Additional Talks – Virtual Workshop, March 30, 31 – April 1

The Time Processor: a New Platform for Next Generation Timescales

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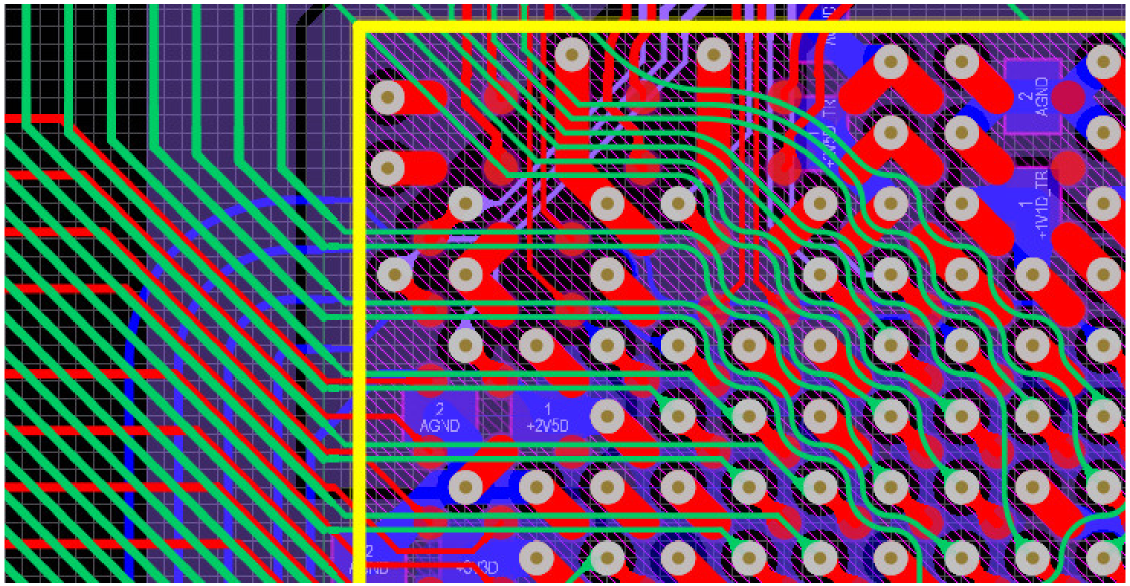
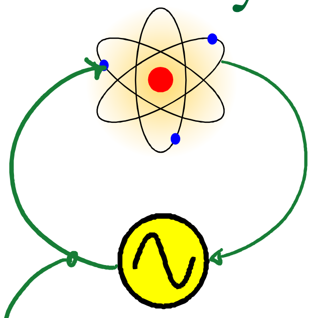


Why a timescale?

To answer the question: «**What time is it?**».

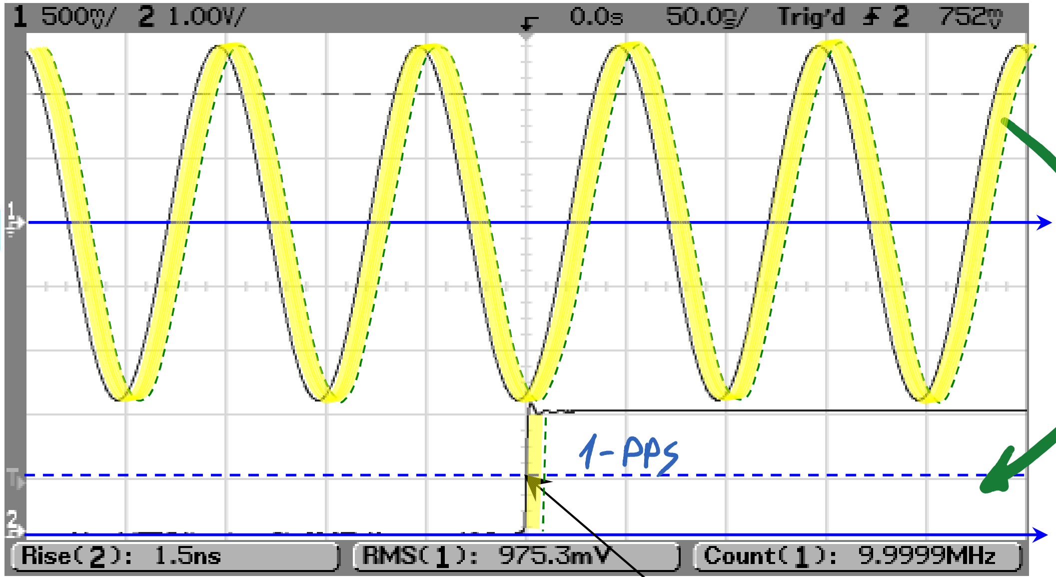


$$V_0 \cos\left[2\pi\nu_0\left(t + x(t)\right)\right]$$

phase

time

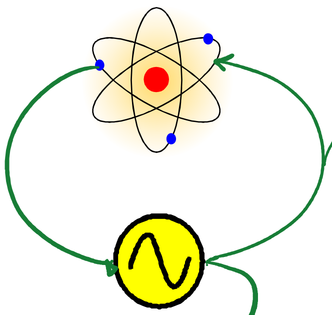
$$\sum_n \delta(t - n + x[n])$$



counter

30-03-2021_06-05-31 MDT

Phase and Time



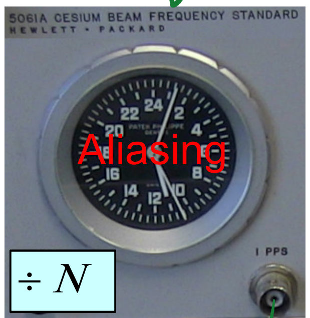
$$v(t) = V_0 \cos\left[2\pi\nu_0 t + \phi(t)\right]$$

$$= V_0 \cos\left[2\pi\nu_0 \left(t + \mathsf{x}(t)\right)\right]$$

$$\mathsf{x}(t) = \boxed{\mathsf{x}_0 + \Delta\mathsf{y}\cdot t + d\cdot\frac{t^2}{2}} + \boxed{\chi(t)}$$

Phase offset
Frequency offset
Frequency drift

Noise



$$\mathsf{x}[n] = \boxed{\mathsf{x}_0 + \Delta\mathsf{y}\cdot n + d\cdot\frac{n^2}{2}} + \boxed{\chi[n]}$$

$$v_{1\mathsf{PPS}}(t) = \sum_n \delta(t - n + \mathsf{x}[n])$$

$$S_\varphi(f) = \sum_{i\le -4}^{\ge 0} \mathsf{b}_i f^i$$

$$\varphi = 2\pi\nu_0 \mathsf{x}$$

$$S_\mathsf{x}(f) = \sum_{i\le -4}^{\ge 0} \mathsf{k}_i f^i$$

$$\mathsf{x}(t) = \frac{v(t)}{\mathrm{SR}}$$

$$S_\mathrm{V}(f) = \sum_{i\le -4}^{\ge 0} \mathrm{h}_i f^i$$

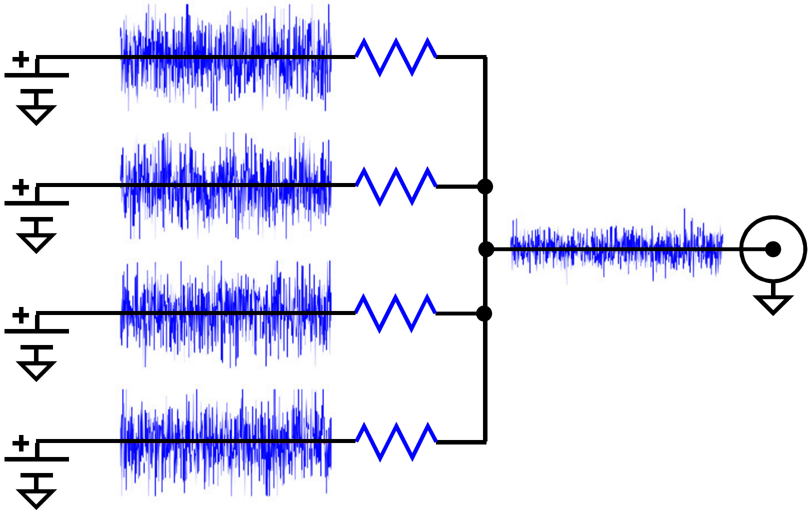
Claudio E. Calosso, Enrico Rubiola, "Phase Noise and Jitter in Digital Electronics", arXiv:1701.00094
Calosso C. E., Clivati C., Micalizio S., "Avoiding Aliasing in Allan Variance: an Application to Fiber Link Data Analysis" IEEE TUFFC, Vol. 633N. 4

What time is it?

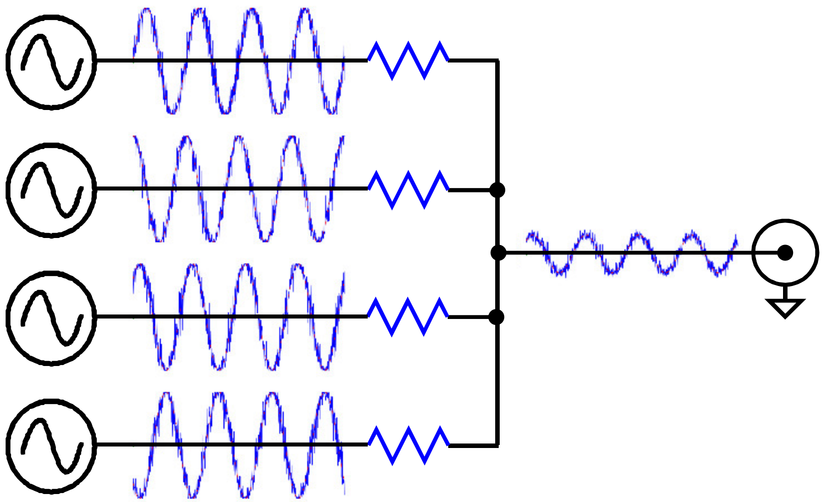
A man with a watch knows what time it is.
A man with two watches is never sure.

Segal's law

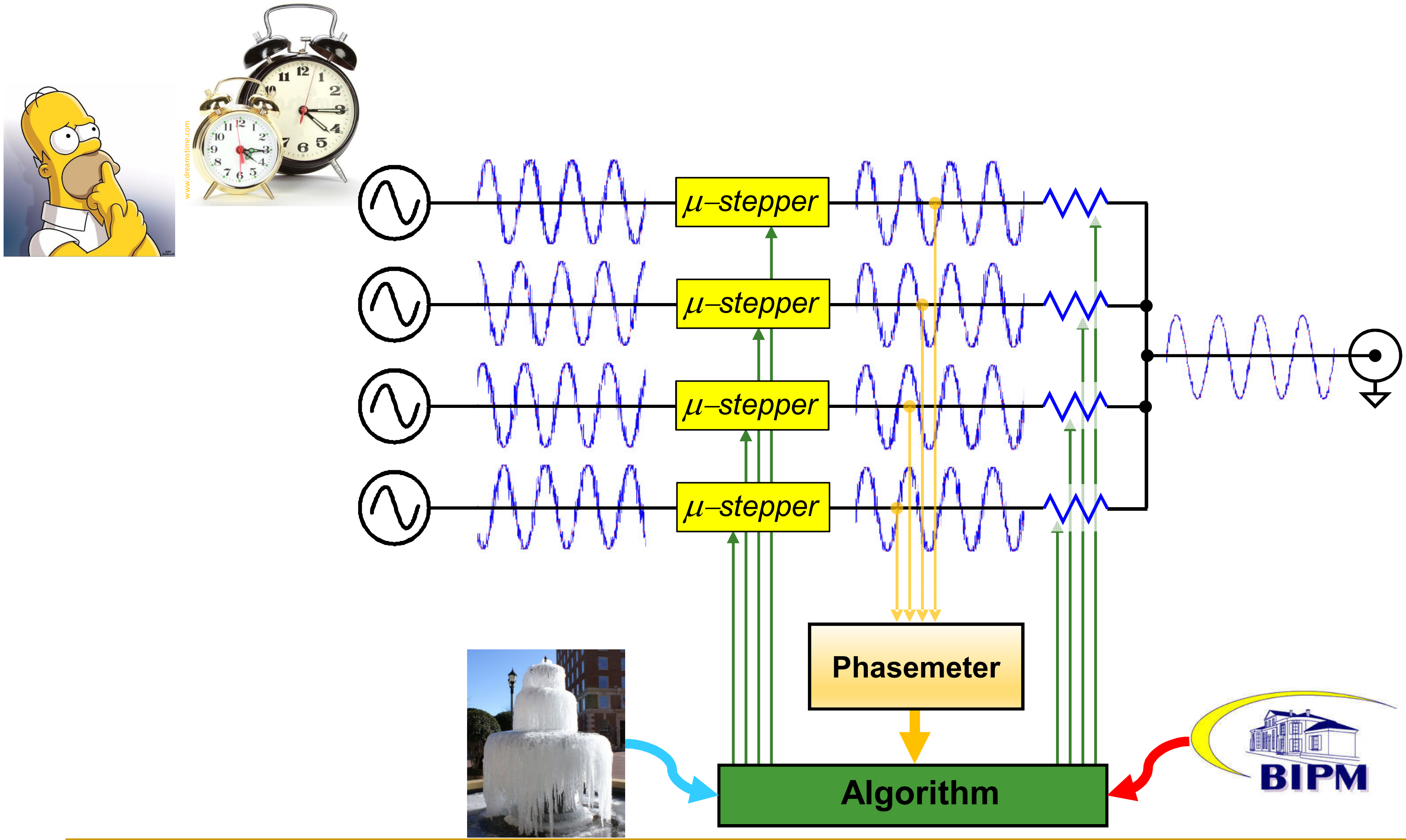
Composing voltages



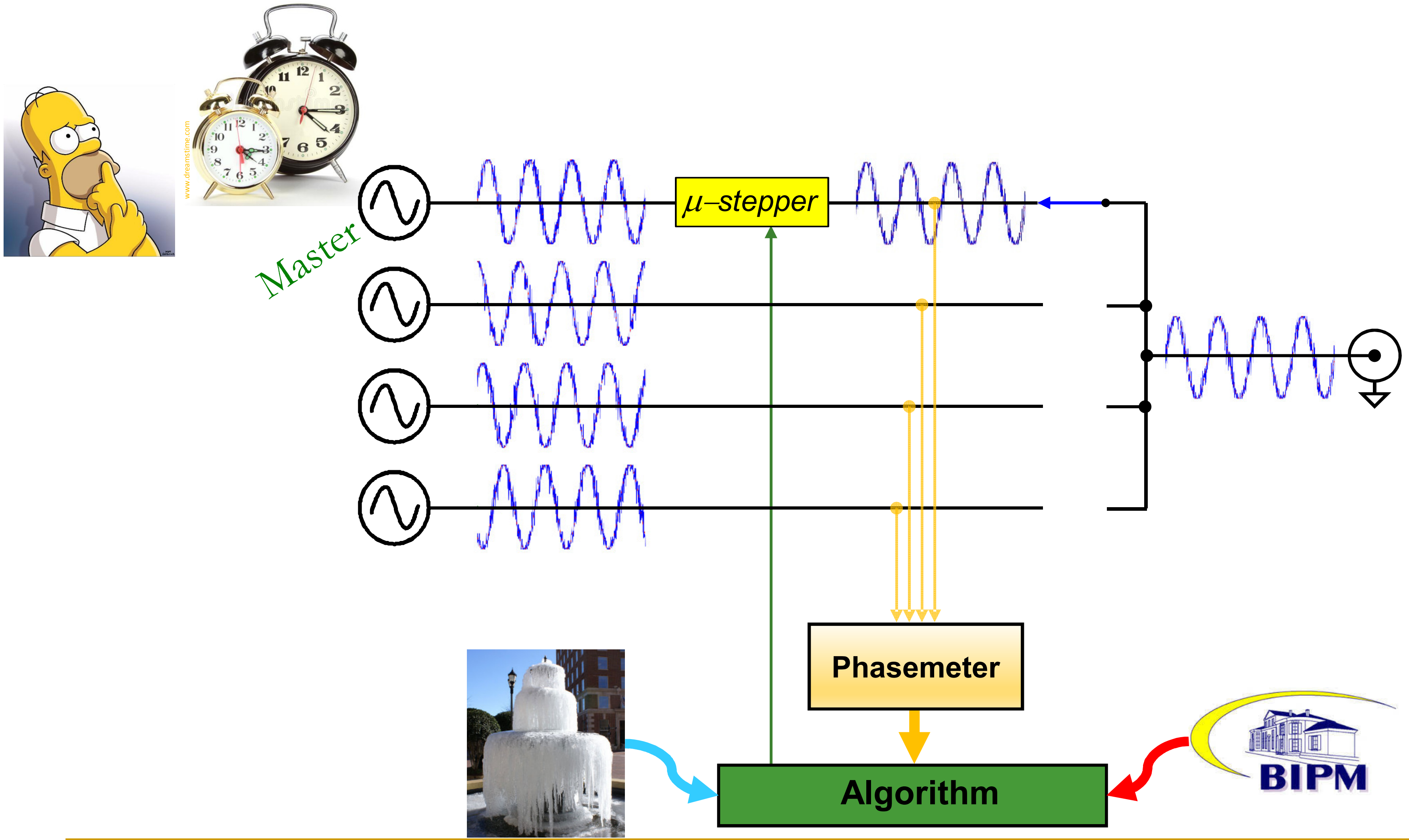
Composing sinusoids



Composing sinusoids

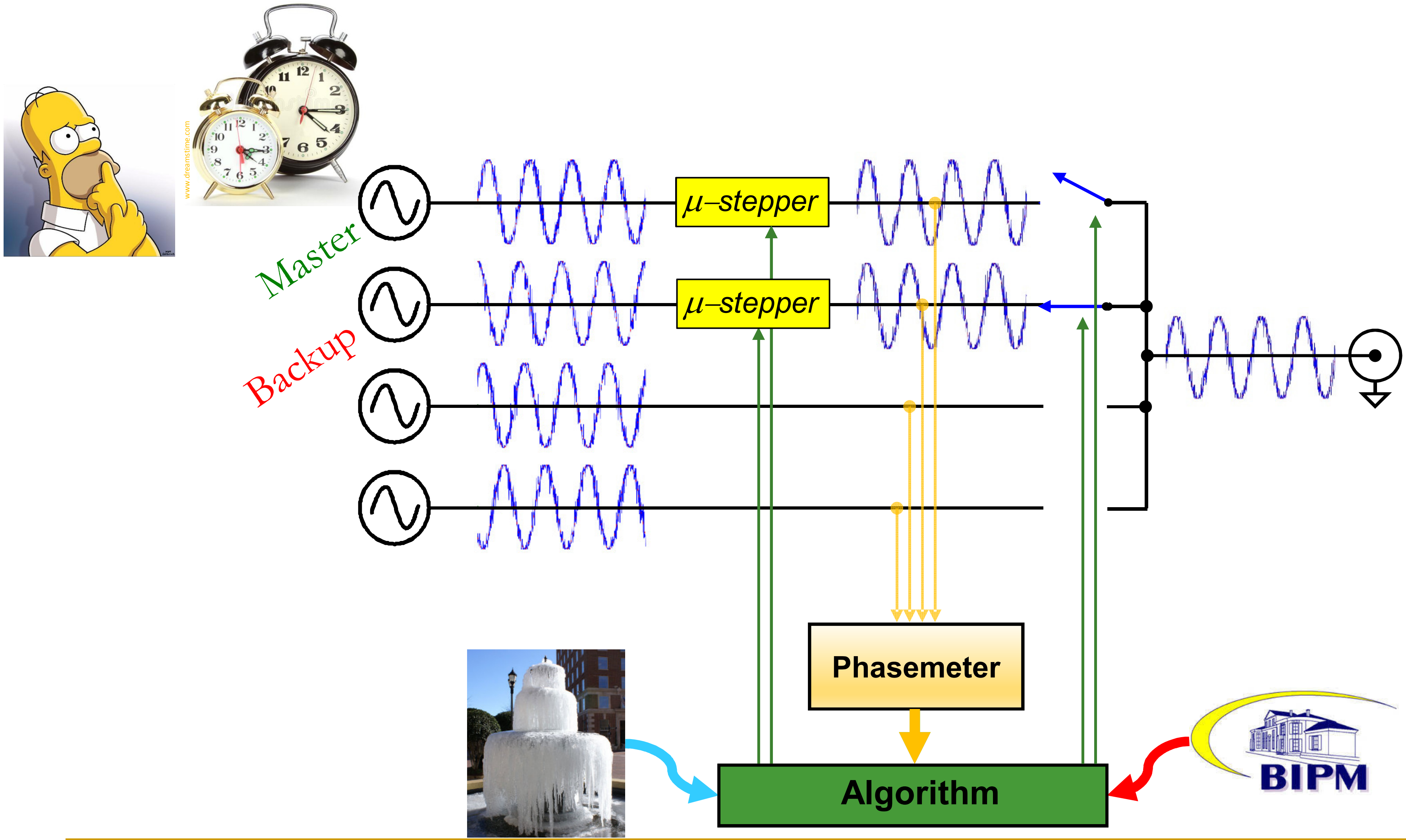


Master-clock solution



Ido, Tetsuya, Hachisu, Hidekazu, Nakagawa, Fumimaru, Hanado, Yuko, "Time Scale Steered by an Optical Clock," Proceedings of the 48th Annual Precise Time and Time Interval Systems and Applications Meeting, Monterey, California, January 2017, pp. 15-17.
https://doi.org/10.33012/2017.15009

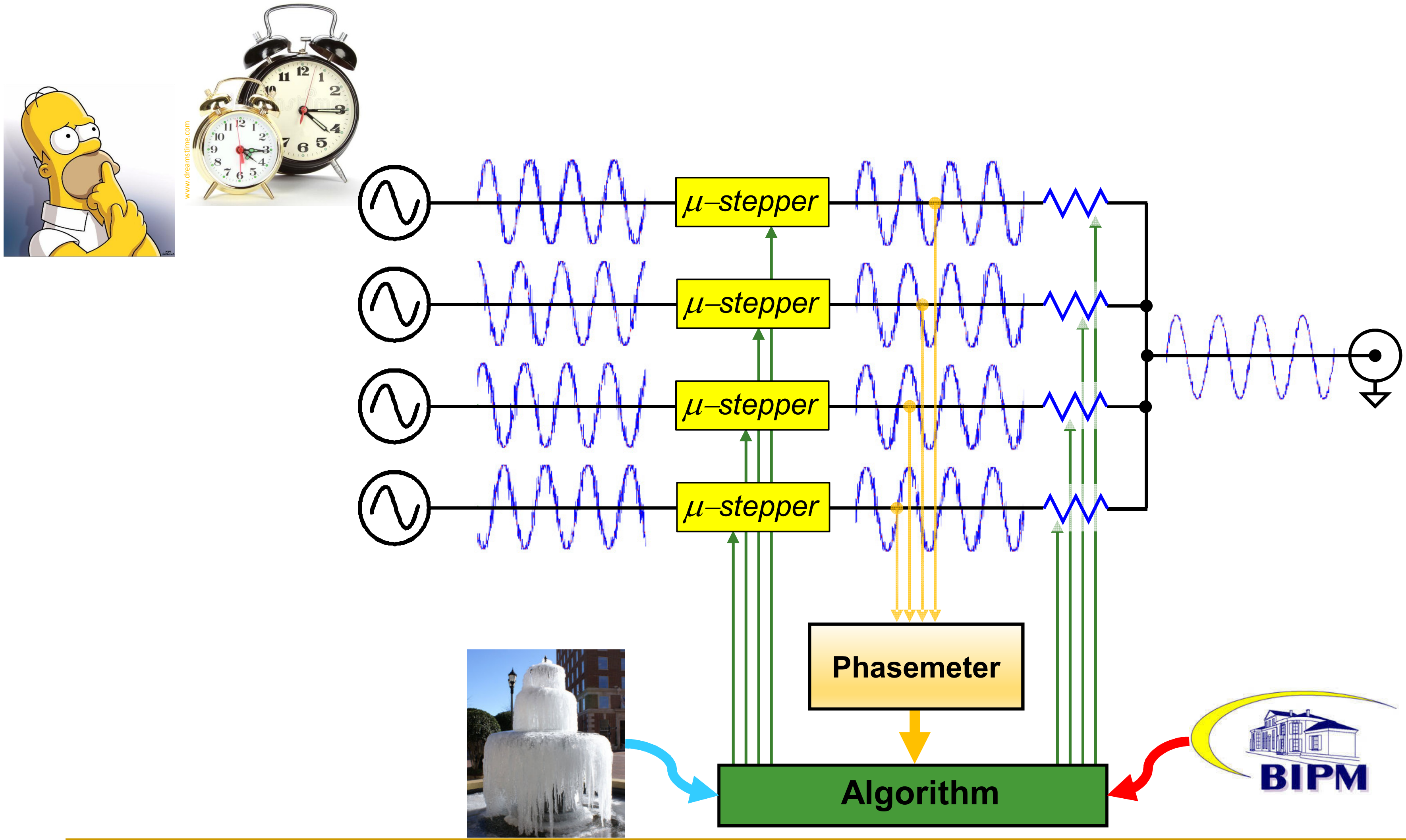
Master-clock solution + backup



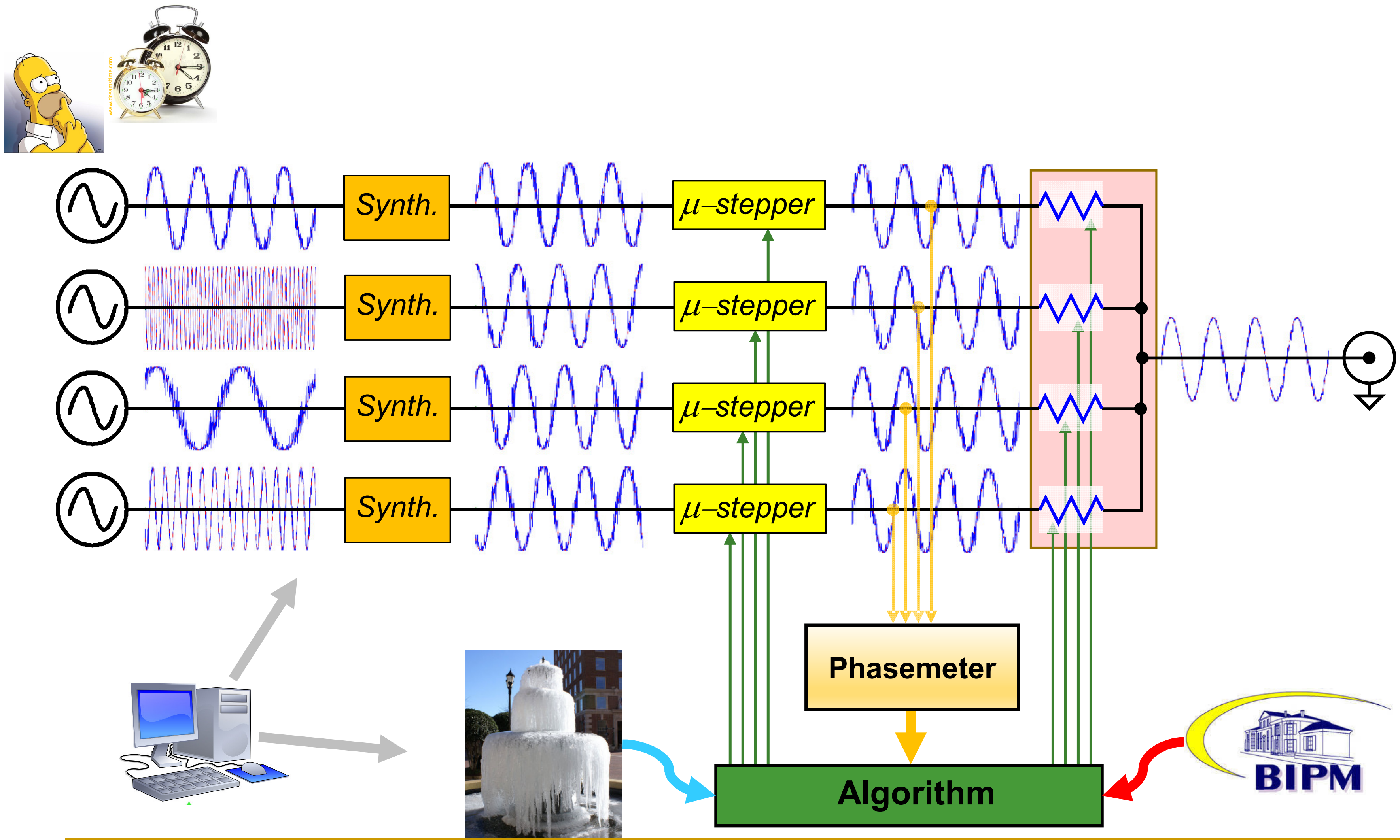
Bertacco, E. et al. (2020). Latest Improvements at INRIM Time Laboratory. 159-168. 10.33012/2020.17296.

G. D. Rovera et al., "The new UTC(OP) based on LNE-SYRTE atomic fountains," 2013 Joint EFTF/IFC, Prague, Czech Republic, 2013, pp. 649-651, doi: 10.1109/EFTF-IFC.2013.6702167.

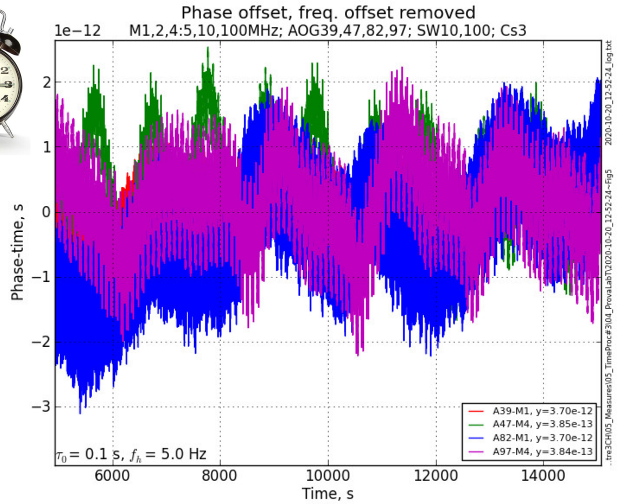
Extension to arbitrary frequencies

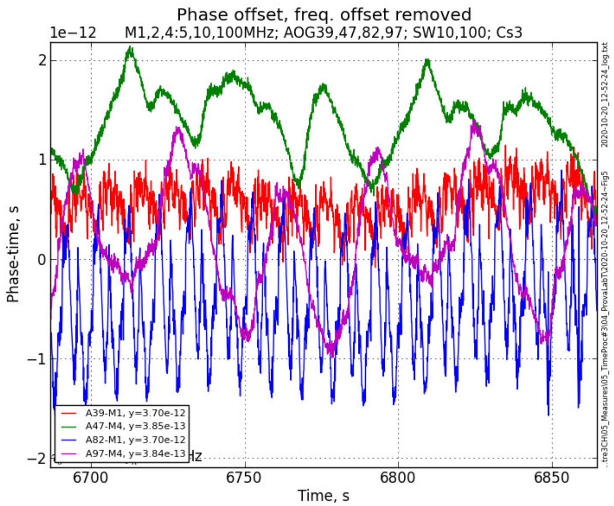


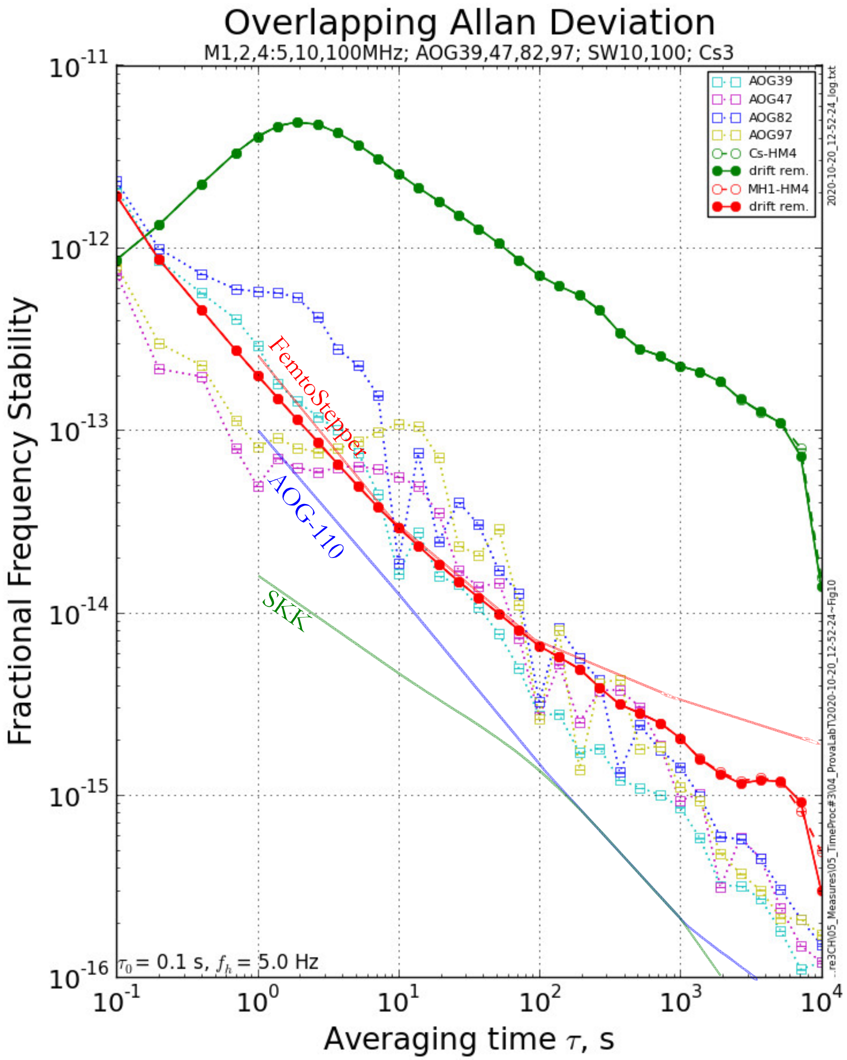
Extension to arbitrary frequencies



Microsteppers







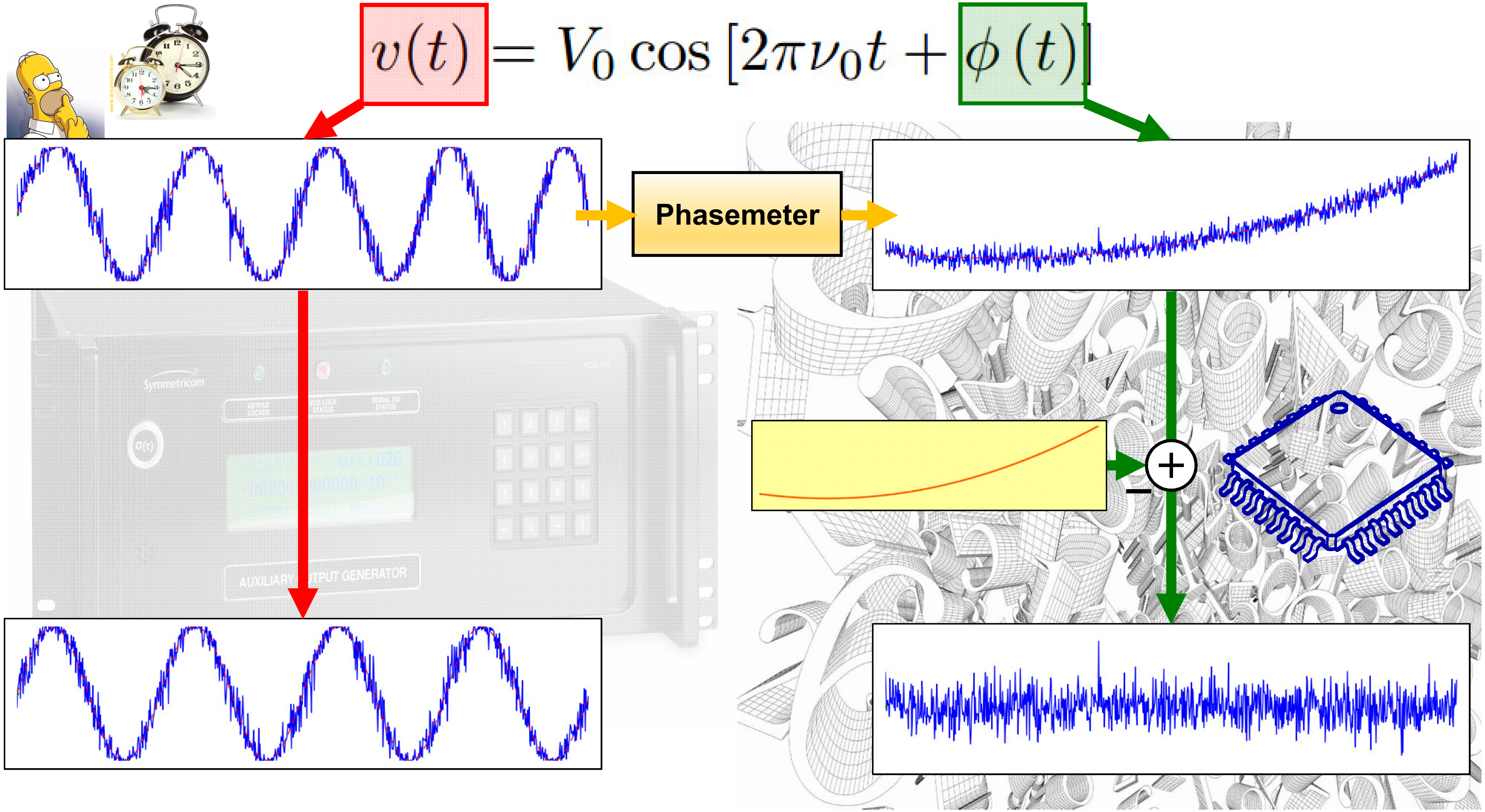
https://www.microsemi.com/product-directory/active-hydrogen-maser/4124-aog-110

https://www.orolia.com/products/atomic-clocks-oscillators/femtostepper

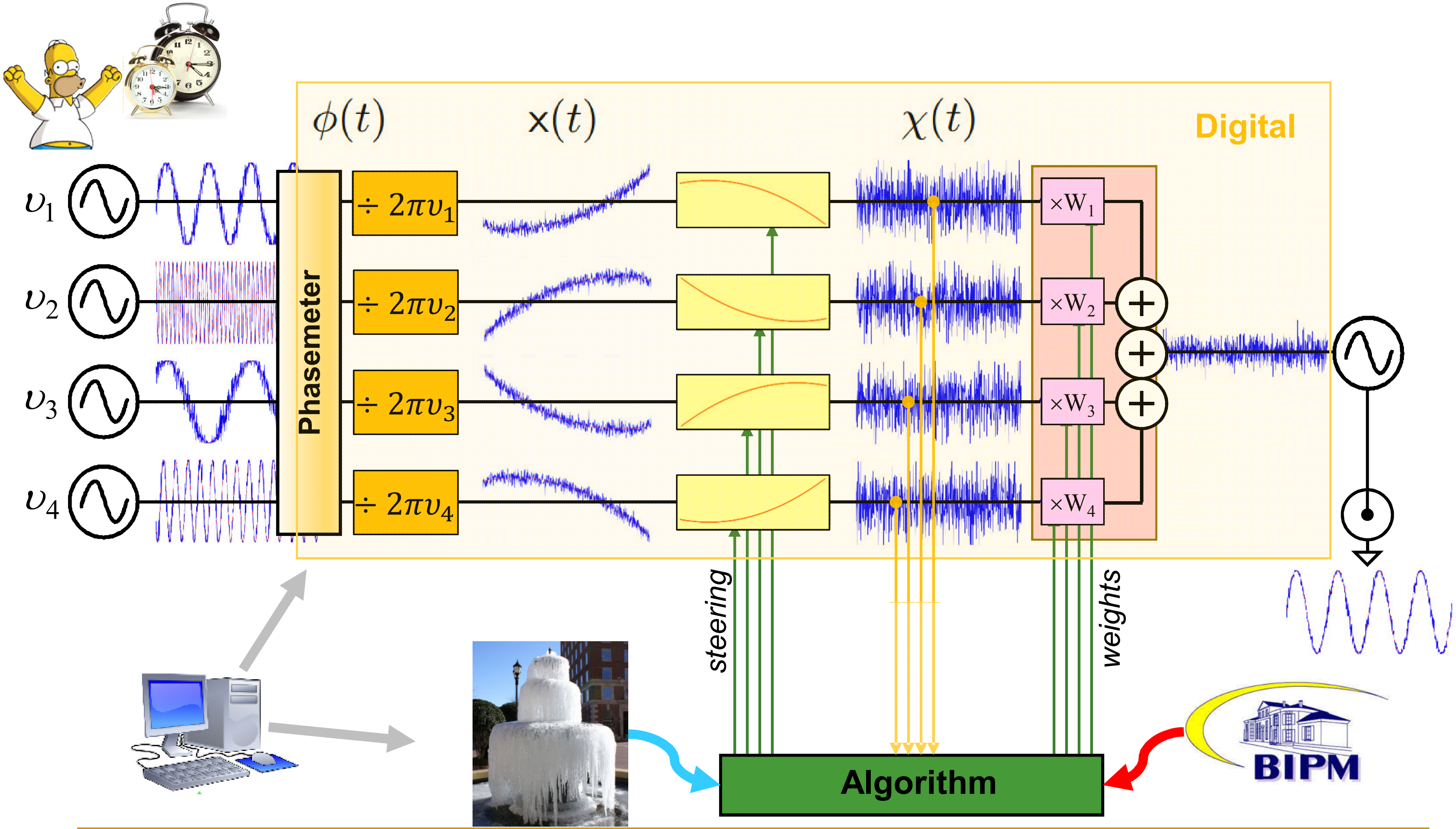
Rovera G., Abgrall M. et Siccardi M., "Characterization of an auxiliary offset generator for steering of H Masers", 26th EFTF-2012.

What's the point?

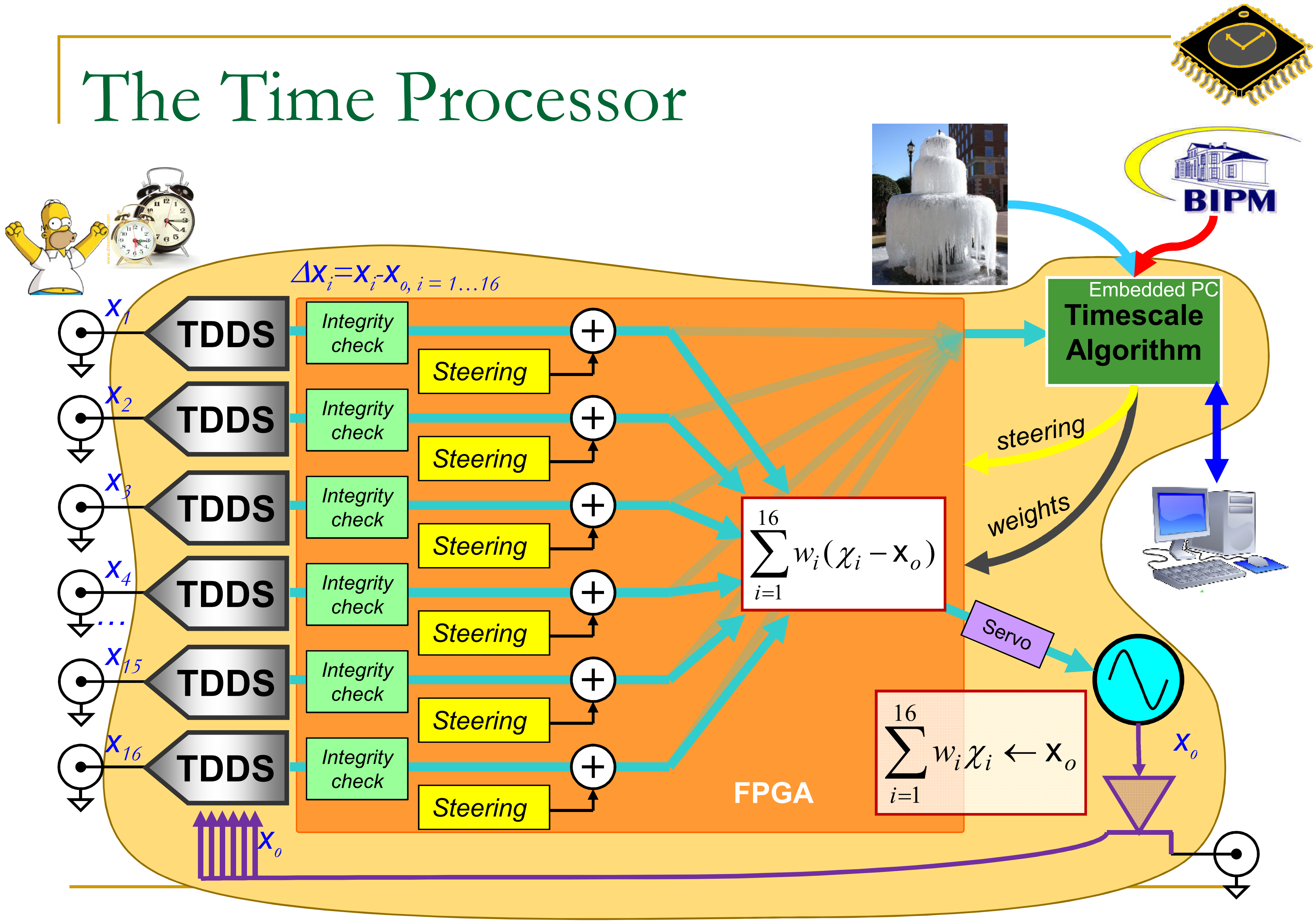
$$\boxed{v(t)} = V_0 \cos\left[2\pi\nu_0 t + \boxed{\phi(t)}\right]$$



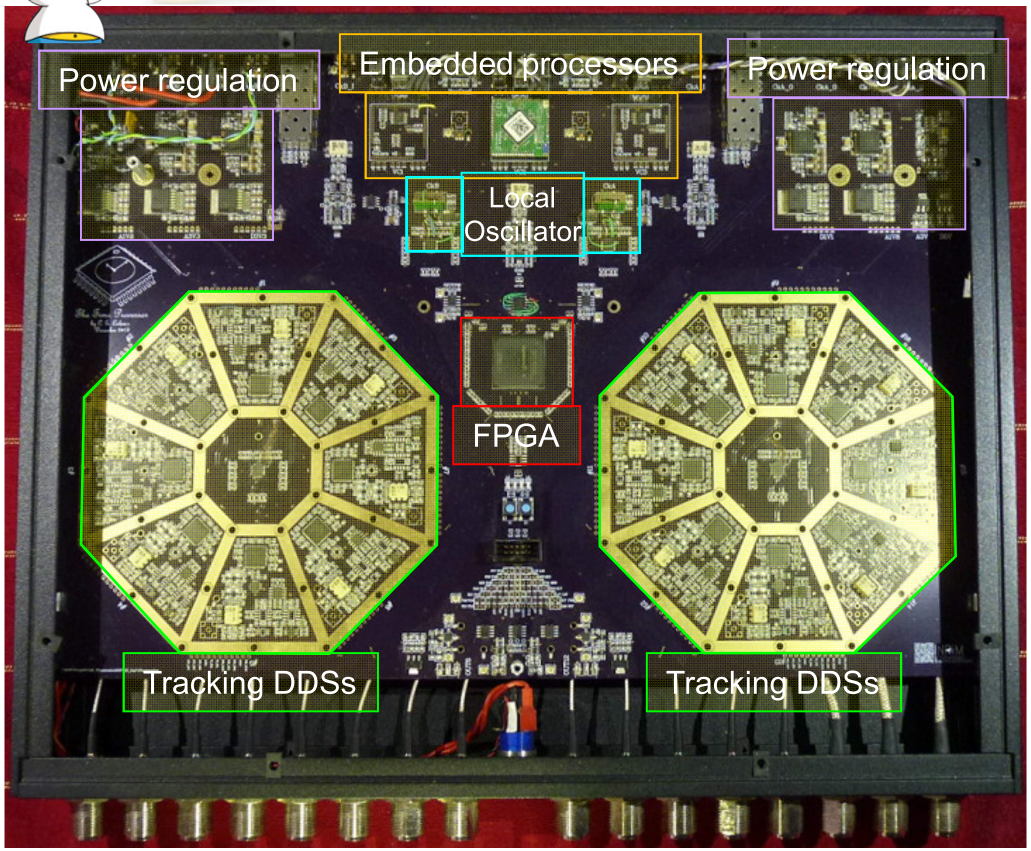
Composing directly the information



The Time Processor

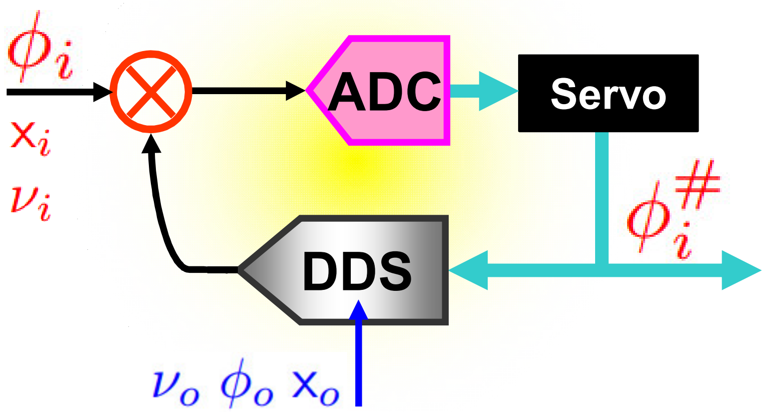


The Time Processor



- Characteristics:
  - Input frequency: 5÷400 MHz
  - Input power: -20 ÷ 17 dBm
  - Output: 1 GHz, 0 dBm
  - Residual noise @ 100 MHz:
    - 1.5×10^{-14} @ 1 s
  - Input isolation:
    - 100 dB @ 100 MHz
    - 130 dB @ 10 MHz
  - T-sensitivity @ 100 MHz:
    - <1 ps/K (input-input)
    - 2 ps/K (input-output)
  - Data rate:
    - Internal: 1 MS/s
    - External: 10 S/s
  - Steering:
    - 1 fs < time offset < ∞
    - 10^{-19} < frequency offset <100 kHz
    - 10^{-20}/day < frequency drift <10 kHz/day
  - Power consumption:
    - <30 W @ 12 V

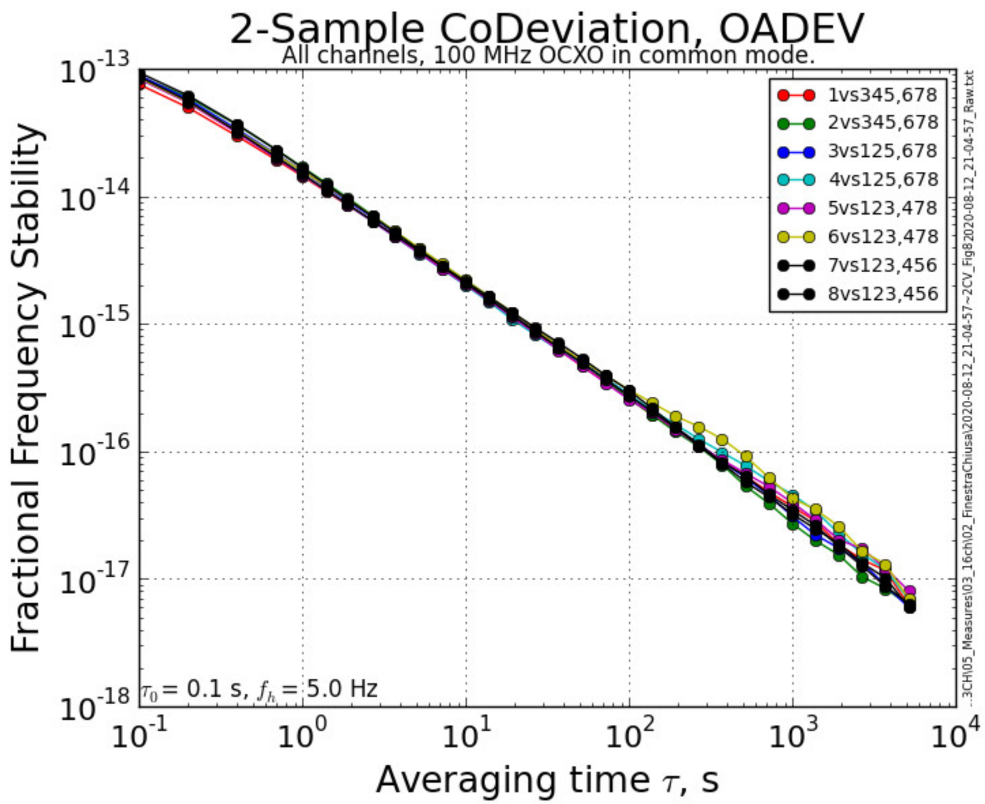
Tracking DDS



$$\boxed{\phi_i^{\#} \simeq \phi_i \text{ for } f < B}$$

$$\Delta\phi_i = \phi_i - \frac{\nu_i}{\nu_o}\phi_o + \phi_n$$

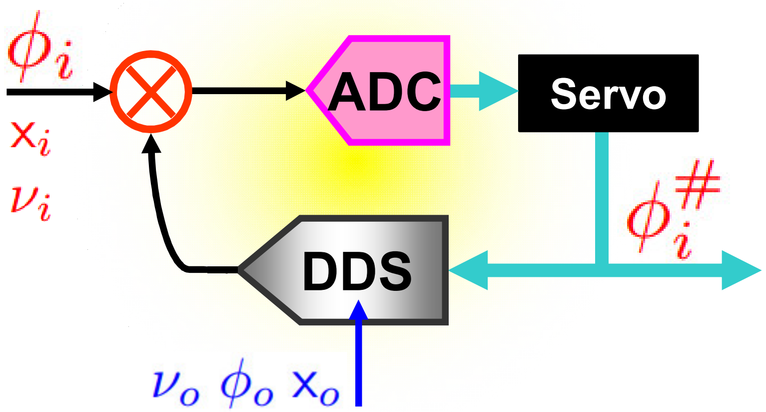
$$\Delta x_i = x_i - x_o + x_n$$



$$\sigma_y^2(1\,\mathrm{s}) = \left(1.5\times10^{-14}\right)^2 + \left(\frac{3\times10^{-8}\,\mathrm{V}}{V_i\nu_i}\right)^2$$

C. E. Calosso, “Tracking DDSs in time and frequency metrology”, EFTF-IFCS 2013, Prague
C. E. Calosso, F. Vernotte, V. Giordano, C. Fluhr, B. Dubois and E. Rubiola, "Frequency Stability Measurement of Cryogenic Sapphire Oscillators With a Multichannel Tracking DDS and the Two-Sample Covariance," in IEEE TUFFC, vol. 66, no. 3, pp. 616-623, March 2019

Tracking DDS



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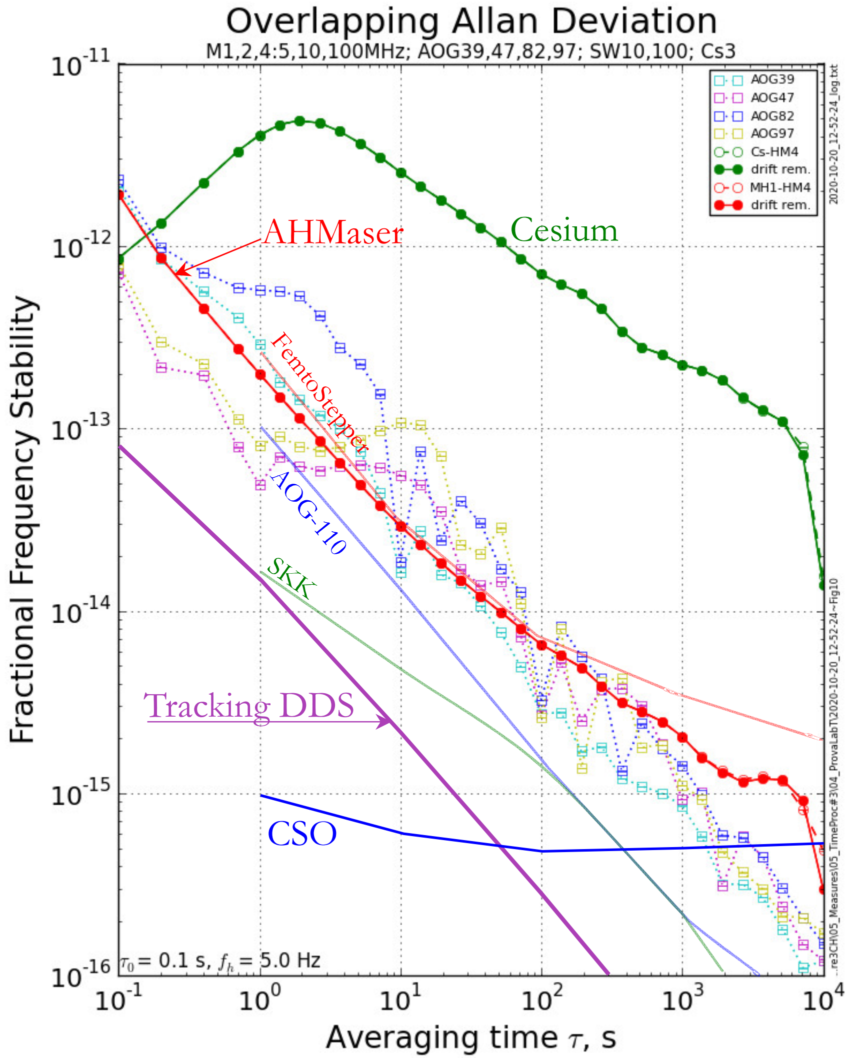

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Conclusions

- The Time Processor is a new platform for implementing next generation time scales.
- It has been developed to:
  - retrieve the phase time information from the inputs,
  - process it in real-time and
  - put the result in the phase of the physical output.
- Processing the information embedded into the signals instead of the signals themselves is the key-point of the instrument and allows great flexibility.
- This scheme is made possible thanks to the Tracking DDS, an original and efficient high-resolution real-time fully-digital phasemeter.

Thank you!

ACKNOWLEDGMENTS
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