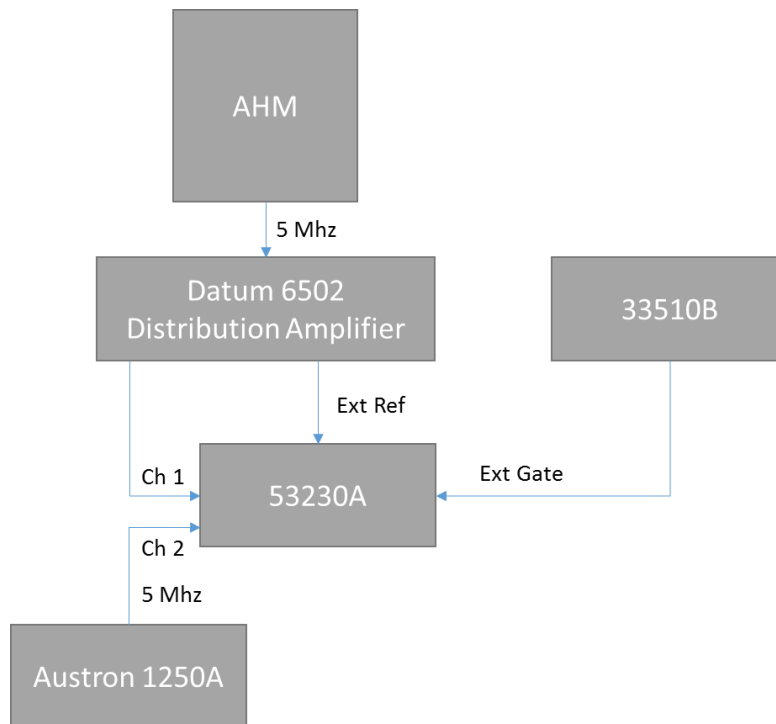


High Resolution Phase Measurement with Keysight 53230A

By “creative” use of the External Gate signal and buffered software triggers, it appears possible to collect (relatively) high speed phase measurements from the Keysight 53230A, at least up to 5 kHz. These measurements can be post-processed to increase the resolution and decrease the noise of the phase measurements.

Measurement set up



In this experiment, an Active Hydrogen Maser was used as Reference-signal. A Datum 6502 Distribution Amplifier was used to also provide the same signal as External Reference input to the 53230A. (The use of a Hydrogen Maser is of course not required – but it was available.)

The AHM did *not* provide an external reference signal to the Keysight 33510B function generator, simply because the AHM provides a 5 MHz output and the 33510B only accepts a 10MHz reference. The available frequency doubler was not expected to be phase stable with temperature, so it was decided to not use this in this experiment.

This is not expected to make much difference, as the 33510B only provides the Gate-signal to the frequency counter; neither the start nor stop edges are directly derived from this signal. Any instability in the 33510B will only result in slight instability in Tau: an edge earlier or later than expected may be counted.

The instrument was connected as shown in the diagram above:

- 53230A External Reference comes from the AHM through the 6502 DA
- 53230A Channel 1 input comes from the AHM through the 6502 DA.
- 53230A Channel 2 input comes from an Austron 1250A

- 53230A Ext gate comes from a 33510B function generator

The counter was configured to take Time Interval measurements from Channel 1 rising edge to Channel 2 rising edge. As the experiment is only a “Proof of concept”, little care was taken in optimizing trigger-levels etc.

Measurement control

Software was written to collect the phase data. The software (a work very much in progress) can be found at <https://github.com/opronningen/53230A-Test>, with some required components at <https://github.com/opronningen/53230A-Toolkit>.

The measurement logic is however simple enough to reconstruct in any language from these notes.

Setup

In this example, data is collected in Real format at a rate of 1 kHz, and the REF/DUT frequency is 5 MHz. The counter will collect 1000 measurements per trigger. The measurement is set to 10 minutes (600 triggers).

33510B: The 33510B was configured to output a 1kHz pulse, 5V amplitude, with a pulse width of 200ns. The pulse width needs to be shorter than twice the period of the measured signal, or the counter might collect two consecutive edges, rather than edges separated by the frequency of the Gate Input signal.

53230A: The settings on the counter is as follows, (settings not shown have their default value):

```
*RST;
:FUNC "TINT";
:FORM:BORD SWAP;
:FORM REAL,64;
:INP:IMP +5.00000000E+001;
:INP:LEV2:REL +90;
:INP2:IMP +5.00000000E+001;
:INP2:LEV2:REL +90;
:SAMP:COUN +1000;
:TINT:GATE:POL POS;
:TINT:GATE:SOUR EXT;
:TRIG:COUN +600;
:TRIG:SOUR BUS;
```

The measurement-loop is as follows:

```
ABORT;
*WAI;
INIT;
*TRG
Loop:
    *TRG;
    :DATA:REMOVE? 1000, WAIT
Goto loop
```

Discussion

The 53230A has a “hard limit” of 1.000.000 samples. It is tricky to get past this limit, as the counter will not, under any circumstance, accept more than 1M triggers. Nor will it collect more than 1M samples per trigger.

The “trick” employed is to use an external gate signal, where the pulse width of the signal is such that only one phase measurement is taken for each gate pulse. When the counter is configured to take i.e. 1000 measurements per trigger, it will take 1000 measurements only when the gate-signal is high. It will not measure on a low gate-signal.

The second trick employed is the use of software triggering. If the counter is configured for internal triggering, it will ignore the “samples per trigger” setting.

The 53230A will buffer up to one software trigger, hence the use of two consecutive triggers in the measurement-loop; this will ensure a new measurement is started immediately, not being delayed by the software reading out the previous samples.

Using these tricks it should be possible to continuously collect up to 5E12 samples, should one feel so inclined..

Phase observations at 5 kHz was readily obtained in this experiment without any particular optimization. It is expected that this number can be pushed higher. Preliminary testing suggests at least 50 kHz should be possible. The volume of collected data at this sample rate is 800kB per second in ASCII-format, and proved challenging to analyse. A preliminary analysis is presented in this report.

With a little care it might be possible to substantially increase this number, the instrument maximum TI sample rate is 90ksps, while its maximum sample transfer rate of over LAN is 600ksps. The bandwidth on the External Gate signal is unknown, and might be the limiting factor.

Results

In this experiment, data was collected at 1 and 5 kHz, for 10 minutes. The data was loaded into TimeLab without any post processing:

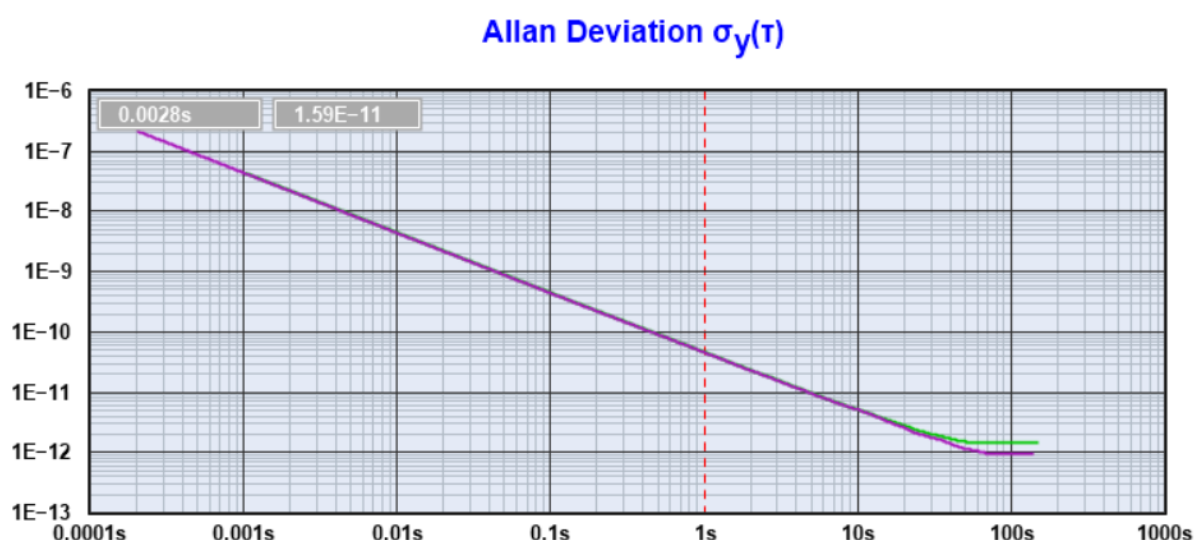


Figure 1: ADEV of 1kHz test (green) and 5kHz test (purple)

As expected, without any care given to the trigger levels, the 1s ADEV (4.73E-11) is a bit higher than the best the 53230A can do.

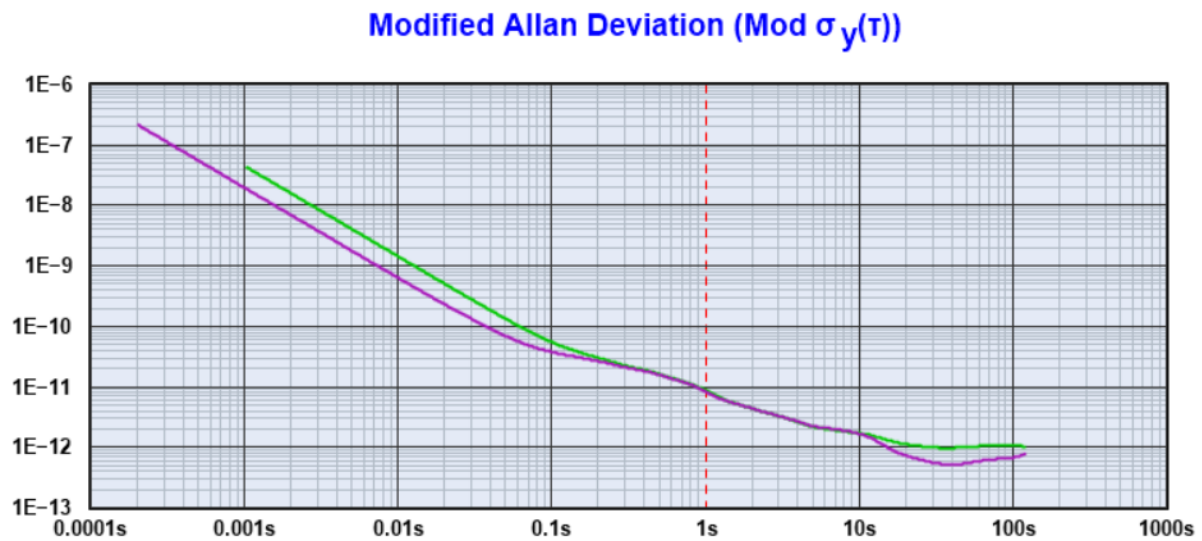


Figure: 2 MDEV of 1kHz test (green) and 5kHz test (purple)

Looking at the MDEV-plot, it seems flicker phase noise starts to dominate from 0.1 seconds. The ADEV is expected to drop by $\sqrt{N}$ when dominated by white noise, so it seems prudent to do the comparison at 10ms.

The collected phase record was unwrapped using Tom van Baak's da.exe, and then averaged down corresponding to tau 10ms. The results are close to what is expected in the presence of white noise:

	ADEV (no averaging)	N	ADEV _{avg} Expected	ADEV _{avg} Actual
1 kHz	4.53E-09	10	1.43E-09	1.45E-09
5 kHz	4.54E-09	50	6.42E-10	6.56E-10

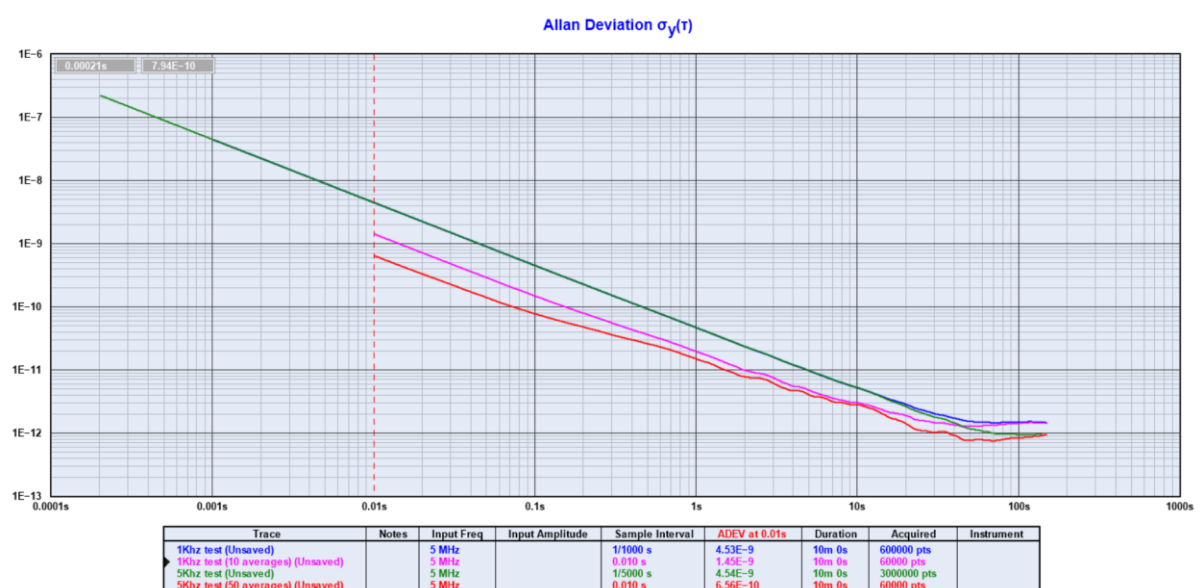


Figure 3: 1/5 kHz raw/averaged ADEV

As a comparison, the Austron 1250A was measured using a TimePod, with the AHM as reference. A measurement bandwidth of 50Hz was selected, to match the 10ms second gate-time.

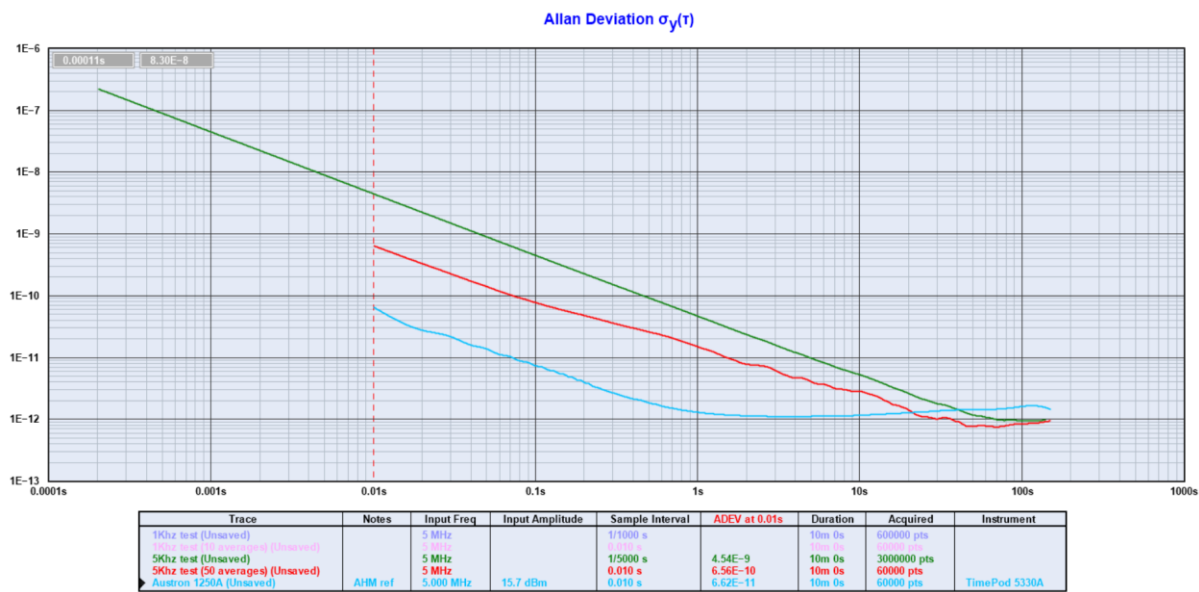


Figure 4: Comparison 5 kHz sample rate raw/averaged to TimePod ADEV measurement

Clearly, a >10KUSD instrument does a better job at characterizing this oscillator, but is interesting how the gap between the two instruments can be almost halved by software abuse.

Further Analysis in Stable32

Stable32 has a limit of 1M samples it will process. Therefore, the 1Khz data, at 600k samples, was selected for further analysis.

The 1 kHz raw phase data was imported in to Stable32, unwrapped and drift removed. Overlapping Allan Deviation was then calculated.

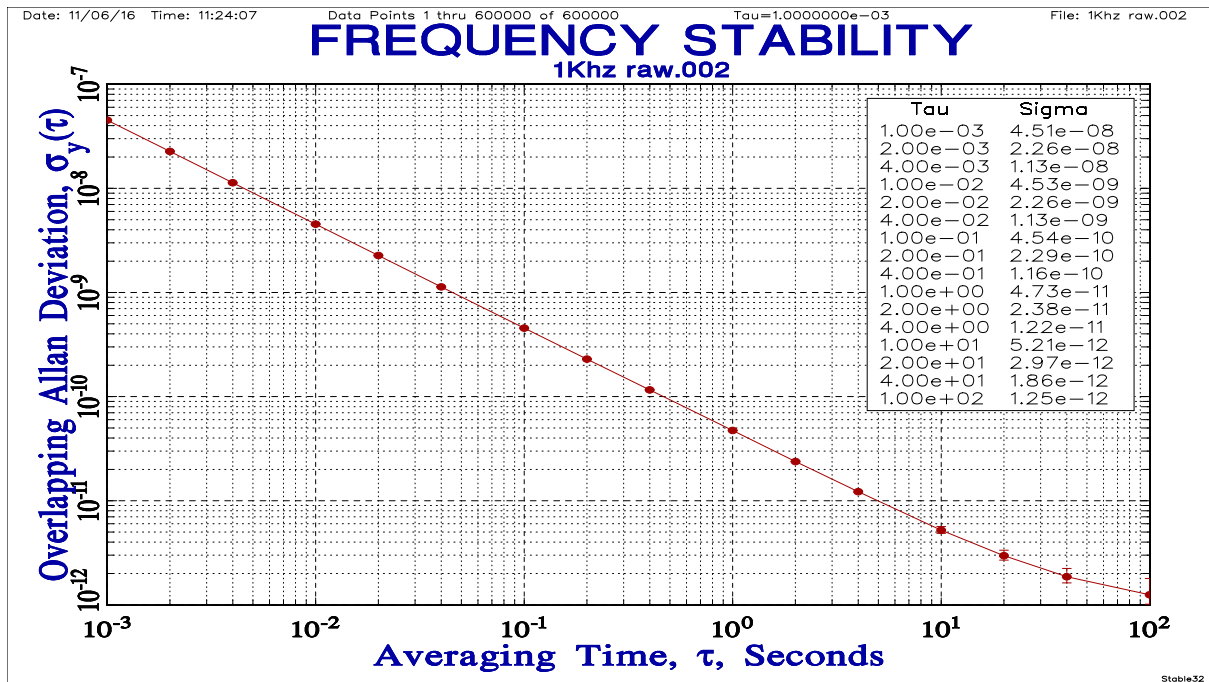


Figure 5: OADEV for the raw 1 kHz phase data

The PSD was then calculated and plotted.

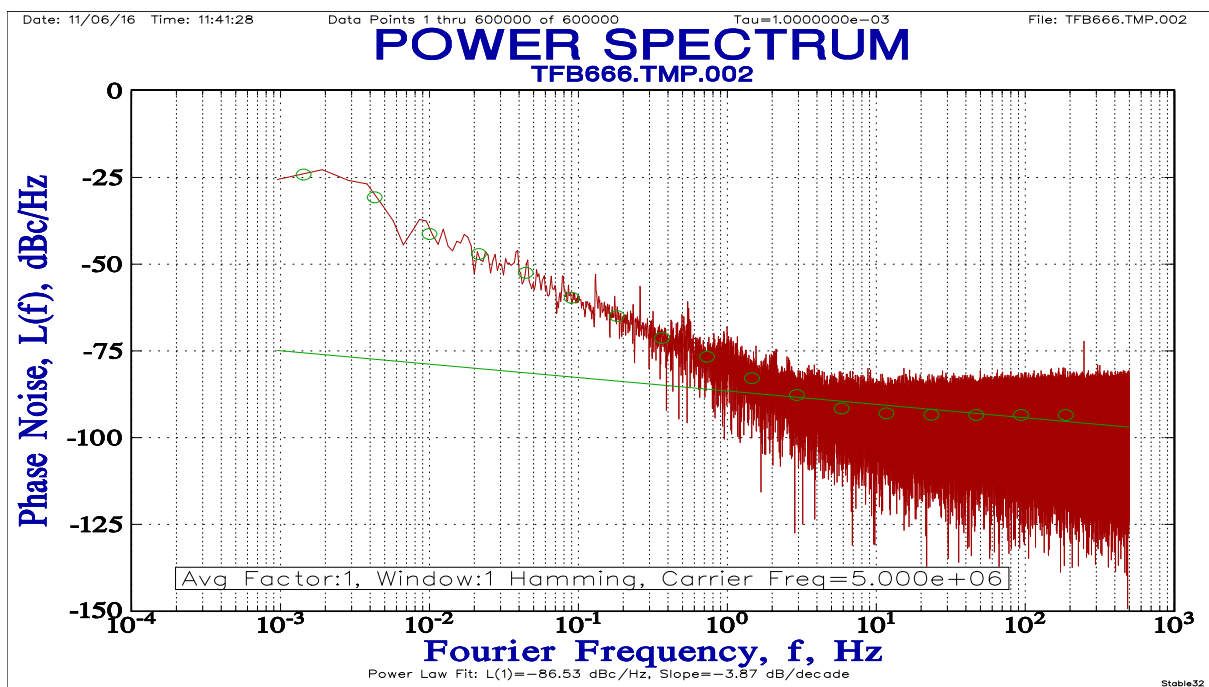


Figure 6: PSD of 1 kHz phase data

Further, a histogram of the phase data was plotted. The data does not follow a normal distribution. It is not understood why this is the case.

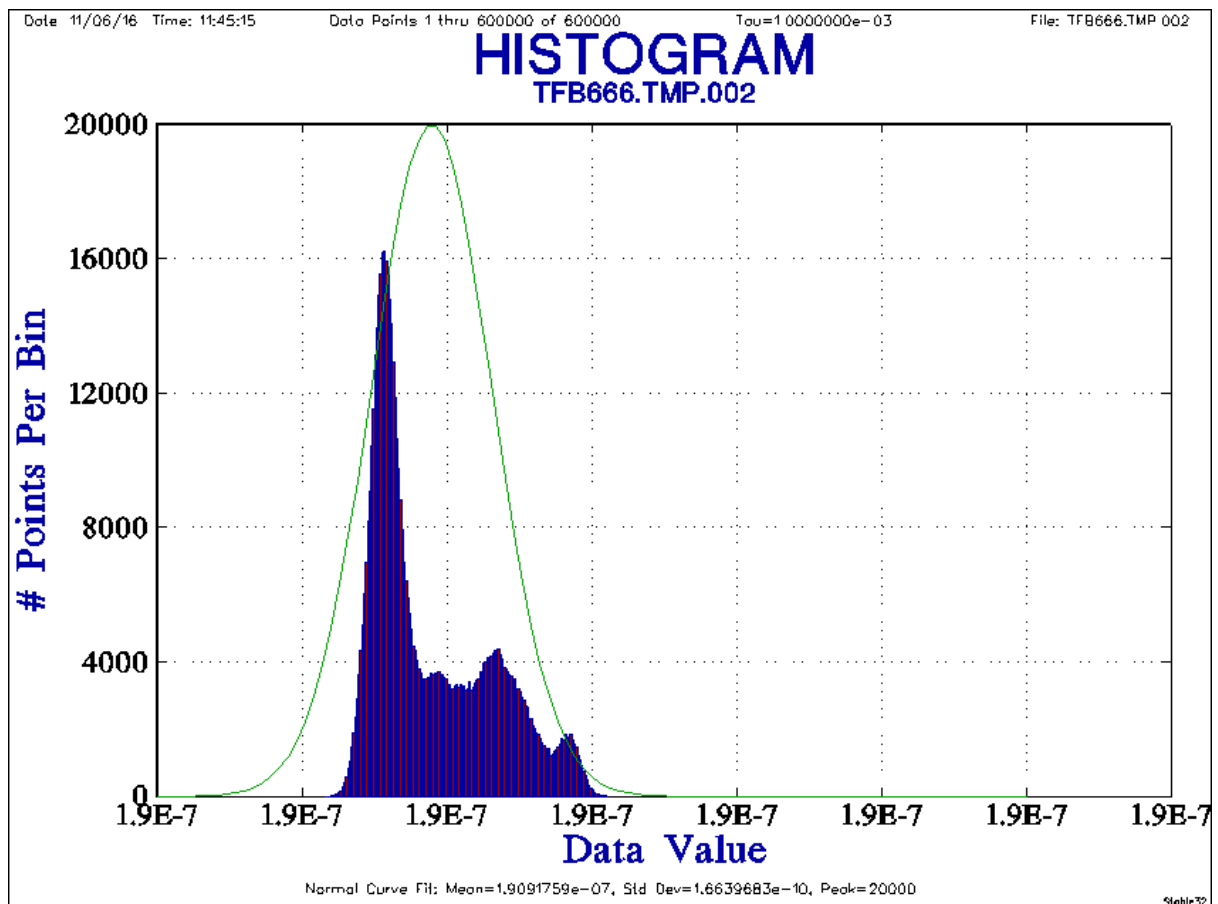


Figure 7: Histogram of phase data

The data was then low-pass filtered in Stable32 with a bandwidth of 50 Hz, and OADEV calculated again:

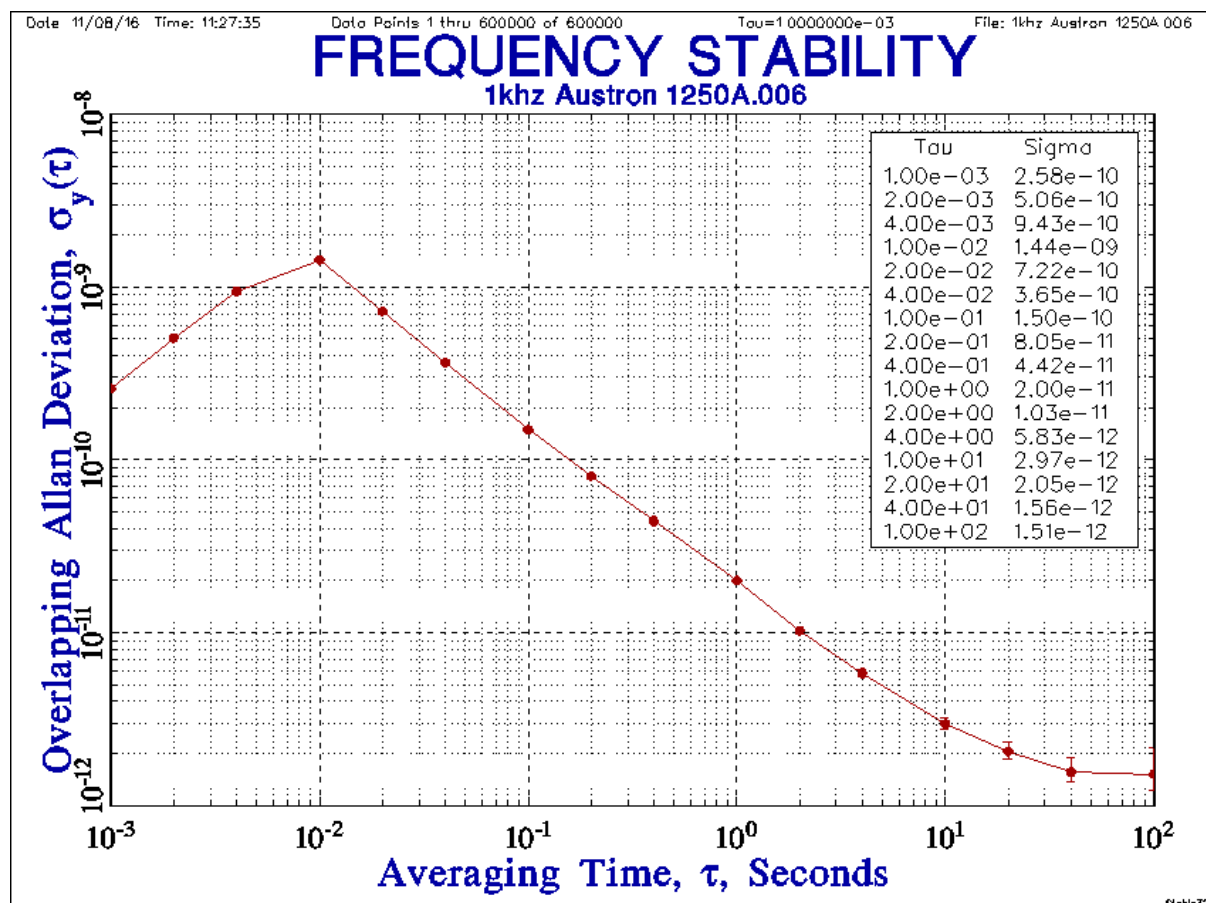


Figure 8: OADEV of 1kHz phase record, LP-filtered at 50 Hz

The data was further filtered with a bandwidth of 0.5 Hz. The results were not as expected:

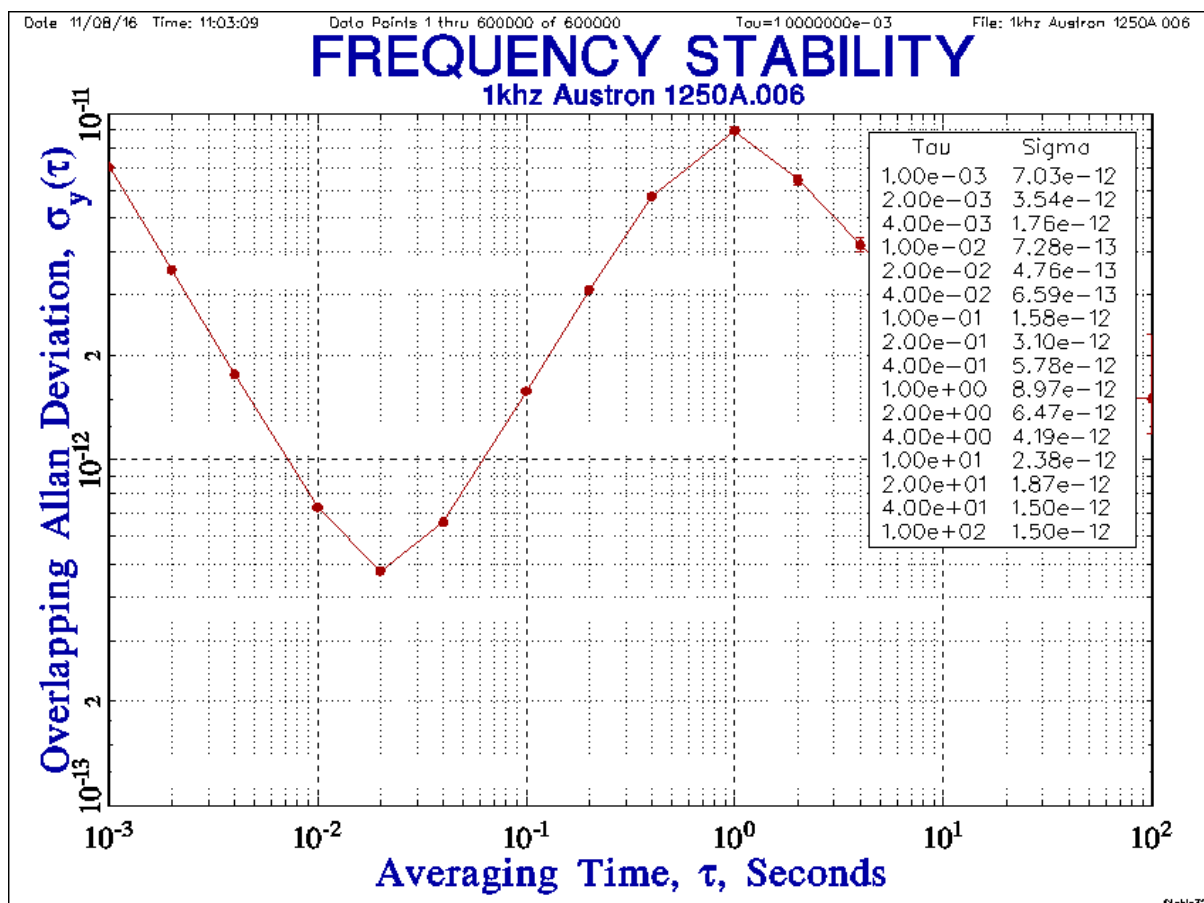


Figure 9: OADEV of 1kHz phase record, LP-filtered at 0.5 Hz

Data files

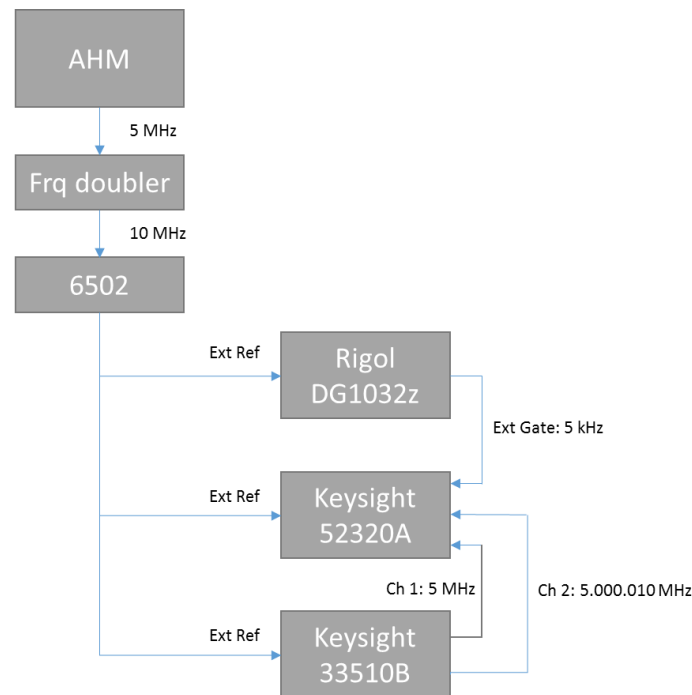
Unprocessed phase data was logged to two data-files:

"1kHz Austron 1250A.txt"
 "5kHz Austron 1250A.txt"

Validation of data collection consistency

In order to verify that there is no dead-time between triggers and that no samples are missed, an experiment was conducted whereby two frequencies of known offset was measured. Any missed samples are expected to show up as discontinuities in the phase record.

Measurement set up



The instruments were connected as shown in the diagram;

- Active Hydrogen Maser was connected through a frequency doubler to the Datum 6502 Distribution Amplifier (as all signals are derived from this source, the presumed instability with temperature of the frequency doubler was not expected to influence the results)
- Ext Ref of the Rigol DG1032z function generator was connected to the 6502 DA 10 MHz signal
- Ext Ref of the Keysight 33510B function generator was connected to the 6502 DA 10 MHz signal
- Ext Ref of the Keysight 52320A universal counter was connected to the 6502 DA 10 MHz signal
- The DG1032z channel 1 output was connected to the 52320A Gate Input
- Channels 1 and 2 of the 33510B function generator was connected to channel 1 and 2 inputs on the 52320A.

The DG1032z was configured to output a 5Vpp 5kHz pulse with a pulse width of 100ns.

The 52320A was configured to take Time Interval measurements between channel 1 rising edge to channel 2 rising edge, as described earlier in the document.

The 33510B was configured as

- Channel 1: Sinewave, 5MHz, 1Vrms

- Channel 2: Sinewave 5.000,010 MHz, 1Vrms

Results

Data was collected for 10 minutes at 5 kHz samplerate, and the raw phase observations was loaded into TimeLab. Any missed samples or dead-time between measurements are expected to show up as jumps in the phase record.

The sample frequency is 5 kHz, and the measured frequencies are 5 MHz and 5.000,010 Mhz. We therefore expect the mean difference between consecutive phase samples to be slightly below 400 ps, $4e-10$. If there are gaps in the collected phase data, the magnitude is expected to be well above this number, i.e. >800 ps, $8e-10$.

On visual examination of the residual phase record, no such discontinuities were observed:

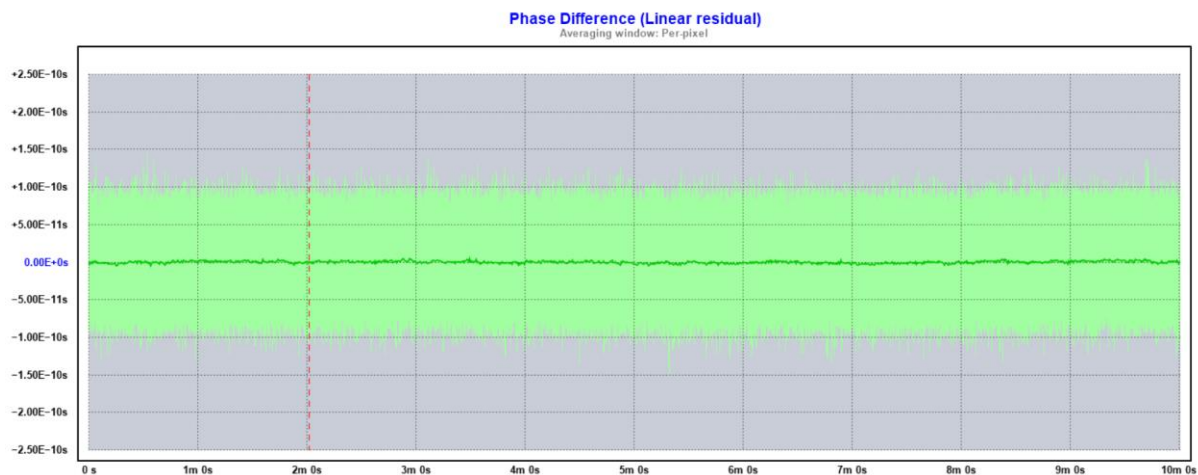


Figure 10: Data validation 5 kHz phase record

As the screen resolution limits what is observable in such a large dataset, a second test was performed using (a modified version of) Tom van Baak's da.exe, where the data is first unwrapped at 200ns, the first differences of the phase data is taken, and the largest value selected:

```
# da unwrap 2e-7 delta minmax < "5khz slip-test.txt"
-5.95703124957499e-10
-2.00195312475941e-10
```

As can be seen, the largest difference between two consecutive samples was 600ps. This was taken as confirmation that the data is collected as expected, without gaps.

The mean difference between samples was also calculated with da.exe, and came to pretty much the expected value of $3.99999990104164e-10$.

The data was further analysed in Stable32. It was not possible to import the full 3M points phase record, so the first 600k points were used. It is expected that this is a significant enough portion of the data that any problems would show up.

Power Spectral Density

The PSD of the first ~600k points were plotted in Stable32. No obviously suspicious peaks or bumps were observed.

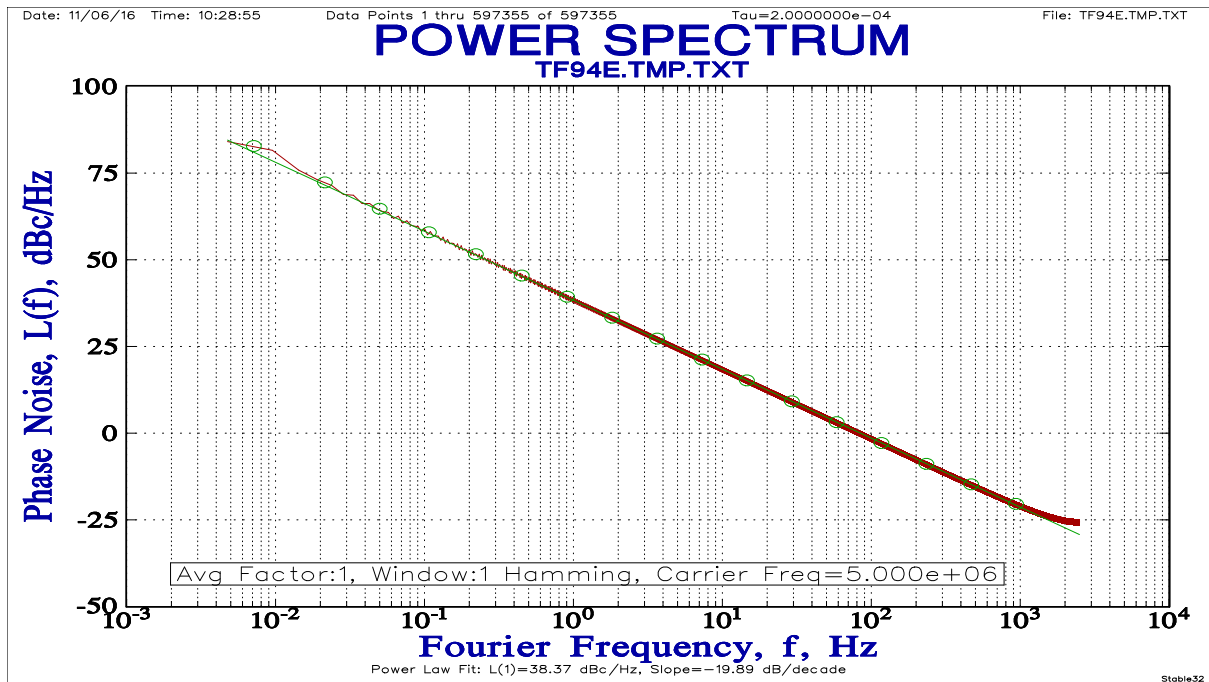


Figure 11: 5 kHz slip test PSD (first 600k samples)

Data files

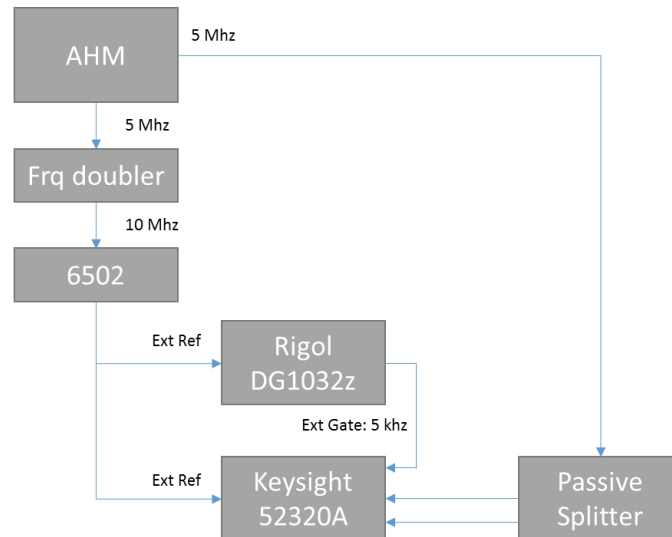
Unprocessed phase observations were logged to two data-files:

"1khz slip-test.txt"
 "5khz slip-test.txt"

Noise floor

A simple noise-floor test was also conducted.

Measurement set up



The instruments were connected as shown in the diagram;

- Active Hydrogen Maser was connected through a frequency doubler to the Datum 6502 Distribution Amplifier
- Ext Ref of the Rigol DG1032z function generator was connected to the 6502 DA 10 MHz signal
- Ext Ref of the Keysight 52320A universal counter was connected to the 6502 DA 10 MHz signal
- The DG1032z channel 1 output was connected to the 52320A Gate Input
- A second 5MHz output from the AHM was connected to a broadband passive splitter (Mini-Circuits ZFRSC-123-S+).
- 52320A Channel 1 was connected to the splitter through a short (~30cm) coax
- 52320A Channel 2 was connected to the splitter through a longer (~1.5m) coax

1 hour of data was recorded on 1 kHz and 5 kHz sample rate, respectively. The data is analysed below.

1 kHz noise floor test results

The unprocessed phase data was loaded in to TimeLab. The phase record, ADEV and MDEV are shown below.

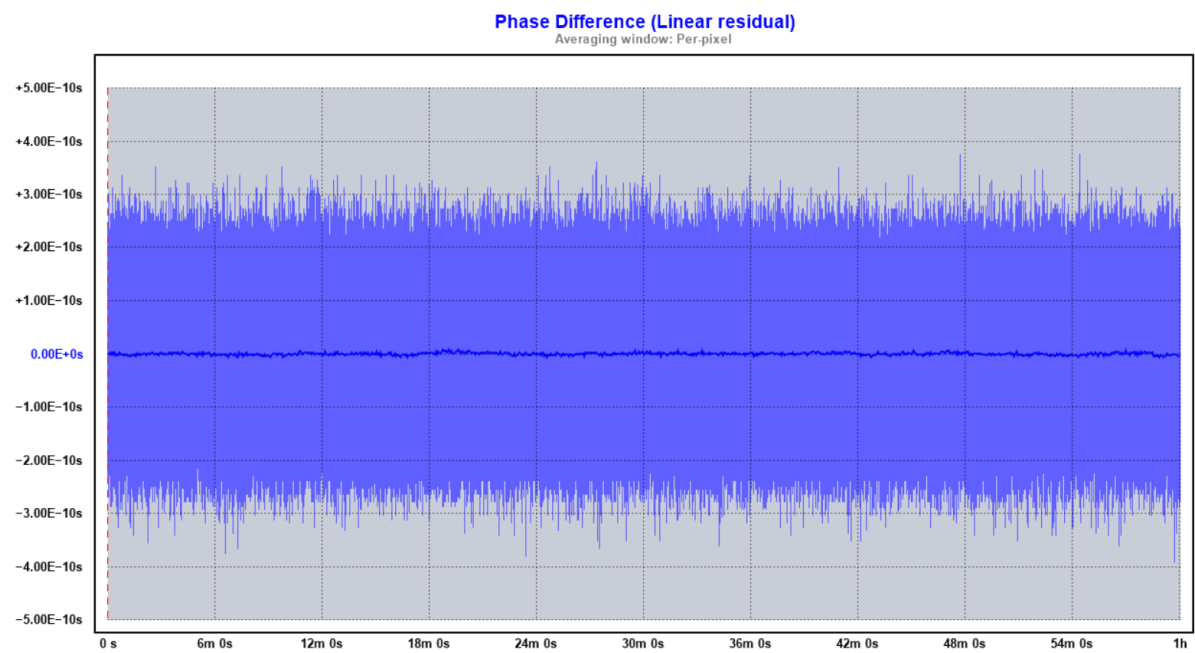


Figure 12: 1 kHz noise floor phase record

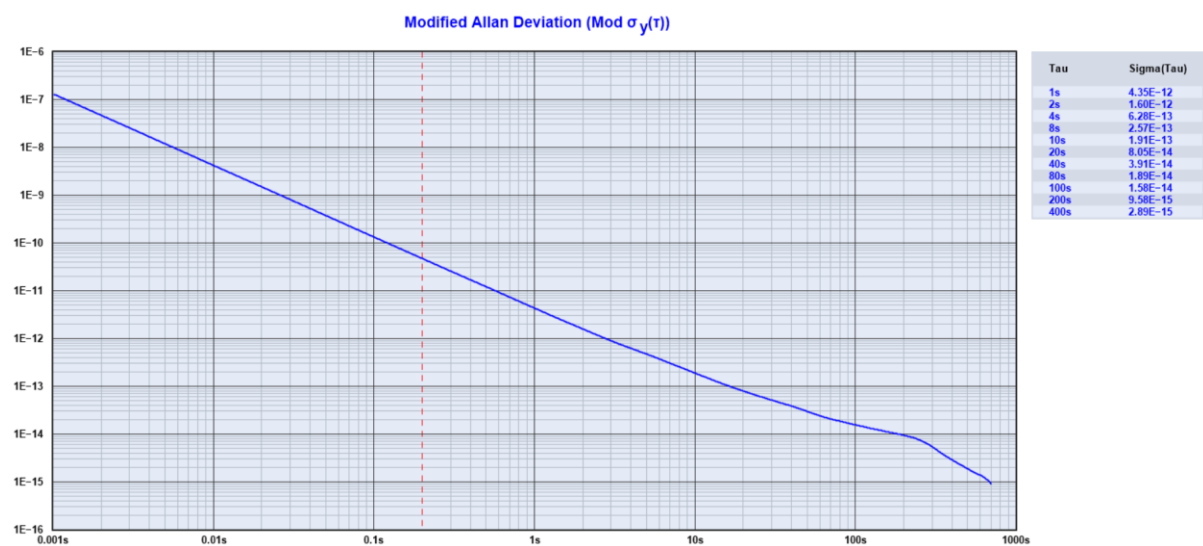


Figure 13: 1 kHz noise floor ADEV

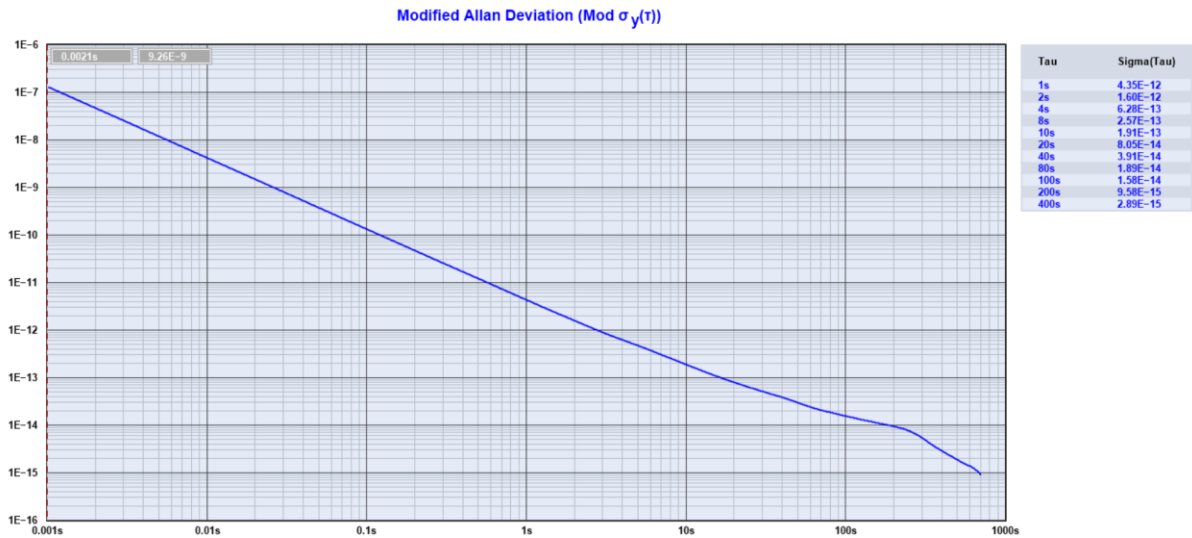


Figure 14: 1 kHz noise floor MDEV

5 kHz noise floor test results

Only 10M samples of the full 18M phase record could be loaded into TimeLab. It is expected that this is enough data to glean some insight into the noise floor of the setup.

The phase record, ADEV and MDEV plots are shown below.

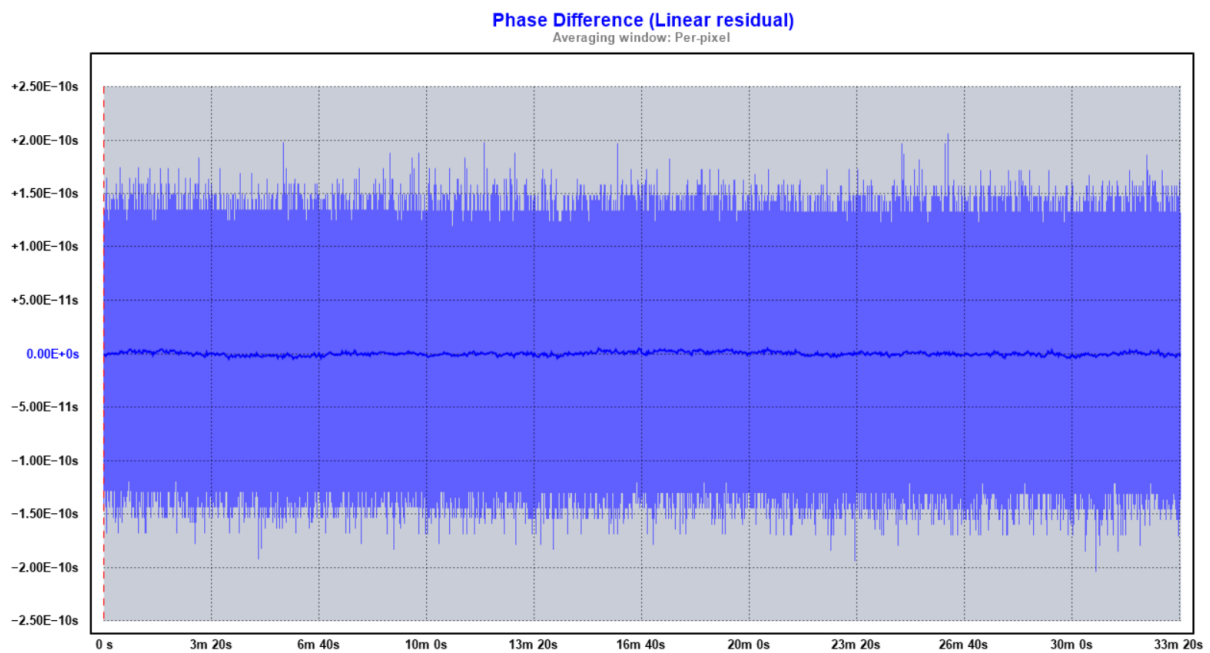


Figure 15: 5 kHz noise floor phase record



Figure 16: 5 kHz noise floor ADEV

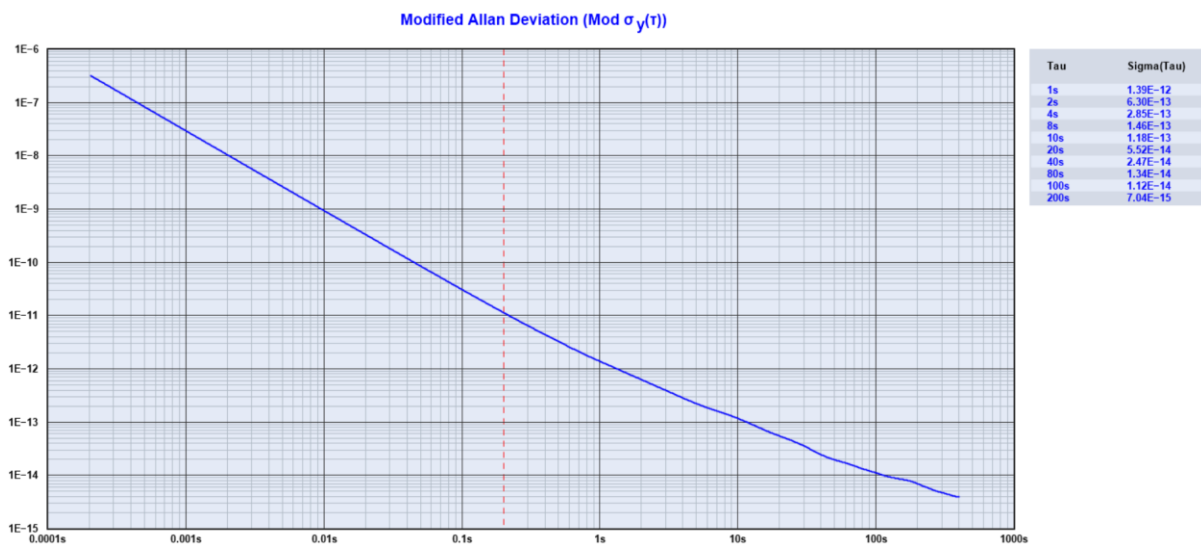


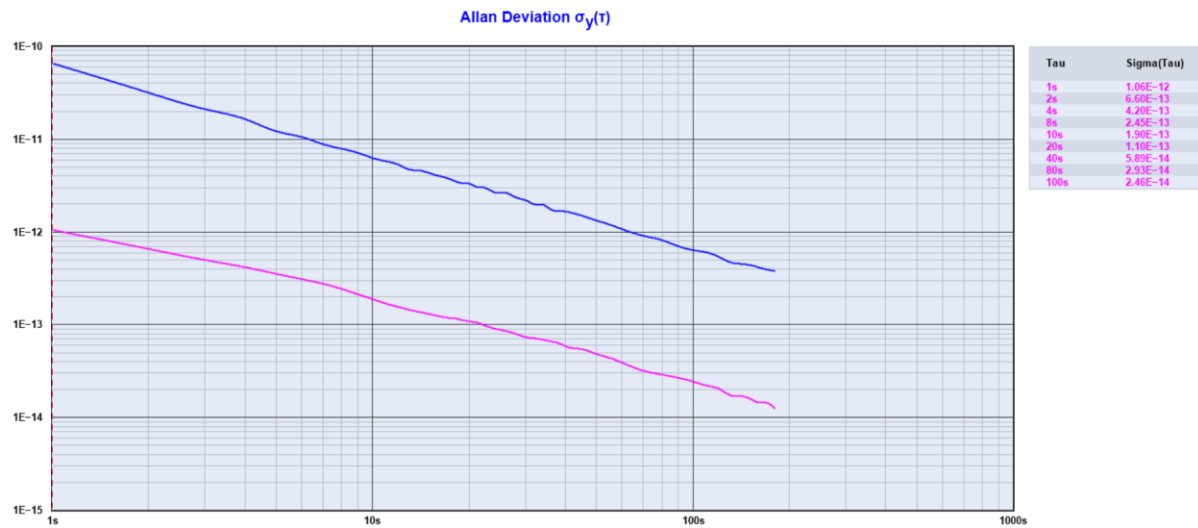
Figure 17: 5 kHz noise floor MDEV

50 kHz noise floor test results (preliminary)

A test was also conducted with a sampling rate of 50 kHz. The data rate at this sampling rate is too high to analyse with the tools available, so only a rudimentary analysis is presented.

It is worth noting that at present, it has not been experimentally confirmed that there are no gaps or missed samples at this sample rate. There are, however, no obvious signs of this in the preliminary data.

Data was collected at a sample rate of 50 kHz, for 20 minutes. To establish a baseline, the data was decimated by 50,000, to yield 1 samples per second. The second data series is a 50,000 average of the phase unwrapped data.



Data files

Unprocessed phase observations were logged to two data-files:

```
"1khz noise floor test.txt"  
"5khz noise floor test.txt"  
"50khz noise floor test.txt"
```