

Comparison on Frequency

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Abstract — By using a Rubidium Frequency Standard, a frequency comparison was done by six calibration laboratories. The results of this comparison are described in this paper. The differences between each laboratory's values and the reference values were not within the measurement expanded uncertainties at a coverage factor $k=2$.

I. INTRODUCTION

A number of laboratories in the Netherlands has the capability to calibrate a Frequency standard at 10 MHz following the ISO/IEC 17025 standard. Six of those laboratories organized this comparison to ensure their capability on Frequency measurement. Yokogawa Europe Solution B.V. was selected as the *pilot laboratory*, which is responsible for providing the traveling standard, coordinating the schedule, collecting, and analyzing the comparison data, and preparing the report.

II. PARTICIPANTS

The six laboratories are participating in this comparison, all situated in the Netherlands.

Table 1. List of Participants

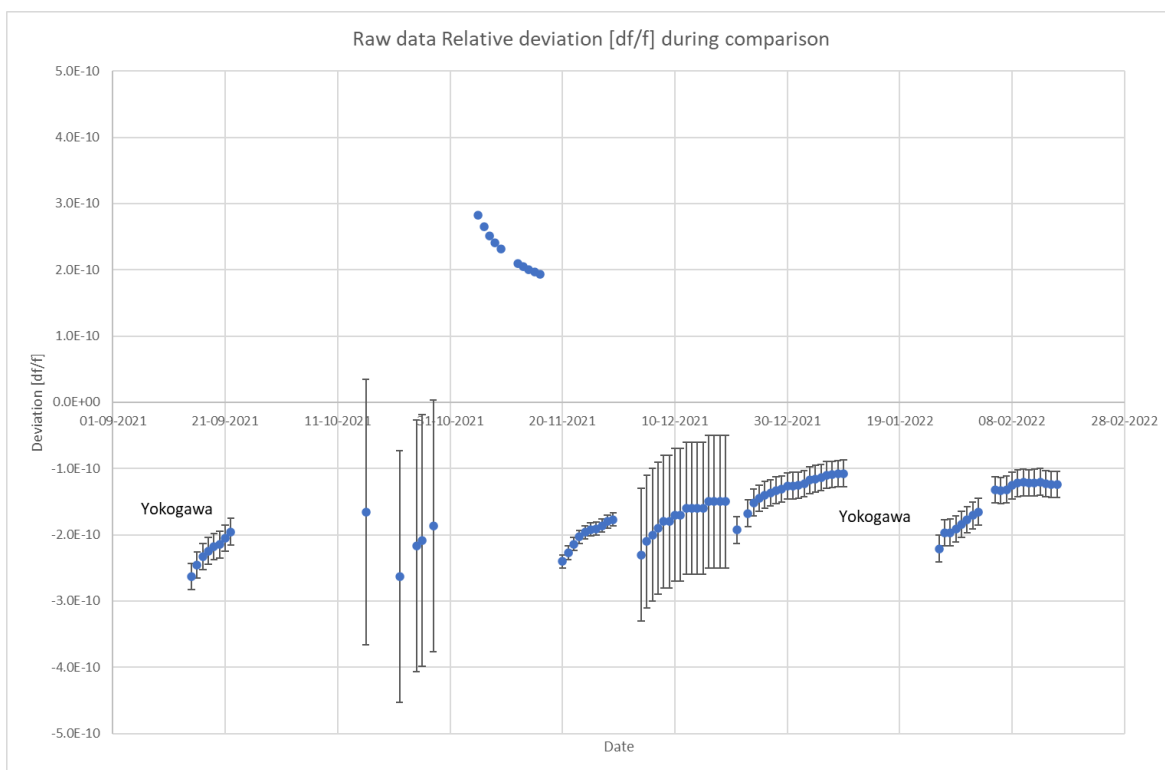
Laboratory
Lab 1.*
Lab 2.
Lab 3.
Lab 4.
Lab 5. (Yokogawa)
Lab 6.

* Lab 1 has accreditation for frequency generating only, not for measurement.

First measurements started at 15 September 2021 and comparison was completed on 16 February 2022.

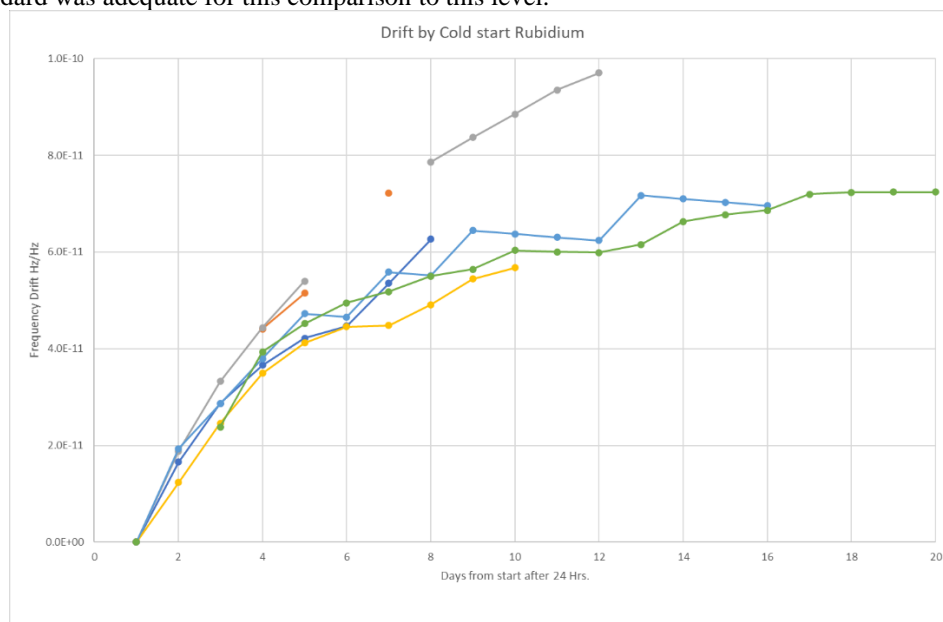
III. TRAVELING STANDARD

A transfer standard is needed with good stability for power during the comparison. The used standard is a Rubidium Frequency Standard Symmetricom Efratom LPRO-101, which was placed in a 19" box by 'Crowntech'. A 10 MHz sine output was provided, and a 1 Plus Per Second as well. The long-term stability was determined by a pre-measurements and closure measurements on the frequency measurement system of Yokogawa. The frequency measurement system is a GPS disciplined Rubidium measurement system. During the comparison, no changes were applied to this system. The relative changes found between the pre- and closure measurements comes from the drift of the rubidium.



Graph (1) Raw data during the comparison.

We assume a linear drift in time during the comparison of $6.325 \cdot 10^{-13}$ Hz/Hz per day. All results in this document are corrected for this drift. However, we observed a short-term stability due to a cold start of the rubidium. This drift was repeatable every time the rubidium was started. See Graph (1). After some examination this looks within $4.8 \cdot 10^{-12}$ Hz/Hz. The uncertainty of the transfer standard is estimated on $2.0 \cdot 10^{-11}$ Hz/Hz, including drift, startup repeatability and uncertainty of the pilot laboratory. The stability of the traveling standard was adequate for this comparison to this level.



Graph (2) Repeatability of the cold start rubidium standard.

This graph was corrected to an equal starting point of all laboratories. Then followed by the relative frequency deviation from day one (Day 0 is the 24 Hrs. warm up).



Picture (1) The transfer standard.

IV. COMPARISON

A. Testpoints

The nominal output frequency of the Rubidium standard is 10 MHz. To prevent the guessing of the frequency deviation, the frequency deviation was given an offset on purpose. This was done by adjustment of the ‘C’ Field. Each laboratory has measured the ‘C’ Field voltage, it was stable during the comparison. The next task was given for the participating laboratories:

‘Start measurements after 24 hours from when the rubidium is powered up. The task is to measure the average 10 MHz (nominal) deviation of the rubidium for several days. The daily reported average frequency deviation must be calculated to 12:00 UTC (noon). Also reported must be the measurement uncertainty and measurement time τ .’

The laboratories could choose their measurement time τ . As long it was calculated to 12:00 UTC. This gives a fixed measurement interval to the combined measurement results of all laboratories. Hence we are able to recalculate the measurement results for the long-term drift of the rubidium. Except for ‘Lab1’ the 10 MHz Frequency measurement are within the scope of calibration for each participating laboratory. From ‘Lab4’ we received only for one day measurement results. Other laboratories have presented several days of measurement results.

B. Reference value

The reference value is based on the weighted average of five laboratories measurement results. The results of the ‘Lab1’ was not clear, and not taken into account by the calculation of the reference value.

This given by the next formula:

$$\bar{x} = \frac{\sum_{i=1}^n g_i x_i}{\sum_{i=1}^n g_i}$$

The weighing is based on the expanded measurement uncertainty, given by each laboratory. The uncertainty of the rubidium is calculated on the averaged weighed uncertainty of the laboratories.

C. En factor

From the results, for each laboratory the $|E_n|$ factor is calculated to the reference value by:

$$E_n = \left| \frac{x_i - X_{ref}}{\sqrt{U_{lab,i}^2 + U_{ref}^2}} \right|$$

The qualification of the results is the following:

$|E_n| \leq 1$ Satisfactory result

$|E_n| > 1$ Unsatisfactory result

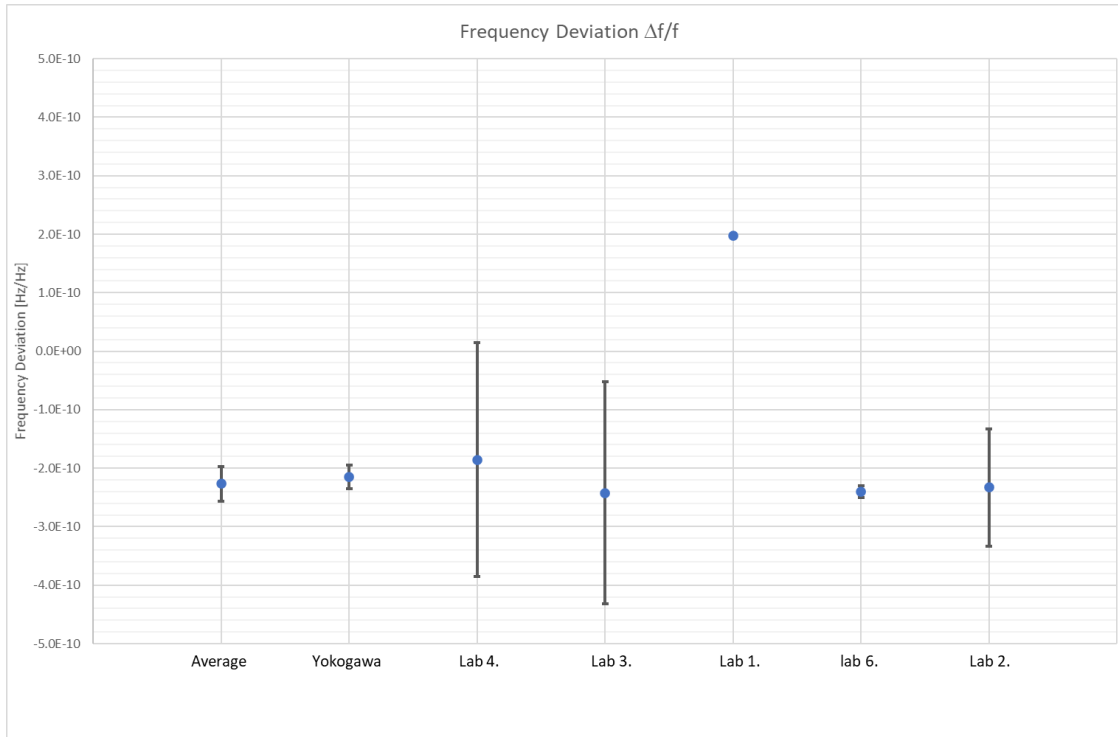
D. Results

For the results of the pilot laboratory the average is taken from the start and closure measurements.

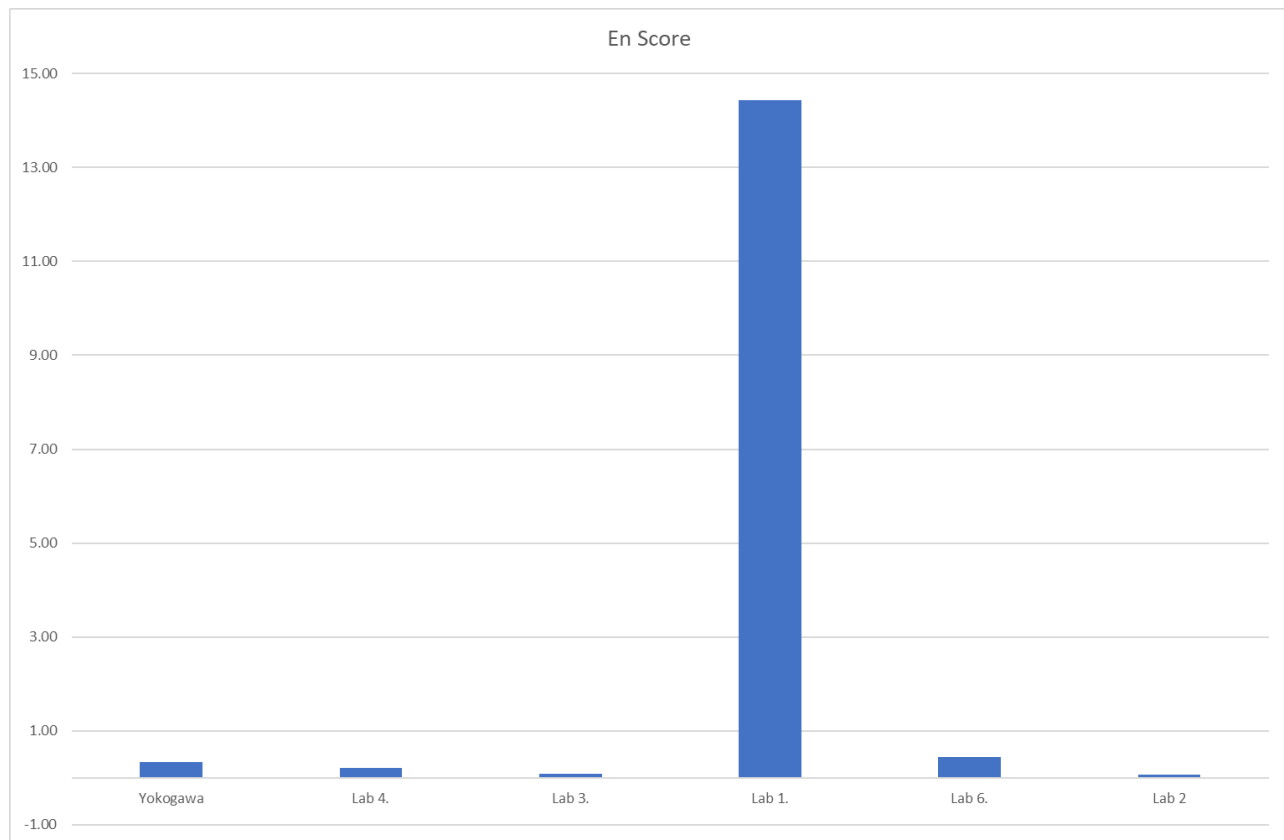
If possible we take the measurement result from the 5th day of the measurement sequence.

Table 1. Results 10 MHz Deviation

	$\Delta f/f$ [Hz/Hz]	$\delta k = 2$ [Hz/Hz]	En Score
Average Rubidium result	$-2.27 \cdot 10^{-10}$	$2.9 \cdot 10^{-11}$	
Lab 5. Yokogawa	$-2.15 \cdot 10^{-10}$	$2.0 \cdot 10^{-11}$	0.34
Lab 4.	$-1.9 \cdot 10^{-10}$	$2.0 \cdot 10^{-10}$	0.20
Lab 3.	$-2.4 \cdot 10^{-10}$	$1.9 \cdot 10^{-10}$	0.08
Lab 1.	$1.97042 \cdot 10^{-10}$	$8.4 \cdot 10^{-15}$	14.43
Lab 6.	$-2.40 \cdot 10^{-10}$	$1.0 \cdot 10^{-11}$	0.44
Lab 2.	$-2.3 \cdot 10^{-10}$	$1.0 \cdot 10^{-10}$	0.06



Graph (3) Results of the measurements.



Graph (4) En score of the measurements.

Except for 'Lab 1' the En scores are $< |1|$. It was not clear how the deviation was calculated in combination with a probably unrealistic uncertainty. However, this measurement is outside their scope of accreditation. By examining the obtained certificates a general item is the lack of information how the deviation is obtained. Only when the measured frequency is also presented we see a different interpretation of $\Delta f/f$. One laboratory has clear information how to interpret the measured deviation by given: $f = f_{\text{nom}} \cdot (1 + \Delta f/f)$ where $f_{\text{nom}} = 10 \text{ MHz}$. This gives for a $\Delta f/f = -2.40 \cdot 10^{-10} \text{ Hz/Hz}$ with a nominal frequency of 10 MHz a frequency of 9.999999976 MHz. While other laboratories state a $\Delta f/f = +2.30 \cdot 10^{-10} \text{ Hz/Hz}$ with a nominal frequency of 10 MHz but have a frequency of 9.999999977 Hz while not explaining the definition of deviation calculation. Some laboratories give additional the error in Hz. Also here presented the frequency on the certificate like 9.9999999737 MHz and has an error of +2.6 mHz. The general definition of calculating the absolute error, is the difference between the measured value and the real value. That would be $9.9999999737 \text{ MHz} - 10 \text{ MHz} = -2.63 \text{ Hz}$. Also, here the used definition is not given on the certificate. This makes it difficult to interpret the measurement results. Furthermore, on a certificate there was no difference between the decimal point and digit grouping symbol, giving a frequency of 9.999.999.998.341MHz That is becoming in the X-ray region. If we change the sign of the 'Lab 1' their En score would be 1.01

V. CONCLUSION

All but one laboratory agrees with the reference value for the expanded measurement uncertainty. The stability of the traveling standard was adequate for this comparison. The comparison is a success and can be used to fill EN-ISO/IEC 17025:2017 § 7.2.2.1e, § 7.7.2. Strongly recommended is; to give the definition how the results can be interpreted when giving the results in absolute error, or relative deviation. This following EN-ISO/IEC 17025:2017 § 7.8.1.2: *The results shall be provided accurately, clearly, unambiguously and objectively, usually in a report, and shall include all the information agreed with the customer and necessary for the interpretation of the results and all information required by the method used.*