A NEW SYNCHRONIZED MINIATURE RUBIDIUM OSCILLATOR WITH AUTO-ADAPTIVE DISCIPLINING FILTER.

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1.ABSTRACT

A new Rubidium line (SRO) with extended PPS (Pulse Per Second) facilities was developed. This new product can not only measure the position of a PPS Ref, but it can also adjust its frequency to be aligned to this PPS Ref. Thanks to an analog ns phase comparator, a low noise PPS Ref signal can be tracked with a phase error limited to a few ns. In the opposite, a noisy but stable signal can be tracked. In this case, the phase error is higher, but the frequency of the oscillator is gently adjusted to the one of the PPS Ref. This frequency is stored in EEPROM memory. In case the PPS Ref disappear, the Rb oscillator will continue to keep its frequency many days with a phase error less than a few µs. This make it ideal to track a PPS signal from a GPS receiver or other. The function of the auto-adaptive filter is to make things easy to the user. The high resolution ns phase comparator is used to calculate the Allan Variance of the PPS Ref signal. Then the time constant of the tracking loop is adjusted in consequence.
Today, this device is able to track a PPS Ref signal with a RMS noise up to 10 ns, without intervention through the serial port.

2.KEYWORDS

Rubidium oscillator, GPS, Glonass, Galileo, tracking loop.

Fig.1 SRO-100 picture.

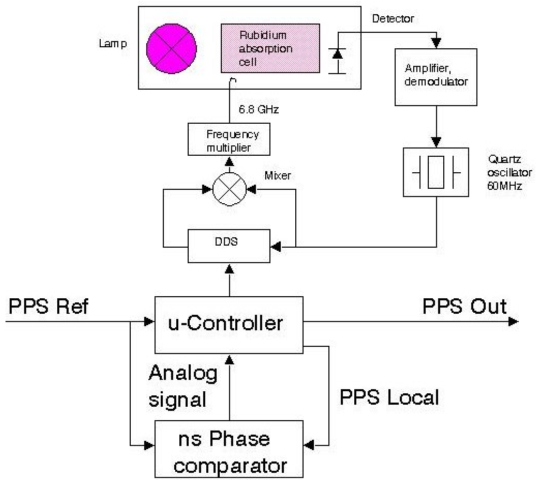

Fig.2 The disciplining filter inside the SRO-100.

3.DISCIPLINING ALGORITHM

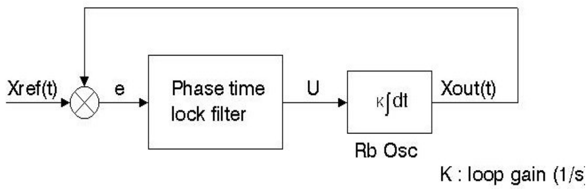

Fig. 3 The phase frequency loop in time domain.

As filter, we choose the simple discrete form of the PI regulator:

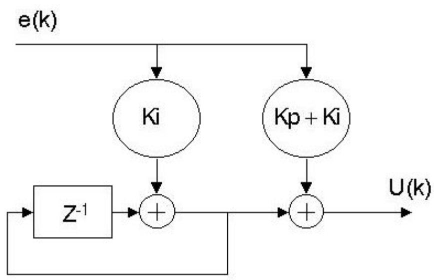

Fig. 4 Structure of a PI regulator.

Belong theory [1], p.228, and with the help of the equivalent analog filter theory, we have:

$$Ki = \frac{T_S}{K \cdot T_L{}^2} \quad \text{and} \quad Kp = \left(\frac{2 \cdot m \cdot T_L}{T_S} - \frac{1}{2} \right) \cdot Ki$$

T_S : filter samplig period. T_L : loop time constant. m : dumping factor = 2.

The term ½ can be neglected and Kp become:

$$Kp = \frac{2 \cdot m}{K \cdot T_L}$$

3.1 The loop time constant

And now, how to choose T_L ? If it is too high, the phase error come big, if it is too low, the filtering is bad.
We admit it as optimum when the input noise have the same magnitude as the noise of the clock itself.

—·—·—·— 10 ns rms input reference noise (GPS).
-·-·-·-·- SRO phase comparator stability.
- - - - - - - - SRO short term satbility with +/- 3 °C temp. Var.

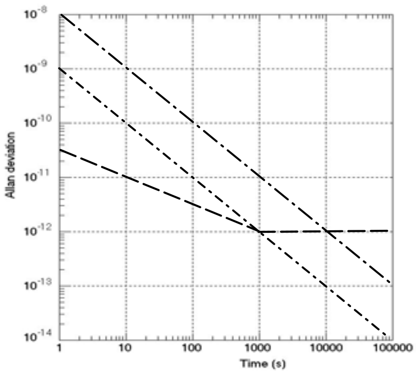

Fig. 5 Typical stability data.

T_L is optimum when the line in τ^{-1} of the input noise cross the line in $\tau^{-1/2}$ of the SRO short term stability.

$$\sigma_{yRb}(1s) \cdot \tau^{-1/2} = \sigma_{y\,\mathrm{Re}\,f}(1s) \cdot \tau^{-1/2} \quad \text{and}$$

$$T_{L1} = \left(\frac{\sigma_{y\,\mathrm{Re}\,f}(1s)}{\sigma_{yRb}(1s)} \right)^2$$

Unfortunately, temperature variations have an influence on long term stability of a industrial Rb clock like the SRO. The flat portion of the Allan deviation is higher. To consider that, we introduce:

$$\sigma_{yRb\theta} = \sigma_{y\,\mathrm{Re}\,f}(1s) \cdot \tau^{-1} \quad \text{and}$$

$$T_{L2} = \frac{\sigma_{y\,\mathrm{Re}\,f}(1s)}{\sigma_{yRb\theta}}$$

In practice, the u-Controller choose the lowest value between T_{L1} and T_{L2}.

4. AUTO-ADAPTIVE TIME CONSTANT TEST

A noisy PPS Ref is generated by a device consisting in a synthesizer synchronized to the 10 MHz of the maser and a adequate divider.
The synthesizer is modulated in phase by a random sequence..

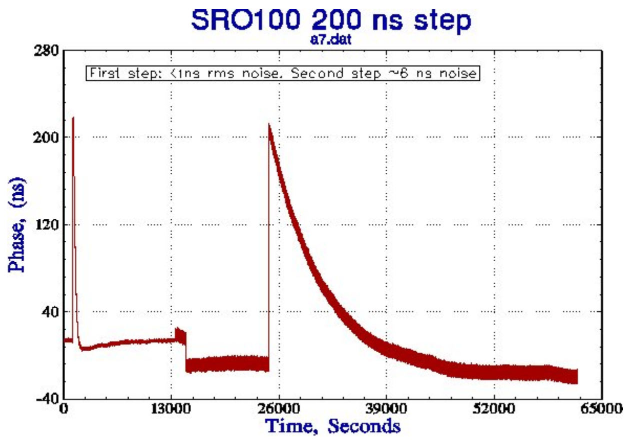

Fig. 6 Step response without/with REF noise.

5.TYPICAL PPS Ref OF GPS RECEIVER

The PPS Ref stability of a Motorola UT+ OnCore and a Conexant receiver was measured by comparaison to a hydrogen maser:H-MASER EFOS-C , from Observatory of Neuchâtel.

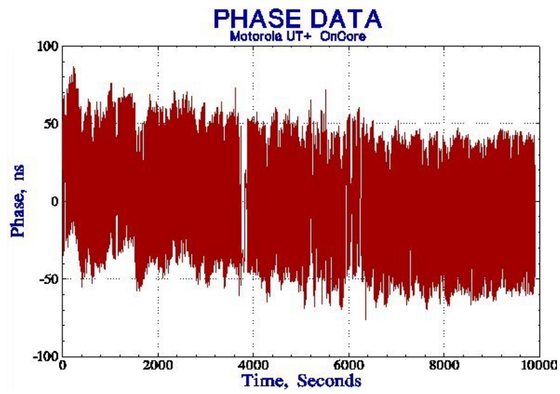

Fig. 7 PPS noise of Motorola GPS UT+ OnCore receiver vs TNT maser.

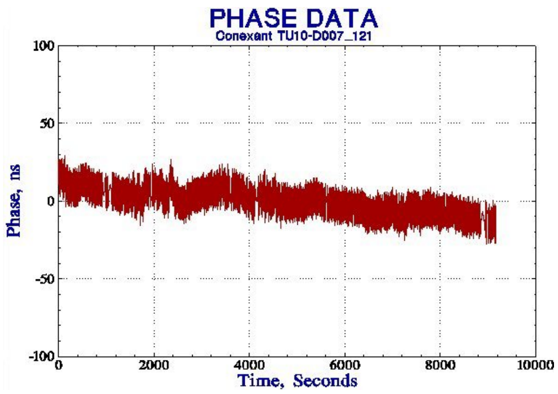

Fig.8 PPS noise of Conexant GPS receiver vs TNT maser.

The signal on the Motorola receiver looks really bad. In fact, it's possible to remove partially the noise by subtracting the negative sawtooth. The command is @@En.., Time RAIM status message. But that is not the goal of our simple device. The slope of both the curves is due to the frequency offset of the maser.

6.SHORT TERM STABILITY OF A SRO IN FREE-RUN AND UNDER TRACKING

The phase stability was measured by comparaison of the 10MHz output of the SRO to the 10MHz output of the maser. The phase comparator was a Picotime produced by TNT. The tests were done in a not air-conditioned lab.

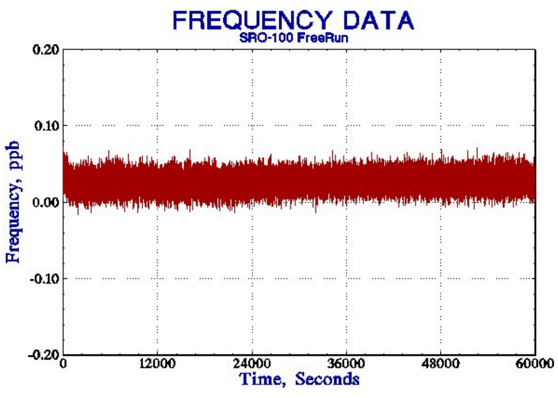

Fig. 9 Frequency stability in free-run mode.. Raw data.

After computation of Allan Deviation :

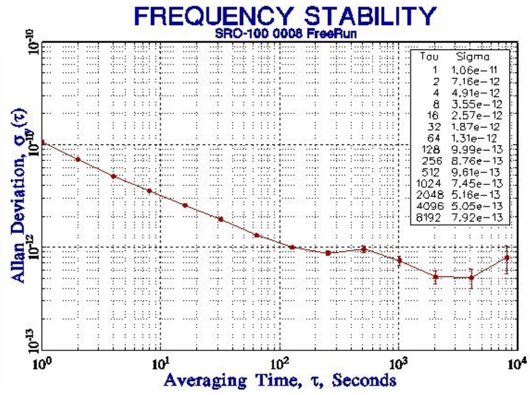

Fig. 10 Frequency stability in free-run mode.

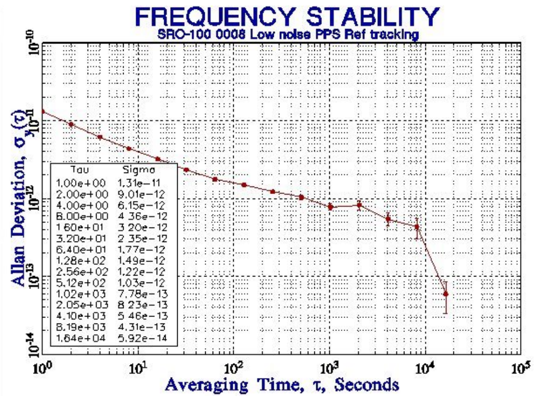

Fig. 11 Frequency stability when tracked by the low noise PPS Ref from the maser.

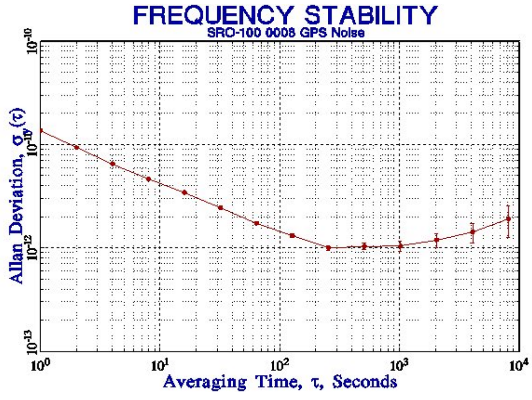

Fig. 12 Frequency stability when tracked by the PPS Ref form the Conexant receiver.

This figures shows that the auto-adaptive filter don't bring supplementary noise. The behavior of the different Allan Deviations after 1000s is only due to thermal fluctuations in the lab during the tests. When tracking a low noise PPS Ref, the phase error was less than a few ns . When tracking the PPS Ref from the Conexant receiver, the phase error was staying in something like +/- 100 ns.

7.HOLD-OVER CHARACTERISTICS

A SRO was let during some days in a oven tracking a PPS Ref from the maser. Then the SRO was put to free run mode by sending a command through the serial port.
After that, the phase time fluctuations were recorded.

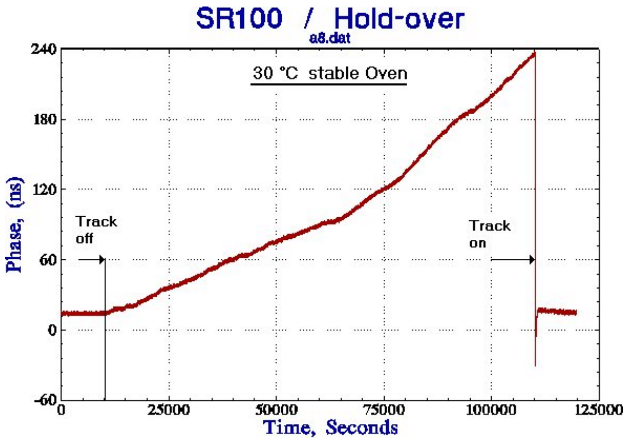

Fig. 13 Hold-over potential of the SRO.

The results looks incredible good for an industrial Rb clock. But of course the conditions of the test are not representative of the reality. First an SRO will never be put in a oven and second it will never have a good master like a maser, during days, to put the exact value of the frequency in the EEPROM.

8.CONCLUSION

It is now possible to have at low cost an independent frequency standard in phase with the "atomic world standard" with uncommon good holdover capacities.
In addition, thanks to its adaptive behavior, this "time machine" just has to be plugged-in and doesn't need any adjustment made by hard or software.

9. REFERENCES

[1] Hansruedi Bühler, Réglages échantillonnés, Presses polytechniques romandes 1982.