Jackson Labs

"the next generation in frequency and timing"

State of the Art GPS Timing Applications

Prepared for CGSIC

September 25th 2017

Table Of Contents

Jackson Labs Technologies, Inc.

- Founded in 2003, Factories in Nevada, California
- Microsemi Private-Labels many JLT products
- 37+ products for Commercial/Industrial/Military; 36,000+ fielded units
- Focus on embedded modules ranging from low-cost to ultra-high performance

HOW ACCURATE ARE GNSS TODAY?

- GNSS UTC(USNO), UTC(SU) and UTC(E) versus UTC over one year:

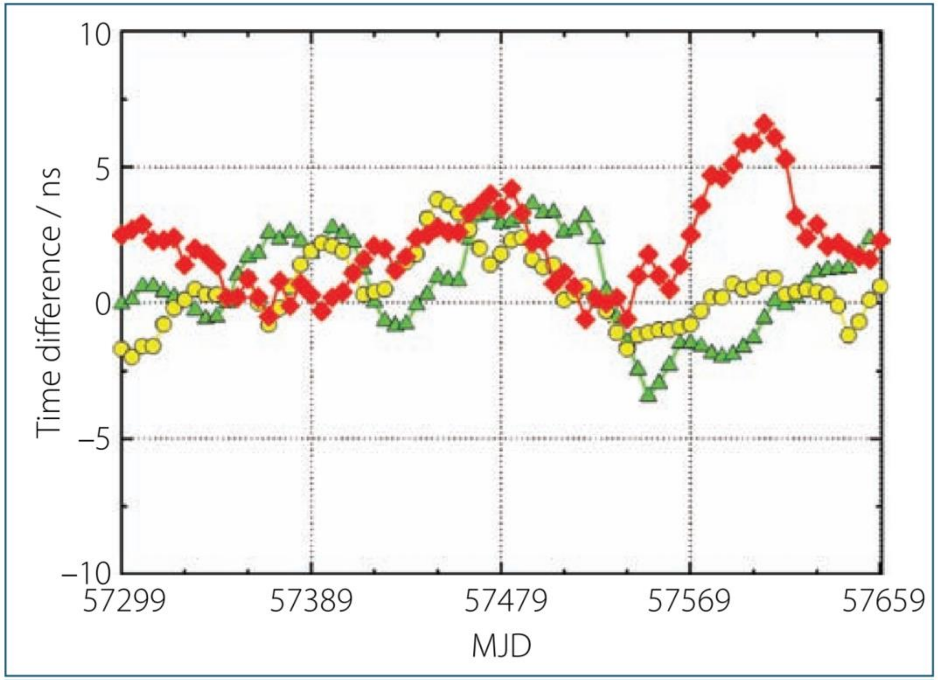


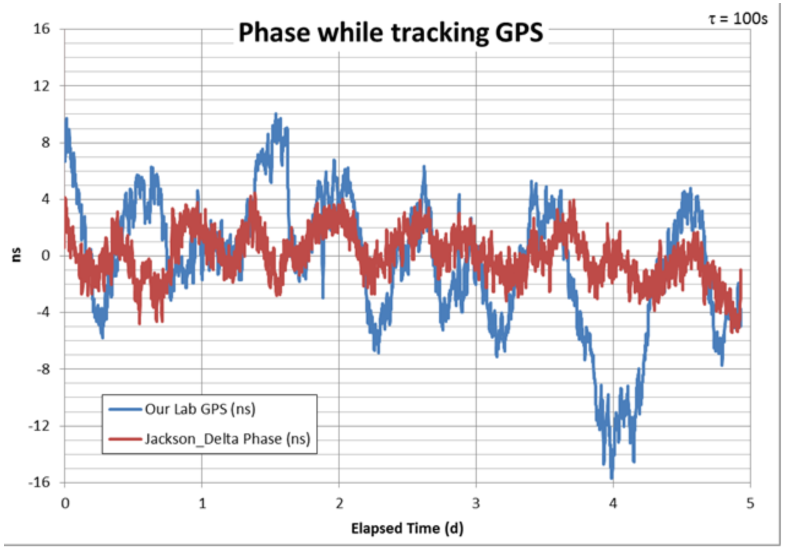
FIGURE 1 Reference time scales for GPS (yellow), GLONASS (red) and Galileo (green) in comparison with UTC during one year, ending at Modified Julian Day (MJD) 57659, September, 28 2016.

Bauch, A. and Whibberley, P., "Reliable Time from GNSS Signals", *Inside GNSS*, March/April 2017, pp. 39-44, 2017

STATE OF THE ART RUBIDIUM

- LN Rubidium GNSDO with latest-gen GNSS receiver (uBlox M8T)
  - Costs $3K to $5K, 1/10 of traditional solutions
  - Comparable performance to Microsemi XLI SAASM-disciplined 5071A Cesium Vapor Standard
  - Selectable UTC source (GPS, Glonass, Galileo, BeiDou, QZSS, or up to 3 concurrent)

GPS-3500: 10ns peak to peak:



GPS-3500 (LN Rubidium Ultimate – Magenta trace) measured versus Microsemi House Maser.

5071A: 12ns peak to peak:

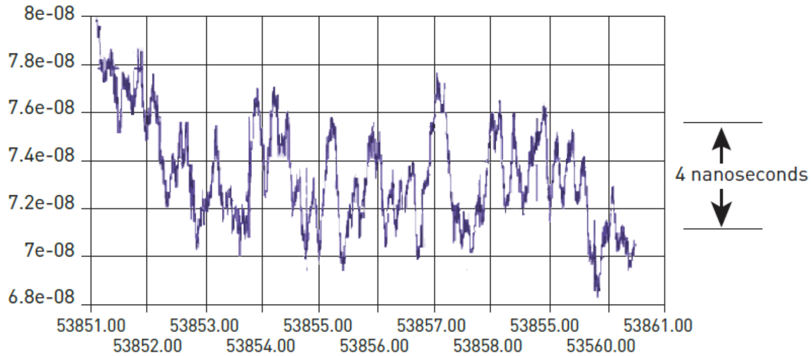
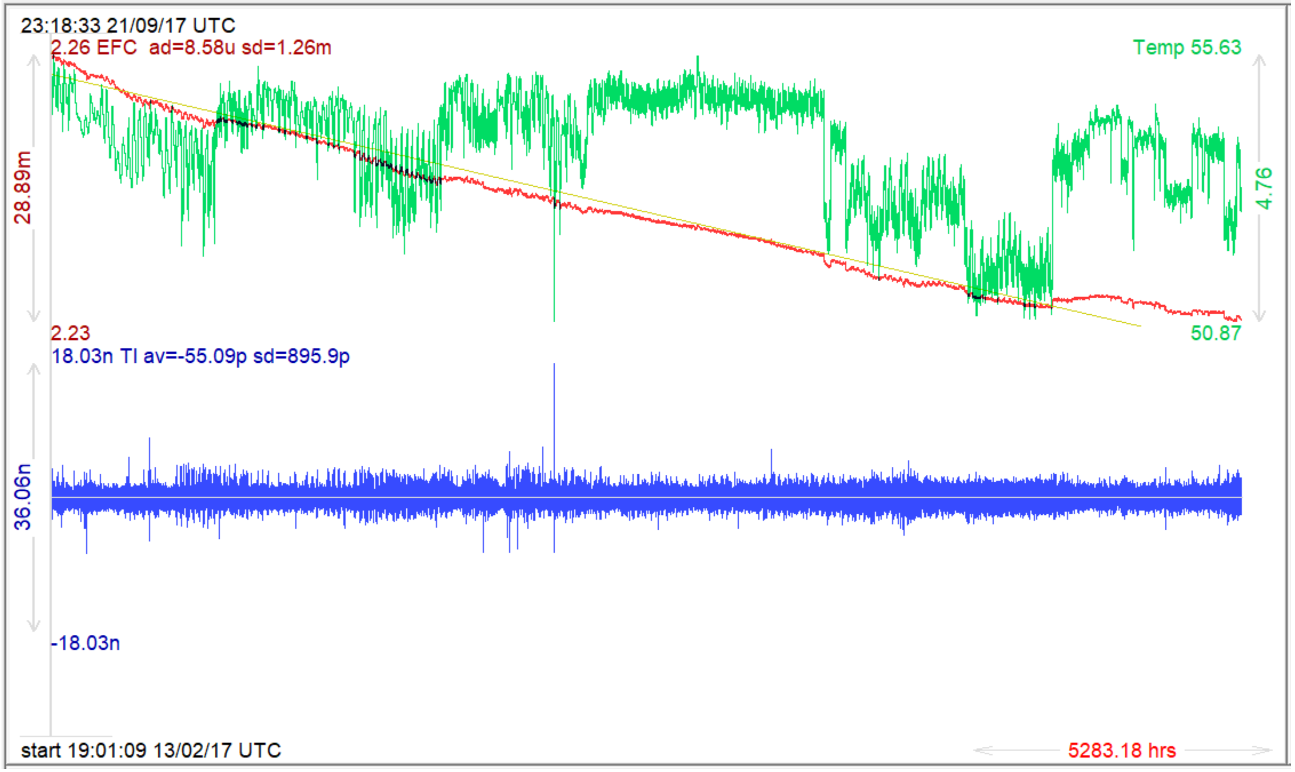


Figure 2. USNO tests of the XLi SAASM Disciplined 5071A Cesium Oscillator option show a clock variation of less than 4 nanoseconds root mean square over the 10 days test period.

Symmetricom, "Time and Frequency System Unites GPS Accuracy with Cesium Stability", *Application Brief*, December 2012, pp. 3, 2012

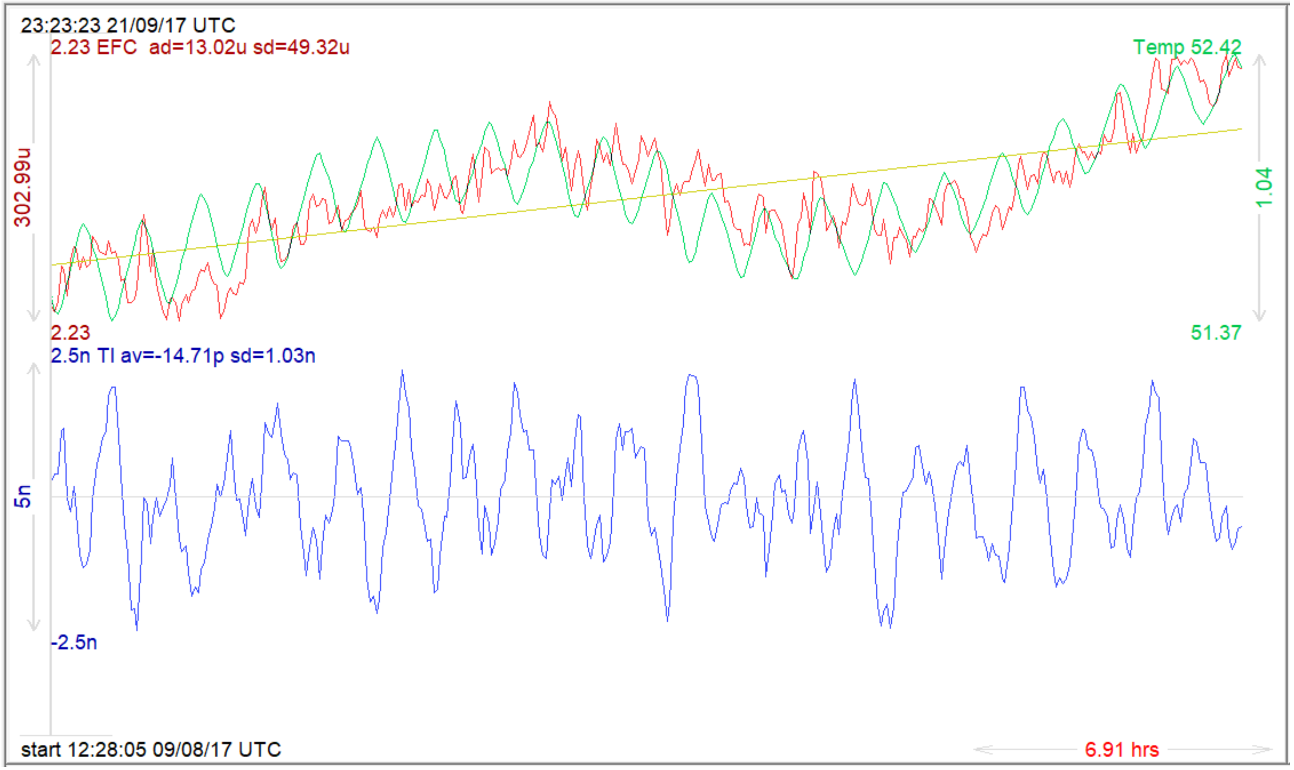
Long Term GPS lock

- 7 months of GPS locked performance: 0.055ns average, 0.9ns SD
- Thermal changes present most error



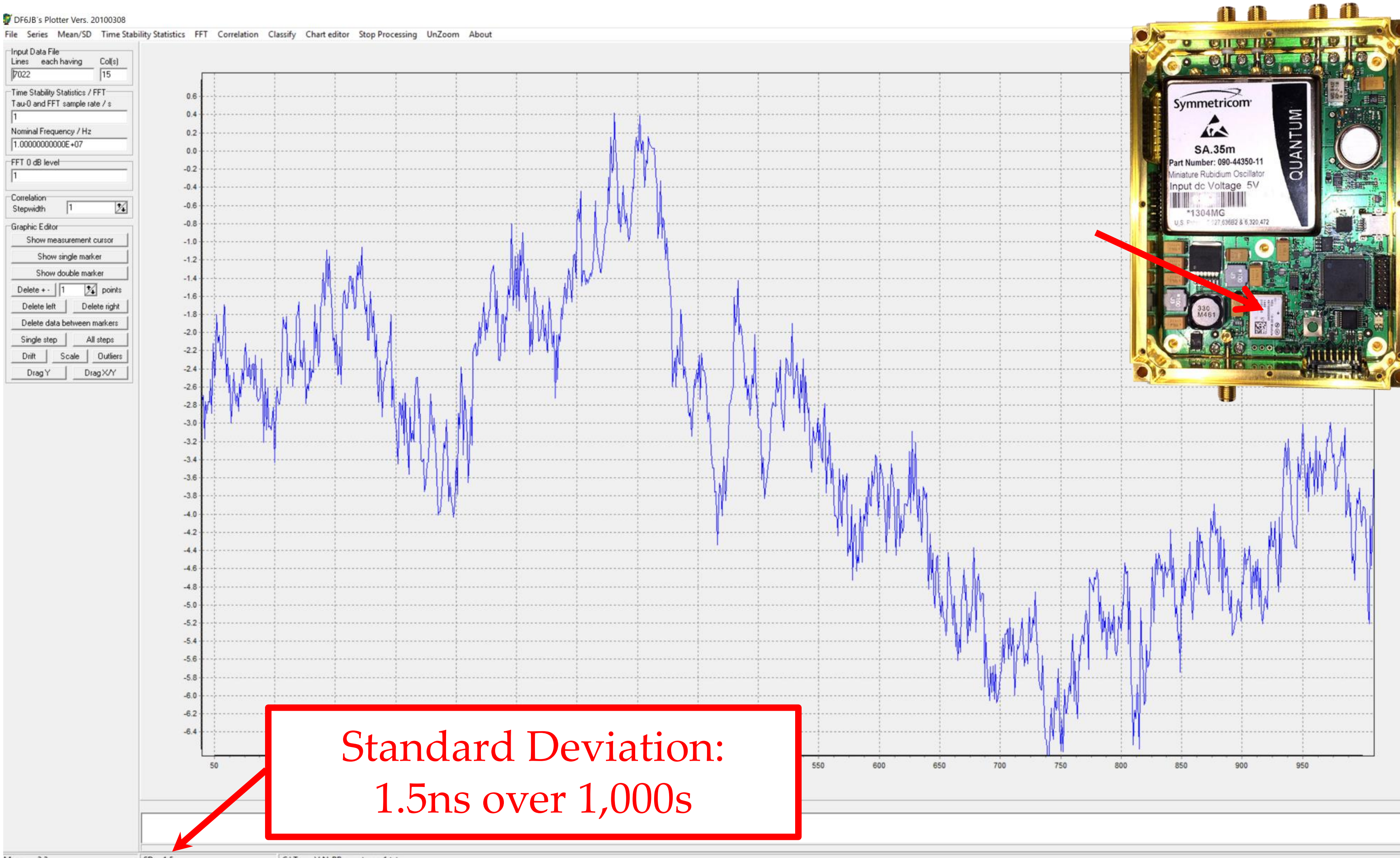
Long Term GPS lock

- Short-term thermal effects clearly visible
- Short-term phase error bounded by +/-2.5ns window



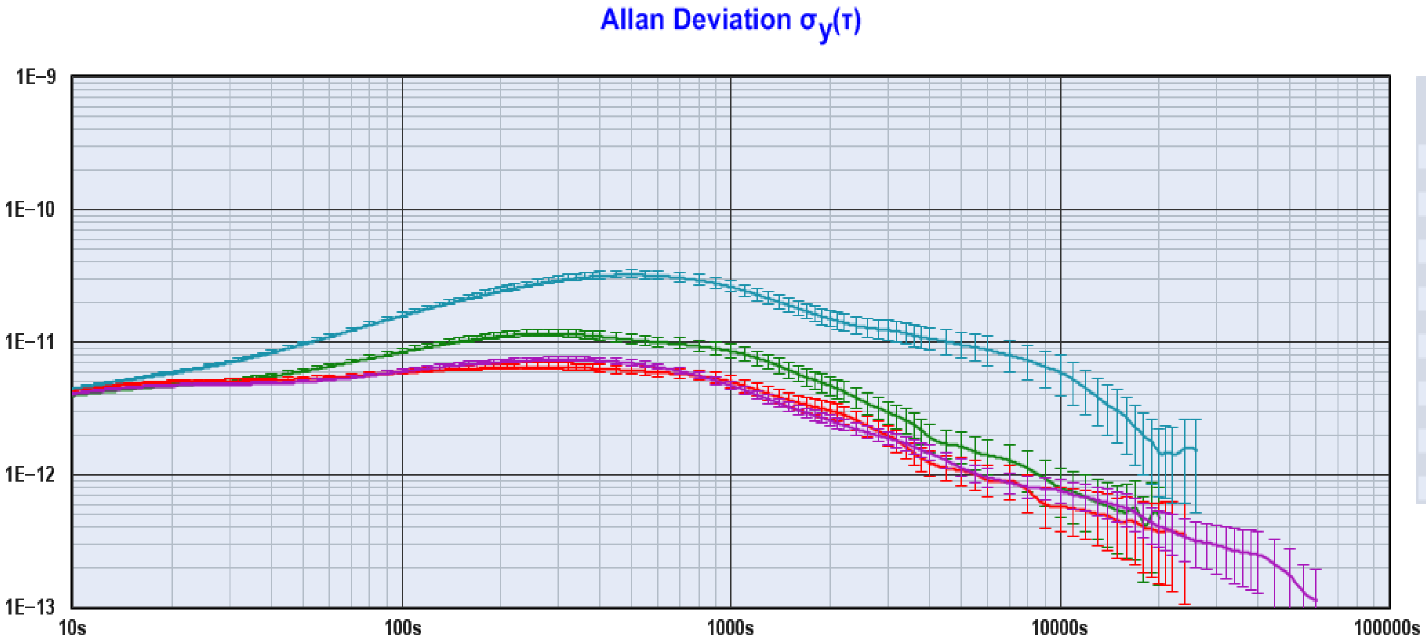
1PPS PERFORMANCE OF M8T

- M8T raw GPS 1PPS phase capture vs. Rubidium, sawtooth corrected



GNSS Comparisons

- GPS-3500 with either GPS or Glonass enabled
- Both stationary (Position Hold) and Mobile (3D) modes tested

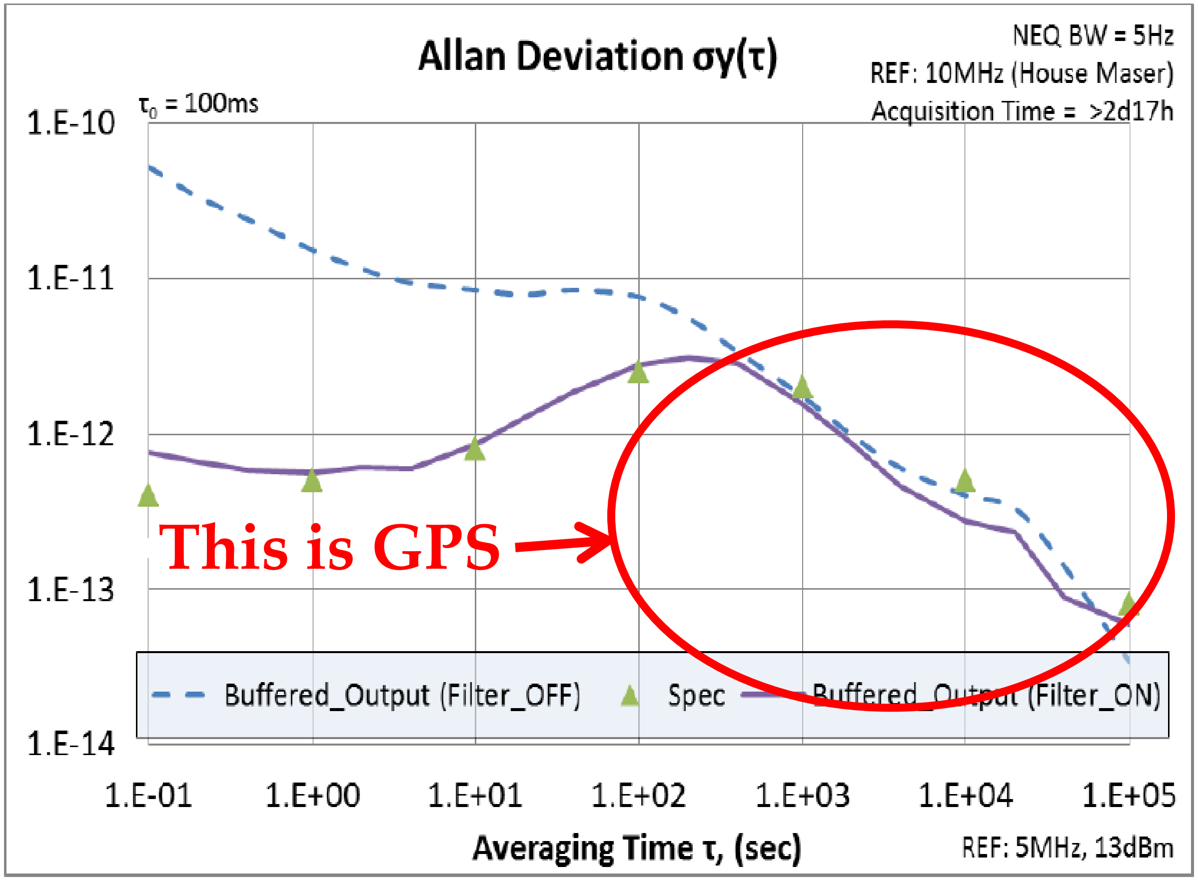


Tau	Sigma(Tau)
1s	1.76E−12
2s	2.25E−12
4s	2.91E−12
8s	3.84E−12
10s	4.15E−12
20s	4.76E−12
40s	4.96E−12
80s	5.71E−12
100s	6.11E−12
200s	7.21E−12
400s	7.36E−12
800s	5.60E−12
1000s	4.74E−12
2000s	2.58E−12
4000s	1.47E−12

Trace	Notes	Input Freq	Sample Interval	ADEV at 7s	Duration	Acquired	Instrument
LN-Rb short holdover tests (Unsaved)		10 MHz	0.100 s		44m 20s	26604 pts	Symmetricom 5115A/512XA
LN-Rb short holdover tests (Unsaved)		10 MHz	0.100 s		6d 0h 0m 0s	5184000 pts	Symmetricom 5115A/512XA
LN-Rb Filter GPS nav mode		10 MHz	0.100 s		22h 48m 0s	820798 pts	Symmetricom 5115A/512XA
LN-Rb Filter GPS tmode on		10 MHz	0.100 s		1d 2h 44m 19s	962591 pts	Symmetricom 5115A/512XA
LTE-Lite 24.567MHz - Eval Board		24.567 MHz	0.100 s		1h 59m 37s	71773 pts	Symmetricom 5115A/512XA
LN Rb Filter GPS tmode on - fast filters (Unsaved)		10 MHz	0.100 s		10m 40s	6400 pts	Symmetricom 5115A/512XA
LN Rb Filter GPS tmode on - fast filters		10 MHz	0.100 s		19h 33m 39s	704185 pts	Symmetricom 5115A/512XA
LN Rb Filter GLONASS tmode on (Unsaved)		10 MHz	0.100 s		2d 19h 11m 39s	2418985 pts	Symmetricom 5115A/512XA
LN Rb Filter GLONASS nav mode (Unsaved)		10 MHz	0.100 s		144 h	1105839 pts	Symmetricom 5115A/512XA

GPS ADEV (L1 C/A) Stability

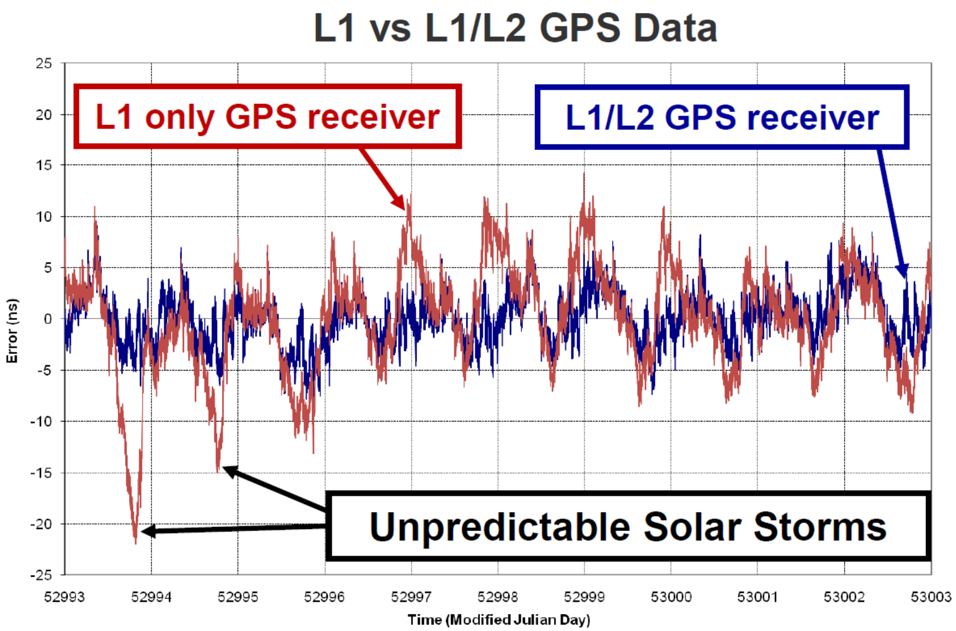
- GPS-3500 disciplined-Rubidium versus Maser, BVA
  - 3.4E-014 over 100Ks achievable with GPS only



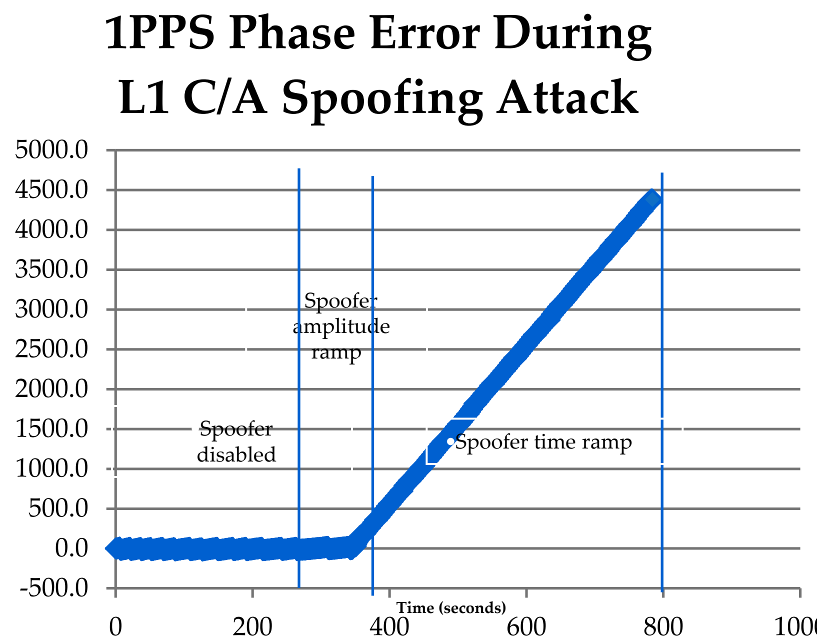
Avg Time	Spec	Buffered_ Out Filter_ON	Buffered_ Out Filter_OFF
1.E-01	4E-13	7.62E-13	5.22E-11
2.E-01		6.56E-13	3.34E-11
4.E-01		5.81E-13	2.41E-11
1.E+00	5E-13	5.62E-13	1.52E-11
2.E+00		6.11E-13	1.15E-11
4.E+00		5.98E-13	9.36E-12
1.E+01	8E-13	8.59E-13	8.42E-12
2.E+01		1.27E-12	7.86E-12
4.E+01		1.87E-12	8.43E-12
1.E+02	2.5E-12	2.77E-12	7.60E-12
2.E+02		3.09E-12	5.56E-12
4.E+02		2.85E-12	3.38E-12
1.E+03	2E-12	1.57E-12	1.74E-12
2.E+03		8.80E-13	9.80E-13
4.E+03		4.60E-13	6.00E-13
1.E+04	5.00E-13	2.70E-13	4.00E-13
2.E+04		2.30E-13	3.30E-13
4.E+04		8.90E-14	1.40E-13
1.E+05	8E-14	5.90E-14	3.40E-14

ADVANTAGES OF DUAL FREQUENCY GPS

- P(Y) L1/L2 Dual Frequency GPS reception has distinct advantages
  - Resilient to low-cost GPS/Glonass jammers (typically operate on L1 only)
  - L2 does not suffer from Ionospheric distortions
  - L2 does not suffer from Solar Storms
  - Cannot be spoofed

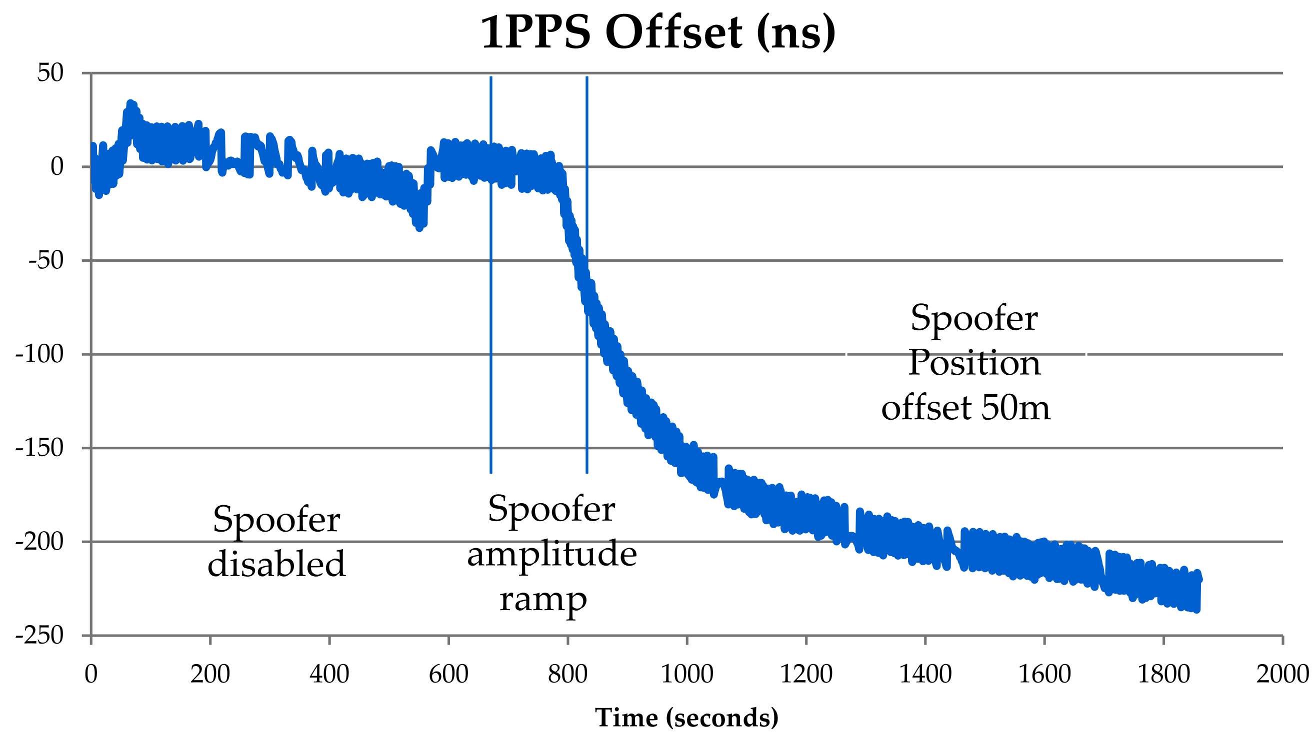


Microsemi, "SyncSystem 4380A Features and Applications", *Presentation*, June 2017, pp. 29, 2017



SPOOFING SIMULATION

- Spoofing Simulation: JLT M12M (u-blox M8T), Position-Hold Mode
  - Spoofer power ramp-rate: 1 min. to +40dB relative to Live Sky
  - Spoofer position pseudorange error offset 50 meters relative to victim ant.
  - Spoofer has no added Phase or Frequency error versus UTC



M12M Position Spoofing

- Position Offset by 50 meters
- Motorola M12M (3D Mobile) with 12dB/minute Signal Ramp, 5 min.

m12-300s-spoof-final.mp4

uBlox M8T Position Spoofing

- Position Offset by 50 meters
- u-blox M8T (3D Mobile) with 12dB/minute Signal Level Ramp, 5 min.

ublox8-300s-spoof-final.mp4

ASSURED-PNT: SAASM CSAC GPSDO

- CSAC and Dual-Frequency SAASM GPS Combo provides:
  - L1/L2 reception for Ionospheric, Solar-Storm, jamming resilience
  - Microsecond level holdover during mission, <10ns rms locked stability
  - Warmup, Atomic Lock, Disciplining (<0.1ppb) within less than 6 minutes typ.
  - Fielded in large volumes for Counter-IED type applications

How to Retrofit Legacy Equipment?

- Objectives:
  - Use both L1/L2
  - Add SAASM and/or M-Code capability
  - Add CSAC and INS Holdover Capability
  - Prevent having to design, or replace 100's of custom solutions
  - Possibly support IS-GPS-250A


World's First RF GNSS Signal-Transcoder
Allows any new GNSS System to be received by legacy GPS receivers.
--> Works like the HD-TV Converter boxes for your old Tube TV.<--
Rockwell Collins
JACKSON LABS
CSAC 10MHz
181100006
Glonass, Galileo, SBAS, BeiDou etc. (8th+ Generation GNSS Receiver)
CAN ALSO WORK AS A GPS PSEUDOLITE TRANSMITTER!
The RSR Transcoder module uses NMEA/ICD-153/SCPI Position-, Velocity-, and Time- (PVT) signal from any GNSS receiver (SAASM, M-Code, u-blox, Trimble, CSAC, etc) and encodes this PVT signal into a GPS RF Signal similar to a GPS Simulator, but encoding is done in Real Time with nanosecond accuracy.
This allows retrofitting ANY GPS receiver with one or more of the following PVT capabilities:
Indoor reception, SAASM, M-Code, Glonass, Galileo, BeiDou, CSAC-Holdover, dead-reckoning INS, etc.
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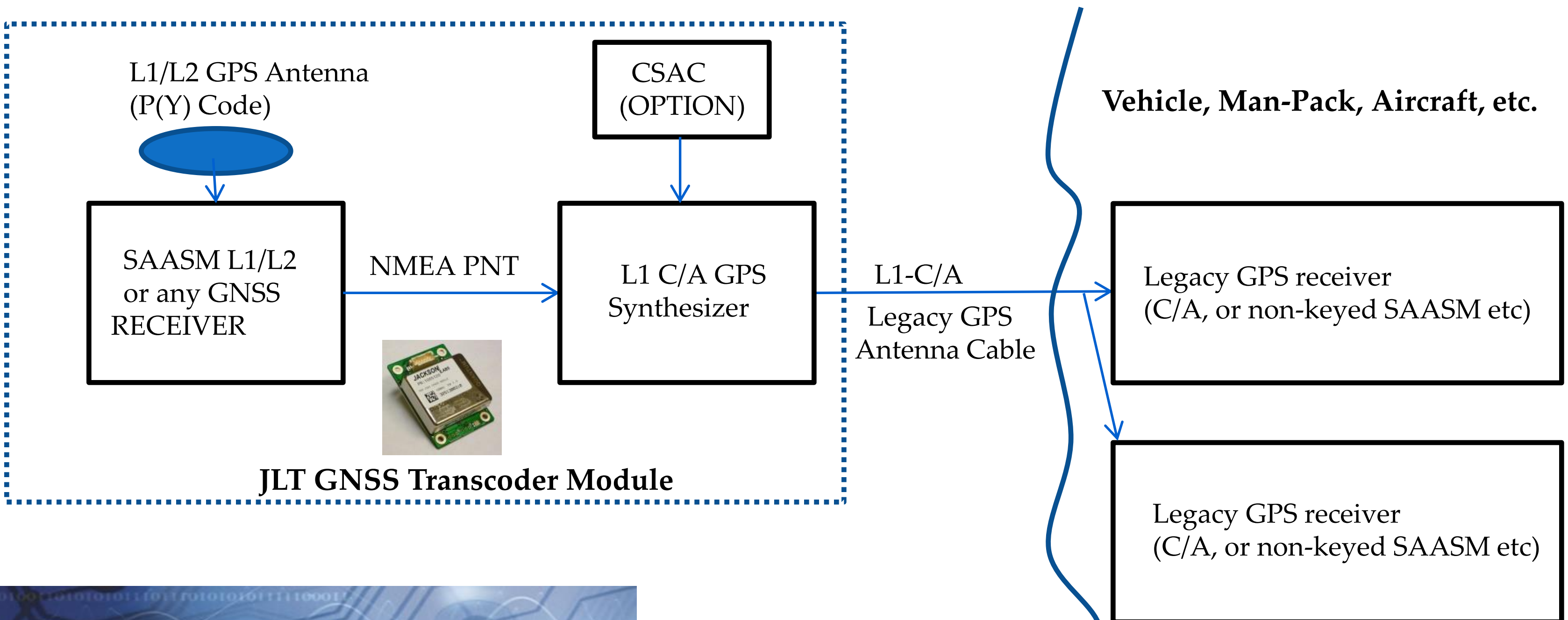
GNSS Transcoding

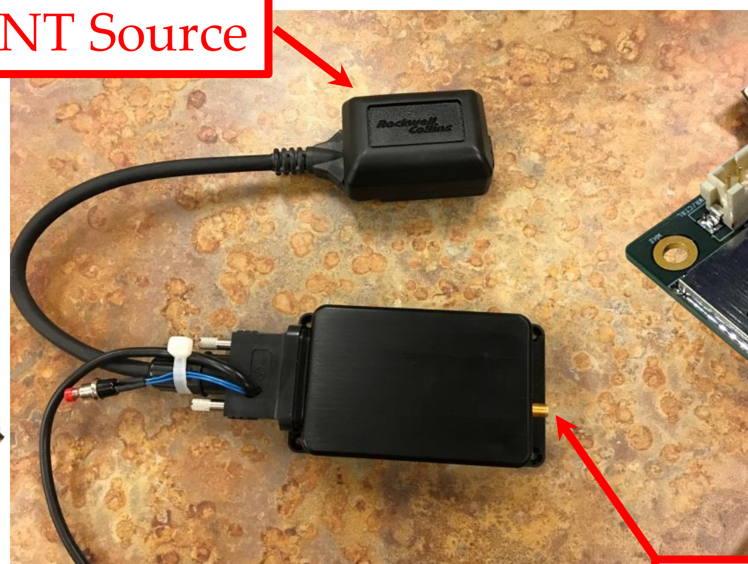
- Transcoding of GNSS signals to defeat commercial L1 spoofer/jammers
  - Use L2, L5 etc., carriers with P(Y) code, transcode signal to L1 C/A
  - Simulate L1 jammers/Spoofers to see effect on L2 SAASM GPS
- Pitfalls, opportunities:
  - Use Live Air Almanac/Ephemeris or Synthesized versions for L1 output?
  - Use IMU/INS and CSAC for completely denied environments



Example Applications

Assured-PNT (SAASM, M-Code, CSAC, INS) Retrofit for:

- 350,000 Armed-Forces vehicles, up to nine GPS per
- DOE Power Generation
- 15,000 aircraft, 12,000 dismounted jammers



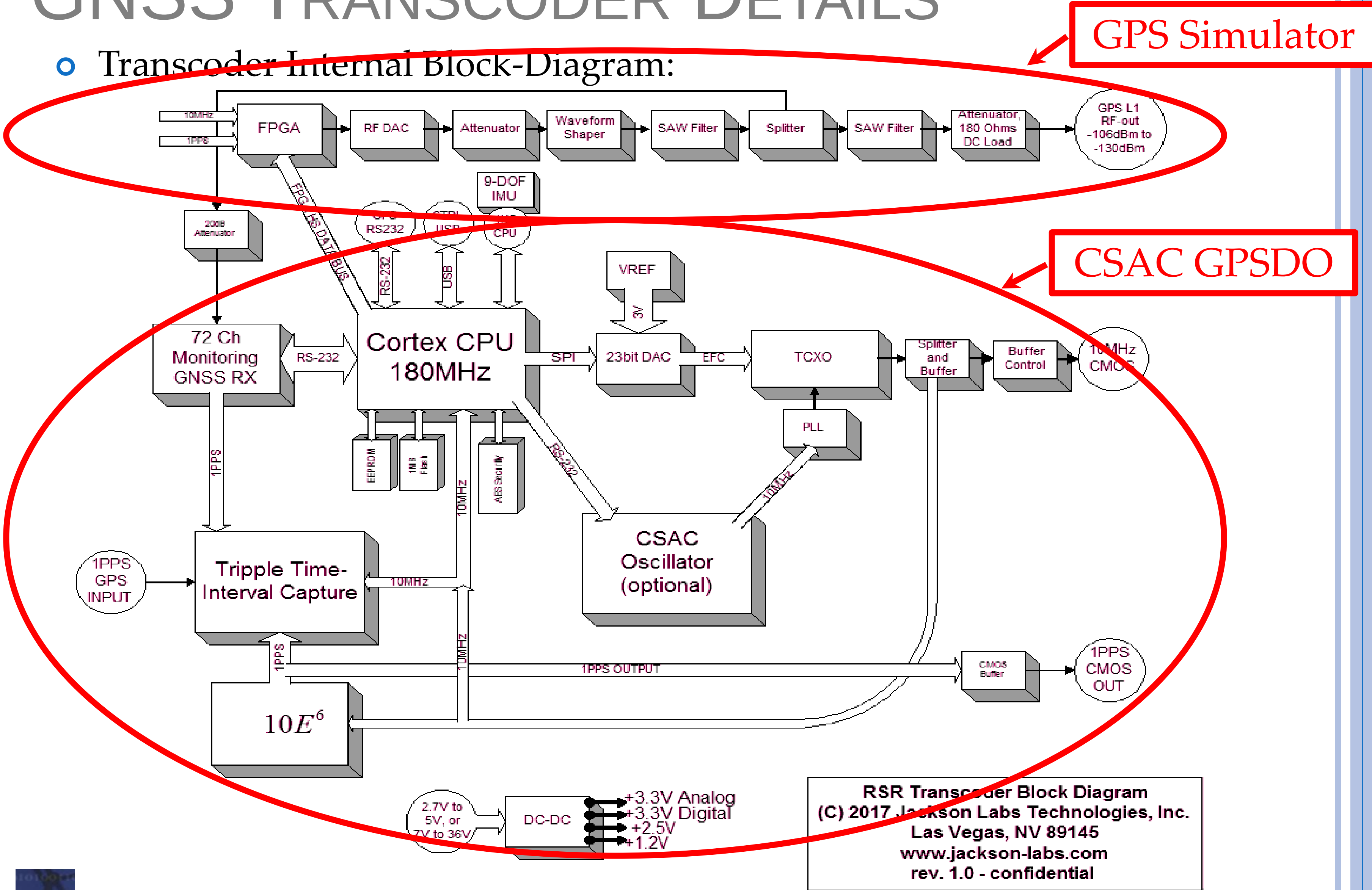
Example Applications

Timing Synchronization CONOP: Counter IED Jammers

- Timing synchronization essential for Blue-Force coms'
- Microseconds drift per hour required during GPS denial
- Jamming signal swamps GPS signal
- Must discipline oscillator to within 0.1ppb within minutes
- May also use jammer as IS-GPS-250A PL Transmitter

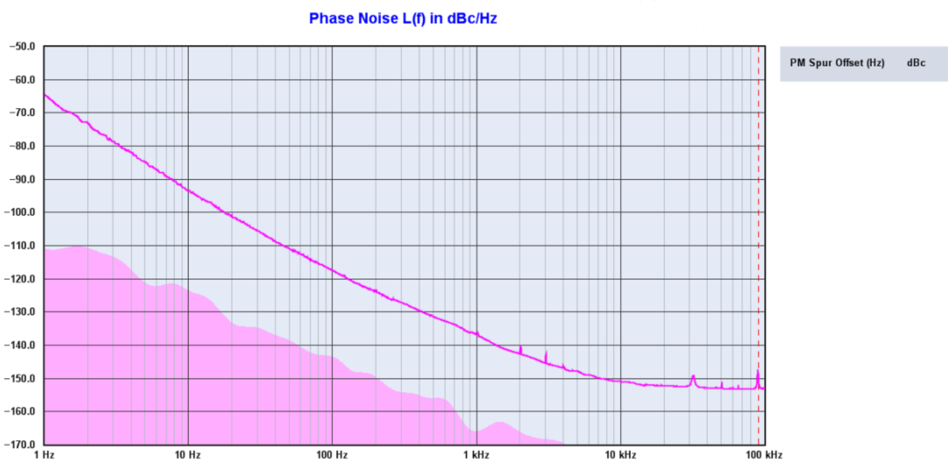
GNSS Transcoder Details

- Transcoder Internal Block-Diagram:

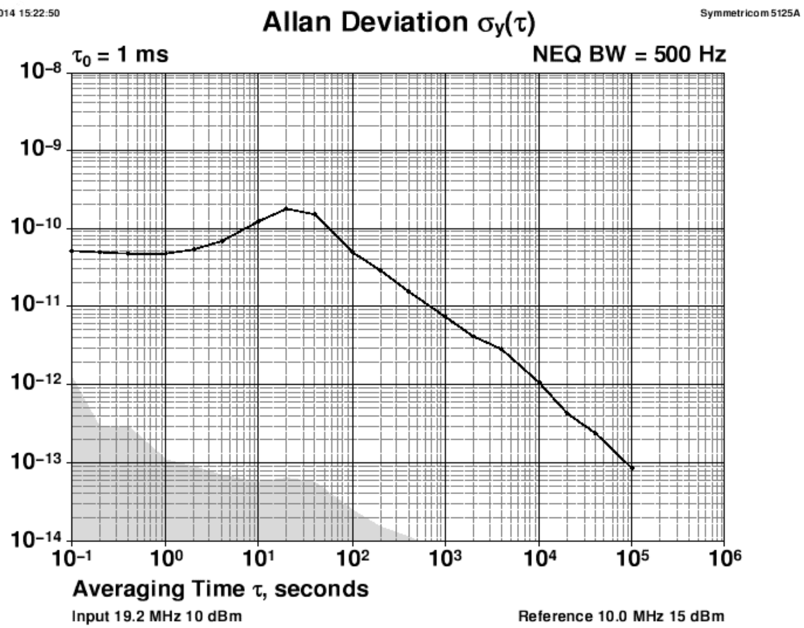


EMERGING LOW COST APPLICATIONS

- LTE-Lite SMT module optimized for high-volume, low-cost applications
  - Stratum-1 Performance for only $72 (10K qty., each)
  - Base-station timing, use LEO Sats for world-wide broadband internet access

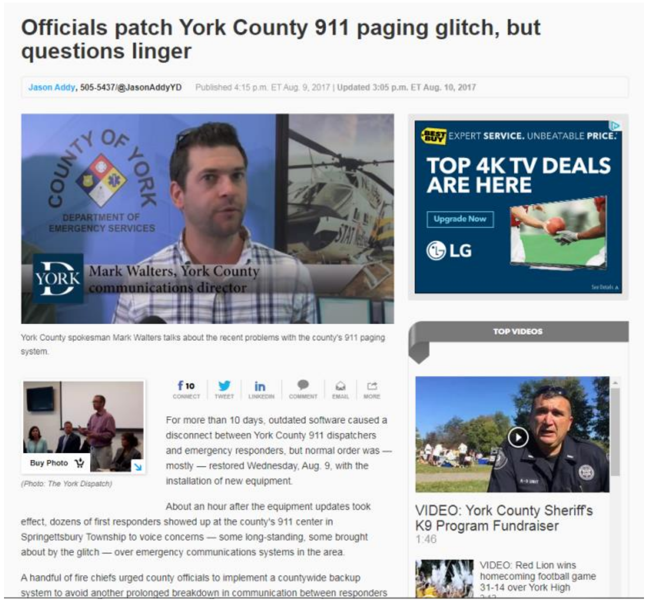


Trace	Notes	Input Freq	Sample Interval	dBc/Hz at 90 kHz	Duration	Acquired	Instrument
		10.000 MHz	1 s		96 h	74750 pts	TimePod 5330A
(Unsaved)		19.200 MHz	1 s	−150.6	96 h	10742 pts	TimePod 5330A



WEEK 1023 ROLLOVER ISSUES

- Background:
  - Trimble products have started rolling-over week 1023 prematurely
  - Many Trimble products are affected, Trimble does not offer a firmware fix
  - Some products producing incorrect date on February 2016 and July 2017
  - A number of first-responder, financial transaction handling, and other applications were rendered non-operational, some for several weeks until the root-cause could be identified
  - Preview of the major issues that can be expected in April 2019 GPS week rollover



Officials patch York County 911 paging glitch, but questions linger

Jason Addy, 505-5437/@JasonAddyYD Published 4:15 p.m. ET Aug. 9, 2017 | Updated 3:05 p.m. ET Aug. 10, 2017

York County spokesman Mark Walters talks about the recent problems with the county's 911 paging system.

Buy Photo

(Photo: The York Dispatch)

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For more than 10 days, outdated software caused a disconnect between York County 911 dispatchers and emergency responders, but normal order was — mostly — restored Wednesday, Aug. 9, with the installation of new equipment.

About an hour after the equipment updates took effect, dozens of first responders showed up at the county's 911 center in Springettsbury Township to voice concerns — some long-standing, some brought about by the glitch — over emergency communications systems in the area.

A handful of fire chiefs urged county officials to implement a countywide backup system to avoid another prolonged breakdown in communication between responders

TOP VIDEOS

VIDEO: York County Sheriff's K9 Program Fundraiser
1:46

VIDEO: Red Lion wins homecoming football game 31-14 over York High

http://www.yorkdispatch.com/story/news/2017/08/09/york-county-911-paging-glitch-fixed-wednesday/553677001/

A.10.30 Report Packet 0x8F-AB Primary Timing Packet

This automatic output packet provides time information once per second if enabled with packet 0x8E-A5. GPS week number, GPS time-of-week (TOW), UTC integer offset, time flags, date and time-of-day (TOD) information is provided. This packet can be requested with packet 0x8E-AB. This packet will begin transmission within 20 ms after the PPS pulse to which it refers.

Data Fields:

Time of Week: This field represents the number of seconds since Sunday at 00:00:00 GPS time for the current GPS week. Time of week is often abbreviated as TOW.

Week Number: This field represents the current GPS week number. GPS week number 0 started on January 6, 1980. Unfortunately, the GPS system has allotted only 10-bits of information to carry the GPS week number and therefore it rolls-over to 0 in just 1024 weeks (19.6 years,) and there is no mechanism built into GPS to tell the user to which 1024 week epoch the week number refers. The first week number roll-over will occur as August 21, 1999 (GPS) transitions to August 22, 1999 (GPS). The ThunderBolt adjusts for this week rollover by adding 1024 to any week number reported by GPS which is less that week number 936 which began on December 14, 1997. With this technique, the ThunderBolt will provide an accurate translation of GPS week number and TOW to time and date until July 30, 2017.

UTC Offset: This field represents the current integer leap second offset between GPS and UTC according to the relationship: Time (UTC) = Time (GPS) - UTC Offset. The UTC offset information is reported to ThunderBolt by the GPS system and can take up to 12.5 minutes to obtain. Before the ThunderBolt has received UTC information from the GPS system, it is only capable of representing time in the GPS time scale, and the UTC offset will be shown as 0.

Appendix: GPS Receiver Challenges

- GPS receivers have numerous issues:
  - Can lock onto Multipath signals
  - Have issues with leapsecond reporting and adjustment (numerous are known)
  - Suffer from incorrect GPS week rollover implementation
  - Do not lock-on properly when powered-up in mid-flight (>200kts)
  - Do not recover properly when antenna is removed/jammed for long time-periods (>days)
  - May not recover from incorrect GPS system setup (see January 2016, 13us offset issue)
  - For optimal performance need to be constantly adjusted by firmware in high-dynamic environments (Kalman filter time-constants, Doppler versus Carrier Phase tracking, etc)
  - Are not designed for Timing Performance (especially SAASM units)
  - Will have numerous unexplained large timing jumps (hours to days to weeks in-between)
  - Must be properly controlled:
    - Static Timing versus Dynamic 3d Mobile Operation
    - 12.5 minutes without Almanac: will cause incorrect Time (seconds) to be output!
    - Cannot handle the 1023 week rollover which happens every ~20 years (**APRIL 2019**)
    - Multi-GNSS selection (Galileo, Glonass, BeiDou, QZSS, SBAS, Gagan, EGNOS, etc)

Jackson Labs

"the next generation in frequency and timing"

Thank You

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