FORMING RESERVED OUTPUT SIGNAL OF AN ATOMIC CLOCK ENSEMBLE

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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
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
Alternative approach

Scheme for output signal reserving in atomic clock ensemble

- CLOCK-1, CLOCK-2, CLOCK-3, ..., CLOCK-n
- $f_1, f_2, f_3, \ldots, f_n$
- Δ$f_{1,i}, \Delta f_{2,i}, \Delta f_{3,i}, \ldots$
- Multi-channel phase (frequency) comparator
- Processor
- DAC
- Voltage controlled quartz oscillator 5 MHz
- Former of output signals
- 1 PPS synch.
- 5, 10, 100 MHz, 1 Hz

Real-time atomic clock combiner VCH-317
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)
PID-control algorithm for frequency stabilization

\[ DAC_{n+1} = DAC_n + \Delta - k^i y_n - k^p (y_n - y_{n-1}) - k^d (y_n - 2y_{n-1} + y_{n-2}) \]

\[ y_n = \frac{1}{\tau} (x_n - x_{n-1}) \quad - \quad \text{relative frequency difference} \]

\[ \Delta \quad - \quad \text{programmed frequency offset} \quad \text{Loop sample time } \tau = 10 \text{ ms} \]

\[ k^i, k^p, k^d \text{ are optimized} \quad \text{Introduced phase noise and AVAR are minimized} \]

Output frequency calculation

\[ f_{out} = \delta + \nu t + \sum_{n=1}^{N} w^n_N f_n \]
Frequency instability introduced by the system

No temperature stab. in the room
No shifts in phase and frequency after adding/removing reference signal
Optimal weights selection problem

\[ f_{out} = \sum_{n=1}^{N} w_n f_n \]

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

\[ \sigma_{out}^2 = \sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sigma_{317}^2 \rightarrow \min \]

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
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
\[ \Delta U_k = -\sum_{n=1}^{N} w^S_n \left( y^S_n - \sum_{m=1}^{N} w^L_m (y^L_n - y^L_m) \right) \]

Weights estimation for two-scale frequency control:

Short time:
\[ w^S_n = \frac{\sigma_n^{-2}(\tau^S)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tau^S)} \]

Long time:
\[ w^L_n = \frac{\sigma_n^{-2}(\tau^L)}{\sum_{k=1}^{N} \sigma_k^{-2}(\tau^L)} \]

Estimation of frequency stability of reference signals is needed.
Modeling

Two types of reference signals: $4 + 4$

$\tau^S = 1$ sec
$\tau^L = 20000$ sec
Results of modeling. Dynamics of weights

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

\[ w_n^L = \frac{\sigma_n^{-2}(\tau^L)}{N} \sum_{k=1}^{\tilde{\tau}^S} \sigma_k^{-2}(\tau^L) \]
Two-scale frequency control

Results of modeling
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 $\tau$. 
THANK YOU FOR YOUR ATTENTION!

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