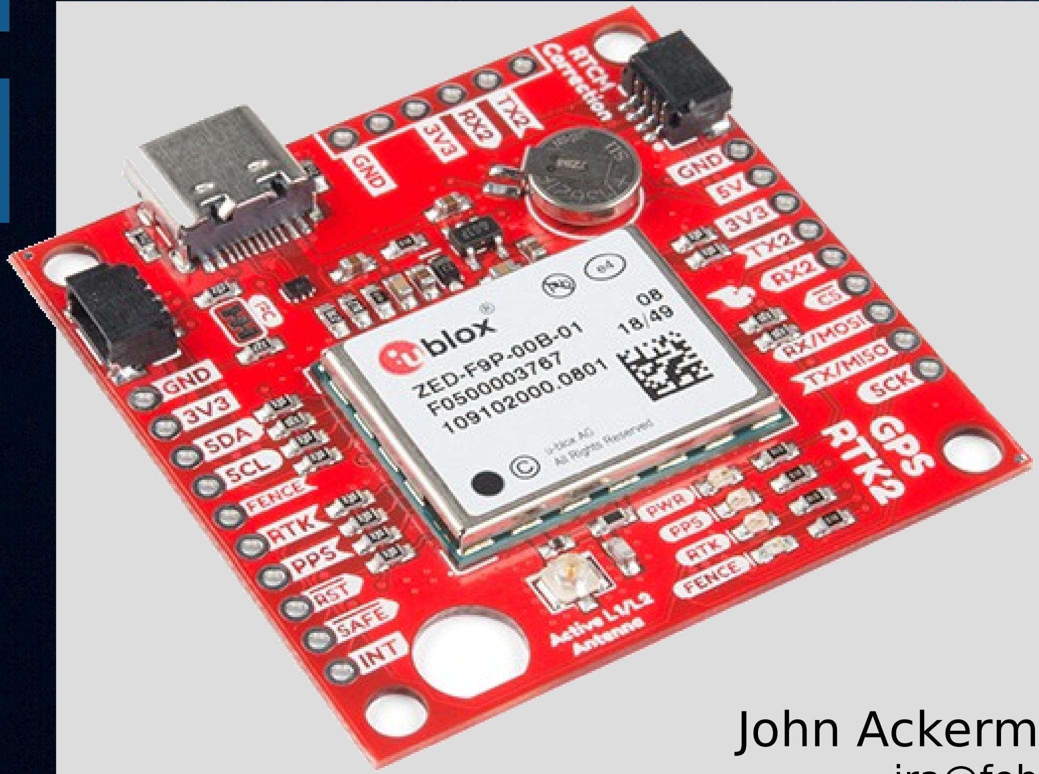
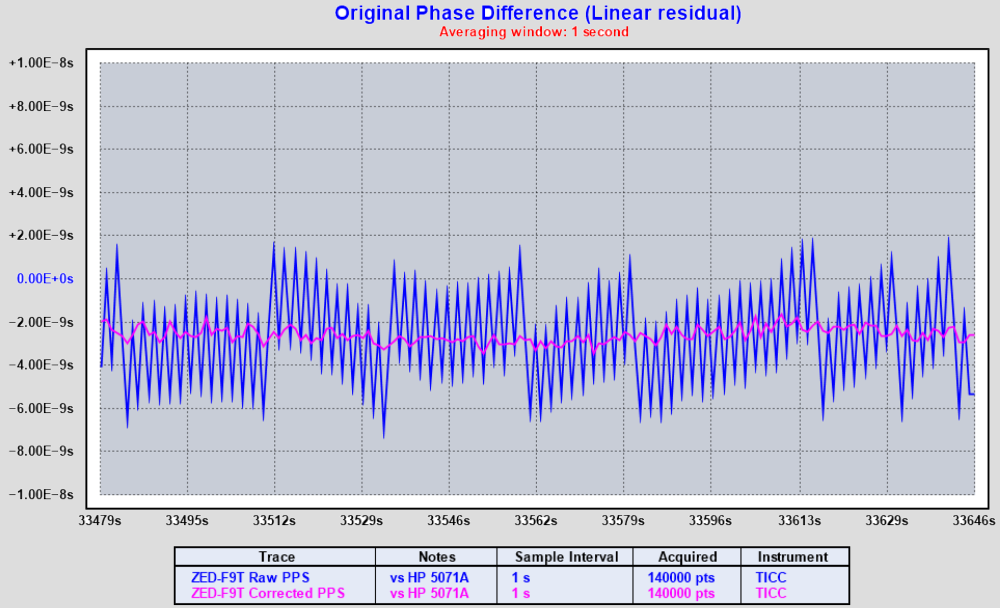
Timing Performance of a New Generation of GNSS Receivers





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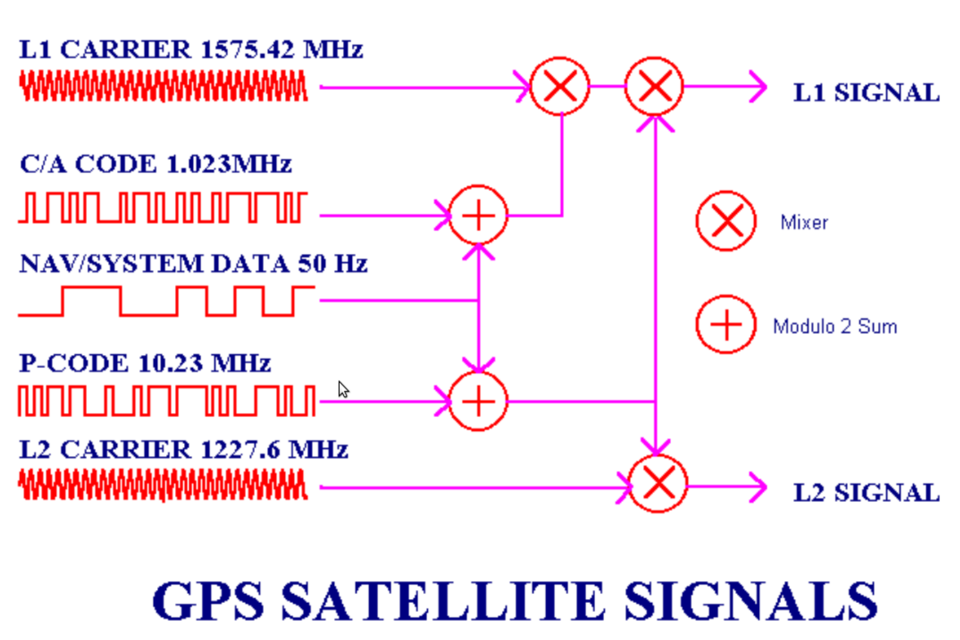
GNSS for Precision Frequency and Timing

- “Board level” GPS receivers have offered a pulse-per-second (“PPS”) output for many years
- Even old receivers can provide accuracy within 100 nanoseconds; toward 10 ns with a lot of effort
- Useful as reference for GPS disciplined oscillator
  - But GPS PPS is “noisy” in the short term; it has second-to-second jitter worse than a local crystal oscillator
  - More on that in my other presentation

What’s Changed?

- New devices incrementally better
- The big news:
  affordable **dual-freq** receivers
  - Used to cost $$$$$
  - Compensate for ionospheric factors
  - Use higher-resolution codes
  - Allow raw phase output
- ZED-F9 units <$200
- How does this affect timing performance?



Time to Test!

- Thanks to the HamSci consortium, I was able to get my hands on several current u-blox receivers:*

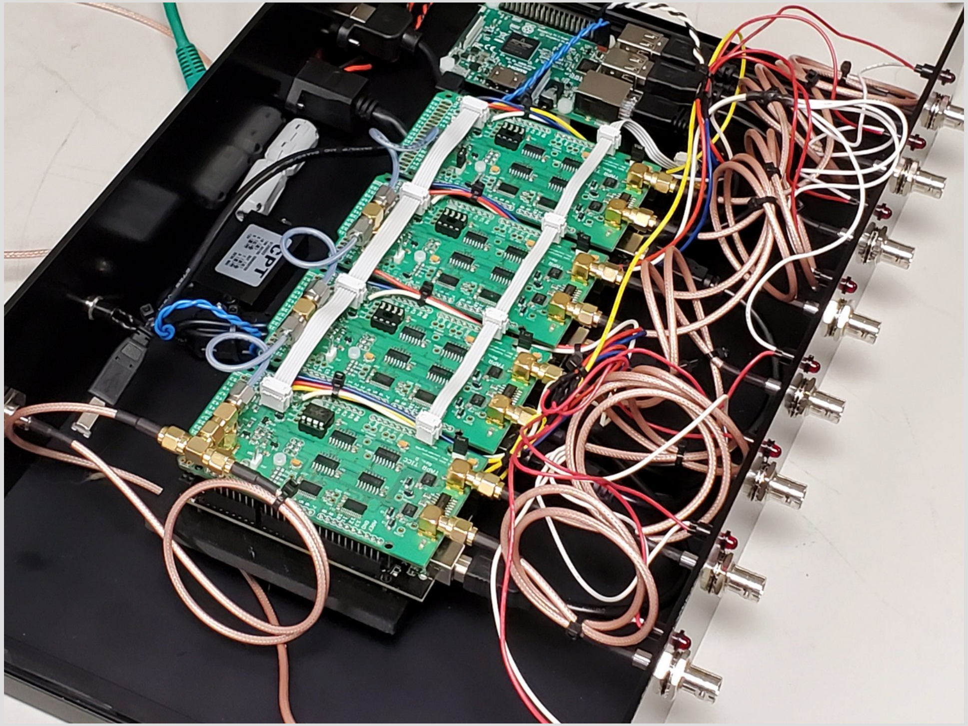
Model	Features
LEA-M8F	L1, frequency and time sync, disciplined oscillator, RAWX, no qErr
NEO-M8N	L1, navigation, no qErr, no RAWX, no 0D
NEO-M8P	L1, positioning, qErr, RAWX, RTK engine
NEO-M8T	L1, timing, qErr, RAWX, no high-precision llh output
NEO-M9N	L1, navigation, no qErr, no RAWX, no 0D
ZED-F9P	L1/L2, positioning, qErr, RAWX, RTK engine
ZED-F9T	L1/L2, timing, qErr, RAWX, no high-precision llh output

*Support to this project from NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972 is gratefully acknowledged.

The Test Plan

- Compare the PPS outputs (which u-blox calls “TIMEPULSE” outputs) from all receivers against atomic clock
- Measure all receivers simultaneously, using the same antenna, to allow direct comparison
- Measure for several days to get long-term data
- Do additional runs targeting specific capabilities/options

Step 0: Build the Test Equipment



- About six months spent designing/building/coding the “multi-TICC” to enable the testing
  - 4 TICC* counters in a box, linked to a common timebase and computer logging system
  - Allows measuring 8 inputs simultaneously with 60 ps resolution
  - See: https://tapr.wpengine.com/tapr-file-area/time-freq/multi-TICC_App_Note_2020-01.pdf

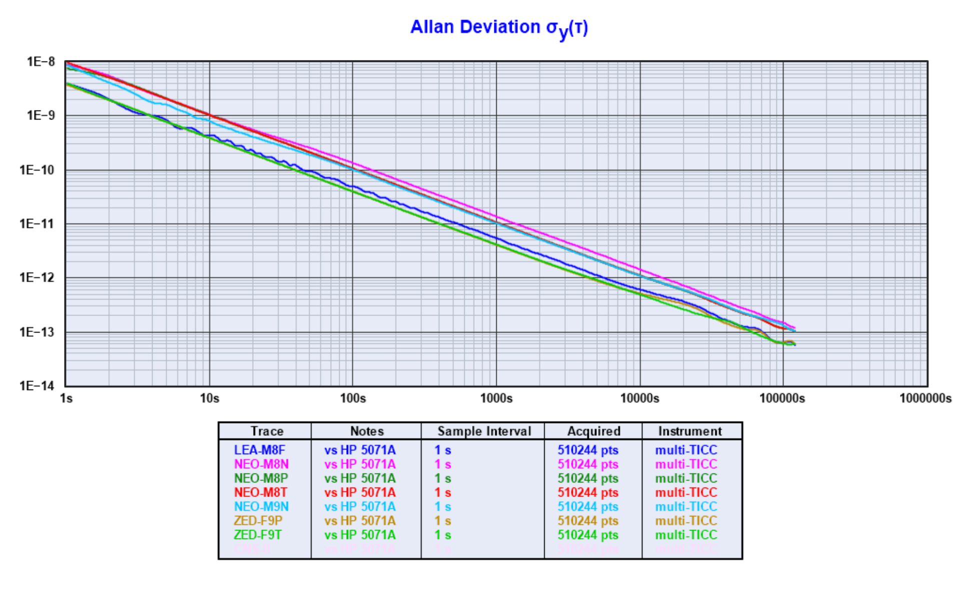
* https://tapr.org/product/tapr-ticc/

Step 1: Capture Data

- Receivers set to default values except:
  - Set to “0D” or “Timing” mode where applicable
  - Fixed location set to surveyed antenna position where applicable
- Receivers connected to common antenna through splitters
- TIMEPULSE outputs connected to multi-TICC inputs
- 10 MHz from HP 5071A cesium standard to multi-TICC reference input
- multi-TICC output logged to computer
- Collected PPS data for just under 6 days (510K samples per receiver) and analyzed with “TimeLab” software

Overview of Results

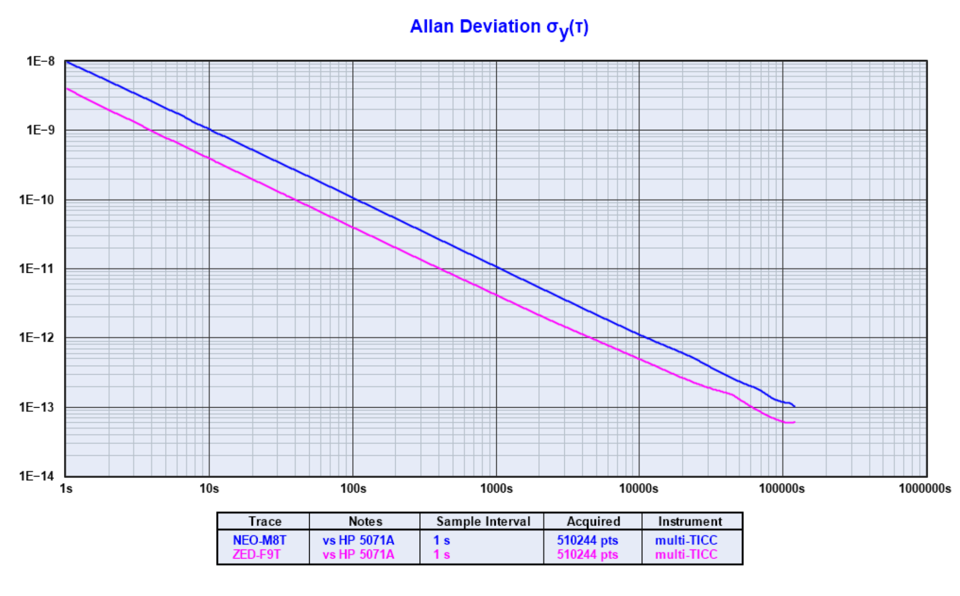
- Overview shows two distinct groups, but differences are hidden in the noise, so let's look at each group separately

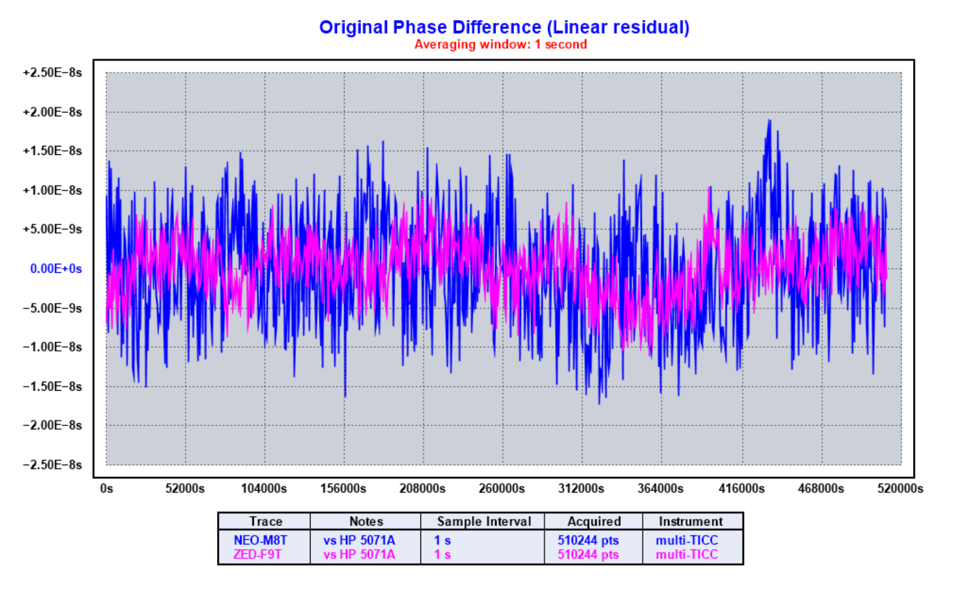


Receiver	ADEV @ 1 Sec	ADEV @ 10K Sec
LEA-M8F	4.07×10^{-9}	6.20×10^{-13}
NEO-M8N	9.03×10^{-9}	1.45×10^{-12}
NEO-M8P	7.71×10^{-9}	1.12×10^{-12}
NEO-M8T	9.99×10^{-9}	1.12×10^{-12}
NEO-M9N	9.02×10^{-9}	1.10×10^{-12}
ZED-F9P	3.85×10^{-9}	5.24×10^{-13}
ZED-F9T	4.13×10^{-9}	4.97×10^{-13}

The ZED-F9 Receivers (or, “Why We’re Here Today”)

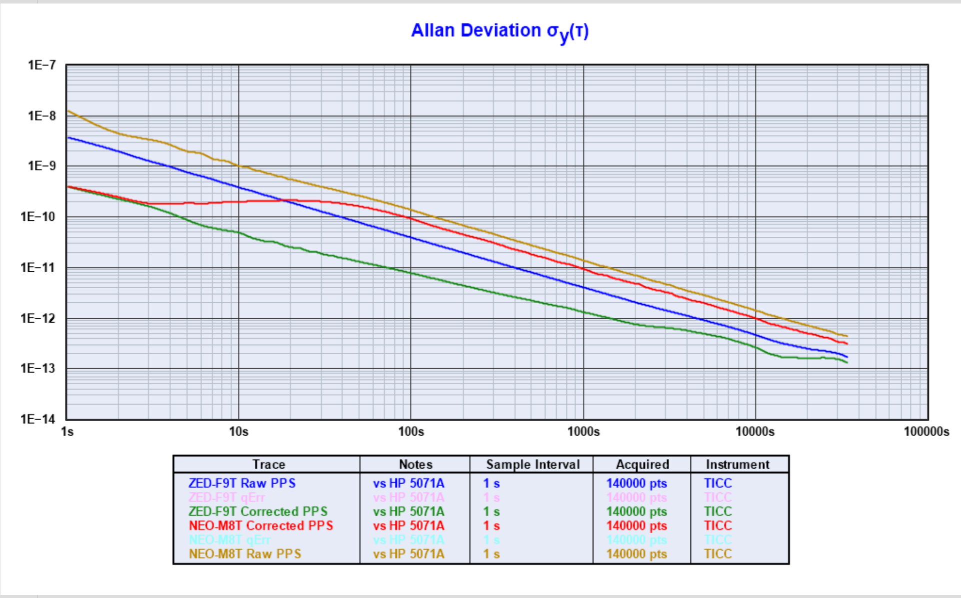
- “P” model has RTK engine; “T” model has extra I/O and a bit lower cost (in quantity)
- Half an order of magnitude better than “8” series!

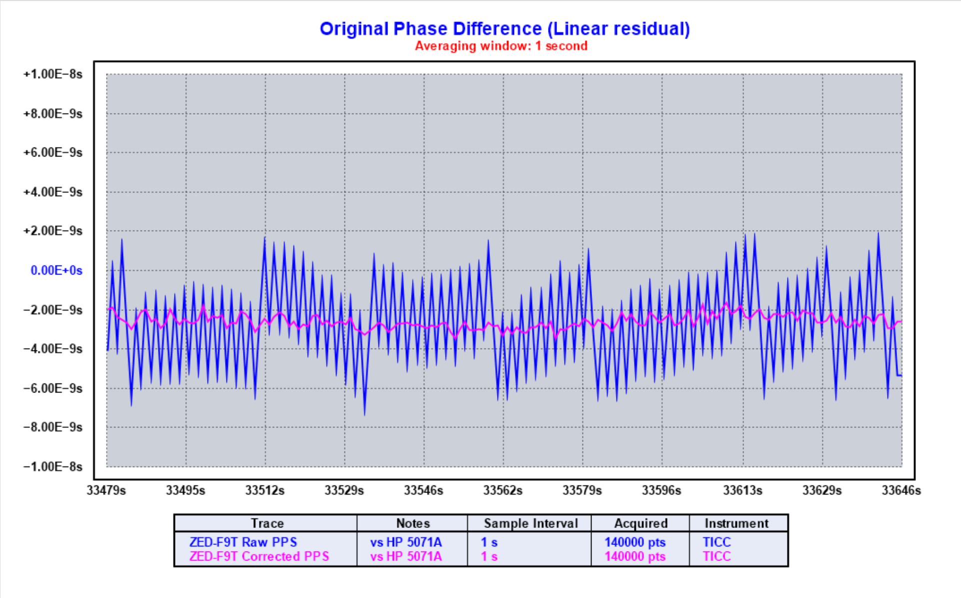




Questions Answered: Does Sawtooth Correction Work?

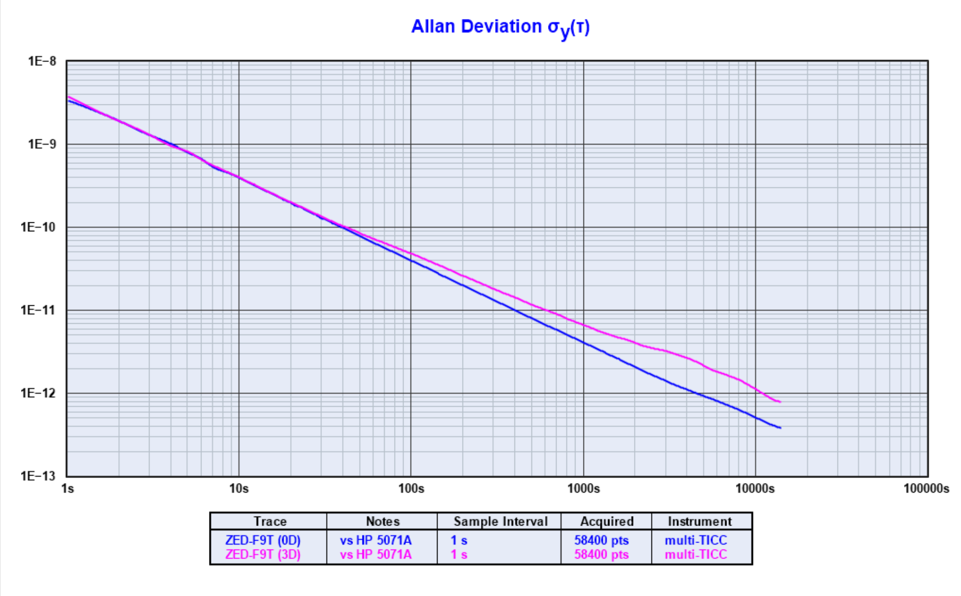
- Yes

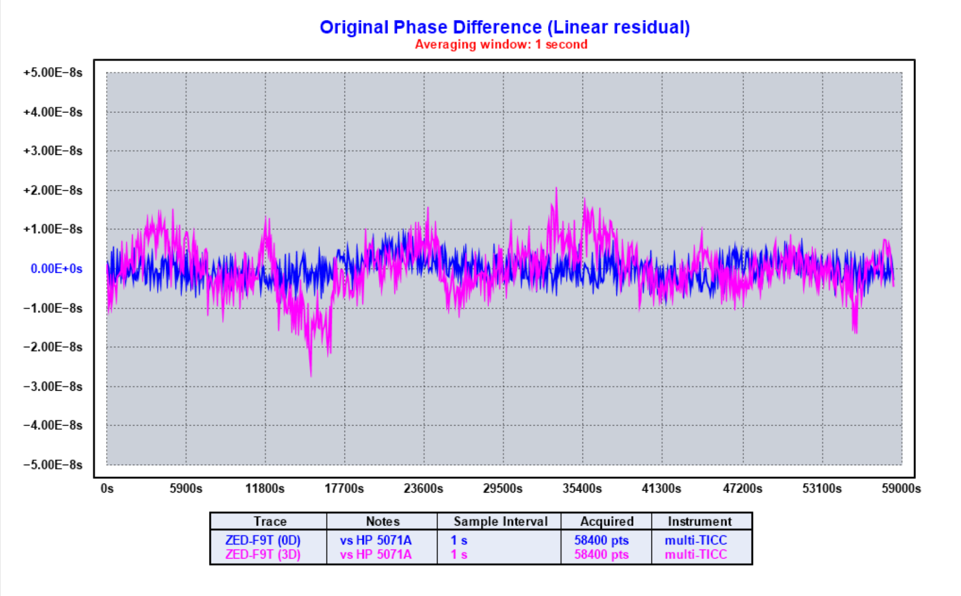




Questions Answered:
Is “0D” Important for Timekeeping?

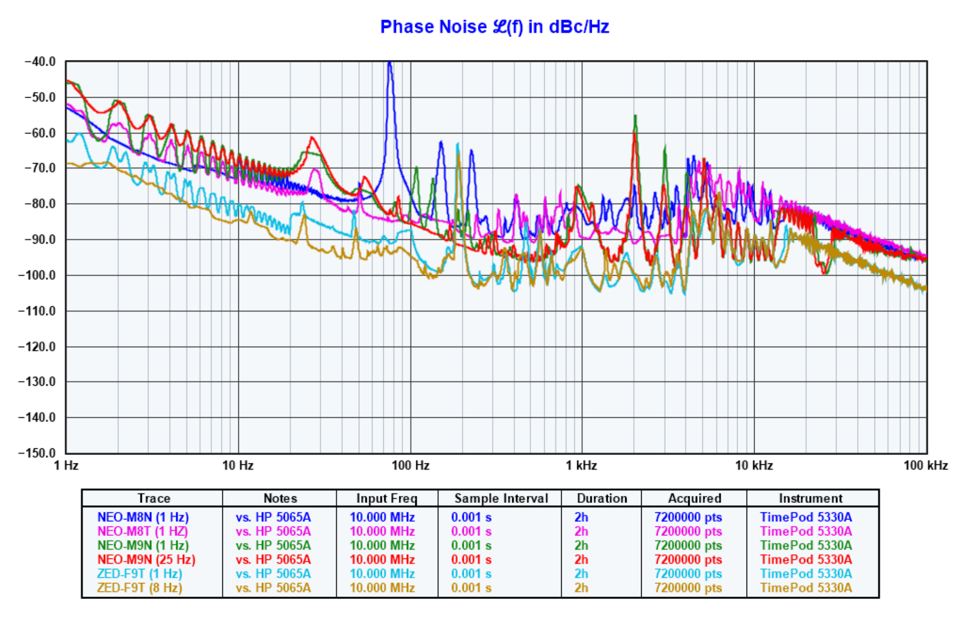
- Yes

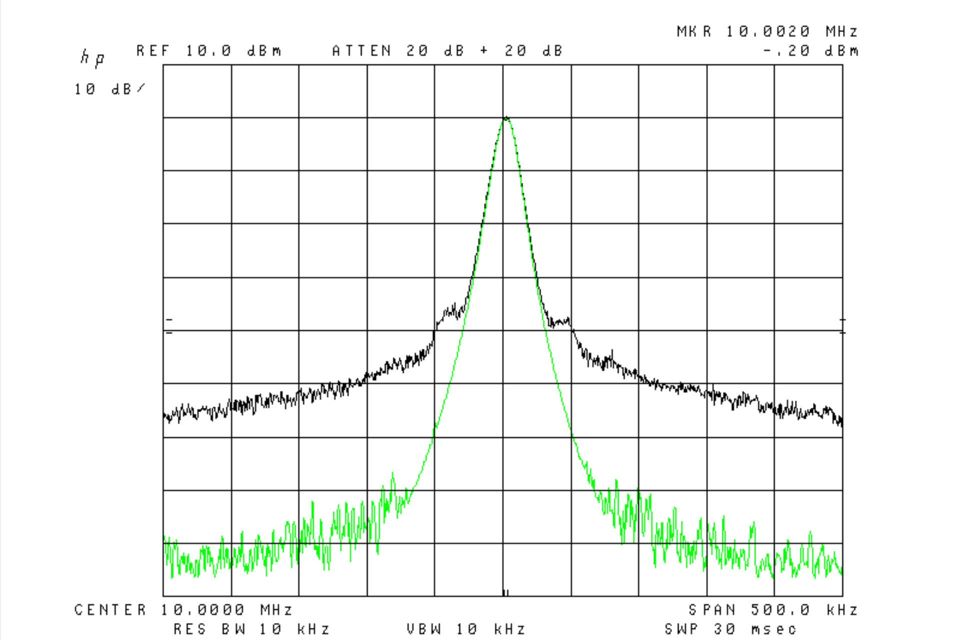




Questions Answered: 10 MHZ TIMEPULSE as an RF Source?

- No





Autonomous Positioning Performance

- 12-hour test logging position data from common antenna
- “CEP” = Circular Error, “EP” = Elevation Error Probabilities

Receiver	CEP – 50%	CEP – 95%	CEP – 99%	EP – 50%
LEA-M8F	1.034	2.900	3.735	1.743
NEO-M8N	1.090	2.302	3.004	1.976
NEO-M8P	1.117	2.319	2.607	1.520
NEO-M8T	1.264	2.271	3.441	1.777
NEO-M9N	0.820	1.684	1.944	1.159
ZED-F9P	0.559	1.449	1.633	0.817
ZED-F9T	1.370	2.457	3.142	1.928

This ain’t right!

Positioning Performance

- "P" receivers have built-in RTK correction processing engine
  - Provide source of correction data, get mm-level data out
- ~8 hour data collection using Ohio DOT reference station network for corrections
- RTK certainly works
  - Why single-freq M8P performance almost equals dual-freq F9P is unknown; M8P is performing better than it should!
  - Consider these results preliminary

Receiver	CEP – 50%	CEP – 95%	CEP – 99%	EP – 50%
NEO-M8P	0.010	0.029	0.035	0.021
ZED-F9P	0.013	0.025	0.033	0.016

Post-Processing Performance

- Collected data from NEO-M8P (GPS), ZED-F9P (GPS), ZED-F9T (GPS+GLONASS) as well as survey-grade unit
- Sent off for post-processing*
- Conclusions:
  - M8P gets to around ½ meter
  - Dual-freq gets to a handful of mm and competes with survey rx
  - Using GPS+GLONASS improves ZED-F9 results vs. GPS only

	NetRS (GPS)		NEO-M8P (GPS)		ZED-F9P (GPS)		ZED-F9T (GPS+GLONASS)	
	24 Hour	Sigma (95%)	24 Hour	Sigma (95%)	24 Hour	Sigma (95%)	24 Hour	Sigma (95%)
LAT ITRF2014	39 xx 42.67100	0.0068	39 xx 42.66852	0.3601	39 xx 42.67067	0.0090	39 xx 42.67086	0.0048
LON ITRF2014	-84 xx 41.53109	0.0124	-84 xx 41.53533	0.4131	-84 xx 41.53164	0.0160	-84 xx 41.53226	0.0084
EL HGT ITRF2014	247.101	0.0247	247.21	0.6522	247.1254	0.0370	247.1548	0.0217

* https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php

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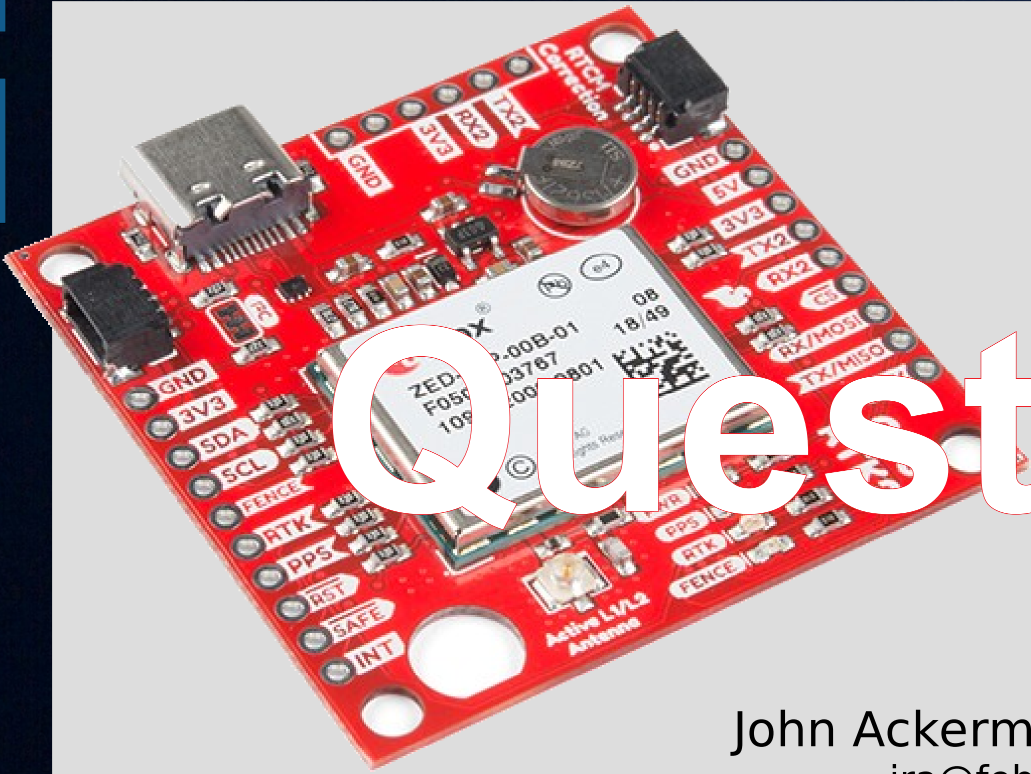

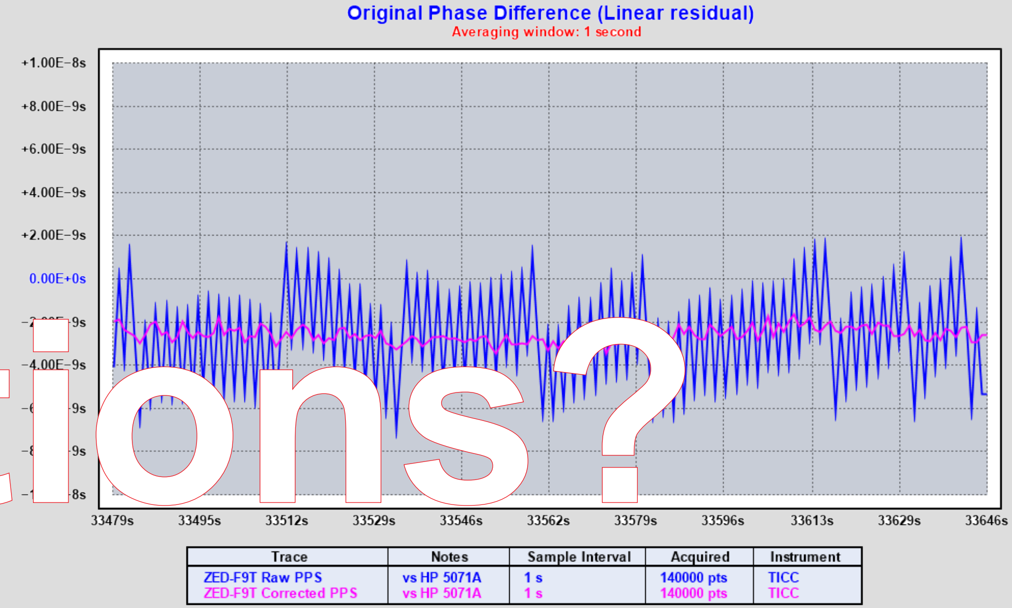

Questions?

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