

The Chronos Support desk took a call on the 27th from Customer E who managed a major transportation telecom network to ask if there had been issues during the previous day. At this point we had not been aware of many Symmetricom (Microsemi) TimeSource systems being affected. Again the impact was not 100% with 30% of systems causing downstream switches to reject the timing inputs and enter free run. These units had no visible alarm warnings.

Summary TimeLine of Events		
Date	**Time – GMT**	**Notes**
25 January 2016	15:36	SVN23 Marked unusable according to NANU **2016006**
25 January 2016	22:00	**SVN23 Decommissioned according to NANU 2016008**
26 January 2016	00:21	First UK based alarm message logged by Chronos
26 January 2016	02:00	First call from Customer A
26 January 2016	07:49	NAVCEN acknowledge that there is a problem on their press release
26 January 2016	09:00	Proactive call up of Chronos Support customers
26 January 2016	12:00	Reported event at second attempt onto NAVCEN website
26 January 2016	13:10	NAVCEN "resolve" the problem (according to press release)
26 January 2016	14:00	Phone contact made with NAVCEN
27 January 2016	09:00	Support calls still coming in
27 January 2016	14:00	Events slowing down
27 January 2016	16:00	NAVCEN call Chronos to confirm issue identified and resolved
28 January 2016	02:00	Last events logged in the early hours of 28th
28 January 2016	09:00	4 hours to clear remaining alarms from Customer C's network

HOLDOVER

Holdover is a standard operational condition of the local oscillator in the SSU when no synchronising input is available. Normally a telecom network quality SSU will choose one of three or more inputs in a priority established by the network architect, e.g. three inputs might be 1- GPS, 2 – Network West, 3 – Network East and these network feeds will eventually lead to a Caesium based Primary Reference Clock. In some of the units impacted by the GPS failure, backup inputs 2 and 3 were not set. This meant that the SSU was in holdover. This is a dangerous condition – although normal for simple GPS timing receivers with no resilience and backup synchronisation feeds. The next thing to consider is the type of local oscillator. Would it be a Rubidium atomic oscillator or an oven controlled crystal oscillator? This will define how long the SSU can stay in holdover before there are network impacting frequency errors.

This issue is discussed extensively in the Chronos White Paper [Dependency of Communications Systems on PNT Technology] . Long holdover with low grade oscillators could well lead to service impact in telecom networks, particularly 3G mobile. New Single Frequency Networks (SFN) in Broadcasting and future 4G services are much more sensitive to time errors and almost certainly an outage of this impact and duration will in the future cause major problems to critical infrastructure unless technically dissimilar backup time transfer technology is implemented.

ALARMS EVENTS

Event Summary Table				
	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**

WHY 13 µsec?

Thanks to an excellent paper presented at ION in Portland 2016 "GPS Receiver Impact from the UTC Offset (UTCO) Anomaly of 25-26 January 2016" by *Karl Kovach, Philip J. Mendicki, The Aerospace Corporation; Ed Powers, US Naval Observatory; Brent Renfro, ARL, The University of Texas at Austin* we now know what went wrong with the data upload.

The UTC Offset term from GPS ICD IS-GPS-200 Page 123 - Section 20.3.3.5.2.4 is

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

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

During the early stages of the anomaly it was noted that the A_0 term was -13.7 µsec.

Date	Time	Δt_{UTC} µs	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

The above data courtesy of John Lavrakas shows the position for SVN 13 just before (23:13) and just after (23:17) the event started. SVN43/PRN13 was the first satellite to be impacted by the wrong data upload.

Zero values had been uploaded into t_{ot} and WN_t. This resulted in -13.7 µsec for A_0 and -13 µsec for Δt_{UTC} the offset experienced by some receivers.

CONCLUSION

This event linked to SVN23 has been one of the most significant service affecting issues for GPS timing users and sits alongside the April 1st 2014 Glonass outage in scale - however its impact on global timing services is much more extreme. The customers listed in the Table above have support contracts with Chronos with helpdesk SLAs ranging from 24x7x365 to next working day and man-on-site options. Due to the severity of the event the Chronos Support team took an executive decision to suspend the next-working-day option and deal with problems outside of normal working hours and in a proactive manner. Their expert knowledge and ability to remotely reconfigure equipment and its inherent resiliency ensured that the problem did not escalate to a traffic impacting situation.

EPILOGUE

Chronos is aware of other more catastrophic impacts from the UTC anomaly event to critical infrastructure networks and non-telecom applications which were not under Chronos supply and support contracts.

Clock issues are not limited to GPS. Both Glonass and Galileo have experienced problems.

Glonass on the 1st April 2014 where all satellites broadcast corrupt data for 11 hours creating massive positional errors and again on the 14th April 2014 where 8 satellites were set unhealthy for 30 minutes.

On the 18th January 2017 BBC news reported that the on-board atomic clocks that drive the satellite-navigation signals on Europe's Galileo network had been failing at an alarming rate. Across the 18 satellites now in orbit, nine clocks have stopped operating.

ACKNOWLEDGMENTS

The author would like to acknowledge contributions from John Lavrakas, Marc Weiss and Brent Renfrew in the preparation and discovery regarding the cause and explanation of the UTC anomaly event.

REFERENCES

Dependency of Communications Systems on PNT Technology – *Charles Curry.* Prepared as a contribution to the Royal Academy of Engineering Report on GNSS Vulnerabilities, 2010

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