The TAPR TICC Counter: Measuring Trillionths of a Second with an Arduino

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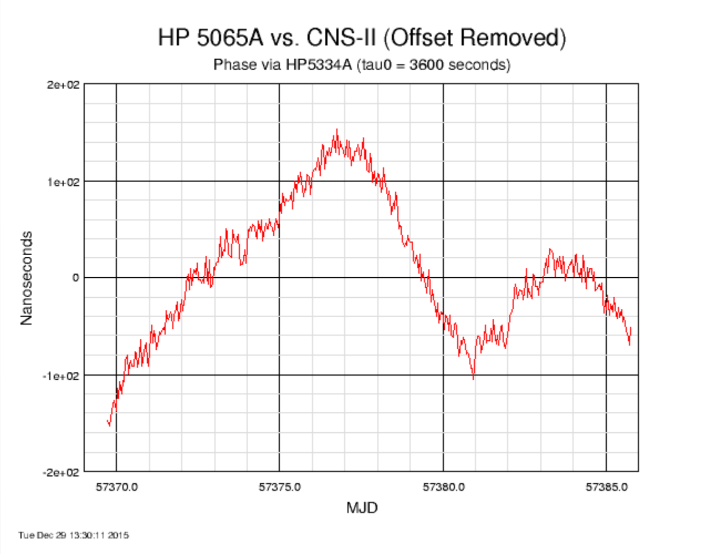
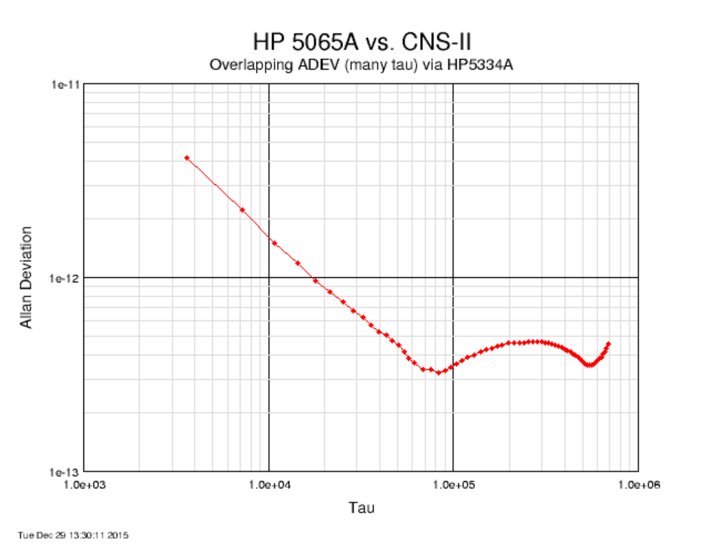
Sneak Preview

- The TICC is an electronic stopwatch that can time events with 60 picosecond resolution
- "Shield" form factor that connects to an Arduino Mega 2560
- Useful for Time-Nut applications: frequency and stability measurements
- Other possible uses: Radar, Ultrasonics, Stock Car Races???
- Open Source Software and Hardware
- Available as assembled unit from TAPR Real Soon Now

The Need

- Measure clock accuracy and stability over long periods (maybe years)
- Example: Compare Rubidium oscillator against GPS





The Method

- Several approaches, but one of the easiest is to compare pulse-per-second signals from the reference and the device under test ("DUT").
- Use a time interval counter to measure the time between reference (e.g., GPS) and DUT over a period of time.
- From that data we can learn a lot:
  - If the time difference increases or decreases steadily over time, one clock is faster than the other.
  - If the measurements bounce around (and they will), that noise can be analyzed to measure the stability of the clocks

The Problem

- We're measuring the change of phase (rate) over time.
  - Seconds per day, or maybe nanoseconds per year
- A traditional counter's resolution is limited by its clock speed.
  - At 1 MHz, 1 microsecond resolution. At 10 MHz, 100 nanoseconds.
  - Faster clock provides more resolution, but how far can you go?
- Fancier counters "interpolate" between clock pulses
  - Best counters can provide 20 picosecond or better resolution.
  - But it's complex and expensive to get there.

Possible Solutions

HP 5370
20ps
32 lbs, 250VA
ebay: $250-500

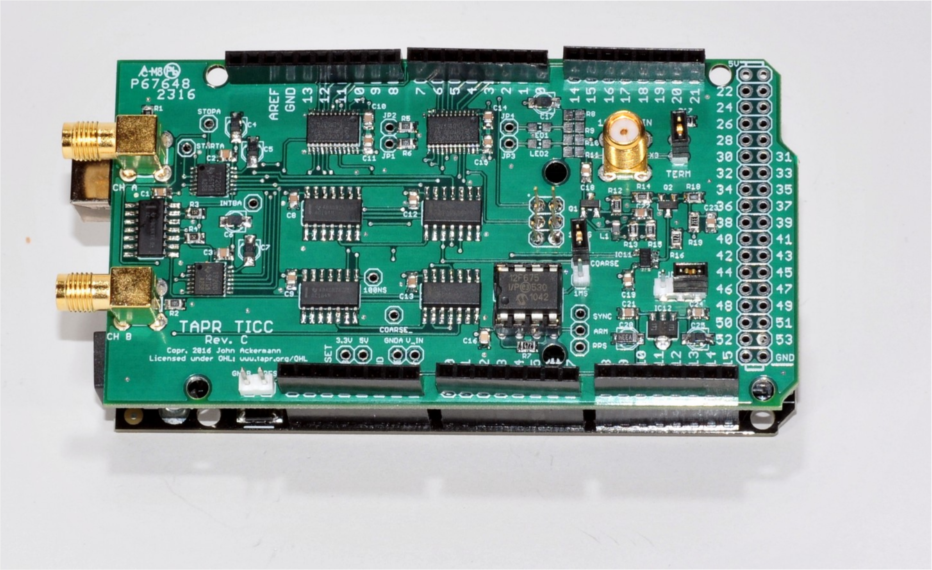
HP 53132
150ps
7.5 lbs, 30W
Ebay: $500-1000

HP 5334
2ns
12 lbs, 50VA
ebay: $100-200

Can Amateurs Do Better?

How About...

The TAPR "TICC"



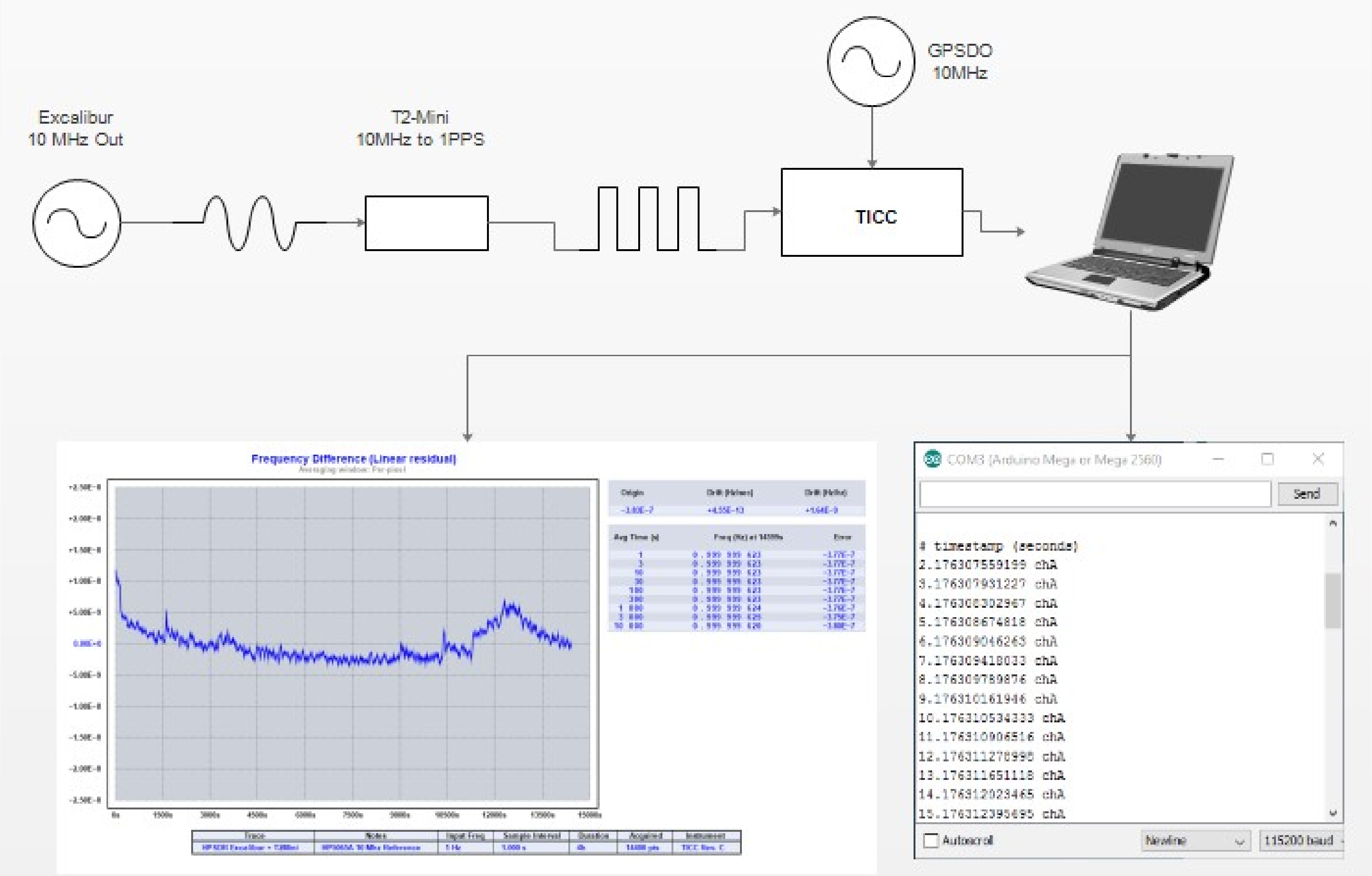
2.6 oz, 0.4W

- 60ps resolution
- 2 timestamping channels
- >100 measurements/second
- USB connection to host
- Arduino shield
- Open Source hardware and software
- Price <$200

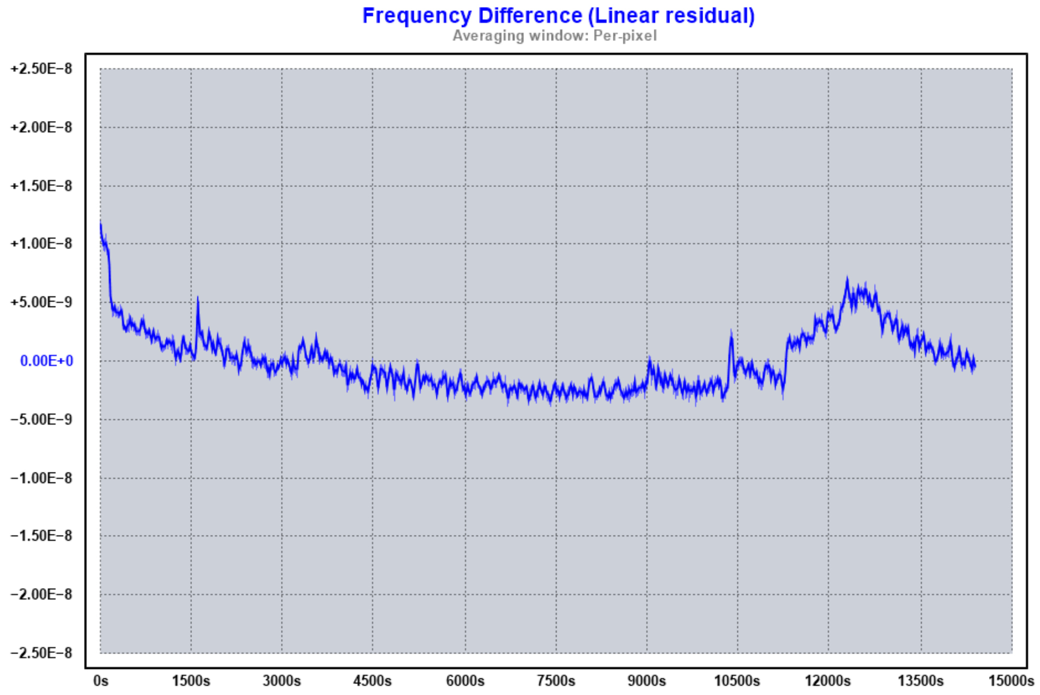
About the TICC

- A "timestamping" counter
  - Each input pulse is timed in seconds with 12 decimal places.
  - Timer is based on external 10 MHz signal.
  - Two channels, so two devices can be measured independently.
- Also a "time interval counter"
  - Can measure the time between a pulse on channel A and one on channel B, measuring the interval between them.
- Can also measure period, total number of pulses, etc.
- The TICC is **not** a frequency counter – it's designed for pulses, not RF.

Using the TICC to Measure HPSDR "Excalibur" Frequency



Excalibur Results

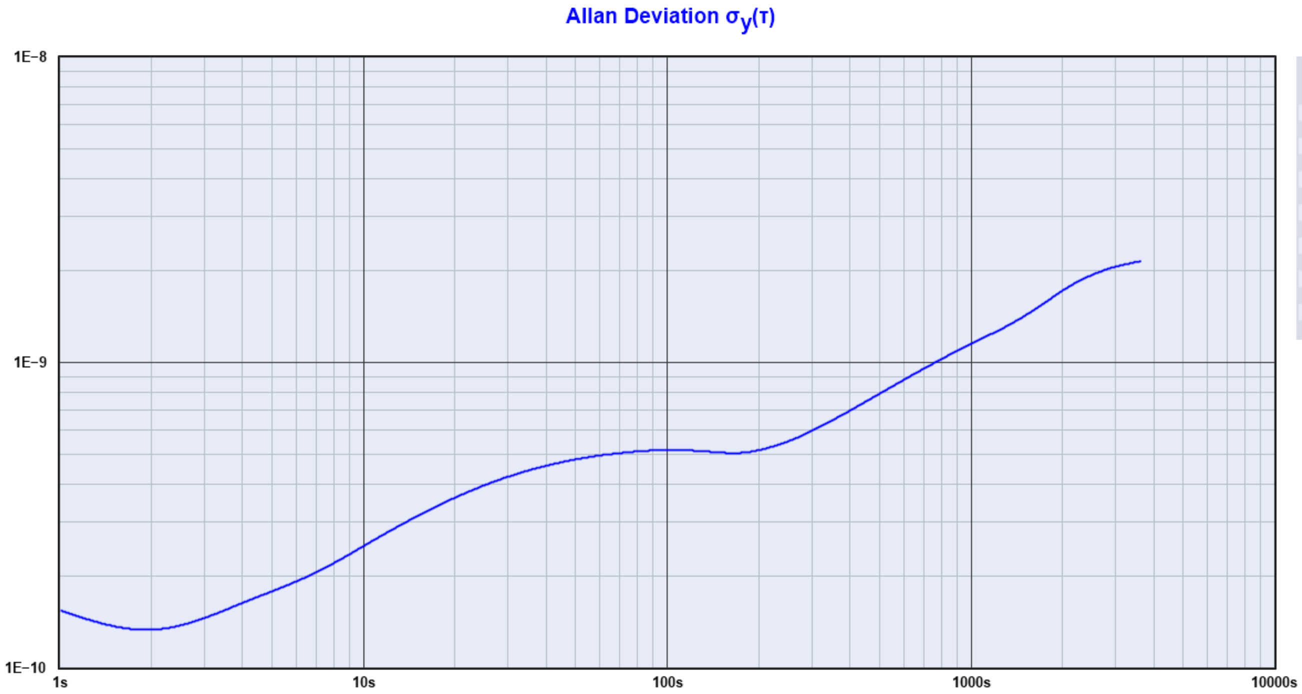


Origin	Drift (Hz/sec)	Drift (Hz/hr)
−3.83E−7	+4.55E−13	+1.64E−9

Avg Time (s)	Freq (Hz) at 14399s	Error
1	0 . 999 999 623	−3.77E−7
3	0 . 999 999 623	−3.77E−7
10	0 . 999 999 623	−3.77E−7
30	0 . 999 999 623	−3.77E−7
100	0 . 999 999 623	−3.77E−7
300	0 . 999 999 623	−3.77E−7
1 000	0 . 999 999 624	−3.76E−7
3 000	0 . 999 999 625	−3.75E−7
10 000	0 . 999 999 620	−3.80E−7

Trace	Notes	Input Freq	Sample Interval	Duration	Acquired	Instrument
HPSDR Excalibur + T2Mini	HP5065A 10 Mhz Reference	1 Hz	1.000 s	4h	14400 pts	TICC Rev. C

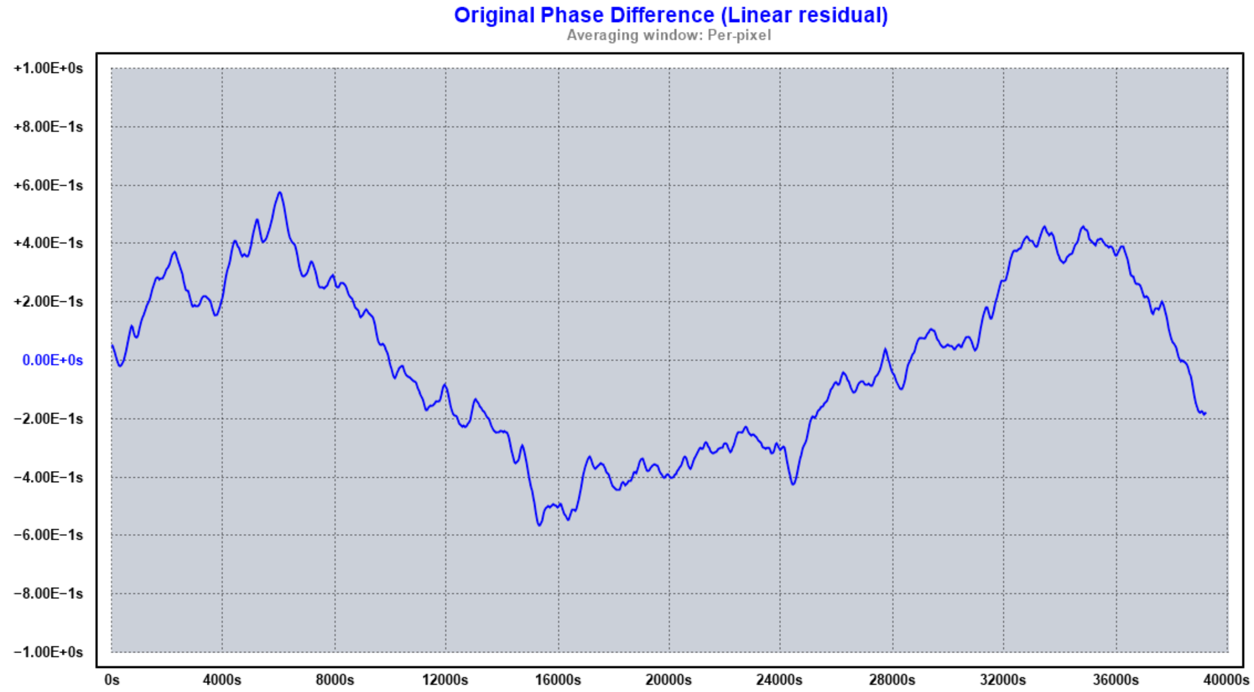
Excalibur Results



Tau	Sigma(Tau)
1s	1.55E−10
2s	1.34E−10
4s	1.65E−10
8s	2.23E−10
10s	2.53E−10
20s	3.64E−10
40s	4.63E−10
80s	5.15E−10
100s	5.20E−10
200s	5.20E−10
400s	7.03E−10
800s	1.04E−9
1000s	1.16E−9
2000s	1.74E−9

Trace	Notes	Input Freq	Sample Interval	Duration	Acquired	Instrument
HPSDR Excalibur + T2Mini	HP5065A 10 Mhz Reference	1 Hz	1.000 s	4h	14400 pts	TICC Rev. C

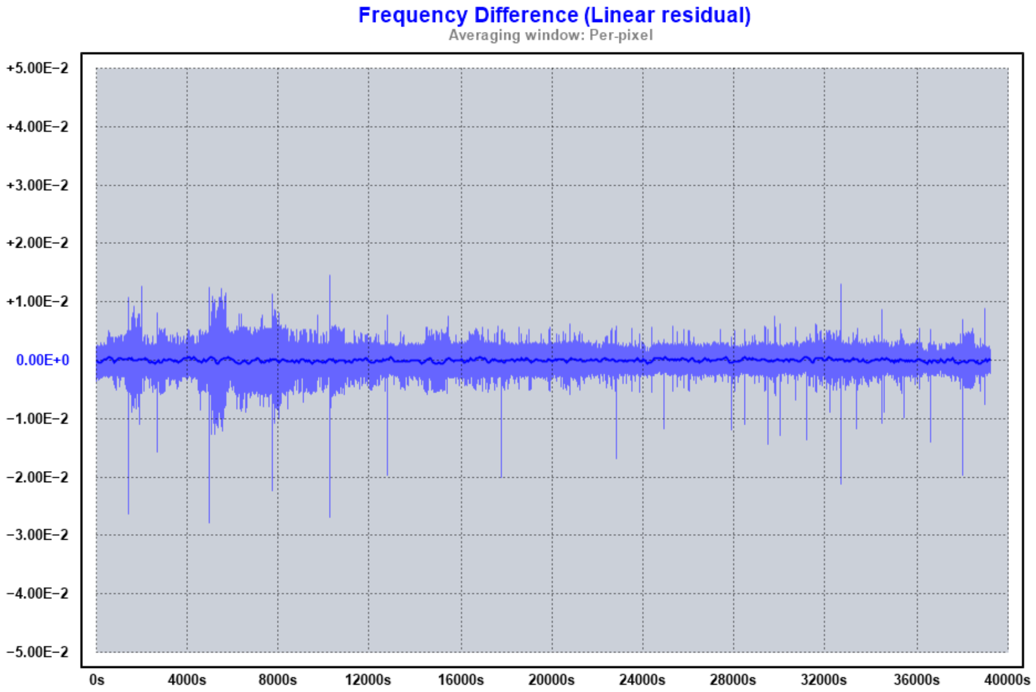
60Hz Main Power



Origin	Slope (sec/sec)
−5.47E−2	+1.71E−5

Trace	Notes	Input Freq	Sample Interval	Duration	Acquired	Instrument
60 Hz Mains (Unsaved)	HP5065A	60 Hz	1/60 s	10h 53m 29s	2352551 pts	TICC

60Hz Mains Power

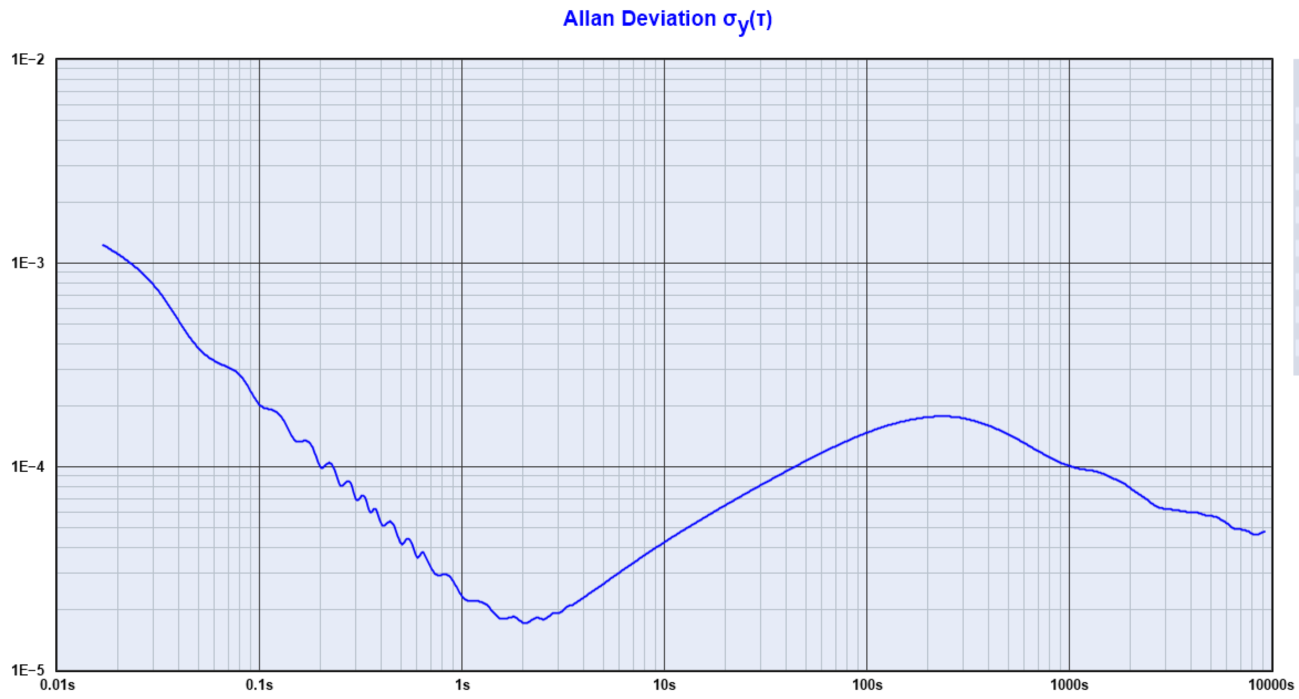


Origin	Drift (Hz/sec)	Drift (Hz/hr)
+2.06E-5	-2.88E-8	-1.04E-4

Avg Time (s)	Freq (Hz) at 39209s	Error
0 . 100	60 . 002 219 960	+3.70E-5
0 . 300	59 . 994 870 865	-8.55E-5
1	59 . 997 225 072	-4.62E-5
3	59 . 997 655 697	-3.91E-5
10	60 . 001 198 521	+2.00E-5
30	60 . 003 679 917	+6.13E-5
100	60 . 005 250 178	+8.75E-5
300	59 . 999 187 331	-1.35E-5
1 000	59 . 989 462 083	-1.76E-4
3 000	59 . 989 635 449	-1.73E-4

Trace	Notes	Input Freq	Sample Interval	Duration	Acquired	Instrument
60 Hz Mains (Unsaved)	HP5065A	60 Hz	1/60 s	10h 53m 29s	2352551 pts	TICC

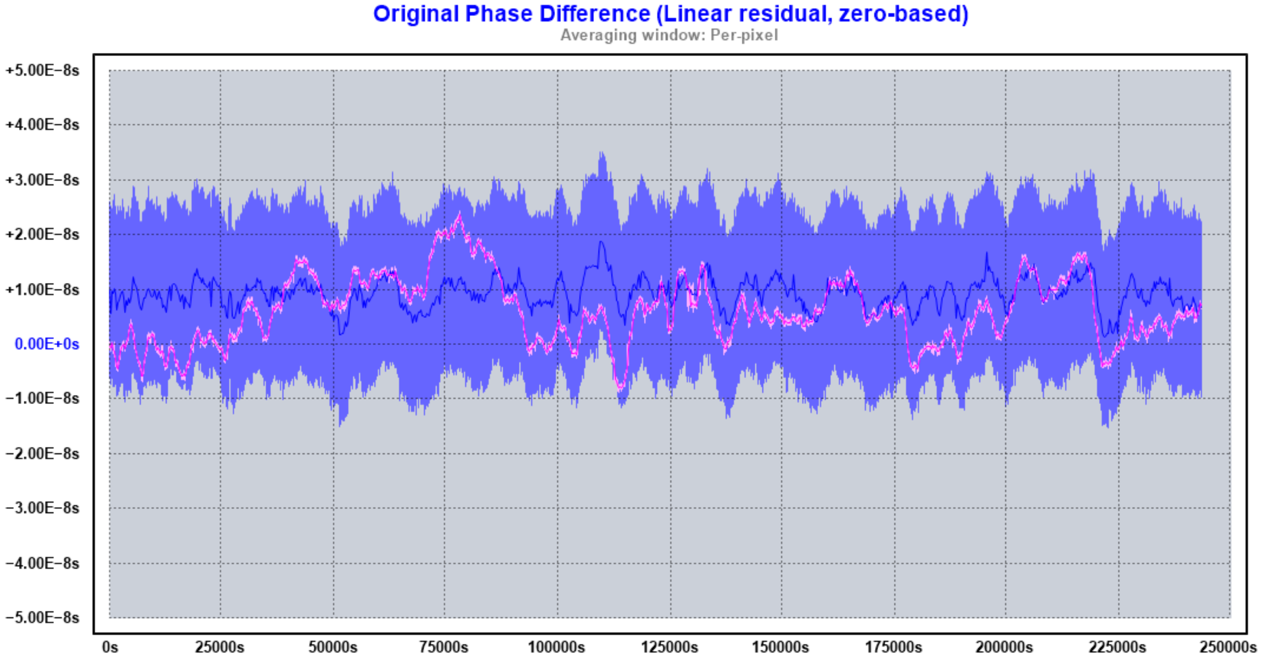
60Hz Mains Power



Tau	Sigma(Tau)
1s	2.32E−5
2s	1.72E−5
4s	2.30E−5
8s	3.73E−5
10s	4.31E−5
20s	6.55E−5
40s	9.62E−5
80s	1.35E−4
100s	1.49E−4
200s	1.77E−4
400s	1.60E−4
800s	1.12E−4
1000s	1.02E−4
2000s	7.89E−5
4000s	6.05E−5
8000s	4.76E−5

Trace	Notes	Input Freq	Sample Interval	Duration	Acquired	Instrument
60 Hz Mains (Unsaved)	HP5065A	60 Hz	1/60 s	10h 53m 29s	2352551 pts	TICC

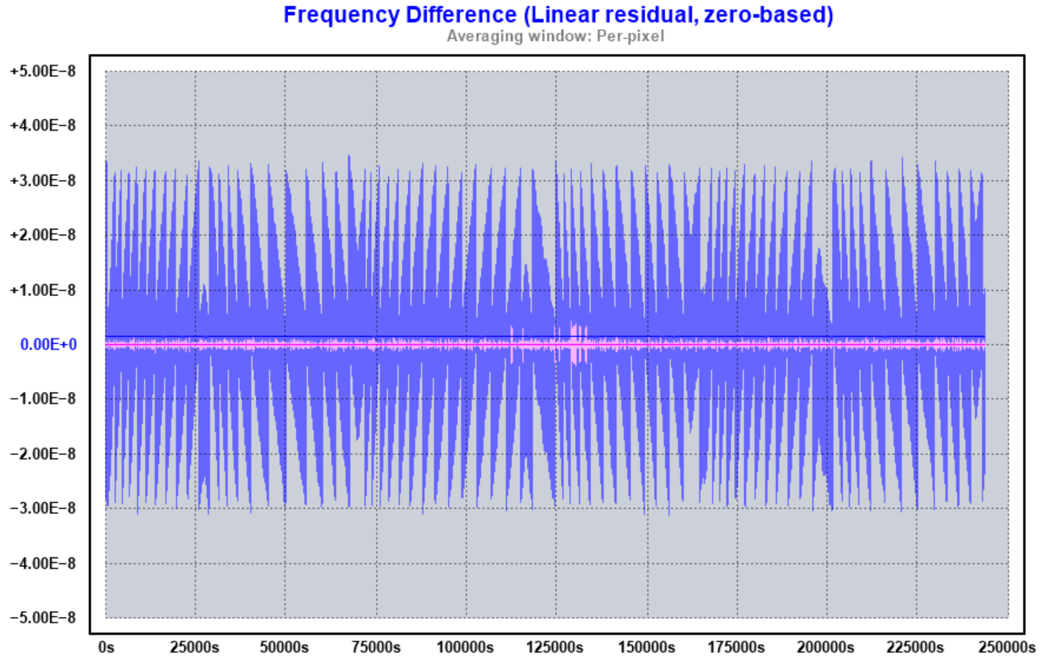
GPS & Cesium Results



Origin	Slope (sec/sec)
+1.84E−8	−2.31E−15
+1.21E−8	−8.03E−13

Trace	Notes	Sample Interval	Duration	Acquired	Instrument
CNS-II GPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C
HP5061A PPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C

GPS & Cesium Results

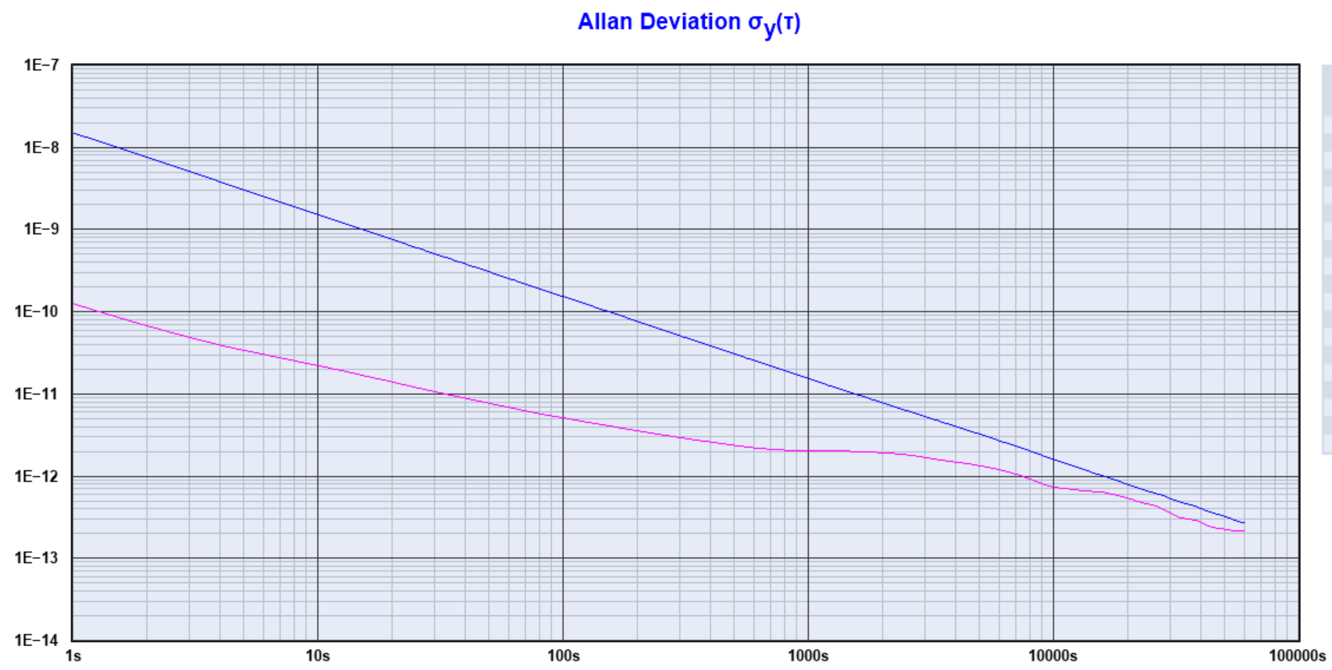


Origin	Drift (Hz/sec)	Drift (Hz/day)
+1.48E−9	−1.28E−18	−1.11E−13
+1.58E−12	−5.20E−19	−4.49E−14

Avg Time (s)	Freq (Hz) at 243436s	Error
1	1 . 000 000 007	+6.64E−9
3	0 . 999 999 997	−2.80E−9
10	1 . 000 000 001	+1.09E−9
30	1 . 000 000 000	+1.94E−11
100	1 . 000 000 000	+3.99E−11
300	1 . 000 000 000	−1.34E−11
1 000	1 . 000 000 000	+7.60E−12
3 000	1 . 000 000 000	+4.37E−13
10 000	1 . 000 000 000	+2.91E−14

Trace	Notes	Sample Interval	Duration	Acquired	Instrument
CNS-II GPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C
HP5061A PPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C

GPS & Cesium Results



Tau	Sigma(Tau)
1s	1.52E−8
2s	7.68E−9
4s	3.83E−9
8s	1.91E−9
10s	1.53E−9
20s	7.65E−10
40s	3.84E−10
80s	1.92E−10
100s	1.54E−10
200s	7.73E−11
400s	3.86E−11
800s	1.94E−11
1000s	1.55E−11
2000s	7.89E−12
4000s	4.04E−12
8000s	2.04E−12
10000s	1.62E−12
20000s	8.01E−13
40000s	4.04E−13

Trace	Notes	Sample Interval	Duration	Acquired	Instrument
CNS-II GPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C
HP5061A PPS	Z3816 10 MHz	1 s	2d 19h 37m 17s	243437 pts	TICC Rev. C

Thanks to...

- Tom McDermott, N5EG
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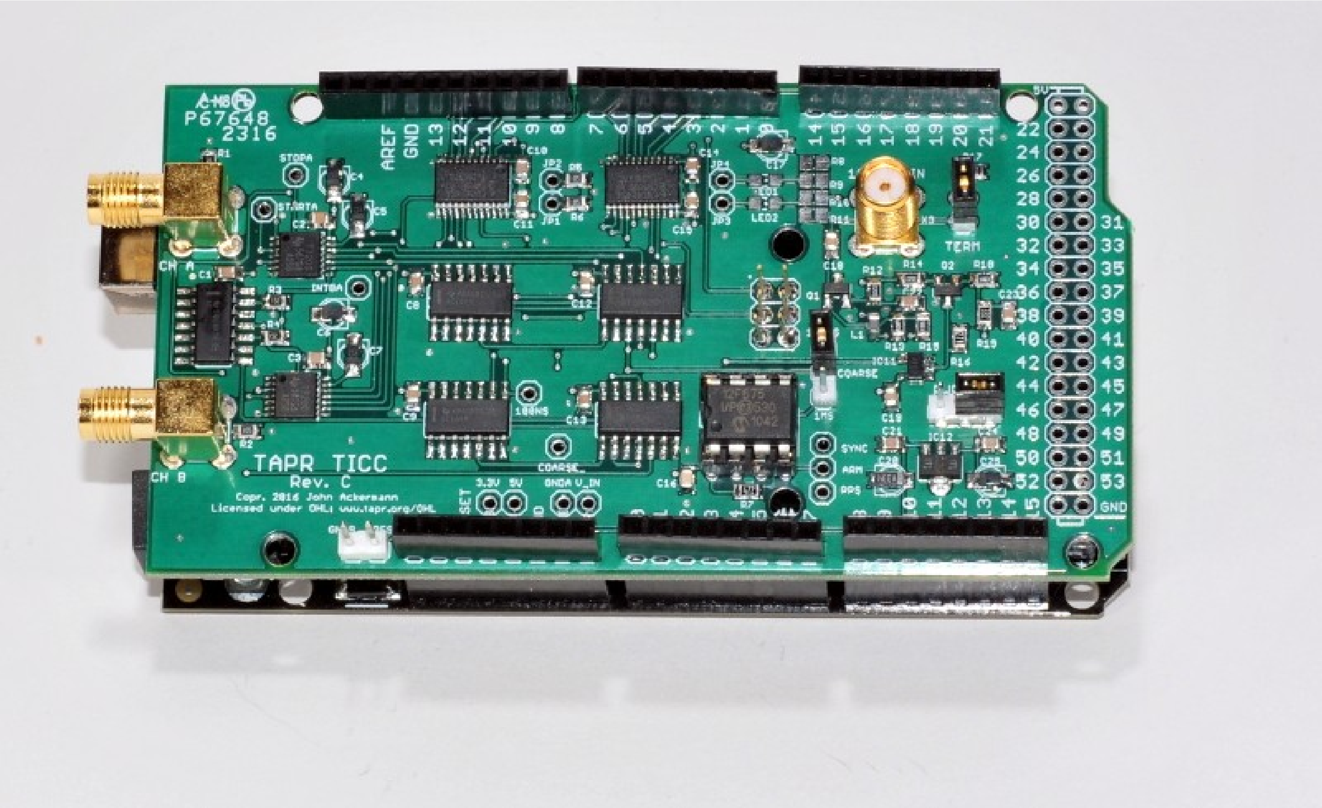
- Tom Holmes, N8ZM
- Tom Van Baak
- John Miles KE5FX

Questions?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GND
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CH B
TERM
COARSE
SYNC
ARM
PPS
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Rev. C
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