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6th International Symposium “METROLOGY OF TIME AND SPACE”

FORMING RESERVED OUTPUT SIGNAL OF AN ATOMIC CLOCK ENSEMLE

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Motivation

Modern atomic clock ensemble etalons are required to produce continuous output signal

- ✓ long continuous measurements
- ✓ critical applications: communication with space stations, etc.

Requirements to reserving system:

- ✓ Failure of certain atomic clock must not lead to phase/frequency jumps of the output signal
- ✓ Designed system is desired to be full-automatic
- ✓ It is attractive to get physical signal possessing frequency stability of ensemble weighted average

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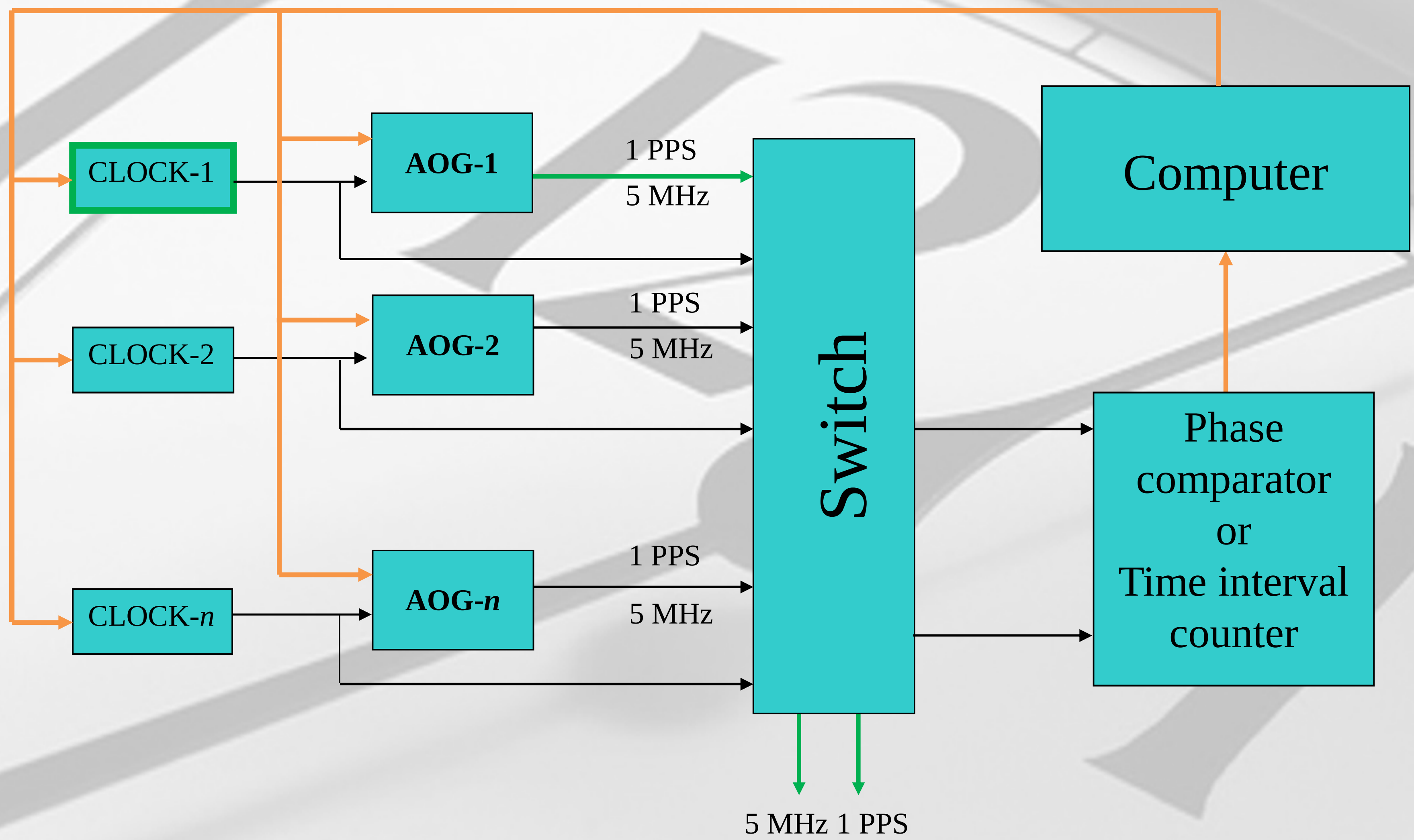
Standard approach to output signal reserving



Standard approach to output signal reserving

Disadvantages:

- Long time for input signal analysis and commutation
- Unavoidable phase/frequency shift during commutation
- System complexity

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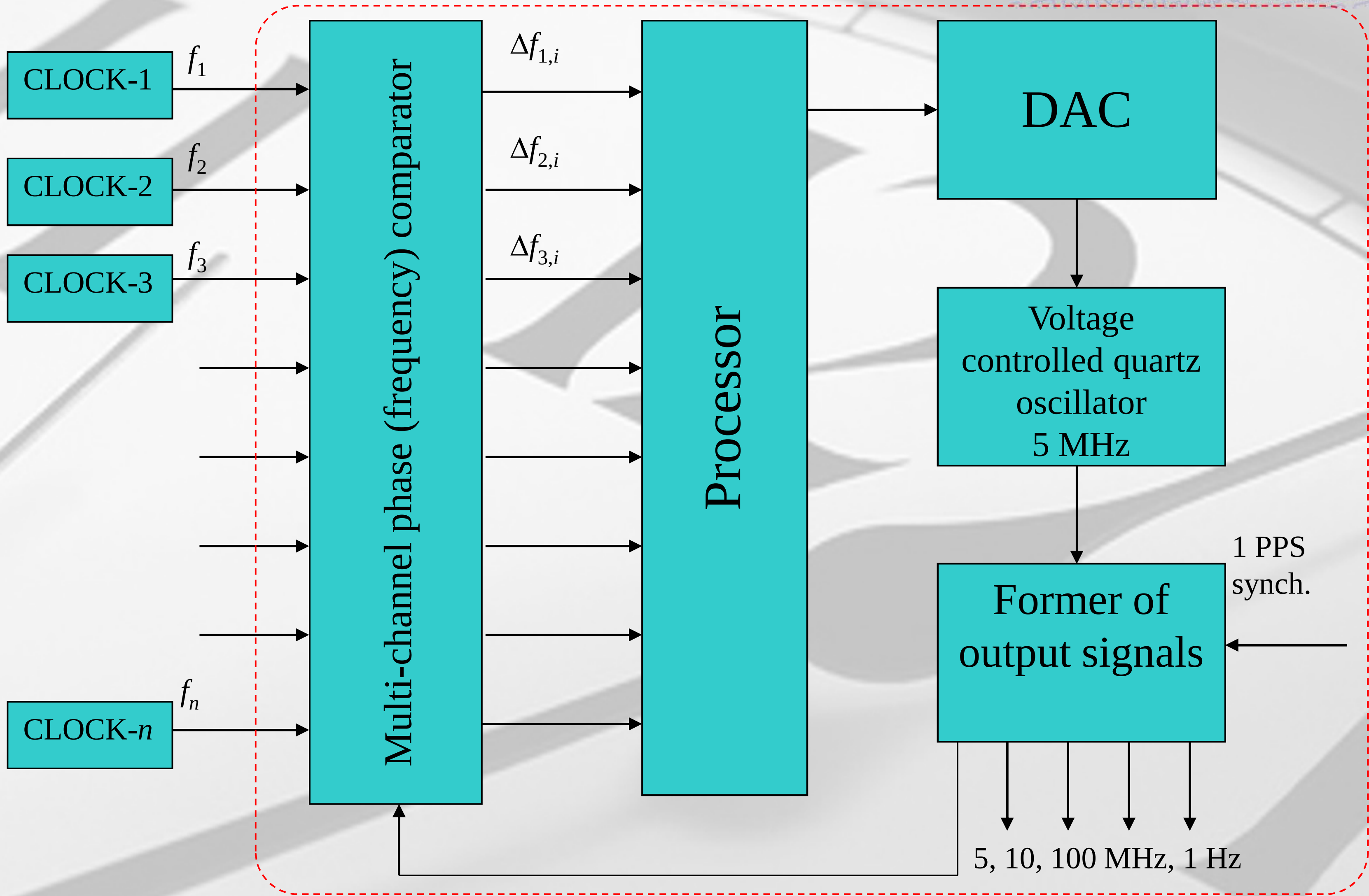
Alternative approach

Real-time atomic clock combiner VCH-317



Scheme for output signal reserving in atomic clock ensemble

Advantages:

- ✓ Fast detection and program detaching of failure signal
- ✓ No phase/frequency shifts due to attaching/detaching input signals
- ✓ Can be realized in one device and reserved additionally
- ✓ Frequency stability of output signal can be improved (it can be better than the stability of the best reference standard)

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PID-control algorithm for frequency stabilization

$$\mathrm{DAC}_{n+1} = \mathrm{DAC}_n + \Delta - k^i y_n - k^p (y_n - y_{n-1}) - k^d (y_n - 2y_{n-1} + y_{n-2})$$

$$y_n = \frac{1}{\tau}(x_n - x_{n-1})$$ – relative frequency difference

Δ – programmed frequency offset

Loop sample time τ = 10 ms

k^i, k^p, k^d are optimized ⟷ Introduced phase noise and AVAR are minimized

Output frequency calculation

$$f_{\mathrm{out}} = \delta + \nu t + \sum_{n=1}^{N} w_n^N f_n$$

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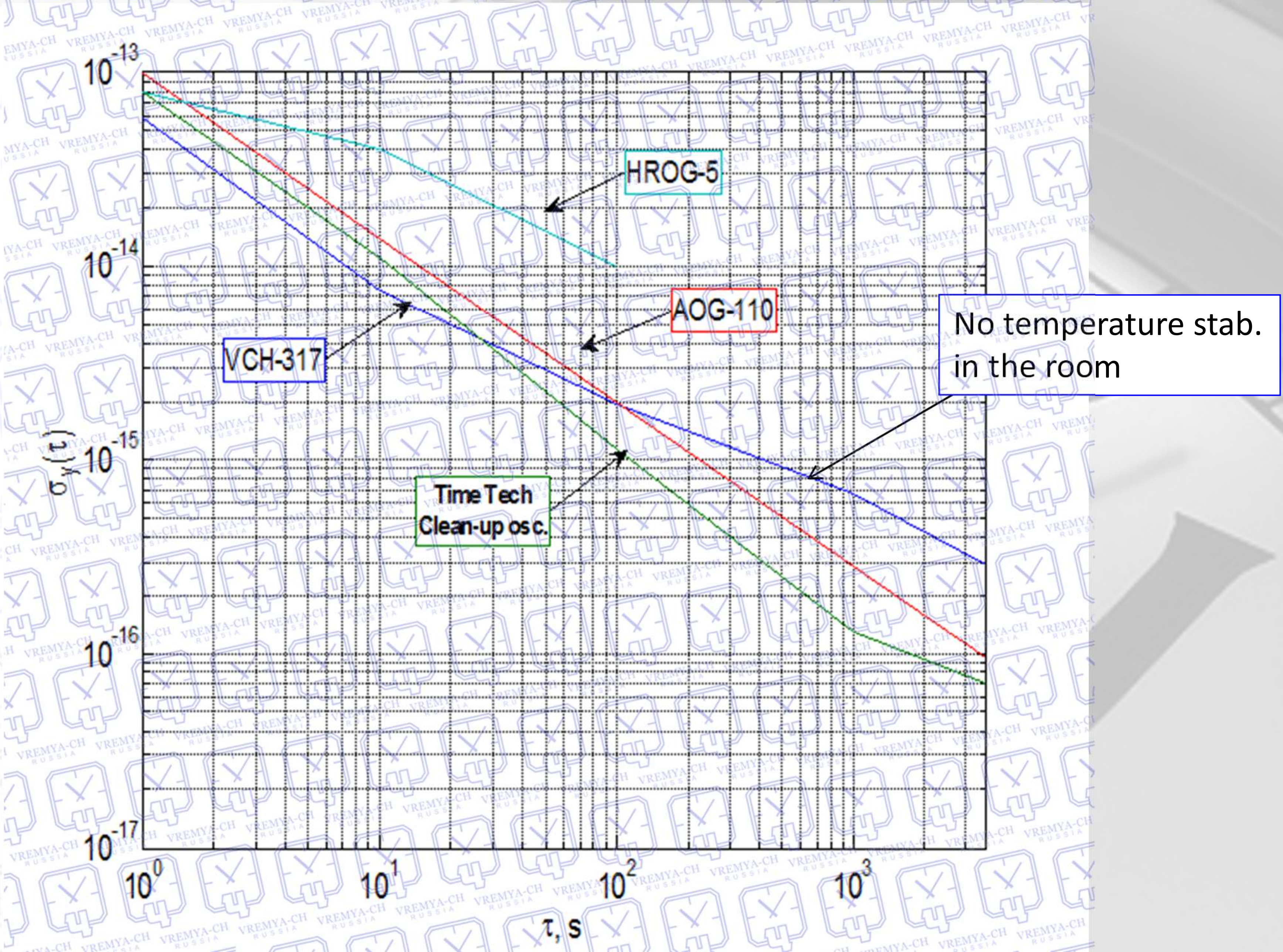
Frequency instability introduced by the system



No shifts in phase and frequency after adding/removing reference signal

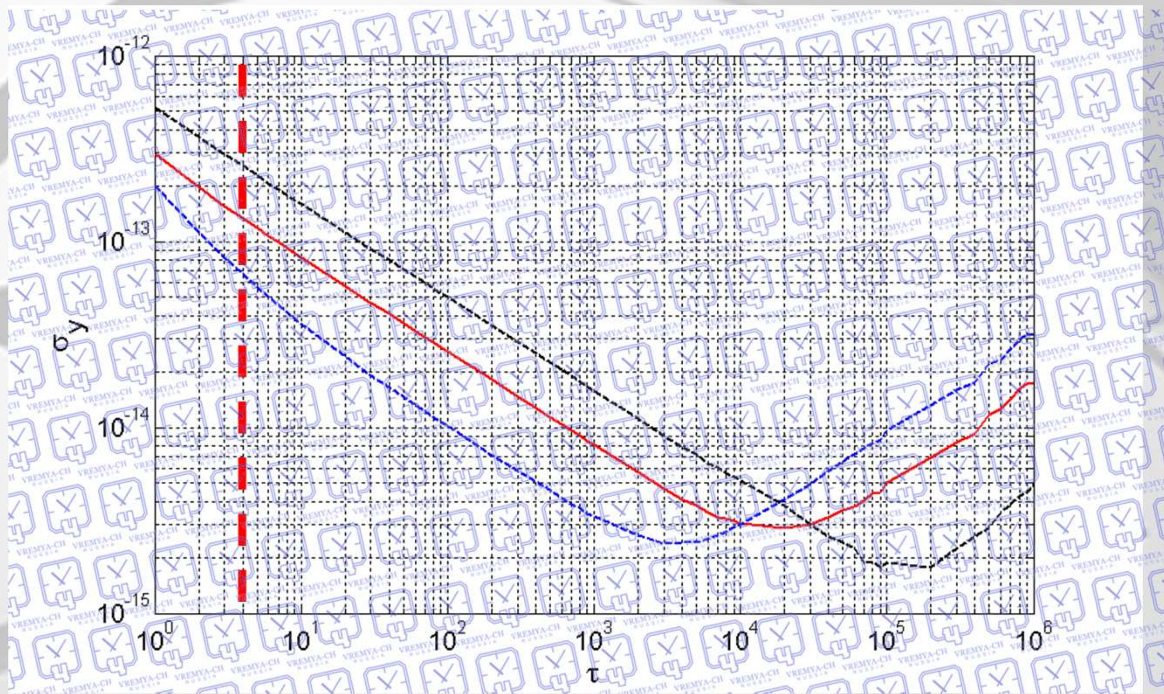
Frequency stability of the output signal

Optimal weights selection problem

$$f_{\text{out}} = \sum_{n=1}^{N} w_n f_n$$

$$\sigma_{\text{out}}^2 = \sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sigma_{317}^2 \to \min$$

$$w_i(\tau) = \frac{\sigma_i^{-2}(\tau)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tau)}$$



Output signal frequency instability is minimized for single averaging time only!

Possible solutions:

1) Virtual atomic time scale + control of auxiliary oscillator

2) Multi-scale control

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One-time-scale control algorithm:

$$\Delta U_k = -\sum_{n=1}^{N} w_n^S y_n^S$$

Two-time-scale control algorithm:

$$\Delta U_k = -\sum_{n=1}^{N} w_n^S \left(y_n^S - \sum_{m=1}^{N} w_m^L \left(y_n^L - y_m^L \right) \right)$$

Addition long averaging time estimation of frequency differences is required

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$$\Delta U_k = -\sum_{n=1}^{N} w_n^S \left(y_n^S - \sum_{m=1}^{N} w_m^L \left(y_n^L - y_m^L \right) \right)$$

Weights estimation for two-scale frequency control:

Short time:

$$w_n^S = \frac{\sigma_n^{-2}(\tau^S)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tau^S)}$$

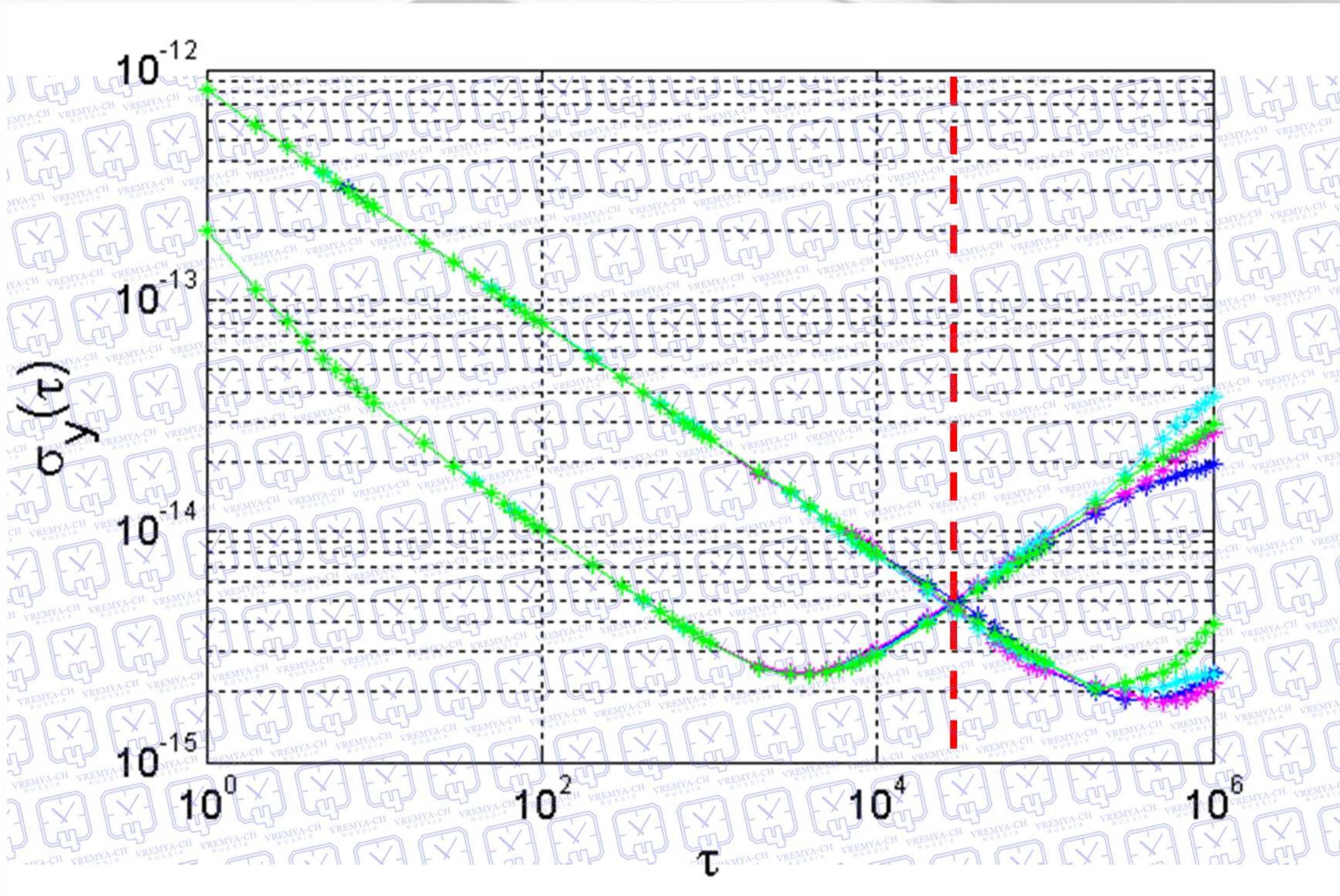
Long time:

$$w_n^L = \frac{\sigma_n^{-2}(\tilde{\tau}^L)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tilde{\tau}^L)}$$

Estimation of frequency stability of reference signals is needed

Modeling

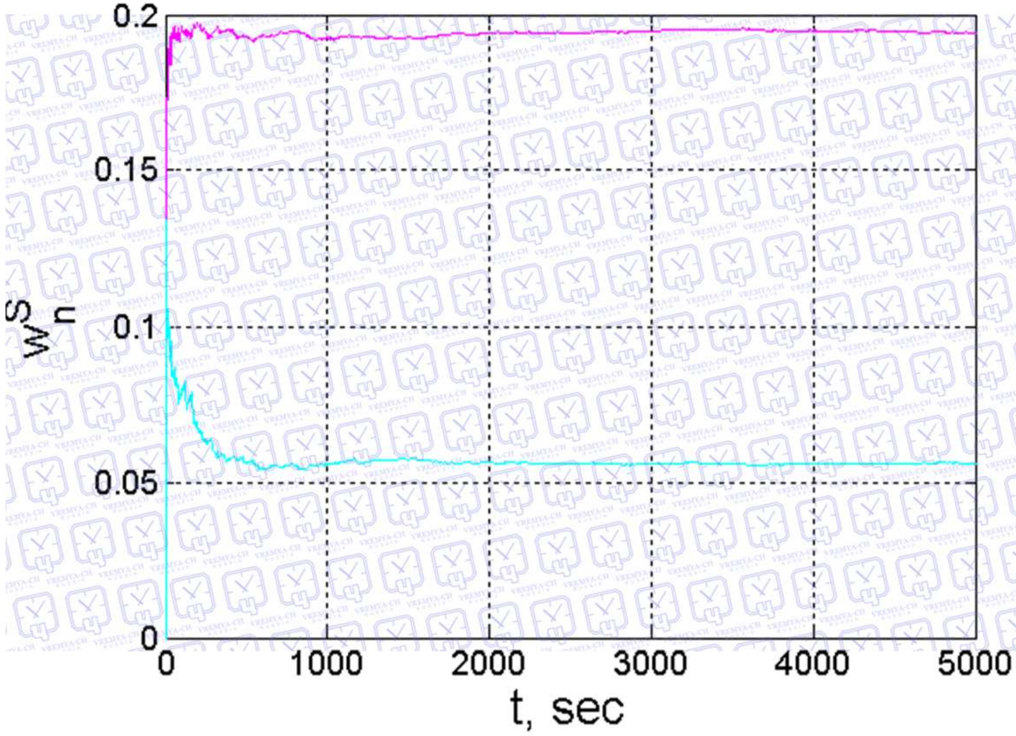
Two types of reference signals: 4 + 4



***τ*^{S} = 1 sec**

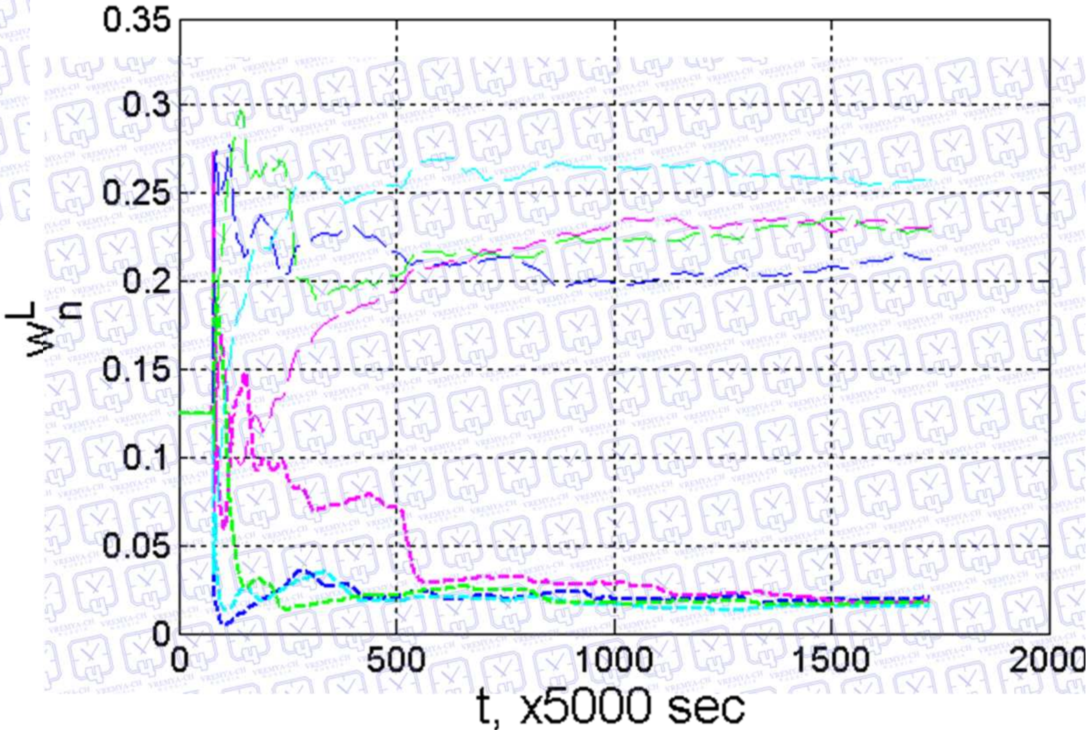
***τ*^{L} = 20000 sec**

Results of modeling. Dynamics of weights



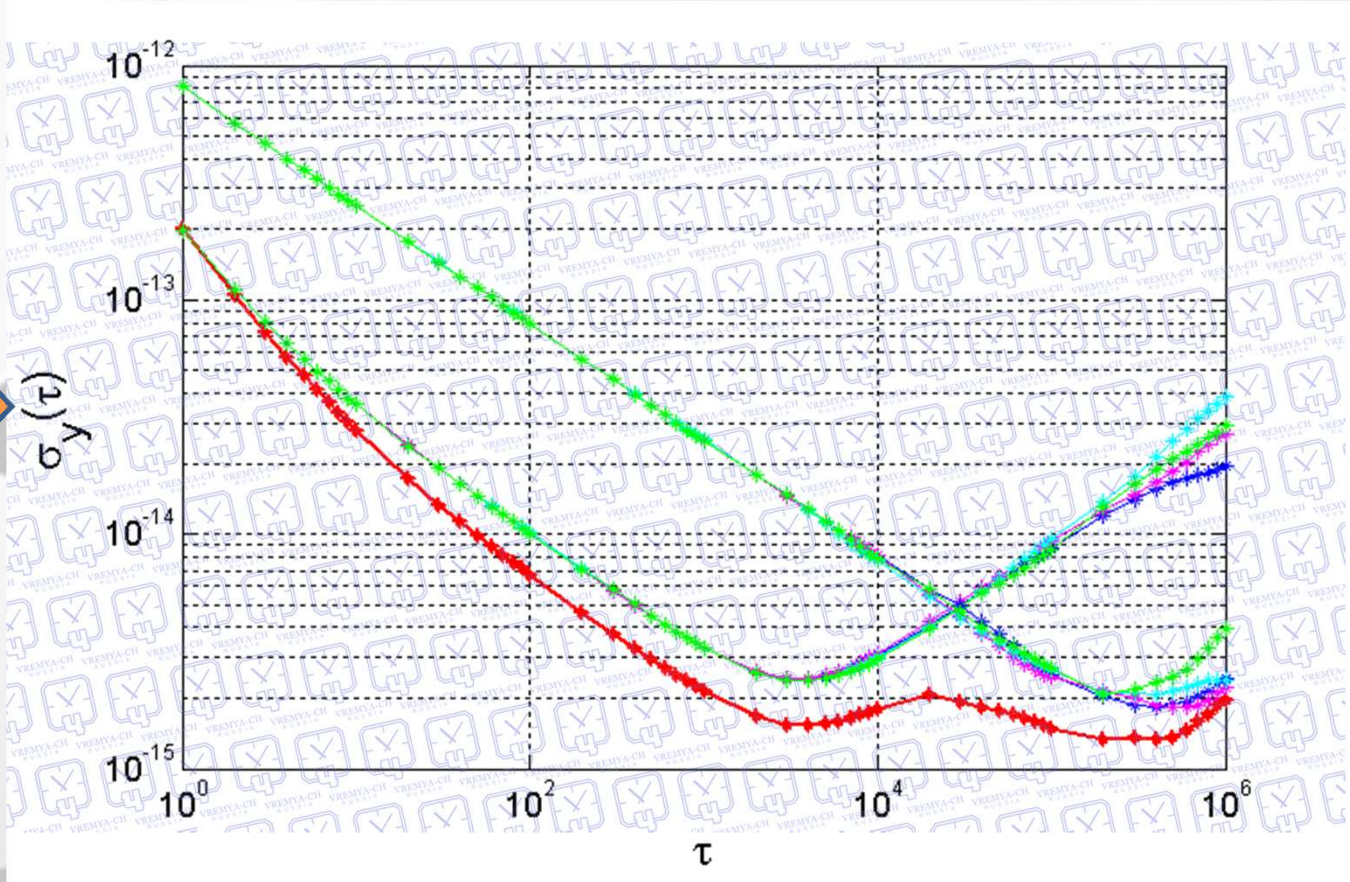
$$w_n^S = \frac{\sigma_n^{-2}(\tau^S)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tau^S)}$$

$$w_n^L = \frac{\sigma_n^{-2}(\tilde{\tau}^L)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tilde{\tau}^L)}$$



Results of modeling

Two-scale frequency control



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Summary

- ✓ **Atomic clock combiner system seems to be effective for output signal reserving (fast detection and exclusion of invalid reference signals, no phase/frequency jumps)**

- ✓ **Simple modification of the algorithm allows to obtain output signal frequency stability better than the best input signal has for all τ**

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