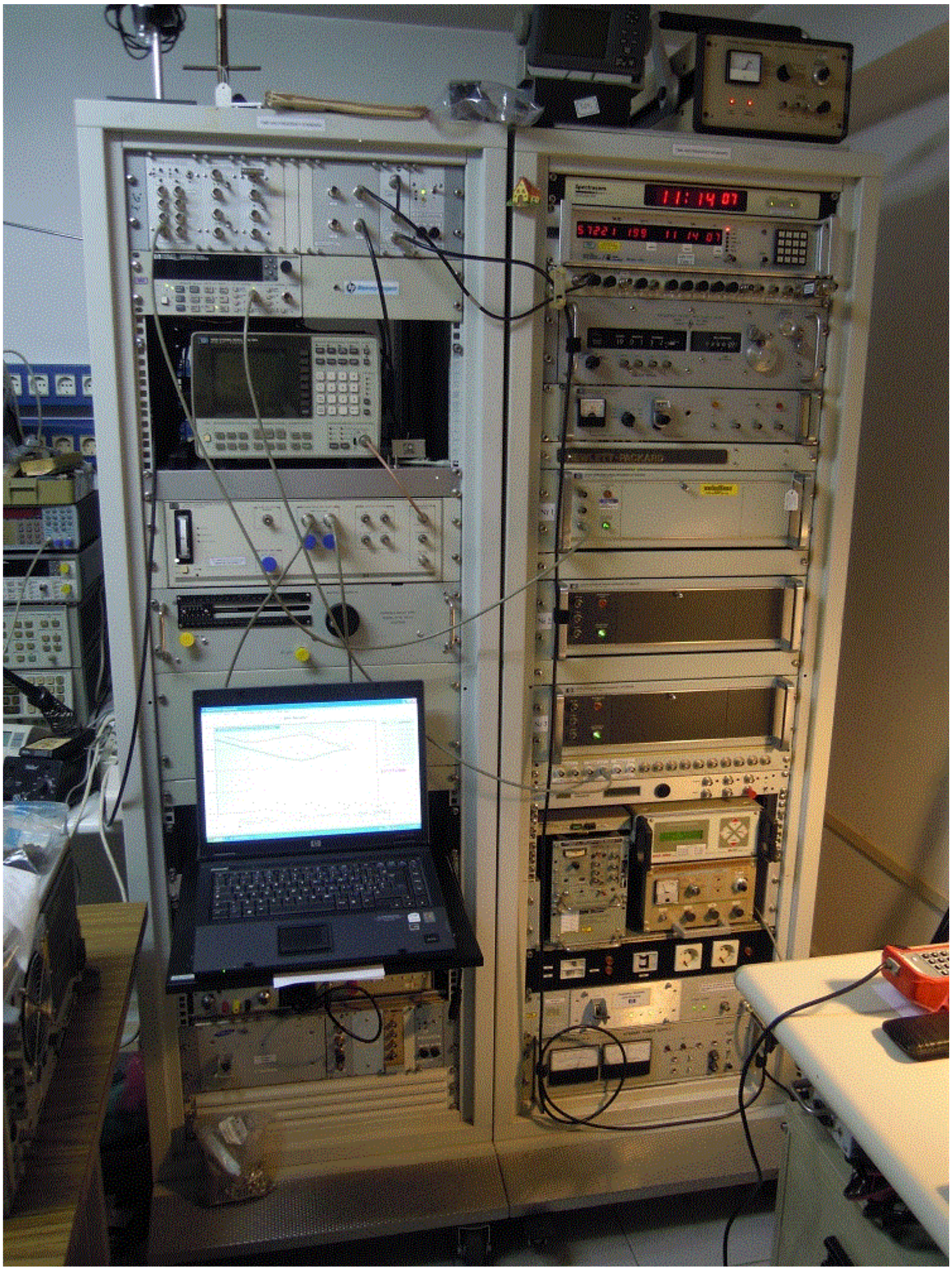
Timeok Time and Frequency House Standard

Ver. 2.1 September 2015

Up from when I began to get interested in electronics, I was fascinated of measurement standards and in particular those relating to the frequency standard. Over the years I tried to improve the specifications of my references by replacing with other Standards of the best features.

Here is the configuration of July 2015.



Currently all equipment relating to time and frequency are housed in two racks.

I split the objectives of these devices into four groups:

- Time and frequency generators and Time display House Standard
- External Time and frequency standard receivers
- Phase Noise references House Standard
- Measurements Test Set

Time and frequency generators and Time display House Standard

The project on the frequency standard has evolved starting from classic HP10811 OCXO before moving to my first Rubidium Efratom, and even a parenthesis then closed, with new generations of small size rubidium and then back to the FRK, MRT, or M100 Efratom. The final solution therefore has been to maintain a series of three HP5065A and, as support, two MRT H and L version. One of the three HP rubidium is planned will be upgraded with the Corby Dawson Kit to turn it into a Super HP5065A (see references).
All the HP Rubidium and the TRAK standard Time Clock are connected to an Austron uninterruptable 24Volts DC power supply.

Fig.1 <- HP5065A Nr 1,2,3 -> Efratom MRK-L and House Time display TRAK6460

The solution to acquire a Cesium as reference has been discarded for the short operational life of the tube and the cost/benefit ratio with respect to a HP5065A was not justified.
The HP5065A is still rated as the best commercial rubidium ever made.
Experts say the HP5065A have exceptional performance of stability and, in order to measure the Allan deviation, it is necessary to compare it with an H-maser

because the the Cesium Reference has not features that allow a realistic measure than the HP Rubidium.

KE5FX write: “Among the well-known time and frequency standards from Hewlett Packard and other vendors, the HP5065A rubidium vapor frequency standard offers the best medium-term frequency stability of any device that the casual (or even hardcore) "time nut" is likely to encounter. The Allan deviation of the best commercial cesium-beam standards like the HP 5071A tends to cross into the E-14 range between t=1000 seconds and t=10000 seconds, while an HP 5065A can reach this level of stability in under 500 seconds. To assess the performance of an HP 5065A fairly, you need an H-maser”.

During the path that led me to the current configuration I have also examined different small size Rubidium, still in production, as the LPRO-101, C-FSR, LPFRS, but although good general characteristics, they have a phase noise above the FRK series and the HP5065A. This aspect is probably due precisely to the size of the internal physical module: Lamp, Cell, Cavity and photo-detector. I therefore abandoned this range of products because, from the point of view of phase noise, stability and reliability the performance did not reach my targets.

So in summary, from my point of view, there are three performance levels of Rubidium standard:

Level 1 HP5065A *
Level 2 Efratom FRK and M100 *
Level 3 Small size Rubidium oscillators

* may be there are others freq standard, brand and models, in the range.

Some drift informations collected by Corby Dawson about some HP5065A:

Unit 1 3.15X10-12/Year 12 years
Unit 2 1.53X10-12/Year 13 Years
Unit 3 7.12X10-12/Year 7 months so far

The HP Long term stability specification is +/- 1x10-11 month!

The Time Display House Standard is a TRAK 6460 (Fig.1 ->) year 2k updated thanks to Tom Van Baak. See: http://www.leapsecond.com/pages/trak6460/

The Track6460 is connected to the 10MHz output of the Z3816A. The actual connection to the GPS Smart clock is due to test the incremental error between the 10MHz recovery frequency standard and the Direct PPS from the GPS network. In the future it will be connected to the Rubidium Nr 1 to became a real Time Home Standard.
The TRAK 6064 can convert and display the following standard time: UTC TAI MJD OMEGA SID GPS.

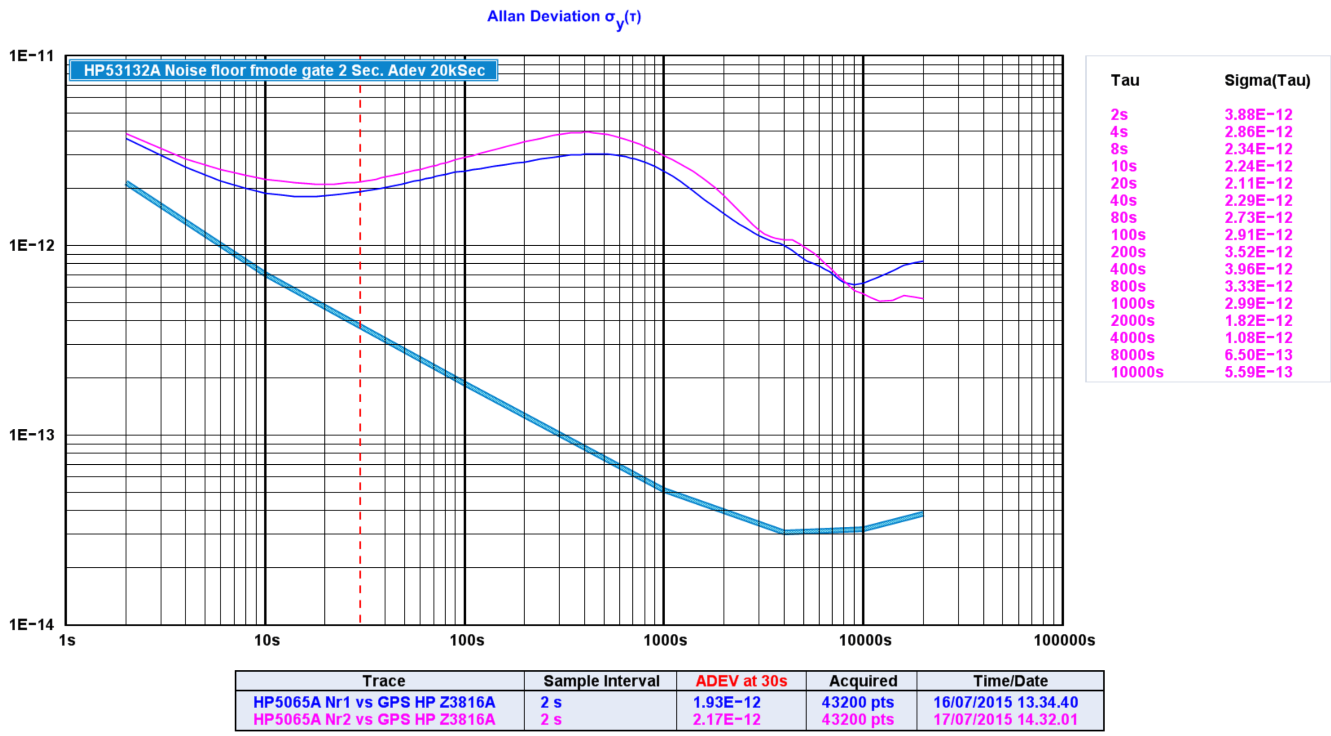
I have modified the input circuit removing the internal Minicircuits frequency doubler because the Trak 6460 originally was wired for a 5MHz as input signal.

External Time and frequency standard receivers

After acquiring one or more frequency standard generators, the first requirement is to adjust the individual standard to the correct frequency and then have to compare them with a minimum ten time more accurate source. If you do not have a friend with a reference of this kind the only way is to buy a GPSDO receiver made for this purpose.
I have chosen two HP GPSDO, the Z3816A is on for 20 years and a Z3805A as spare unit. I also tried various Trimble models with the same excellent results. The

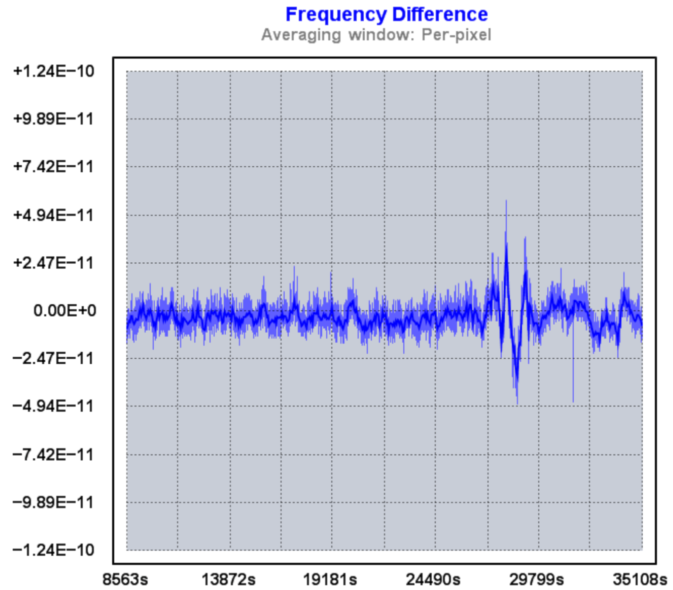
GPSDO receivers are connected to an Austron uninterruptable 24Volts DC power supply. The antenna is on the roof and afer a 30 meters long cable is connected to a 12 ports splitter. Four ports are used inside the two Lab racks, the others are for test. Some time happen I had ten GPSDO under test.

The GPS network is the most commonly used to compare the frequency standards located in remote places. There are various ways of use but the most common is to compare the 10 MHz output from GPSDO with the local standard using a frequency counter.
Making several acquisitions 24 hours long I could find the limit of accuracy of GPSDO direct method.
The measurement was done using Timelab and an HP53132A counter. The settings are as follow:
10MHz from GPSDO connected to the HP53132A external time base
10MHz from HP5065A (option H10-2) to the HP53132A input channel 1
Measurement type: Frequency
Measurement mode: Allan Deviation
Gate Time: 2 Seconds (for the max. counter resolution/min. time gate)



The lower track is the noise floor of the measurement system and the two upper tracks are the GPS compared with my HP5065A Nr 1 and 2.
The minimum Allan Deviation value is around 4E-12, we can consider this value as the border line of the GPSDO stability. So we can evaluate as real GPSDO Adev resolution reading value, using the HP53132A in this configuration, 5E-12.

A very important consideration that is often not taken into consideration is the 10MHz frequency instability of the GPSDO as a function of atmospheric factors. The effects of the ionosphere generally change slowly, and can be averaged over time and a correction factor is transmitted by the satellites network to the ground receivers but the humidity also causes a variable delay, resulting in errors similar to ionospheric delay, but occurring in the troposphere. This effect both is more localized and changes more quickly than ionospheric effects, and is not frequency dependent. These traits make precise measurement and compensation of humidity errors more difficult than ionospheric effects. The Atmospheric pressure can also change the signals reception delay, due to the dry gases present at the troposphere. Typically these are Packaged Instability, are events that have the most obvious effects in limited periods of time and can be identified by monitoring the stability of the GPSDO comparing it with a linear drift high stability reference as the HP5065A. To verify if the GPSDO reference is in a phase of greater stability, it is necessary to take measures for the duration of hours to understand when the reference signal is in a stability phase.



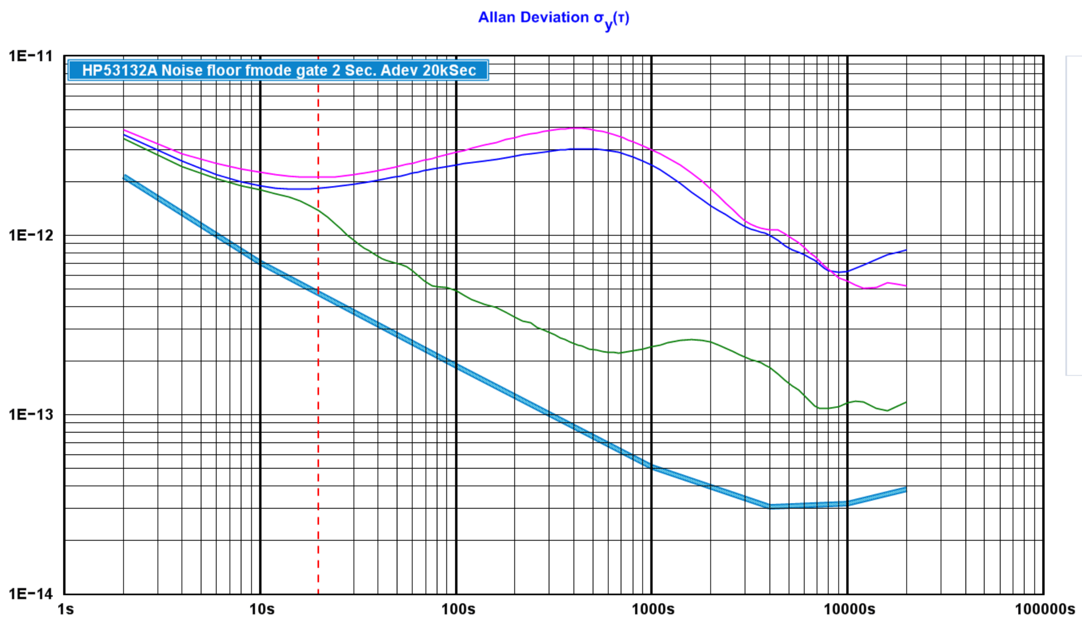
Origin	Drift (Hz/sec)	Drift (Hz/hr)
−2.71E−12	−5.14E−11	−1.85E−7

Avg Time (s)	Freq (Hz) at 35108s	Error
2	9 999 999 . 999 980 001	−8.00E−12
3	9 999 999 . 999 985 000	−7.50E−12
10	9 999 999 . 999 976 000	−8.40E−12
30	9 999 999 . 999 984 000	−7.60E−12
100	9 999 999 . 999 997 800	−6.22E−12
300	10 000 000 . 000 019 934	−4.01E−12
1 000	10 000 000 . 000 053 581	−6.42E−13
3 000	10 000 000 . 000 011 353	−4.86E−12
10 000	10 000 000 . 000 038 102	−2.19E−12

Trace	Notes	Duration	Remaining
HP5065A Nr2 vs GPS HP Z3816A	10Mhz fmode	1d 0h 0m 0s	Done

Example of GPS Frequency Differece evolution over time

To verify the HP5065A is a good source for the GPSDO testing in medium-term as frequency stability I have done a verification test comparing Rubidium Nr.1 with the Nr2 (green line).



Tau	Sigma(Tau)
2s	3.47E−12
4s	2.42E−12
8s	1.90E−12
10s	1.79E−12
20s	1.37E−12
40s	7.63E−13
80s	5.16E−13
100s	4.92E−13
200s	3.51E−13
400s	2.50E−13
800s	2.27E−13
1000s	2.40E−13
2000s	2.54E−13
4000s	1.83E−13
8000s	1.08E−13
10000s	1.17E−13

Trace	Sample Interval	ADEV at 20s	Acquired	Time/Date
HP5065A Nr1 vs GPS HP Z3816A	2 s	1.83E−12	43200 pts	16/07/2015 13.34.40
HP5065A Nr2 vs GPS HP Z3816A	2 s	2.11E−12	43200 pts	17/07/2015 14.32.01
HP5065A Nr1 vs Nr2	2 s	1.37E−12	43200 pts	18/07/2015 16.32.04

As you can see in the range 20 to 20K Seconds the two rubidium, Nr1 and 2, perform better than GPSDO vs Rubidium Nr1 and 2 , so this is the verification the HP5065A is a valid reference to test the Adev for the medium-term response of a standard GPS Disciplined Oscillator.

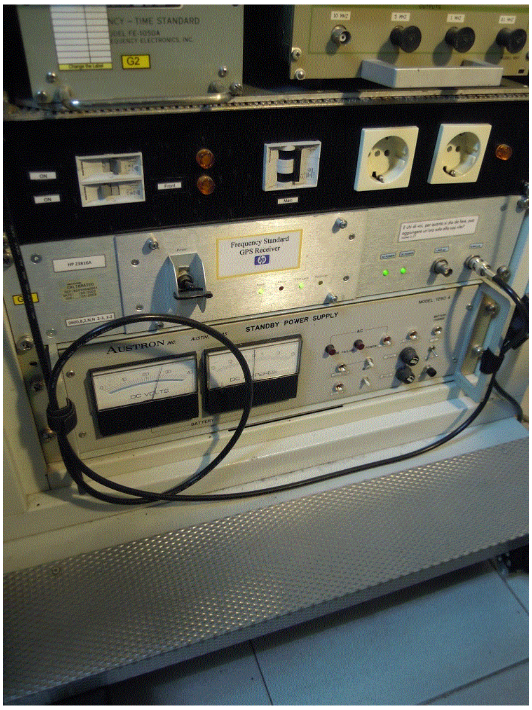


Fig.2 <-GPSDO HP Z3816A, bottom Austron 1290A DC UPS -> GPSDO Z3805A

The master GPSDO is connected to an Austron UPS 24Volts DC power supply.

For External TF receivers section there is a FM receiver ESAT RAD2000 tuned on the local broadcast frequency of RAI 1 that periodically transmit a tone code for the clock synchronization. This device gives me an additional input on the local time. A Spectracom GPS receiver with modest frequency stability on 10MHz is used to display the GPS Time. This device is installed above the other clock, the Home Time Standard, so as to make possible a quick visual comparison of synchronization between the two.

Fig.3 <-FM RAI Time Code receiver -> Spectracom GPS Net Clock

Phase Noise references House Standard

The actual Phase noise Reference I have tested are the HP105B (old style oscillator) and the Frequency Electronics AN/URQ23. As you know a simple method to select a pair of good source is to compare between them all the available sources. Analyzing the data obtained will be a pair that will produce the best results. I found so the two 5MHz sources.

	1Hz	10Hz	100Hz	1kHz	10kHz	100kHz
HP105B vs AN/URQ23	-115	-135	-148	-160	-167	-171
Specific.AN/URQ23	-	-130	-140	-160	-165	-

HP5065A also has some excellent performance:

	1Hz	10Hz	100Hz	1kHz	10kHz	100kHz
HP5065A vs HP105B	-107	-127	-150	-157	-159	-161

Test Frequency 5 MHz

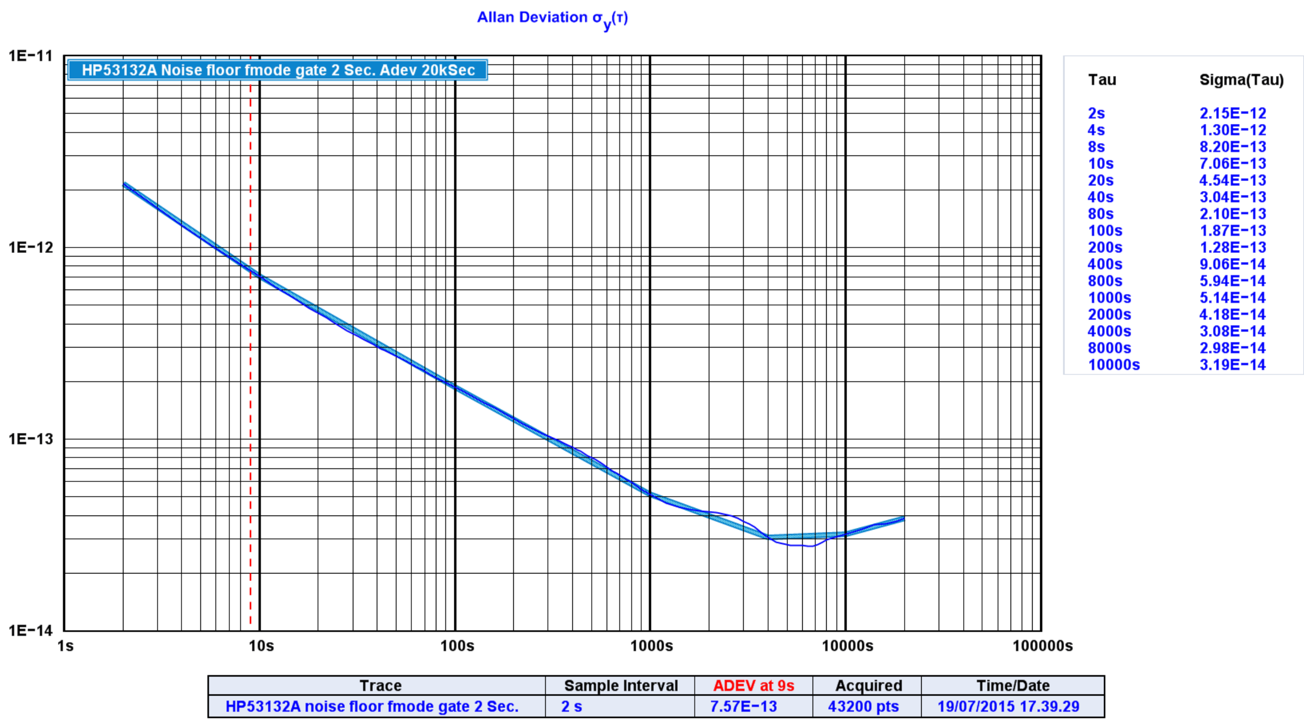
Fig.4 <- HP 105B ->Frequency Electronics AN/URQ23

At present I have not selected 10MHz sources I have in the laboratory, but I plan to do it soon.
Another real possibility to expand the low Phase noise range of the sources in the microwave region, is to use some brick PLL using a 100MHz low noise external souce as reference input (10x2x5 MHZ).
See http://www.timeok.it/files/10_to_100_mhz_multiplier.pdf

Measurements Test Set

The section Measurements is divided into two different parts, one dedicated to the measurement of frequency stability and the time difference, the other to measure the phase noise for both oscillators and amplifiers or other types of circuits.
For time and frequency measurements is used the universal counter HP50132A. This counter is controlled by an external reference frequency, which may vary through a patch panel, depending on the desired source.
The software used to perform data acquisition is Timelab written by John Miles using a National GPIB-USB interface.
The maximum resolution is obtained by using the HP53132A counter, using the frequency function and selecting a 2 seconds as gate time.

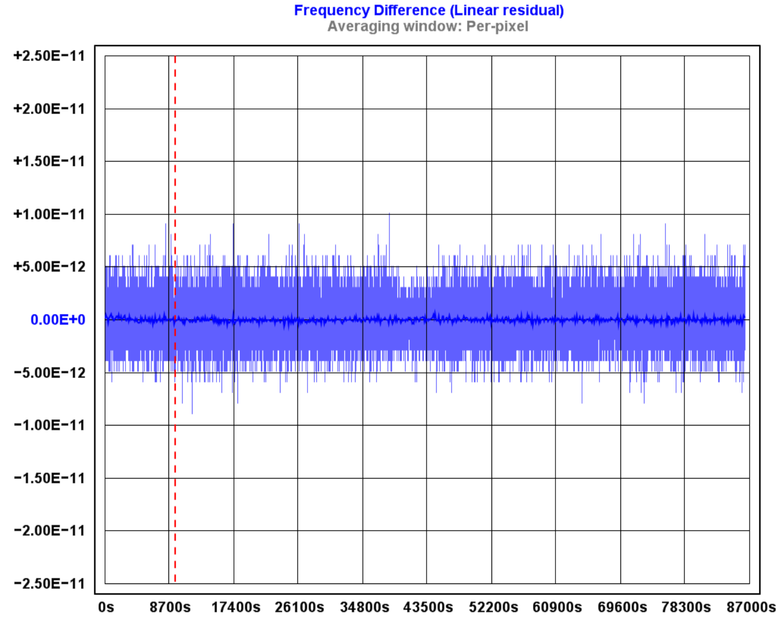
To measure the Noise floor of the instrument, so the maximum possible resolution of this measurement system, I have connected a stable, low phase noise source to the A input and external Time Base input via a power splitter Minicircuits PSC – 2-1. In this way the reference and the frequency to be measured are the same, the two signals have a theoretical result of variance equal to zero, the remaining "numbers" will be the noise floor of the measurement system.



Adev Noise floor table

Tau	Sigma(Tau)
2S	2.15E-12
10S	7.06E-13
100S	1.87E-13
1kS	5.14E-14
10kS	3.19E-14

Looking at the following graph about the frequency difference in noise floor measurement condition, as above, we can estimate a valid snapshot reading equal to +/-1E-11.



Origin	Drift (Hz/sec)	Drift (Hz/day)
-1.11E-12	+1.97E-12	+1.70E-7

Avg Time (s)	Freq (Hz) at 86398s	Error
2	10 000 000 . 000 000 000	+6.00E-12
3	9 999 999 . 999 960 000	+2.00E-12
10	9 999 999 . 999 938 000	-2.00E-13
30	9 999 999 . 999 932 000	-8.00E-13
100	9 999 999 . 999 930 600	-9.40E-13
300	9 999 999 . 999 932 267	-7.73E-13
1 000	9 999 999 . 999 929 000	-1.10E-12
3 000	9 999 999 . 999 928 853	-1.11E-12
10 000	9 999 999 . 999 928 899	-1.11E-12

Trace	Sample Interval	Freq at 9502s	Acquired	Time/Date
HP53132A noise floor fmode gate 2 Sec.	2 s	-6.00E-12	43200 pts	19/07/2015 17.39.29

The Test set for Phase noise measurements is different and I have decided to use the old and more known HP3048A system.

Originally this system ran on an UNIX operating system, and then problematic to setting up today. Luckily an hobbiest have converted the software on a Windows platform. More details here:http://www.ke5fx.com/pn3048.htm

A Wiltron 3114 60cm variable delay line is added to have a fine quadrature tuning.

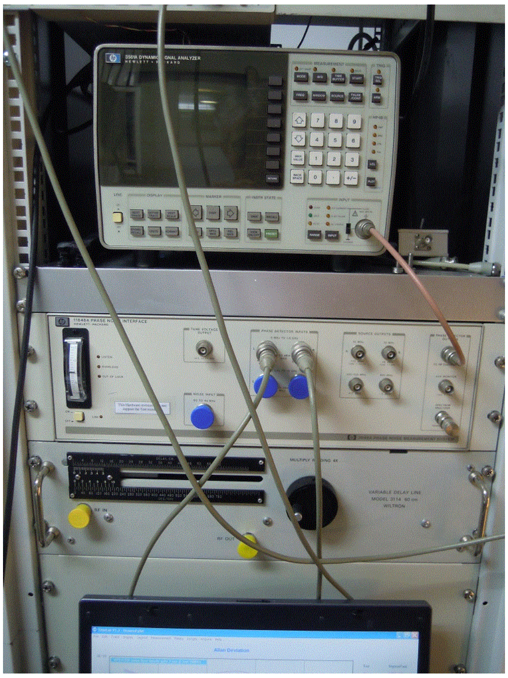


Fig.5 HP3084 Phase noise Test Set

In a time and frequency laboratory are often needed some accessories that allow you to convert signals to make them compatible with the measuring bench.
For this purpose I have built and/or designed some valid aids that have high performance in order not to worsen the quality of input signals.
All these modules were built so that you have two equal and independent channels to have greater flexibility to use in case you need to have a pair.

They are:

- Dual channel PPS divider 5/10MHz to 1PPS. Using the TAPR project.
- Dual channel 10 to 5MHz regenerative divider.
- Dual channel 5 to 10MHz doubler.

See reference.

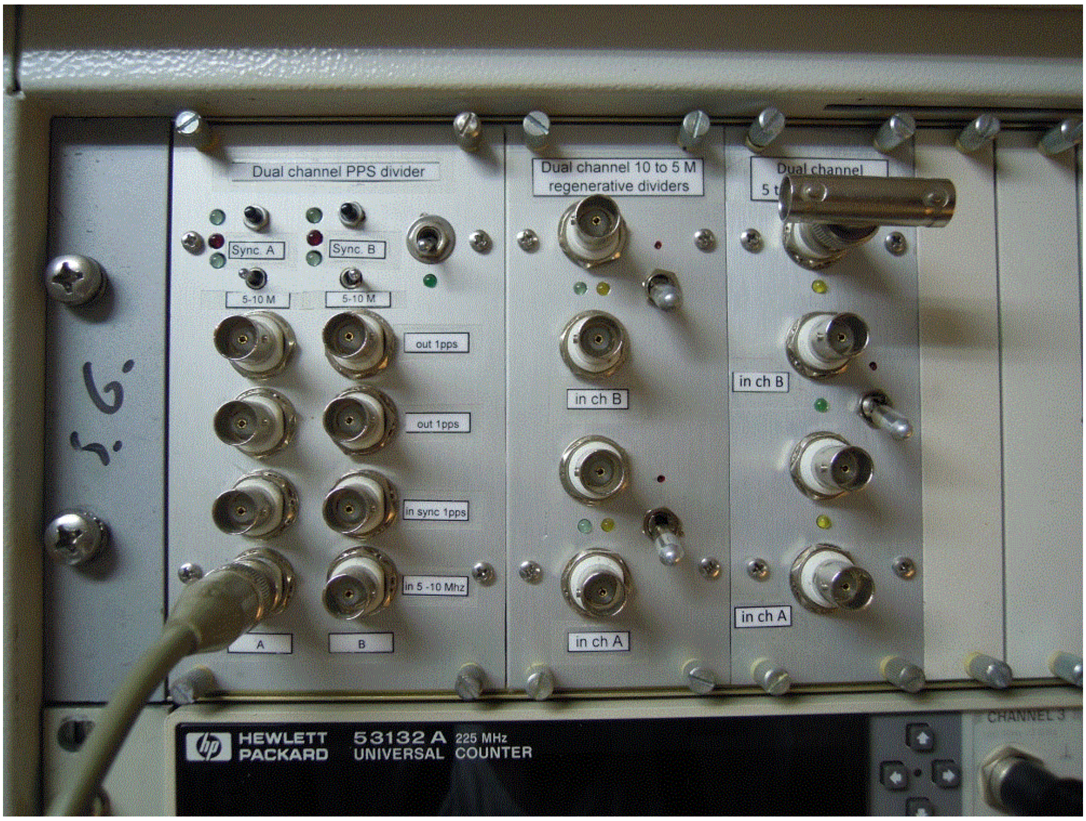


Fig.6 Some Measurement tools like PPS divider and frequency divider/multiplier (see: www.timeok.it)

www.timeok.it
timeok@timeok.it

reference:

To join time-nuts: www.febo.com/cgi-bin/mailman/listinfo/time-nuts.
TVB site: www.leapsecond.com
Super HP5065A http://leapsecond.com/corby/Super-5065A-Project.pdf
TIMELAB www.ke5fx.com/timelab/readme.htm
H10-1/2 opt. www.timeok.it/files/hp5065AoptH10v200.pdf
RAI time code www.inrim.it/res/tf/src_i.shtml
Regenerative div www.timeok.it/files/low_noise_regenerative_divider.pdf
Frequency doubler www.timeok.it/files/high_performance_frequency_doublerv13.pdf