Phase noise inter-laboratory comparison preliminary results

P. Salzenstein[1], F. Lefebvre[2], R. Barillet[3], J. Čermak[4], W. Schaefer[5], G. Cibiel[6], G. Sauvage[7], O. Franquet[8], O. Llopis[9], F. Meyer[10], N. Franquet[1], X. Vacheret[1], A. Kuna[4], L. Šojdr[4] and S. Gribaldo[9]

[1]FEMTO-ST, CNRS, Associated to LNE, 32 av. Obs., F25044 Besançon Cedex, France
Phone: +33(0)381853974 Fax: +33(0)381853998
[2] OSCILLOQUARTZ, rue des Brévards 16, CH-2002 Neuchâtel 2, Switzerland
[3] Observatoire de Paris, CNRS, LNE-SYRTE, Bât B, 61 av. Obs., F75014 Paris, France
[4] Czech Academy of Science, Dpt of Standard Time & Frequency, Chaberska 57, 18251 Praha 8, Czech Republic
[5] TimeTech GmbH, Curiestrasse 2, D70563 Stuttgart, Germany
[6] CNES (Centre national d'Etudes Spatiales), 18 av. E. Belin, F31404 Toulouse Cedex France
[7] AEROFLEX, 5 Place du Général De Gaulle, F78990 Elancourt, France
[8] AR Electronique, rue du Bois de la Courbe, F25870 Châtillon-le-Duc, France
[9] LAAS CNRS, 7 av. du Colonel Roche, F31077 Toulouse France
[10] Observatoire de Besançon, CNRS, Associated to LNE, 41bis av. de l'Obs., BP1615, F25010 Besançon, France

[1]Electronic address: patrice.salzenstein@femto-st.fr

Some benches used and developed into the different research and commercial laboratories have to be tested. The problem is not to compare the performances of several oscillators, but to compare and to make an evaluation of the uncertainties, and of course, to compare the resolution and the reproducibility of the measurements, that interest phase noise measurements benches manufacturers. This comparison allows us to determine the ability to get various systems traceable together in order to increase the trust that one can have in phase noise measurements. Standards to be characterized during this comparison are 5 MHz, 100 MHz and microwave commercial oscillators. Obtained spectra can be affected by the measurements environment: temperature, hygrometry, electromagnetic rays, voltage alimentation of oscillators under test and measurement instrumentation, but they also depend on starting conditions of the oscillators and due to their intrinsic nature, and to the time they have been stocked after being alimented and to the benches themselves. The problem consists in evaluating the possible different contributions. These goals are ambitious, so it is preferable to investigate in priority the inter-laboratory reproducibility in using comparable benches or benches that use equivalent methods, but also measurements resulting from various methods, while we stay in the context of measurements performed in a laboratory. It began in October 2005 and will be achieved in april 2006. Preliminary results are now available.

1. INTRODUCTION

An international comparison of phase noise was organized in 1993 and its results published in Germany during EFTF in 1994 [1]. More than ten years later, the new benches developed into the different laboratories and commercial benches have to be tested. LNE (Laboratoire National de Métrologie et d'Essai, that now play the rule that BNM owns in the past) asked FEMTO-ST institute, as it is an LNE associate laboratory, (COFRAC accredited under number 2.13), to organize a comparison of phase noise with 5 MHz, 100 MHz and microwave oscillators. The problem is not to compare the performances of several oscillators, but to compare and to make an evaluation of the uncertainties, and of course the resolution and the reproducibility of the measurements, which interest phase noise measurements benches manufacturers. The aim of this comparison is not to led a competition between different means of measurements but have the ability to get several systems traceable together in order to increase the trust that one can have for phase noise measurements. Oscillators to be characterized during this comparison are commercial oscillators. At 5 MHz, BVA oscillators are provided by Oscilloquartz company and FEMTO-ST. For 5 MHz oscillators, FEMTO-ST institute provides AR Electronique commercial oscillators. A commercial MITEQ Dielectric Resonator Oscillator (DRO) provided by LAAS-CNRS is to be used for 3.5 GHz microwave characterization. Ten laboratories from four different countries participate to this comparison.

II. GENERALITIES CONCERNING SPECTRAL MEASUREMENTS

Frequency stability can be characterized in the frequency domain by studying spectrum or in time domain, it consists in statistical treatment of different results of counting signal frequencies. Spectral density of phase noise is defined by integrating the ratio between lateral bands and power of the carrier versus Fourier frequencies. In the time domain, Allan variance is determined by statistical treatment of counted frequencies. It allows characterization of the frequency stability versus integration time. Near the carrier, an oscillator presents Flicker frequency noise, i.e. 1/f in the frequency fluctuation domain, which means $1/f^3$ for the phase noise density in the spectral domain. It corresponds to a Flicker floor for Allan variance in the time domain (We must be careful about it, because the correspondence is not bijective : a $1/f^3$ phase noise gives an Allan variance floor, but the opposite is not always true, so one should not write "equivalent" but "that gives").

The main principle of the phase noise measurements consists in phase demodulating a signal by locking an oscillator, that is the Unit Under Test (UUT), on a reference signal, using a Phase Lock Loop (PLL).

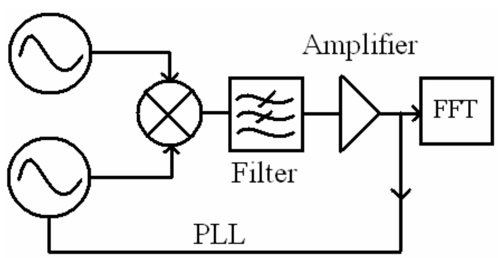

Figure 1: Usual principle for phase noise measurement of a couple of oscillators using a PLL

Especially in microwaves, the UUT has to be locked and not the reference that is already locked on a low frequency oscillator. The error bias of this locking is then proportional to the phase difference between the free running UUT and the reference. Outside the PLL bandwidth, it is proportional to the phase difference between the free running UUT and the reference. In the PLL bandwidth, it is proportional to frequency fluctuations. Nevertheless it seems not to be always true as it depend on the detailed characteristics of the PLL, especially taking into account the number of integrations in the band pass of the locking. It is true when there is only one integration, which is the one coming from the phase comparison in addition to a single amplifier. But for noisy oscillators or in microwaves, as it is necessary to use two integrations in phase advance, it is not true, except close to the PLL cutoff frequency. Results in the band pass of the locking cannot be systematically used because they too much depend on the PLL characteristics. If these characteristics are well known, the change of slope for the phase noise of the UUT can be estimated. The error bias is amplified and a FFT analyzer calculates the spectral density of phase noise fluctuations.

III. REPRODUCIBILITY OF THE MEASUREMENTS

Obtained spectra can be affected by the measurements environment: temperature, hygrometry, electromagnetic rays, voltage alimentation of oscillators under test and measurement instrumentation, but they also depend on starting conditions of the oscillators and due to their intrinsic nature, and to the time they have been stocked after being alimented and to the benches themselves.

The problem consists in evaluating the possible different contributions. These goals are ambitious, so it is preferable to investigate in priority the inter-laboratory reproducibility in using comparable benches or benches that use equivalent methods, but also measurements resulting from various methods, while we stay in the context of measurements performed in a laboratory. As it is written in the introduction, the aim of this comparison is not to compare performances of oscillators, but to compare and evaluate uncertainties and, resolution of the benches and reproducibility of the measurements. It is not a competition between measurement means but a way to have the ability to get several systems traceable together in order to increase the trust that one can have for phase noise measurements done in labs.

IV. PROTOCOL OF MEASUREMENTS

Preliminary measurements:

Oscillators were to be measured at first by the reference lab at the beginning and at the end of this comparison.

Reception of the standards:

When receiving the oscillators, each lab précised how the packing is and what information was important. Oscillators have been immediately put under alimentation during 48 hours before starting any phase noise measurement in the appropriate room. Frequency and power was preliminary verified. Note that the frequency stability is affected by the duration of the un-alimented oscillator period. It has not to be forgotten that the performances, specified by the manufacturers, are guaranteed at the end of one 90 days period without any interruption. However, it is not thinkable, within the framework of the circulation of the standards, to respect this time. In an empirical way, it must be envisaged latency doubles time of cut period. Moreover oscillators are sensitive to the shocks.

Measures:

Oscillators have been measured in term of power spectral density of phase noise versus Fourier frequencies in the range 1 Hz - 100 kHz. However one is careful in microwaves, a DRO cannot be measured too close to the carrier due to free-running fluctuations that can be in the range of several rad^2/Hz. So the indicated range was only suitable for 5 MHz and 100 MHz. The DRO has to be characterized after about 1 kHz. Measurements were given at 1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, and 100 kHz within the 2 σ uncertainty. When it is possible, results given as a calibration certificate are appreciated, as several participants are usually calibration center, accredited or not.

Some laboratories have different kind of phase noise measurement benches. They may use them in order to be compared to each other in the same laboratory. That should be interesting.

Here are different commercial benches potentially identified:

- Hewlett Packard benches
- Europtest benches
- Femtosecond benches
- Timing Solutions benches
- AR Electronique benches

Some laboratories which have short term frequency stability benches could have used them. It may be possible to deduce interesting information concerning phase noise.

In order to limit environmental effects in the different laboratories, it is interesting to know conditions of ambient measurements.

Such parameters are: room temperature, hygrometry rate, but also it is interesting to specify if oscillators or benches are in a special Faraday cage or something equivalent, and what voltage alimentations are used, for example, batteries for the oscillators or sector for the instruments composing the bench.

It has been also written if uncertainties are calculated from such parameters or given by an accreditation.

Re-forwarding of the standards:

The oscillators were then packed and sent back to the following laboratory, except if it was specified that there must be an inversion by the person in charge for the comparison.

Any information considered to be useful was transmitted to the person in charge for the comparison.

Transmission of the results:

The complete results were transmitted to the person in charge of the comparison, before the standards finished circulating between the participating laboratories.
It was specified: environmental conditions of the measurements as explained above, the type of bench, and method used, as well as uncertainties.
The comparison is planned to be achieved in March 2006. When it is finished, a report will be written with mention of the authors and their laboratories. However, in the graphs and in the presentation of the results, the different participating laboratories will be codified by letters.

V. FIRST RESULTS

The obtained results concern at first phase noise measured values for each standard at 5 MHz, 100 MHz and 3.5 GHz. Comparison also gave interesting results in the way of knowing the benches. Finally it also helps our knowledge in criticizing obtained curves.

dBc/Hz	10^0 Hz	10^1 Hz	10^2 Hz	10^3 Hz	10^4 Hz	10^5 Hz
LR 1	-125.5 ±2	-145 ±2	-151.5 ±2	-156 ±2	-154 ±2	-156 ±2
LR 2	-125±2	-136 ±2	-140 ±2	-154 ±2	-154 ±2	-155 ±2
A (3)	-126±2	-145 ±2	-151.5 ±2	-155 ±2	-155 ±2	-155.5 ±2
B (4)	-113 ±5	-135 ±5	-143 ±5	-149 ±5	-155 ±5	-157.5 ±5
C* (5)	-126	-145.5	-151.5	-155	-155.5	-156.5
D* (6)	-125.5	-145.5	-152	-156	-155.5	-156.5
E (7)		-144 ±2	-154 ±2	-158 ±2	-158 ±2	-159 ±2
F* (8)	-126			-155	-155	-155
G (9)	-126 ±2	-144.5 ±2	-151.5 ±2	-155.5 ±2	-155.5 ±2	-156 ±2
H (10)	-126.08 ±3	-145.30 ±3	-152.08 ±3	-155.57 ±3	-155.50 ±3	-157.59 ±3
I						
LR						

Table 1: SSB phase noise versus Fourier Frequency at 5 MHz for each laboratory codified by a letter. Uncertainties given at 2σ

Table 1 presents results without any correction at 5 MHz for the two oscillators of the comparison. Notice that in the tables, sign * mentioned here indicates that uncertainties have not yet been established.

The results are presented also in figures 2 and 3. The first focuses on SSB phase noise at 1Hz from the 5MHz carrier. One participant had problem of stability. As three other laboratories did not send yet their uncertainties, the one taken into account is maximized on this representation. The noise floor seems to be much similar for all participants despite from a strong variation not already explained. Laboratories are codified by a letter, and a number has been indicated for the correspondence on figures.

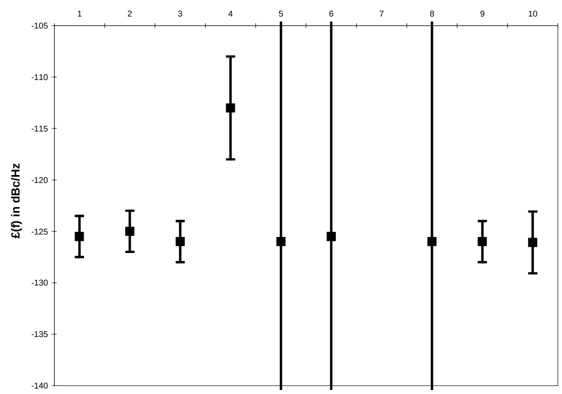

Figure 2: SSB phase noise at 1Hz from the 5MHz carrier. Uncertainties given at 2σ

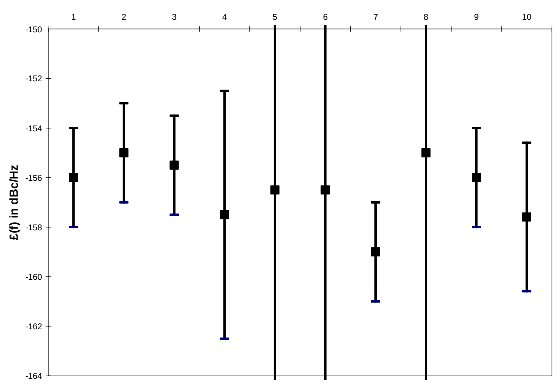

Figure 3: SSB phase noise at 100 kHz from the 5MHz carrier. Uncertainties given at 2σ

At 100 MHz, the results are presented abroad also without any correction and comments.
The measures are coherent in a first approach. But closed to the 100 MHz carrier, it seems that problems of stabilize the phase lock loop made the measure uncertain, especially at the 1 Hz Fourier frequency. For a 100 MHz quartz oscillator, it is common to present its specification at 100 Hz from the carrier. According to this, results are presented on figure 4 considering the SSB phase noise at 100Hz from the 100MHz carrier. Non negligible variations appear for some participants and would be investigated in order to understand why it occurs.

dBc/Hz	10^0 Hz	10^1 Hz	10^2 Hz	10^3 Hz	10^4 Hz	10^5 Hz
LR 1	-64 ±2	-96 ±2	-131 ±2	-153 ±2	-161 ±2	-162 ±2
LR 2	-58 ±2	-98 ±2	-129 ±2	-155 ±2	-162 ±2	-162 ±2
A (3)	-64 ±2	-95.5 ±2	-129.5 ±2	-153.5 ±2	-160 ±2	-160 ±2
B (4)	-65 ±3	-100 ±3	-133.5 ±3	-152 ±3	-160 ±3	-161 ±3
C* (5)	-70	-102	-134	-155	-163	-163
D* (6)	-73	-100	-131	-156.5	-162	-162.5
E (7)			-135 ±2	-151 ±2	-158 ±2	-159 ±2
F* (8)	-68		-128		-163	-163
G (9)	-67 ±2	-97 ±2	-129.5 ±2	-153.5 ±2	-160.5 ±2	-160.5 ±2
H (10)	-76.3 ±3	-96 ±3	-130.5 ±3	-154.8 ±3	-161.6 ±3	-161.7 ±3
I						
LR						

Table 2: SSB phase noise versus Fourier Frequency at 100 MHz for each laboratory codified by a letter. Uncertainties given at 2σ

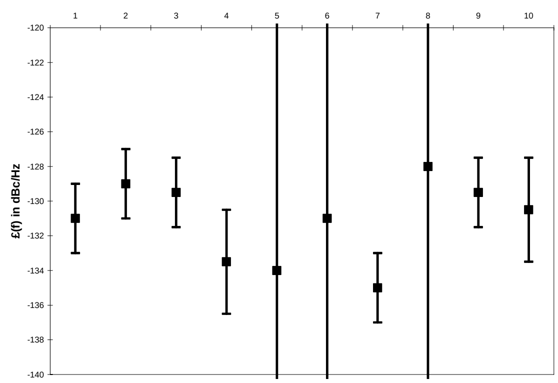

Figure 4: SSB phase noise at 100Hz from the 100MHz carrier. Uncertainties given at 2σ

The noise floor far from the carrier is presented on figure 5.

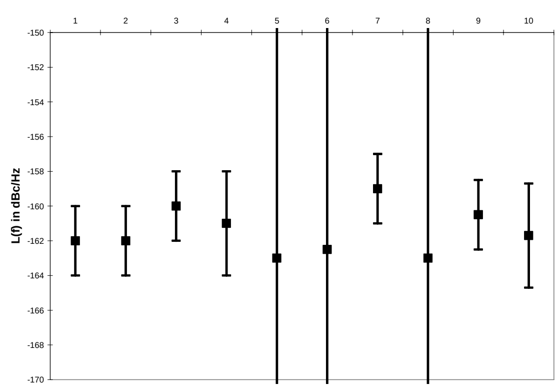

Figure 5: SSB phase noise at 100 kHz from the 100 MHz carrier. Uncertainties given at 2σ

Despite these measures are much closer the differences should be explained by a very precise analysis of different parameters and in considering the way each participant led its measurements campaign.
Starting from a 2 dB variation for a noise floor, investigation should cover a large field of parameters.

VI. DISCUSSION

Environmental conditions are précised in table 3. In this table are reported several parameters like temperature or hygrometry rate, and it is précised if the oscillators under test were alimented by batteries or not. It is written also if the measures were realized in a Faraday cage to protect from electromagnetic fields.

	Temperature (°C)	Hygrometry (%)	Batteries	Faraday cage
LR 1	21.5 ±2.5	?	NO	NO
LR 2	25 ±2	36 ±5	NO	NO
A	23	44	YES	NO
B	22.5 ±1.5	?	NO	NO
C	23.5 ±2.5	42.5 ±12.5	YES	NO
D	20.5 ±2	?	YES	NO
E	23 ±3	?	YES	
F	room temperature	?	NO	NO
G	21 ±1	?		
H	23 ±1	16 ±5	YES	YES
I				
LR				

Table 3: Measurement environmental conditions

Conditions of measurements are not already précised yet for what concerns the starting conditions. Some data are not yet collected at that step of the comparison. The oscillators are still under measurement in the last laboratory, waiting for their final measures in the reference laboratory of this comparison in order to close the turn and begin the next step that is the very precise analysis of the results.
One can notice that reproducibility of phase noise measurements seems not to be well affected by similar conditions in what concerns in lab temperature.
Hygrometry has to be better known before to think about any conclusion.
Contribution of any battery is a fact that does not clearly appears when we examinee tables and figures. Anyway, by seeing curves issued from each lab, 50 Hz harmonics are reduced by the use of batteries. Harmonic's effects are also reduced by increasing averaging spectra.
Faraday cage helps to define a better resolution for phase noise measurements.
A combination of each good condition is reasonability helpful for such phase noise measurements.

VII. CONCLUSION

Aim of this comparison: This phase noise inter-laboratory comparison main goal is to evaluate reproducibility of the measurements given by different kind of benches used in metrological laboratories.
First results confirm the phase noise measurements uncertainties are about ±2 dB.

Acknowledgements

We would like to thank LNE (Laboratoire de Métrologie et d'Essai) and CNRS (Centre National de la Recherche Scientifique) for their financial support on this project.

REFERENCE

[1] F. L. Walls, R. Barillet, R. Besson, J. Groslambert, P. Schumcher, J. Rufenacht and K. Hilty, "International Comparison of phase noise", 8th EFTF, Technical University Munich, Weihenstephan, Germany, march 1994, pp. 439-456 (1994)