Design of the TangerineSDR Clock Module

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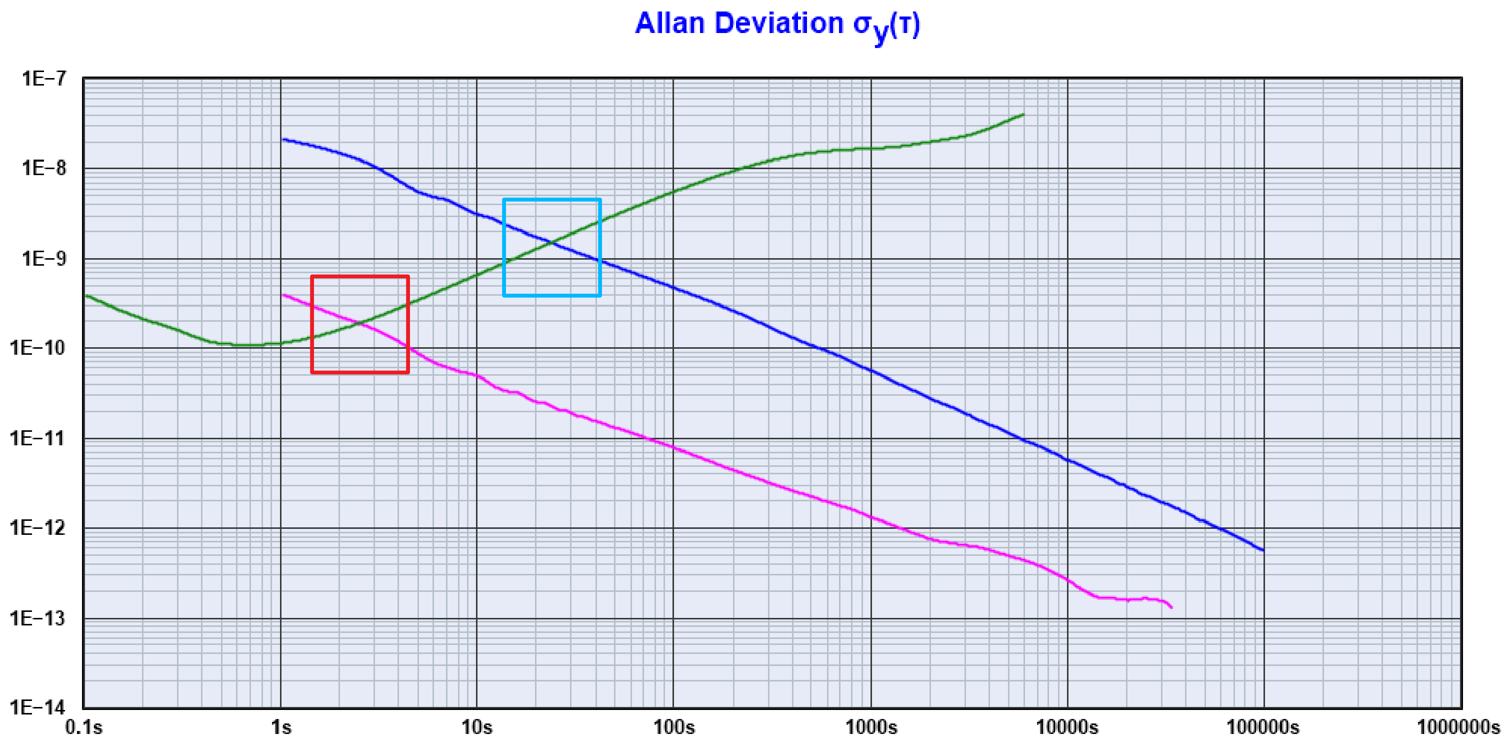
TangerineSDR
Clock Requirements

- 122.88 MHz clock to drive RF modules
- Pulse-per-second and timestamps for data tagging
- 10 MHz general purpose reference signal
- Total Electron Count observation/reporting
- Specifications (as declared by the team):
  - Frequency accuracy (long-term): $<1x10^{-12}$
  - Frequency stability: $<1x10^{-9}$ (1 part per billion) at tau >= 1 second
  - PPS accuracy: within 100 nanoseconds of UTC(USNO)
  - PPS jitter: <10 nanoseconds
  - Phase noise (122.88 MHz):
    - -80 dBc/Hz @ 100 Hz offset
    - -150dBc/Hz @ 100 kHz offset

GPSDO Concepts

- GPS has long-term accuracy and stability, but short term noise
- Crystal oscillator has short-term stability but drifts and is environmentally sensitive.
- Use phase-lock loop with suitable time constant to steer crystal to stay lined up with GPS
- Goal is to match rising ADEV of XO with falling ADEV of GPS as measurement period (“tau”) increases

The Magic Plot

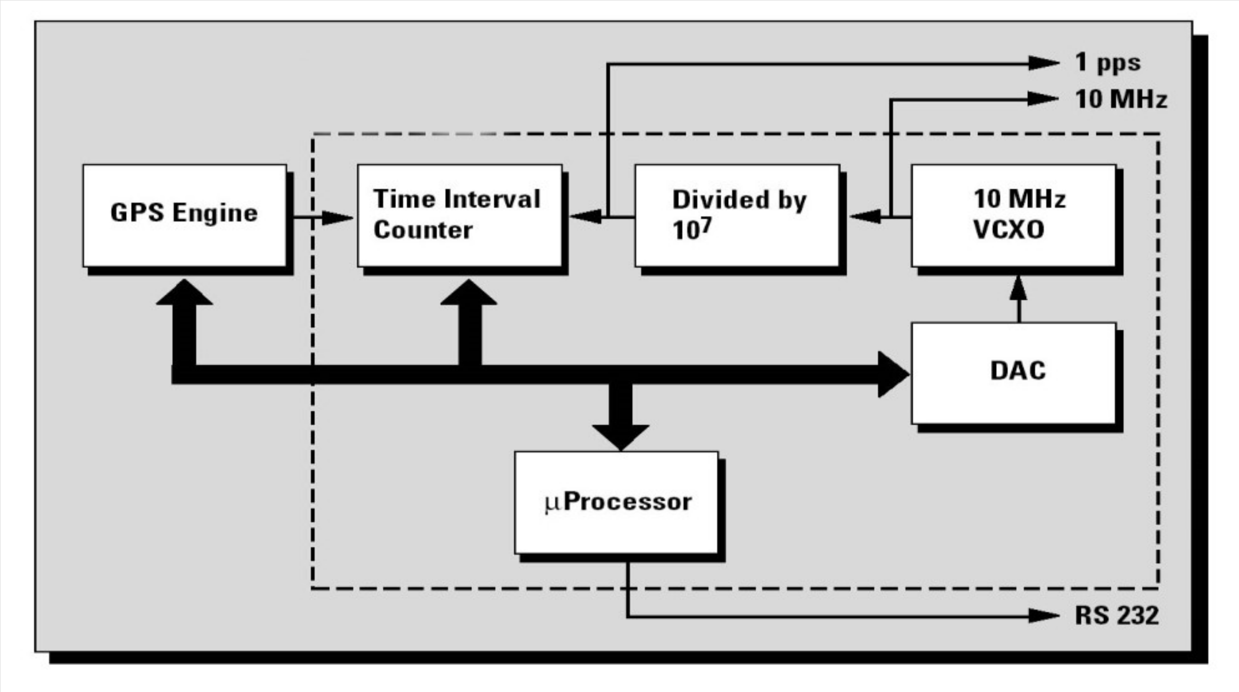


Trace	Notes	Sample Interval	Acquired	Instrument
Sparkfun EM-406A (SiRF III)	TVB Maser	1 s	400000 pts	HP 53132A
ZED-F9T Corrected PPS	vs HP 5071A	1 s	140000 pts	TICC
Vectron 125 MHz TCXO	vs HP 5071A	0.100 s	246082 pts	TICC

GPSDO Concepts

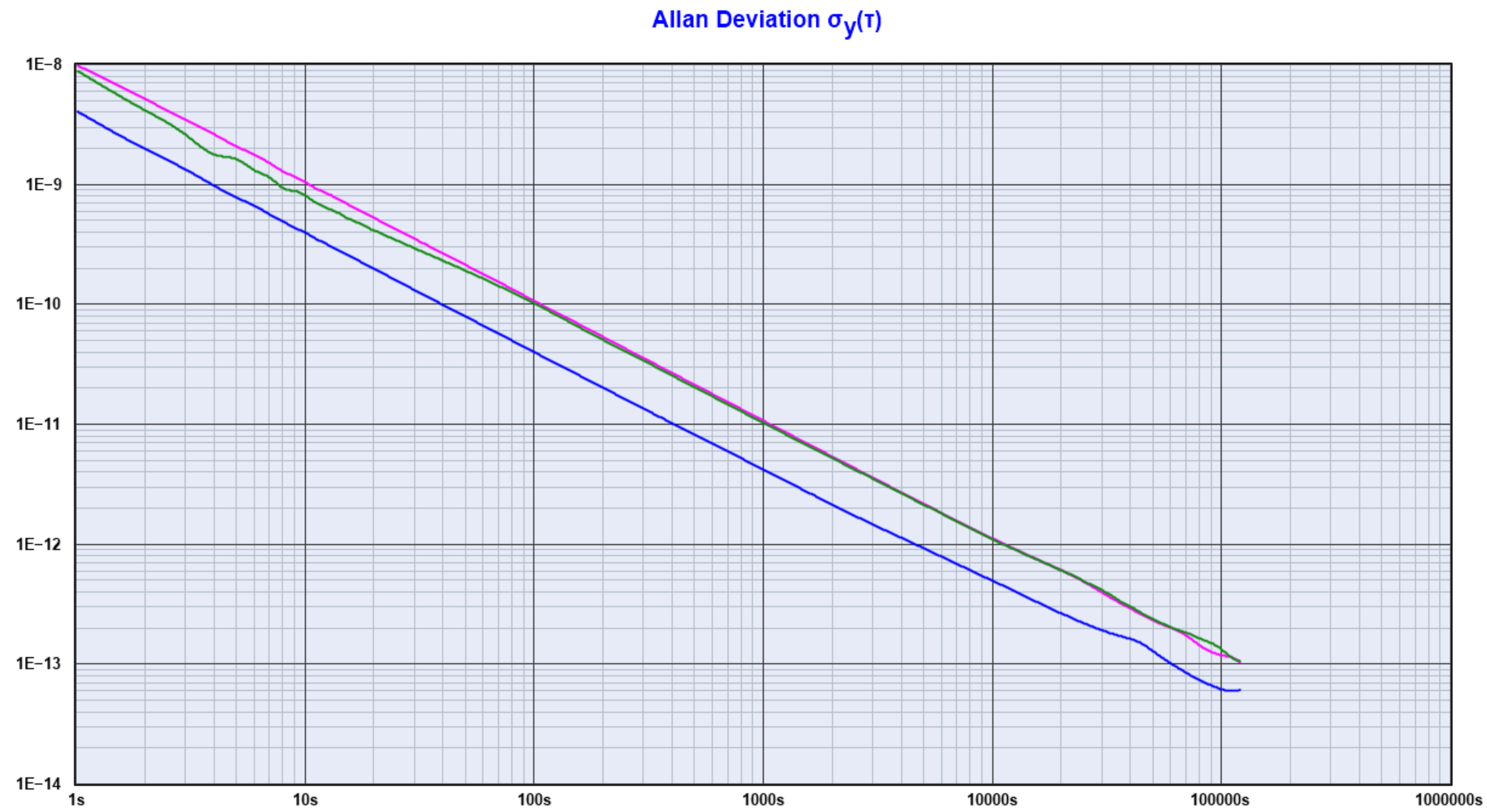
- Traditional implementation:
  - GPS with pulse-per-second (“PPS”) output
  - 10 MHz TCXO/OCXO divided down to PPS
  - Compare phase of PPS and steer oscillator to follow GPS
    - PLL time constant typically 100 to 1000 seconds
    - Tune loop to ADEV crossover point
  - Added features:
    - “Holdover” to keep reasonable frequency if GPS signal lost
    - MCU “learns” aging and tempco of oscillator to improve holdover
    - Variable loop bandwidth for faster acquisition

Traditional GPSDO Architecture



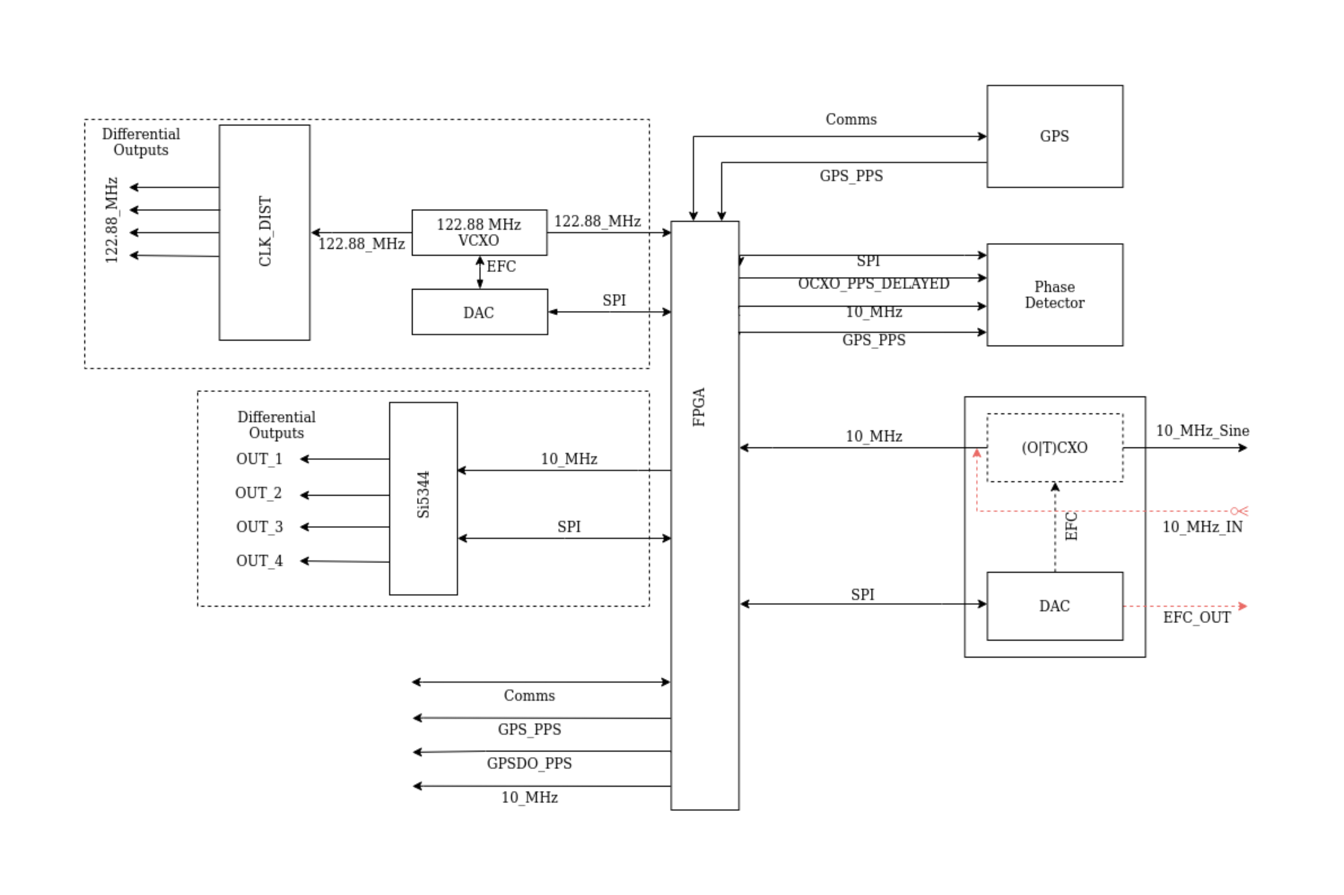
Do Newer GPS Modules Offer Advantages?

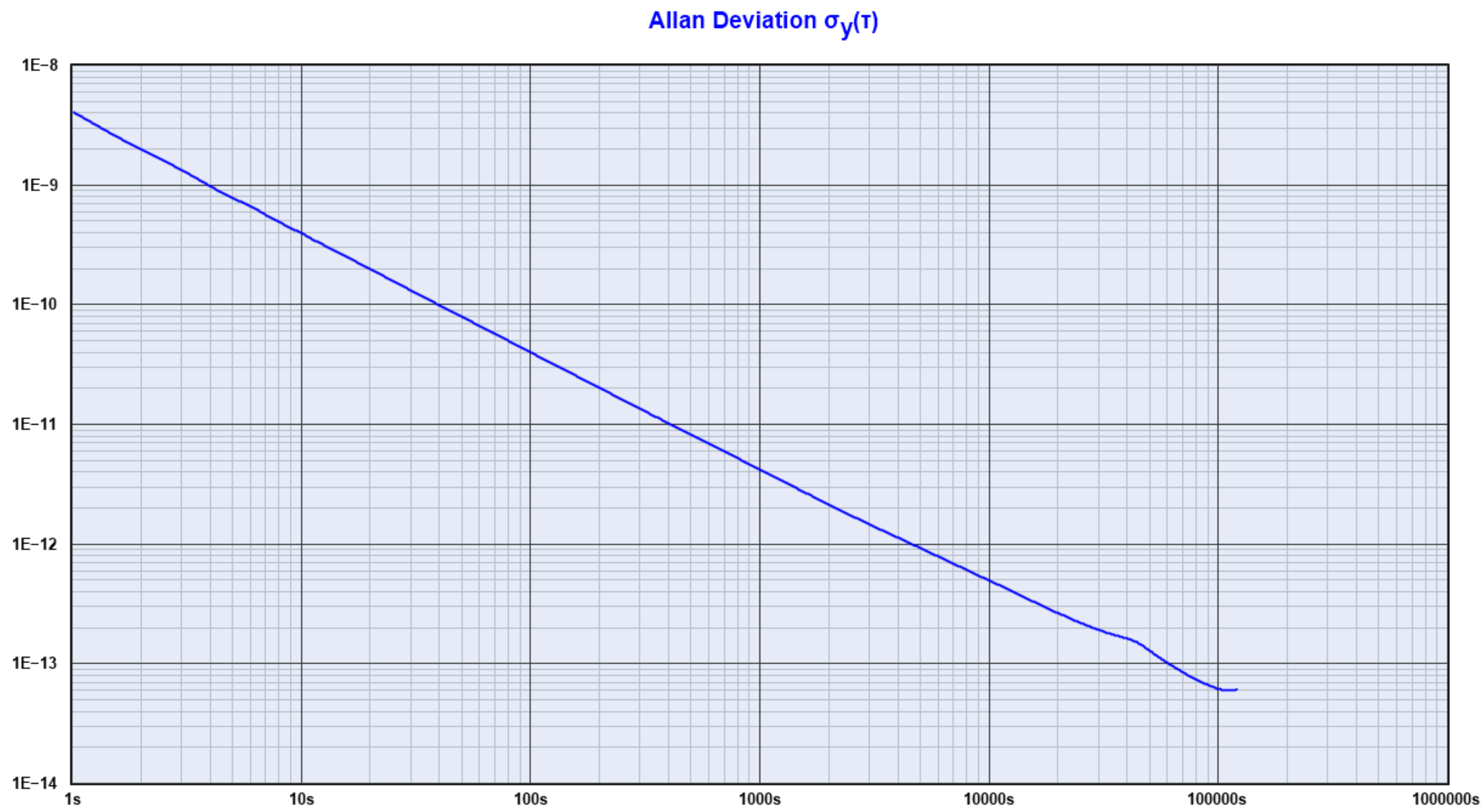
- Traditional GPS PPS have jitter of ~10–50 nanoseconds
  - That establishes the ADEV starting point
  - Lower jitter means shorter PLL time constant, means maybe cheaper oscillator will do
- Newer GPS modules offer:
  - Higher internal clock frequency to lower jitter
  - “Sawtooth” error correction
  - Dual-Frequency operation (ZED-F9 modules)



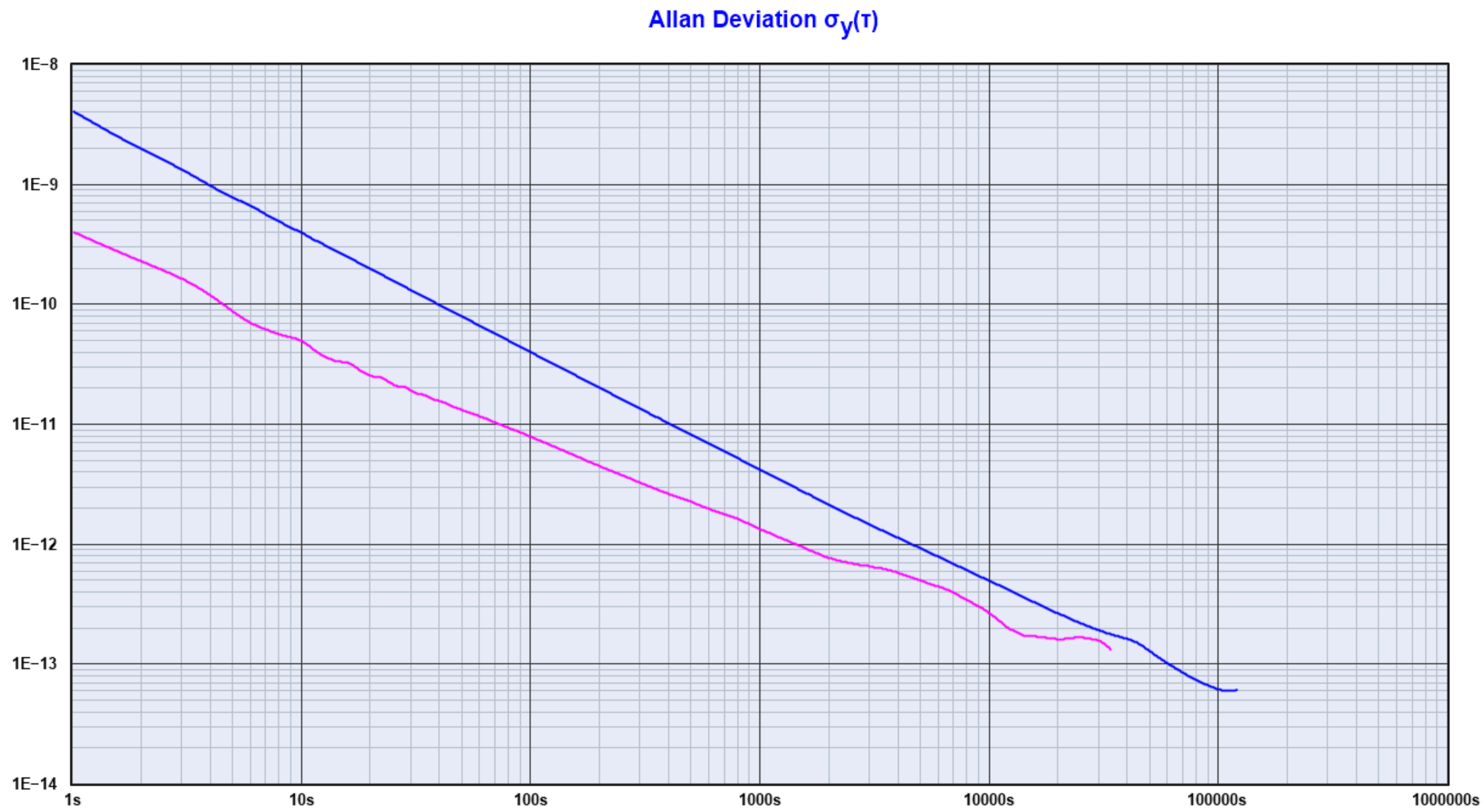
Trace	Notes	Sample Interval	Acquired	Instrument
ZED-F9T	vs HP 5071A	1 s	510244 pts	multi-TICC
NEO-M8T	vs HP 5071A	1 s	510244 pts	multi-TICC
NEO-M9N	vs HP 5071A	1 s	510244 pts	multi-TICC

Clock Module Mark I





Trace	Notes	Sample Interval	Acquired	Instrument
ZED-F9T	vs HP 5071A	1 s	510244 pts	multi-TICC
ZED-F9T Corrected PPS	vs HP 5071A	1 s	140000 pts	TICC
10 MHz from ZED-F9T	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A



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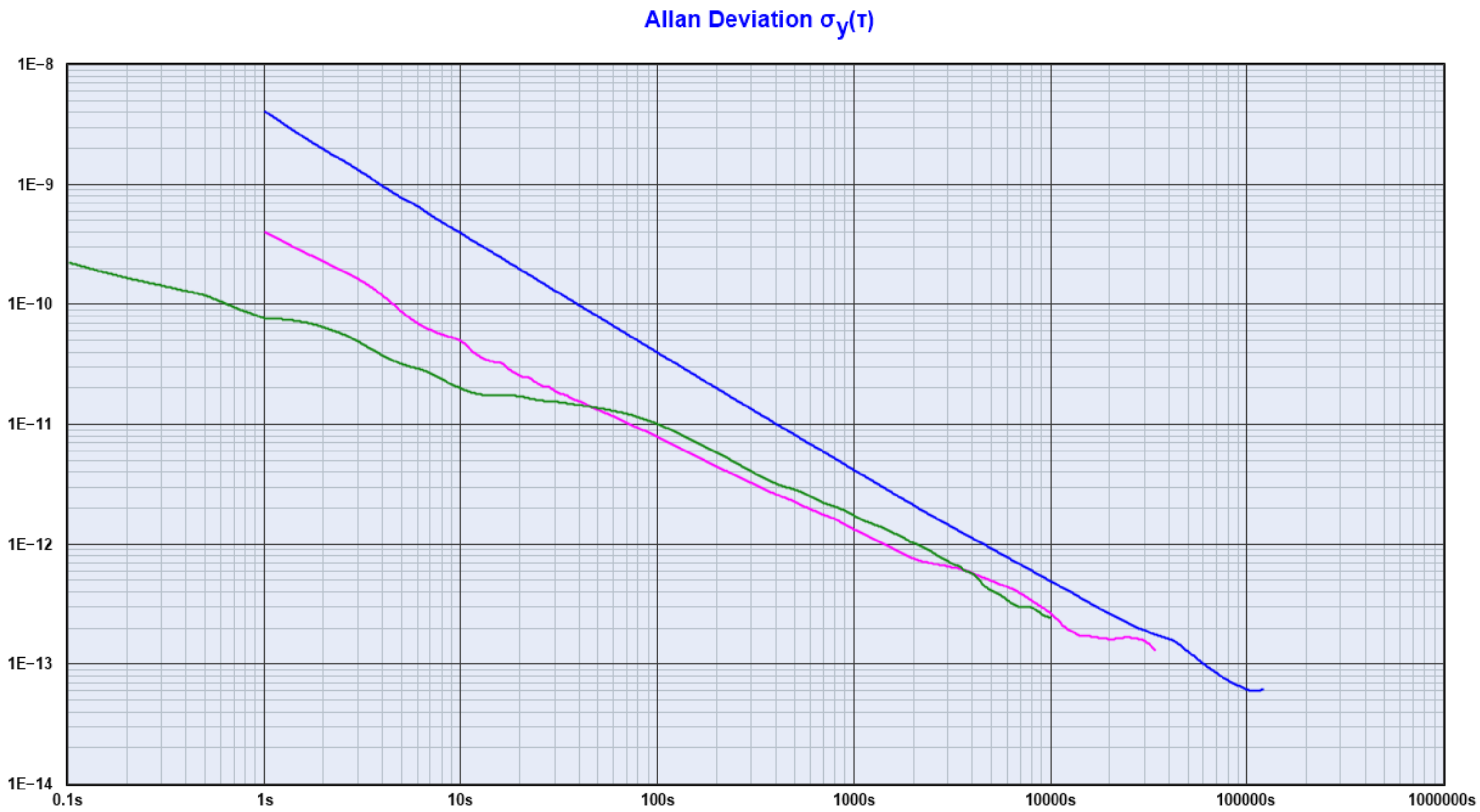

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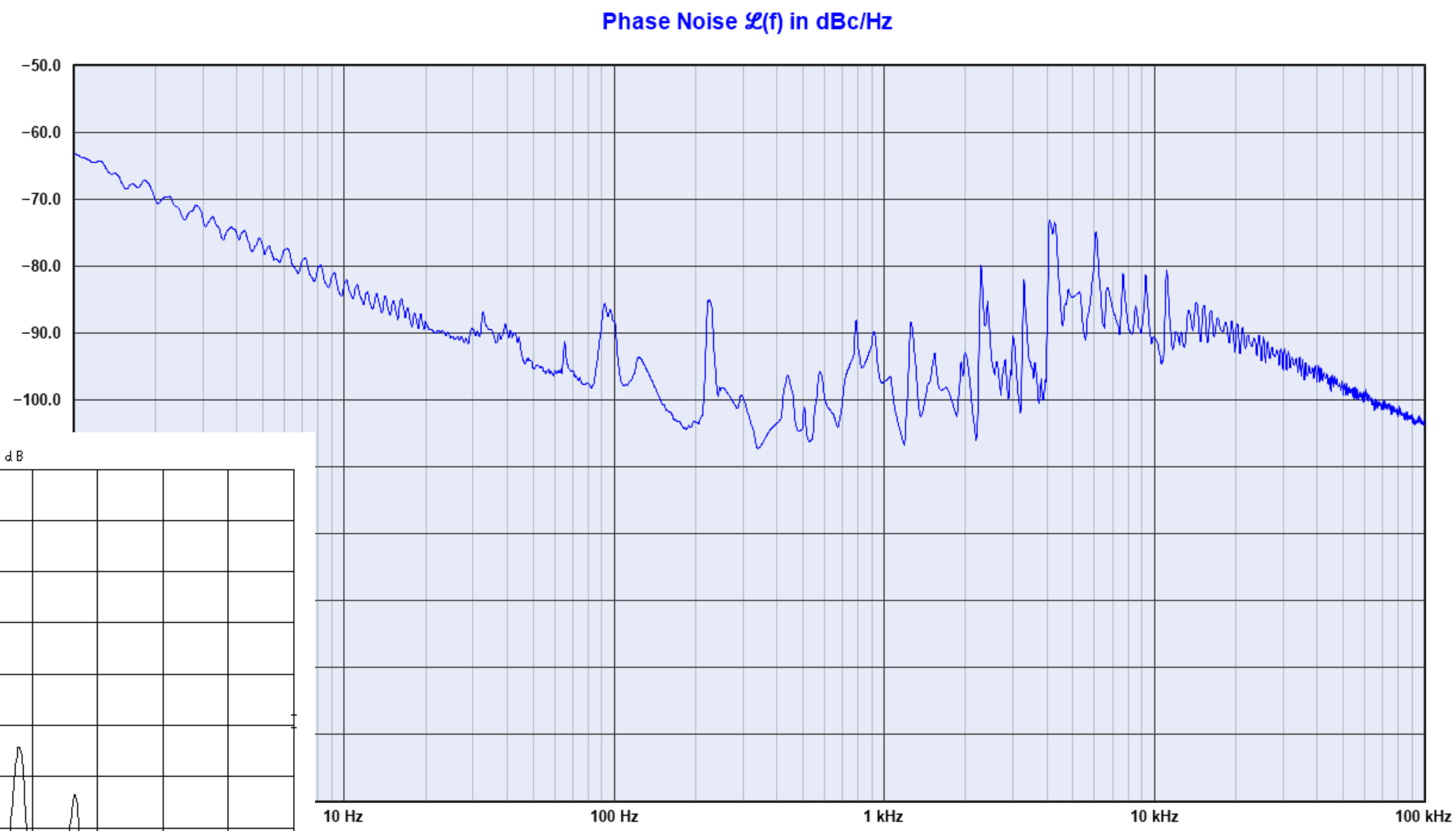
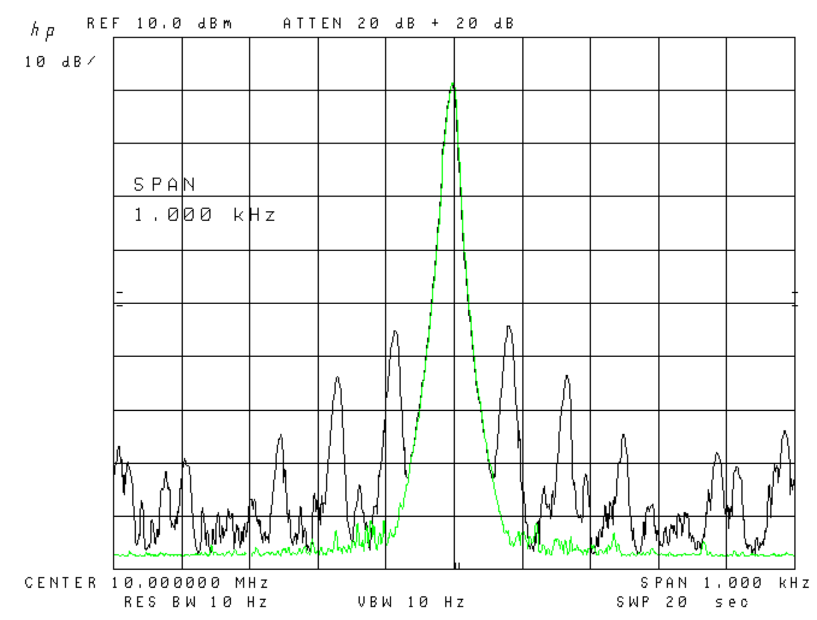


Trace	Notes	Sample Interval	Acquired	Instrument
ZED-F9T 10 MHz	vs. ULN	0.001 s	300000 pts	TimePod 5330A



The Si5344 “Jitter Attenuator” Chip

- Intended for on-board cleanup of distributed clock signals
- Locks internal low-noise reference to external clock input
  - Dirty input, clean output!
- 4 independent outputs at any freq from 100 Hz to 1028 MHz
- 4 inputs from 8 kHz to 750 MHz
- Programmable PLL bandwidth
- Modest holdover capability
- Fail-over between inputs

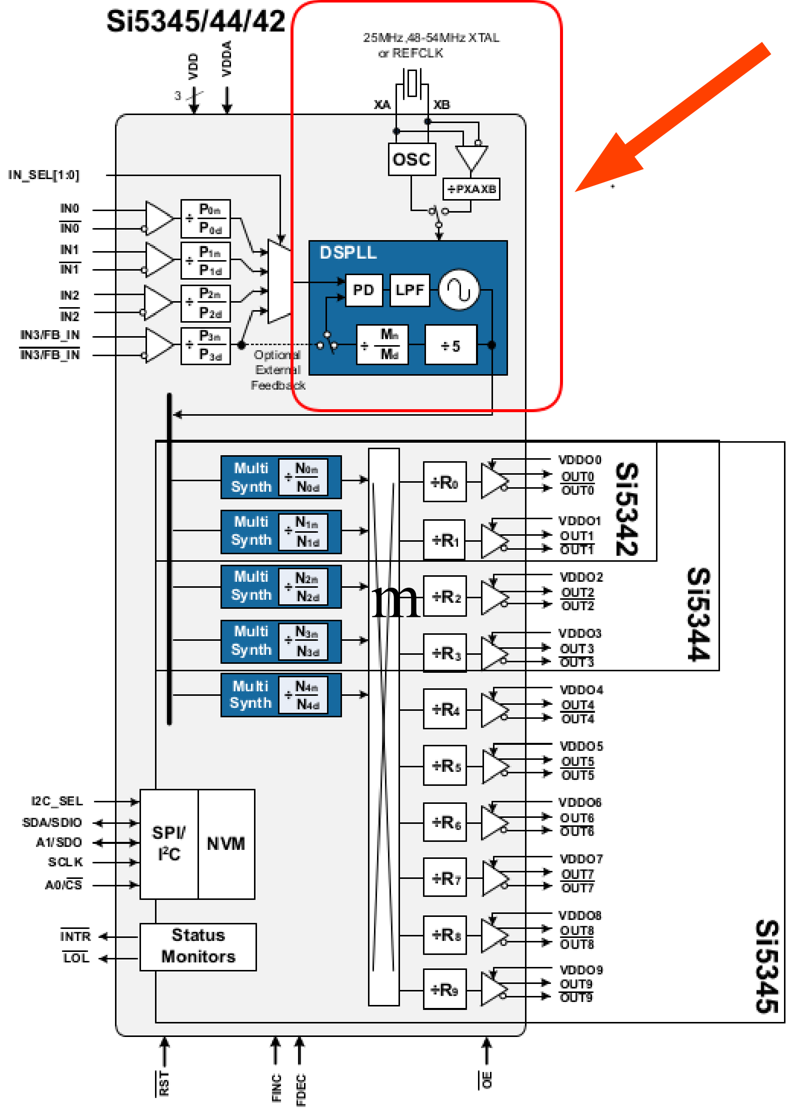


Figure 2.1. Block Diagram Si5345/44/42

Phase Noise

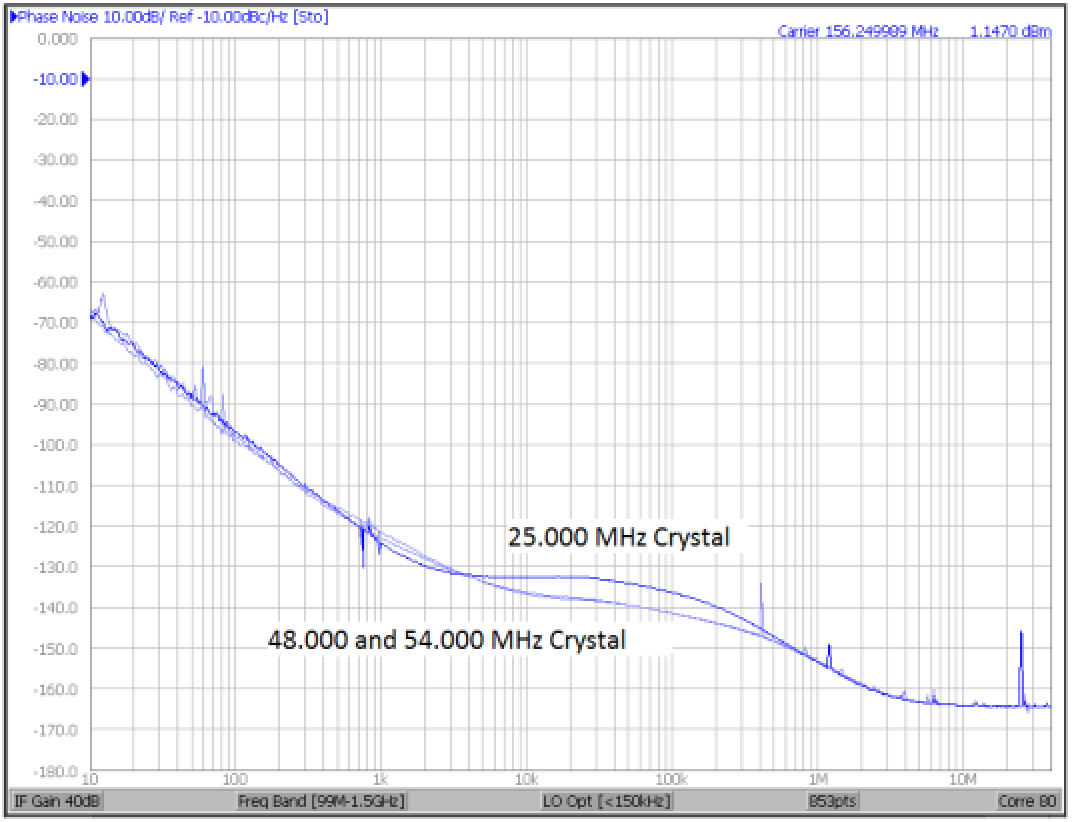
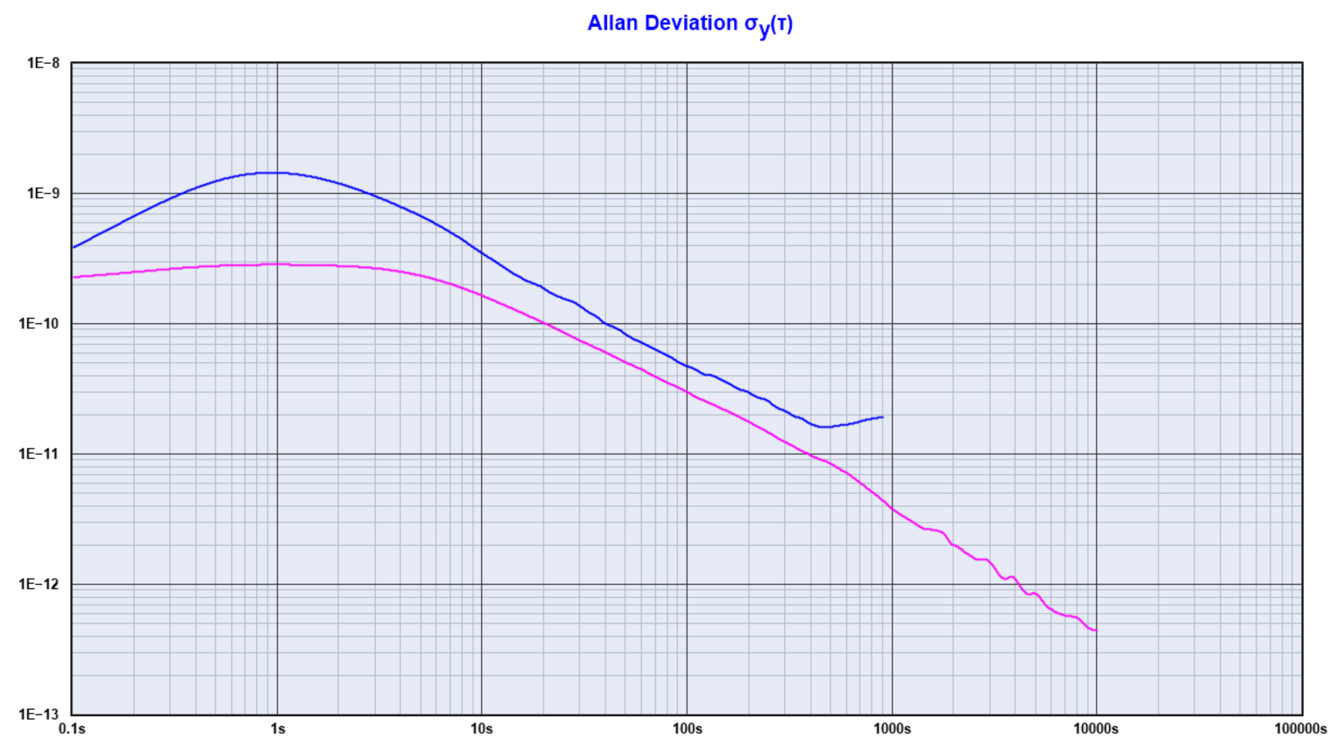


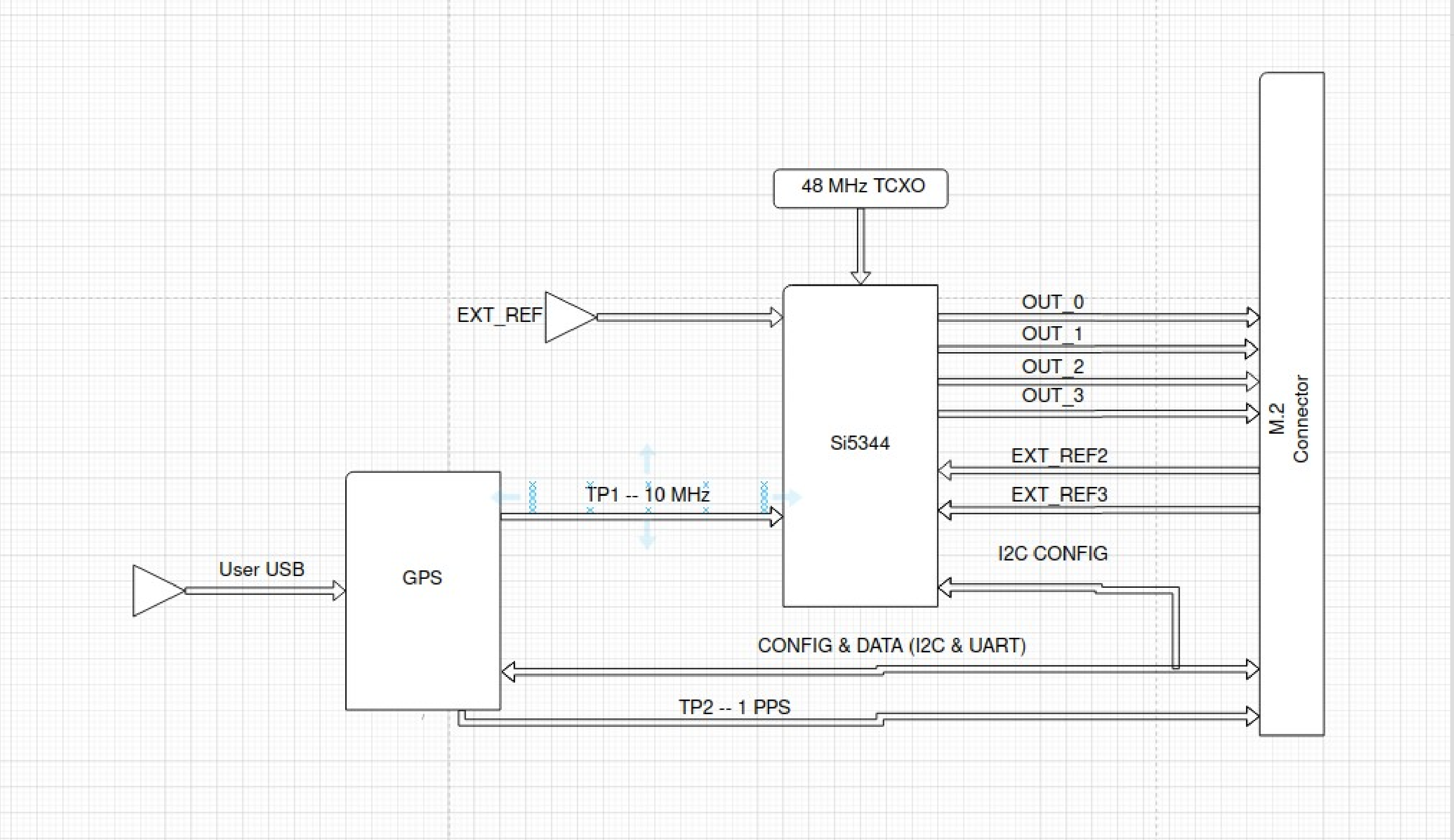
Figure 2. Si5345 156.250 MHz Phase Noise Comparison Using 25.000, 48.000, and 54.000 MHz Crystals as the XA/XB Reference

Short-Term Stability



Trace	Notes	Sample Interval	Acquired	Instrument
Si5342 (XO) 10 MHz from ZED-F9T (BW=0.069)	vs. HP 5071A	0.100 s	36000 pts	TimePod 5330A
Si5328 (TCXO) 10 MHz from ZED-F9T (BW=0.088)	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A

Clock Module Mark 2

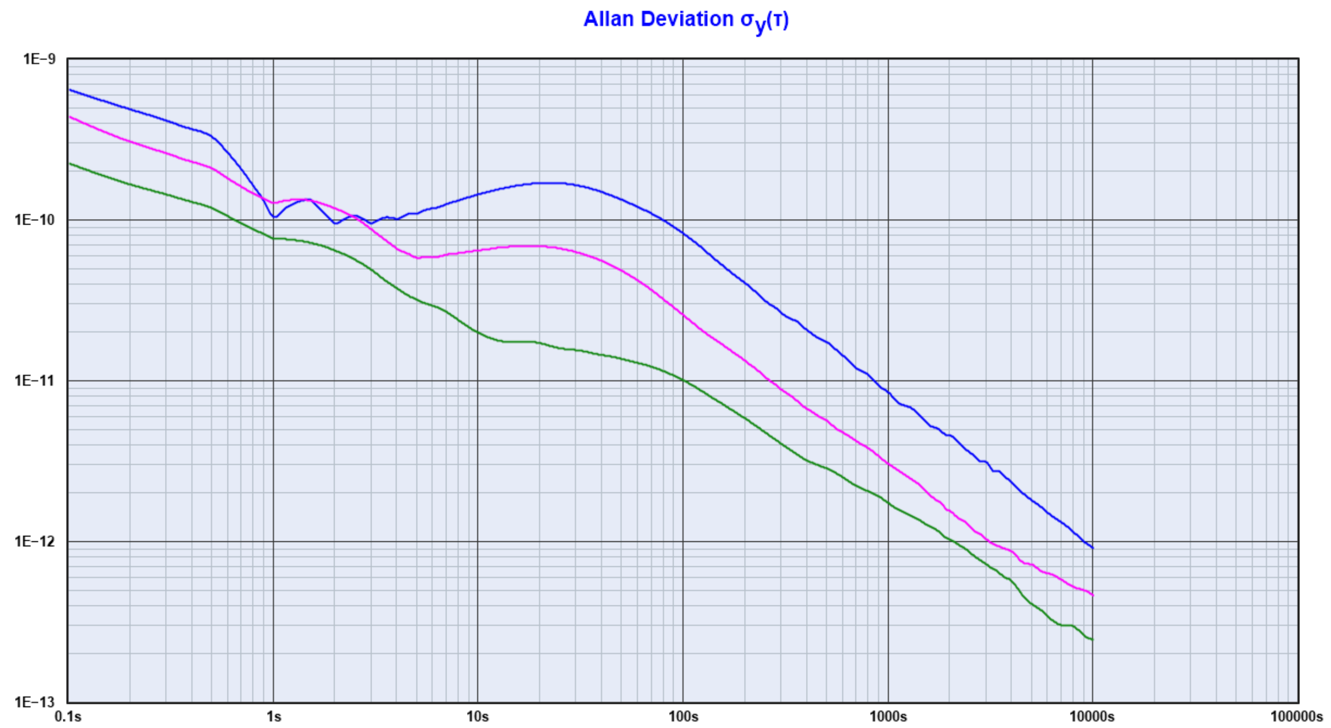


Performance Levels

- Base – No GPS, requires external frequency reference
- Bronze – NEO-M9N; modest RF; no PPS ($14.15*)
- Silver – NEO-M8T; better RF; has PPS ($51.85*)
- Gold – ZED-F9T; best RF; has PPS; TEC ($154.33*)

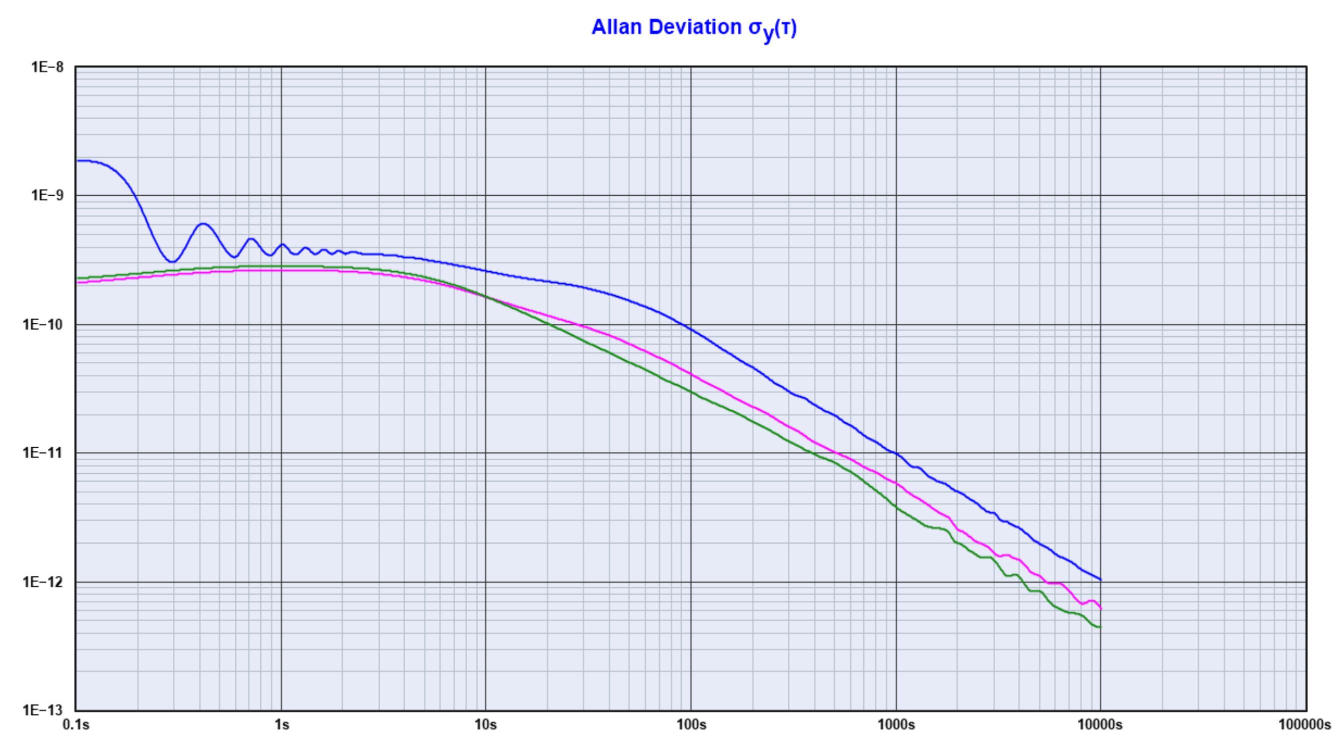
* u-blox qty. 100 price as of 23 Nov. 2020 for GPS module only

GPS Raw 10 MHz Performance



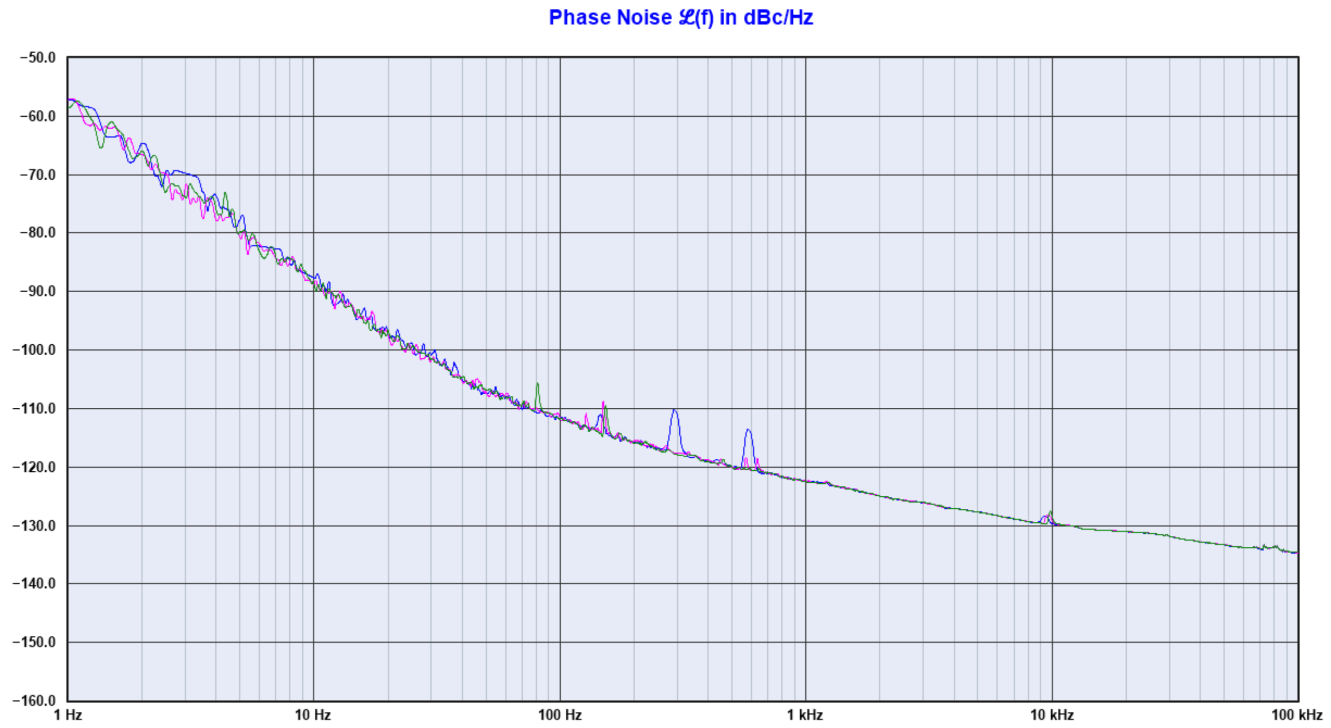
Trace	Notes	Sample Interval	Acquired	Instrument
10 MHz from NEO-M9N	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A
10 MHz from NEO-M8T	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A
10 MHz from ZED-F9T	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A

Si5328 Narrow Bandwidth Performance



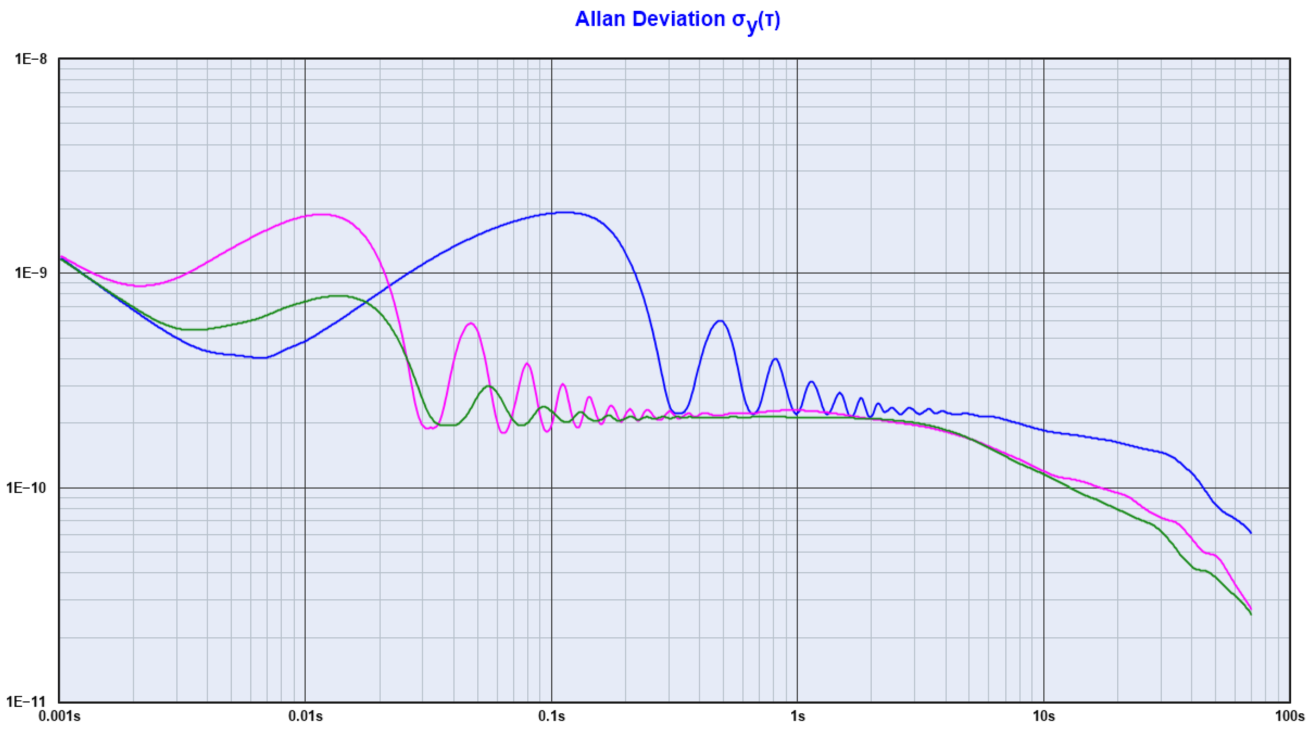
Trace	Notes	Sample Interval	Acquired	Instrument
Si5328 (TCXO) 10 MHz from NEO-M9N (BW=0.088)	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A
Si5328 (TCXO) 10 MHz from NEO-M8T (BW=0.088)	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A
Si5328 (TCXO) 10 MHz from ZED-F9T (BW=0.088)	vs. HP 5071A	0.100 s	432000 pts	TimePod 5330A

Si5328 Narrow Bandwidth Phase Noise



Trace	Notes	Sample Interval	Acquired	Instrument
Si5328 from NEO-M9N 10 MHz (BW=0.088)	vs. ULN	0.001 s	300000 pts	TimePod 5330A
Si5328 from NEO-M8T 10 MHz (BW=0.088)	vs. ULN	0.001 s	300000 pts	TimePod 5330A
Si5328 from ZED-F9T 10 MHz (BW=0.088)	vs. ULN	0.001 s	300000 pts	TimePod 5330A

Si5328 Narrow Bandwidth Fast ADEV



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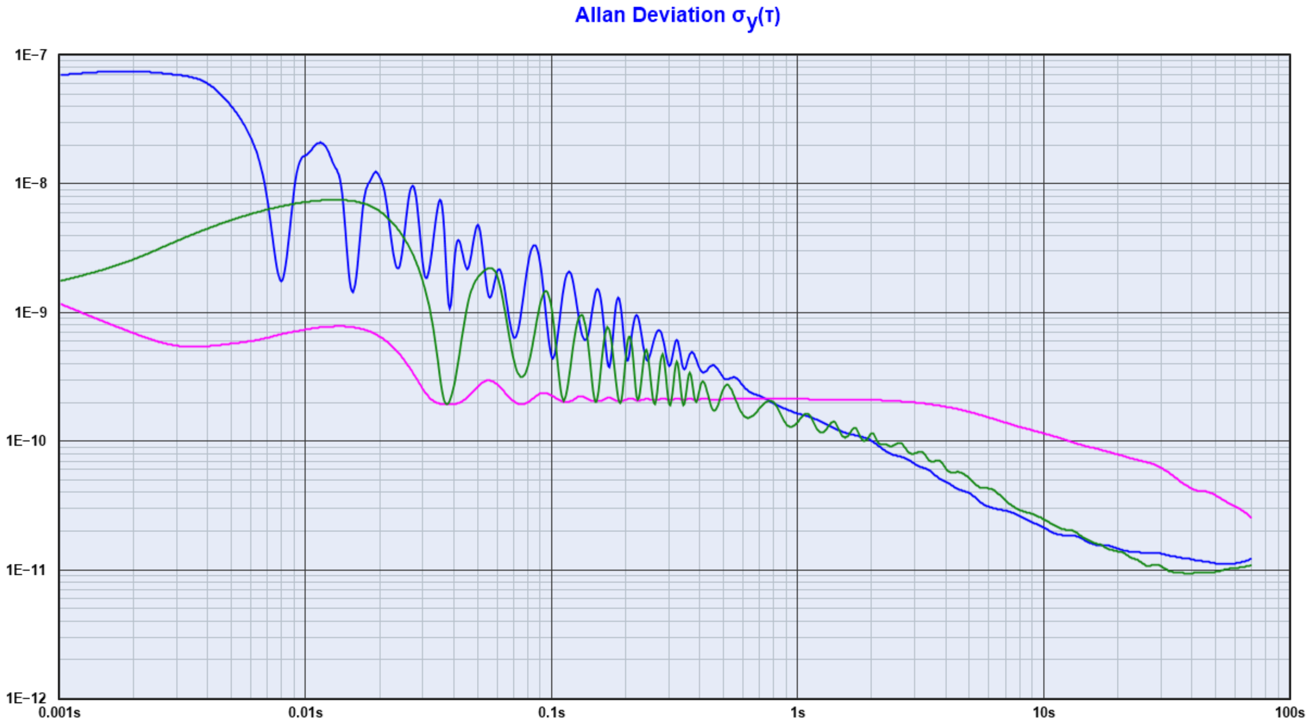
Si5328 from ZED-F9T 10 MHz (BW=0.088)	vs. ULN	0.001 s	300000 pts	TimePod 5330A

Si5328 Bandwidth Impact on ADEV



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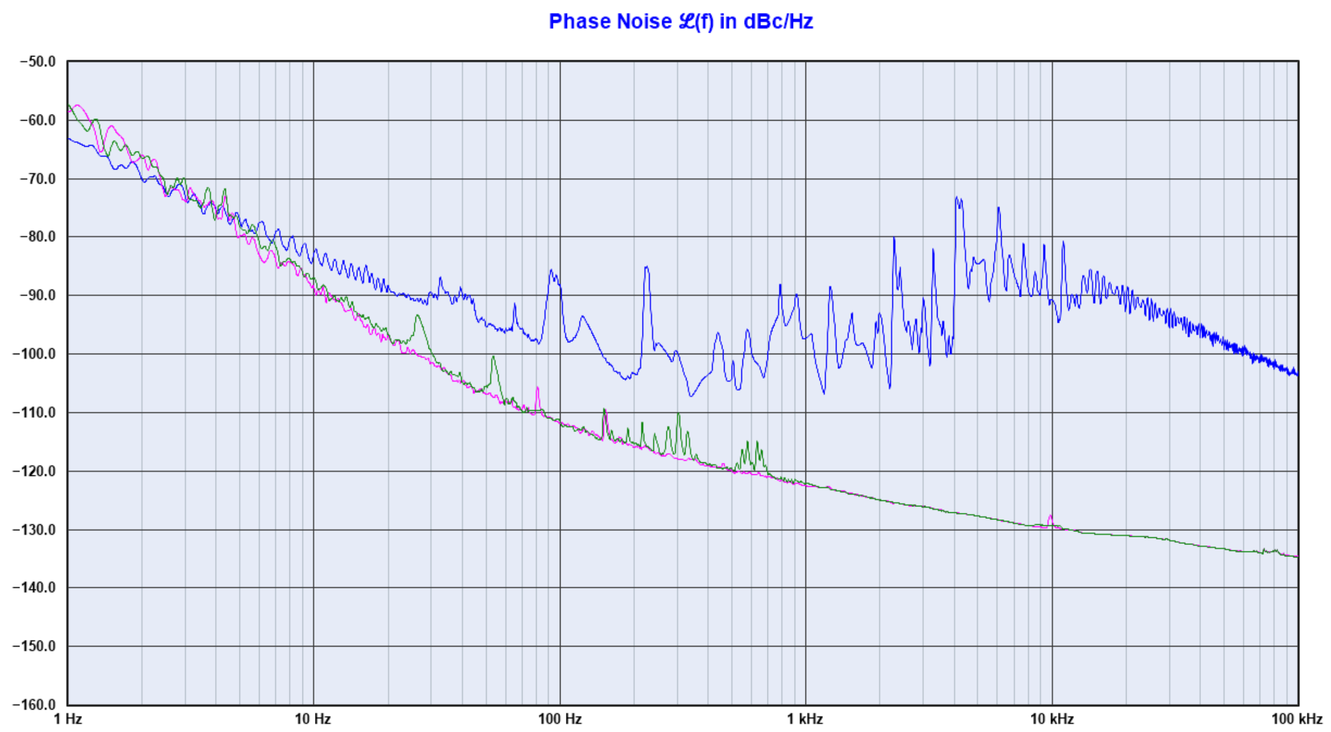
Si5328 Bandwidth Impact on Phase Noise



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Si5328 from ZED-F9T 10 MHz (BW=0.709)	vs. ULN	0.001 s	300000 pts	TimePod 5330A

Breadboard Performance

- Switch to TimeLab...