GPS DISCIPLINED OSCILLATORS, LONG TERM RESULTS

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ABSTRACT

Two different kinds of GPS disciplined oscillators, Datum model 9390-6000 and HP 58503A, have been studied during years 1998…2001 at MIKES (National Standards Laboratory of Finland). Stability properties of five devices were measured by using a HP 5071 Caesium frequency standard as the master clock. In the short term stability measurements the Datum 8040 rubidium oscillator without the GPS timing signal was utilised as a reference. The results show that the performance gap between the controlled OCXOs and rubidiums is quite narrow, which suggests the use of OCXOs due to their longer life-span.

1. INTRODUCTION

GPS disciplined oscillators are commonly used to replace Cs-atomic clocks due to the longer life-time, lower price and maintenance costs. Assuming that European Galileo satellite navigation system will be advanced, the interest to use oscillators locked to satellite signals will grow.

One interesting question is the type of controlled oscillator, OCXO or rubidium? OCXOs' benefit is the long life-time (20..40 years) compared to that of the compact rubidium one (5..10 years). The short-term (<1 h) noise level of the GPS-signal ruins easily the good short-term stability of above mentioned oscillators, depending on control algorithm. A rubidium clock allows a longer integration time up to a few hours.

The studied GPS disciplined oscillators are shown in Table I. First measurements have been carried out during the year 1998 when the SA prosperity of the GPS was actived.

Datum device exploits both the rubidium and OXCO as a master oscillator whereas HP device applies OXCO only. In the short-term stability measurements the Datum 8040 rubidium oscillator without the GPS timing signal was utilised as a reference.

Table I: Studied disciplined oscillators

Device	Local osc. type
Datum 9390-6000	GPS/rubidium
Datum 9390-6000	GPS/rubidium
Datum 9390-6000	GPS/OXCO
Datum 8040	rubidium
HP 58503A	GPS/OXCO

2. METHODS

MIKES has an automatic time interval measurement system /1/ into which the oscillators under study were connected for several weeks in turn. Time interval between successive measurements is 600 s instead of common 1 s which deteriorates short term Allan variance results. The long term stability of the master clock, HP 5071 Cs, is ensured by comparison with several GPS-receivers of MIKES. Allan FDEVs and TDEVs were calculated from the measured phase data by applying a modified Allan variance –method to data to remove the second order effects. To reveal possible periodic fluctuations, MEM spectra was calculated from phase observations.

Spectral presentations were calculated by the Maximum Entropy Method spectral analysis. The MEM offers a tool to observe and to reveal the noise process of the system from the slopes of spectral curves and periodic fluctuations and actions as control changes from the relative spectral peaks.

Analyses employ the autoregressive modelling by determining the values of the coefficients in the time series of x_k of the equation of

$$x_t = \mathbf{A_t}\, x_k + n_t = a_1 x_{t-1} + a_2 x_{t-2} + \ldots + a_M x_{t-M} + n_t$$

where

x_t is the predicted value,
$\mathbf{A_t}$ is the coefficient matrix,

x_k	are measured values, $x_k = (x_{t-1}, x_{t-2},\ldots, x_{t-M})^T$ (T refers to transpose),
a_k	are the prediction error filter coefficients, $a_k = (a_1, a_2,\ldots, a_M)$ and
M	is the length of the prediction error filter
n_t	is a white noise process of x_t

The theoretical way to calculate the values for the a_k:s are determined by maximising the entropy (rate) of the information for the time series according to formula:

$$H = \int_{-\infty}^{\infty} p(x)\log_2(p(x))dx$$

where p(x) is the probability distribution of x. In principle, the more surprising information is concerned the higher entropy is achieved.

In practice, the coefficients of a_k are calculated applying e.g. the Levinson algorithm to the measured values and the same a_k:s are used to compute the relative MEM power spectrum.

Spectral analysis utilizes the formula:

$$S(f) = \frac{N_0}{2f_N\left|1 - \sum_{k=1}^{M} a_k z^{-k}\right|^2}$$

$$z = e^{j\omega\frac{1}{N-1}T}, \qquad \omega = 2\pi f$$

S(f)	is the power spectrum of the time series,
N_0	is the power of the noise process (white noise),
f_N	is the Nyquist frequency,
a_k	are the prediction error filter coefficients,
f	is frequency,
T	is the sampling interval and
N	is the number of measured values

Some advantages of the MEM spectral analysis are:

- no pre-features are assumed from the signal outside of the measurement interval,
- the sin(x)/x -effect does not exist,
- the number of samples can be whatever
- etc.

In addition, the drifts of the oscillators without GPS signal were monitored.

3. RESULTS AND DISCUSSION

Fig. 1 shows the stability of studied rubidium's. The uppermost curve (year 1998) presents Allan deviation of the oldest Datum device during the SA as active. The next curve (year 2001) is that of a new Datum one. The shapes of curves are the same, the difference is probably due to the SA. The last curve (year 2001) is as a reference since the Datum rubidium oscillator in question has no GPS inside.

According to this curve, a simple rubidium oscillator starts to drift significantly after integration time of $2{\cdot}10^4$ s (or 5 hours). At shorter time intervals, disciplined oscillators cannot be the best due to interferences caused by the control algorithm, as shown by the corresponding curves. After about one day ($1{\cdot}10^5$ s) integration, disciplined oscillators are superior to plain rubidium ones.

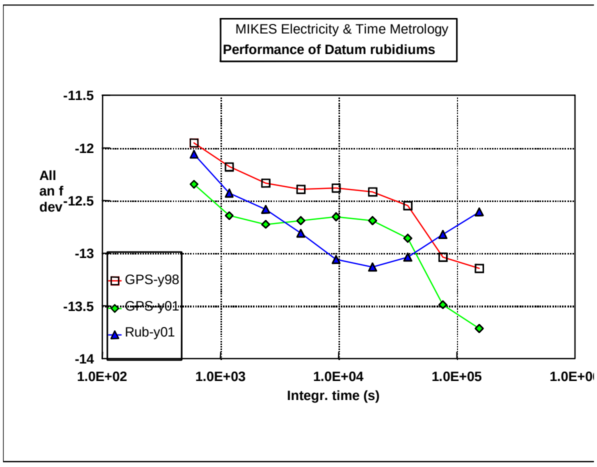

Fig. 1. Allan deviations of rubidium oscillators.

Fig. 2 shows the stability of studied disciplined OCXOs. Three uppermost curves (years 99, 00 and 01) present Allan deviation of the same HP unit. The short-term (< $1{\cdot}10^4$ s) seem to differ surprisingly much, even in one decade. We have no idea why. Maybe, the OCXO has been quite a "fresh" one in the first measurements (1999) or, maybe, e.g. the satellite constellation has been changed! The last results date from the times of the Afghanistan war.

The short-term stability of the Datum unit seems to be best, the long-term stability's seem to be about the same.

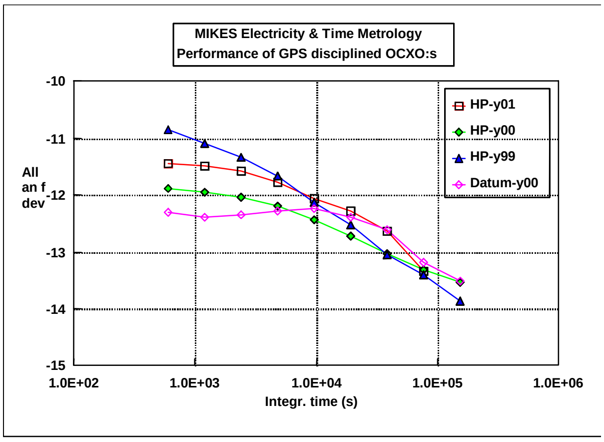

Fig. 2. Allan deviations of the disciplined OCXOs.

In Fig. 3 there is, finally, compared the "best" OCXO to the best rubidium one. The difference is at maximum between 2000 s and 30000 s and lower elsewhere. The short-term (<1000 s) and long-term (> 1 day) stabilities seem to be about the same. According to our opinion, the observed difference 1:3 (or 0.5 in log scale) is surprisingly low and probably reflects recent improvements of crystal /2/ oscillators.

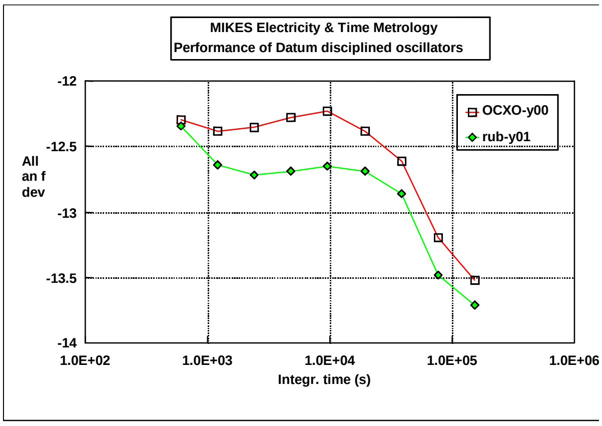

Fig. 3. Comparison of the OCXO and rubidium oscillators.

From the results, it can be deduced that the short-term (from $1{\cdot}10^3$ to $3{\cdot}10^4$ s) performance of the devices with rubidium master oscillator is much better than those of OXCOs. The long-term performances seem to be nearly equal.

The lifetime of the spectral lamps in the compact rubidium oscillators appears to be short which is a harmful problem. Our experience includes about a half-dozen Efratom FRS-CE units, achieving typically about a 5 years lifespan.

By the spectral analysis was found out that the spectral behaviour varies much between the measured values of different equipment's. There are some effects which has to be interpreted as abnormal in the conventionally known features of frequency standards. However, since they exist in some processes (and both in the HP's and Datum's devices) about the same way, they should be taken seriously. The reason of them can be environmental affects but this is not proved, yet. One of these phenomena is the existence of the components of the power law of the rather high orders. In general, the orders of one or two are expected to be significant.

Some other interesting results were achieved. For example, there are two assembles of data. In first one no statistically significant spectral peaks were observed and in the second one half of existing peaks were at the frequency band from 1 to 10 cycles per day. In the HP case, the noise power at low frequencies in the years of 00 and 01 was much lower than in the year of 99, at the higher frequencies the noise powers were about the same.
The long-term noise behaviour of the measurements assembles varied having the values of the slope of the power spectra from 0 to –60 dB / decade.

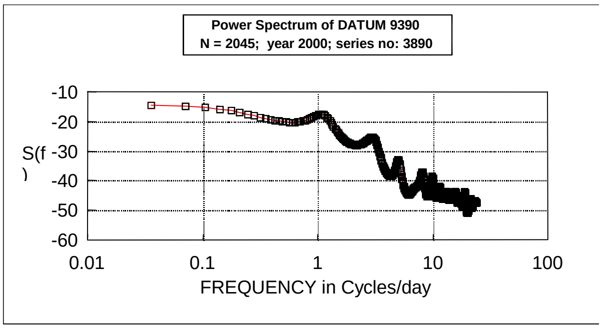

Fig. 4. Power Spectrum of the Datum OCXO/GPS.

Power Spetrum of the phase data of the Datum OCXO/GPS (see Fig. 4) reveals some peaks, which could be correlated with the OCXO control period and the daily variation. The spectrum of the HP58503A device is quite similar but the peaks are at different places. The corresponding frequency spectrum between 1 and 10 cycles per day is clearly the 1/f -type.

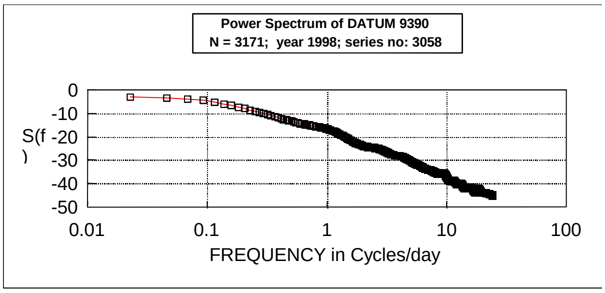

Fig. 5. Power spectrum of the Datum rubidium/GPS.

The power spetrum of the Datum rubidium/GPS is smoother and no statistically significant peaks can be find. The corresponding frequency spectrum between 1 and 10 cycles/day is in all cases of the 1/f -type.

4. CONCLUSIONS

All studied disciplined oscillators behaved well and were locked in less than 10 minutes to GPS-satellites (cold start) . The long-term (> 1 day) phase stability was excellent, typically 20 ns_{pp} but better than 50 $ns_{pp.}$ (daily average).

According to Allan FDEV spectra the frequency stability is better than $1 \cdot 10^{-11}$ at any time but improves quite fast to $1 \cdot 10^{-13}$ level at one day integration time. Naturally controlled rubidium oscillators are somewhat better than oxco's but difference seem to surprisingly small. This reflects improvements with oxco's whereas compact rubidium's suffers from limited lifespan.

Power spectral analyses revealed that e.g. the SA option of the GPS has disappeared and most of the peaks are created by the control actions or by environmental phenomena.

5. REFERENCES

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