Holdover Requirement: High Stability OCXO Challenges

Presenter: Cyril Datin (R&D Engineer – Technical Leader)

OCXO Solutions for Holdover Requirements

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Agenda

- What is time and phase alignment?
- What is Accuracy or stability?
- Holdover mathematical definition
- Holdover graphical approach
- How to measure holdover?
- Phase Noise (PN) over time (long term)
- Short/mid/long term stability – mathematical tool
- Typical clock stability $\sigma_y(\tau)$
- ADEV interpretation medium / high stability comparison
- OCXO fundamentals
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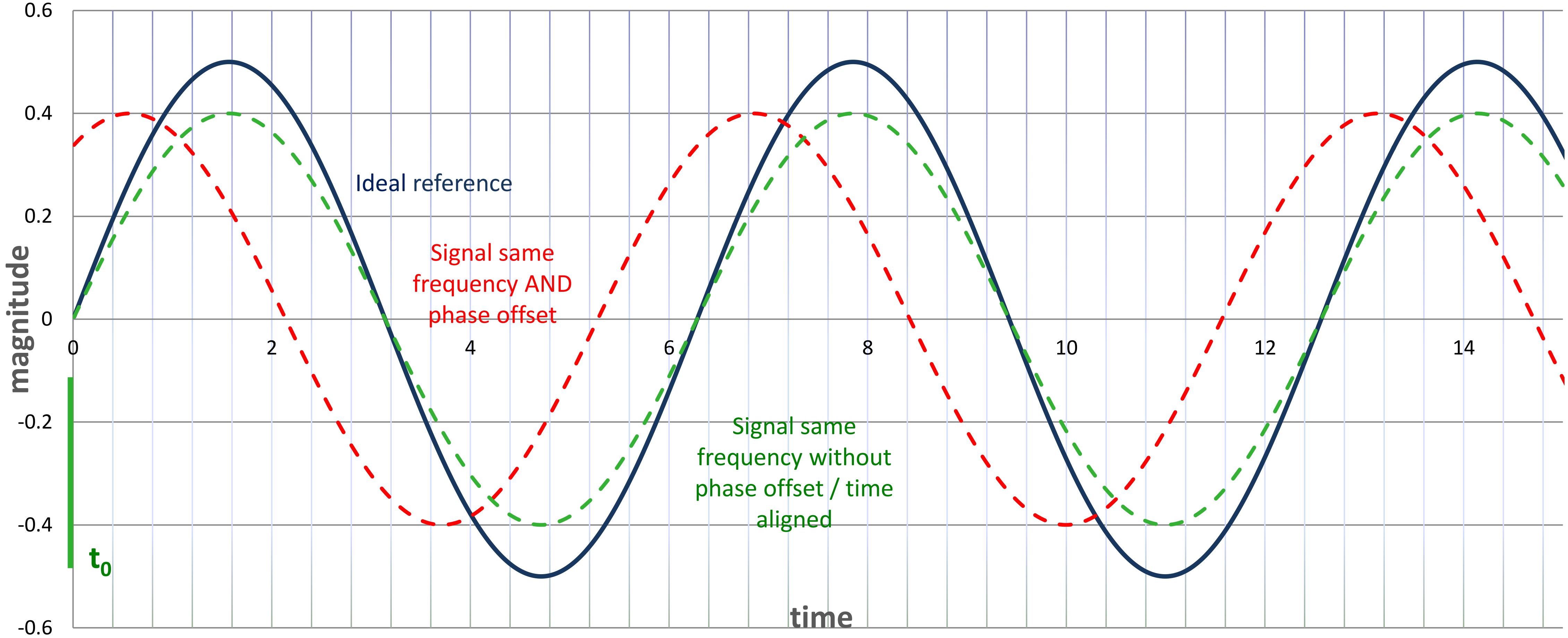
- Telecom system requirement:
- High end digital compensation OCXO topology:
- Frequency instability contributor ADEV translation
- Thermal compensation limitation
- Ageing prediction limitation:
- Ageing prediction limitation:
- Summary
- Conclusion: The next generation requirement?

What is Time and Phase Alignment?



- **Frequency holdover:** Ability to maintain a frequency alignment over a time period (Stratum 2, 3 3E requirement)
- **Time holdover:** Ability to maintain a phase accuracy over time (Time division requirement)

Accuracy or Stability ?

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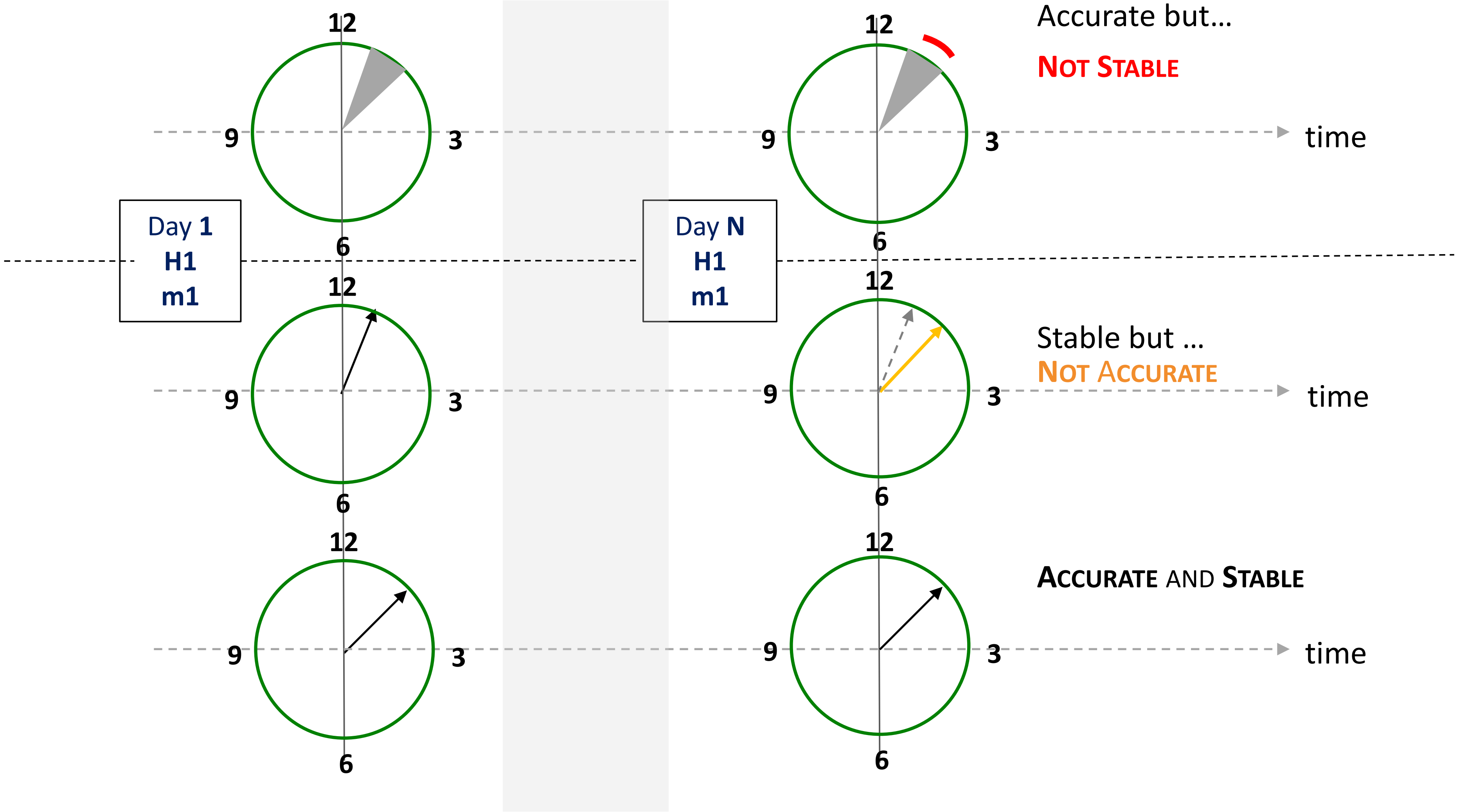
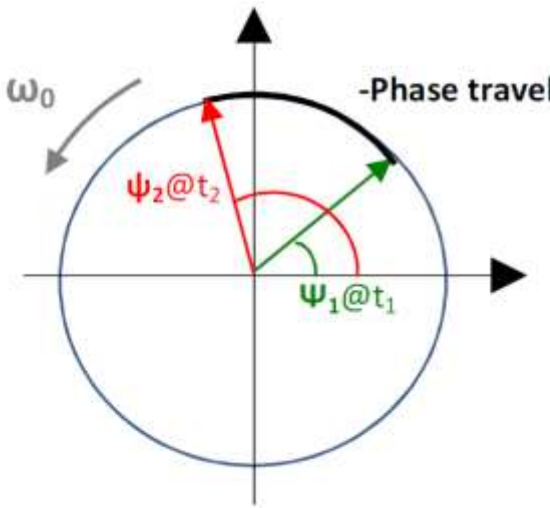
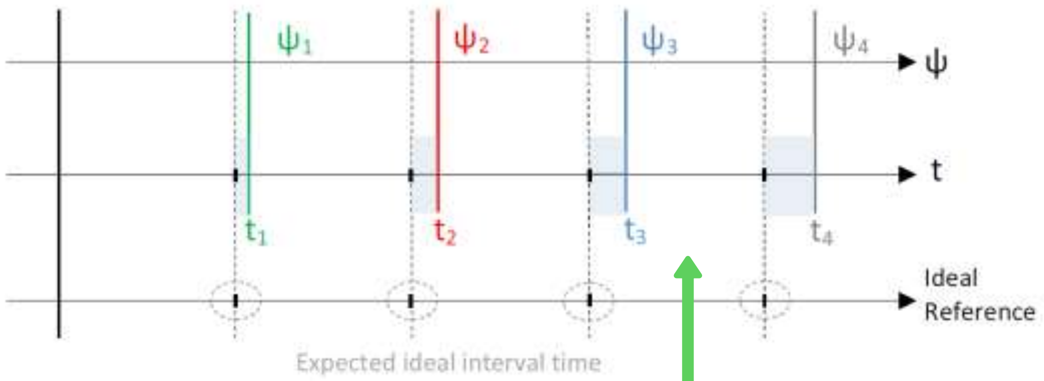


Holdover Mathematical Definition

Ideal harmonic signal is represented	$v(t) = V_0[1 + \alpha(t)]\cos[2\pi f_0 t + \varphi(t)]$
Phase time	$x(t) = \frac{\varphi(t)}{2\pi f_0}$
Fractional frequency fluctuation	$y(t) = \frac{f(t) - f_0}{f_0}$



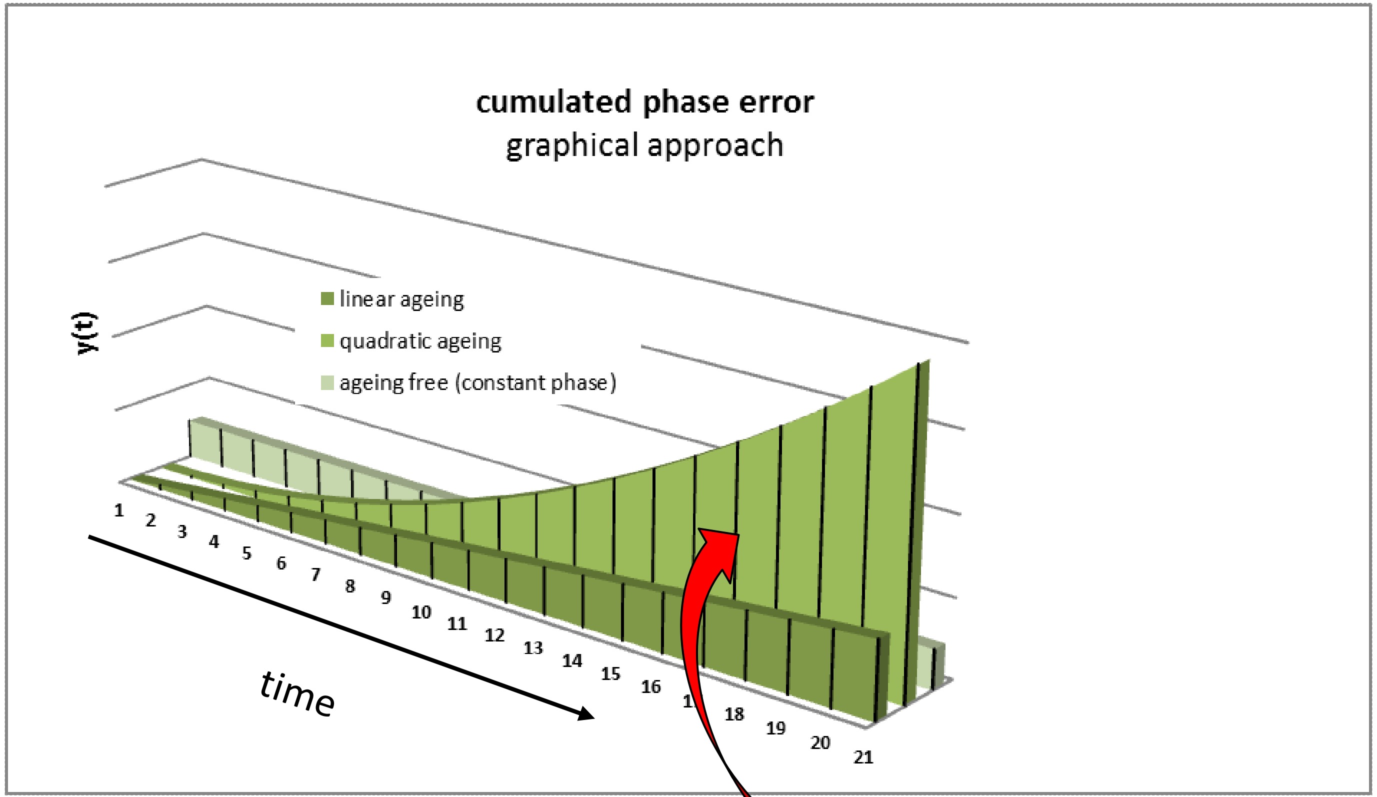
$$\Delta\psi = \psi_2 - \psi_1 = 2\pi f_0(t_2 - t_1)$$



The frequency drift is cumulating *phase error* **x(t)**
This is also called **time Holdover**

Holdover Graphical Approach

- Phase error is cumulating gradually over time following frequency evolution



- **Linear**
  if frequency constant (ageing free)
- **Quadratic**
  if frequency linear (constant ageing)
- **Cubic**
  if frequency quadratic (linear ageing)

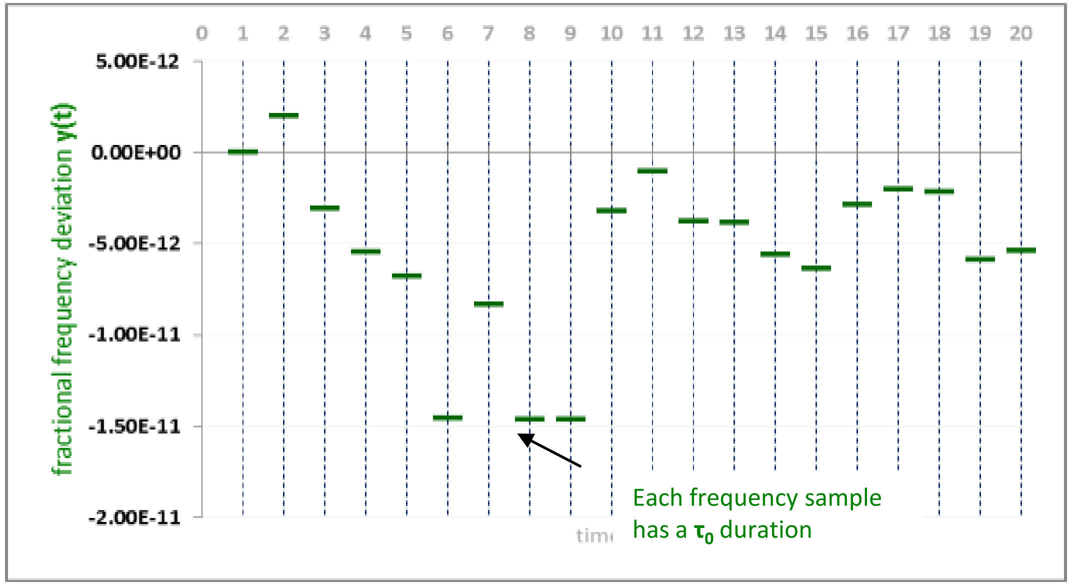
Holdover (phase time)
Is the **area underneath the curves**

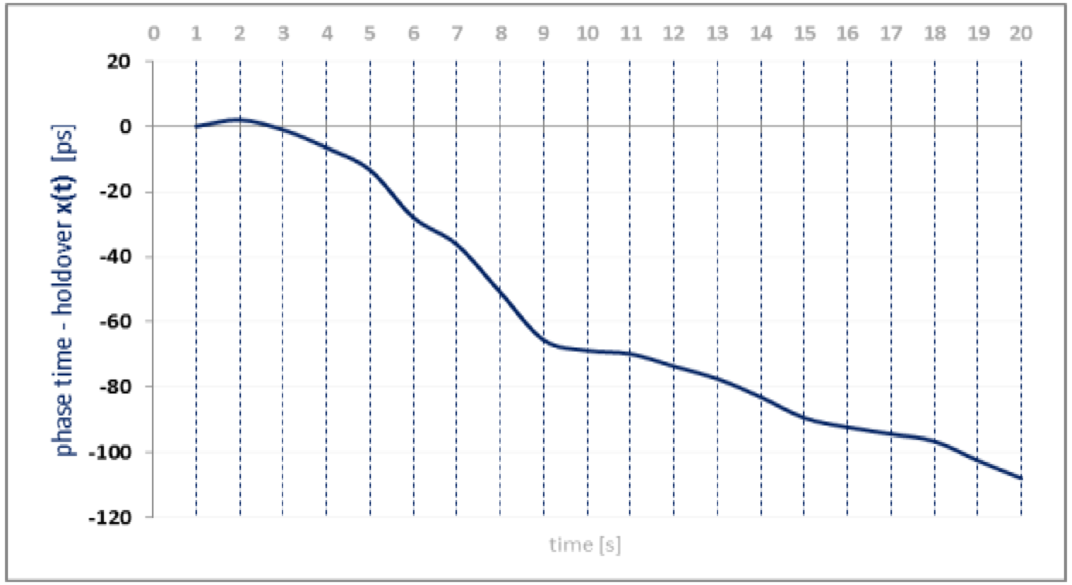
How to Measure Holdover?

As an oscillator manufacturer we deal predominantly in the frequency domain, and convert to the time domain…

τ_0 counter integration time

$$x(t) = \int_0^{T_{obs}} \frac{f - f_0}{f_0} dt = \int_0^{T_{obs}} y(t)\, dt$$



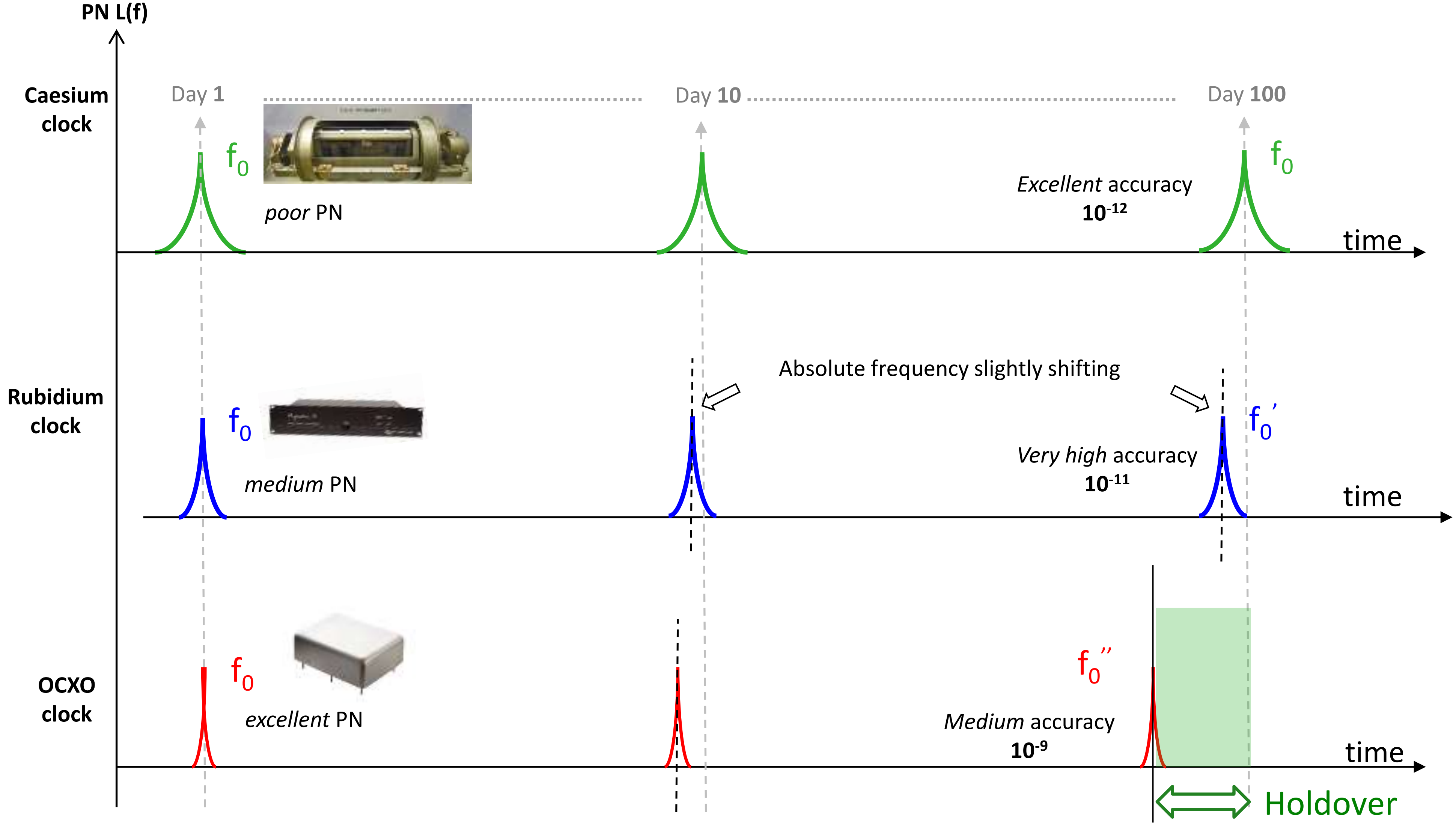


y(t) fractional frequency deviation

x(t) phase time… => **time Holdover**

Phase Noise (PN) Over Time (Long Term)

Graphical approach – Phase Noise (PN) **over time (long term)**



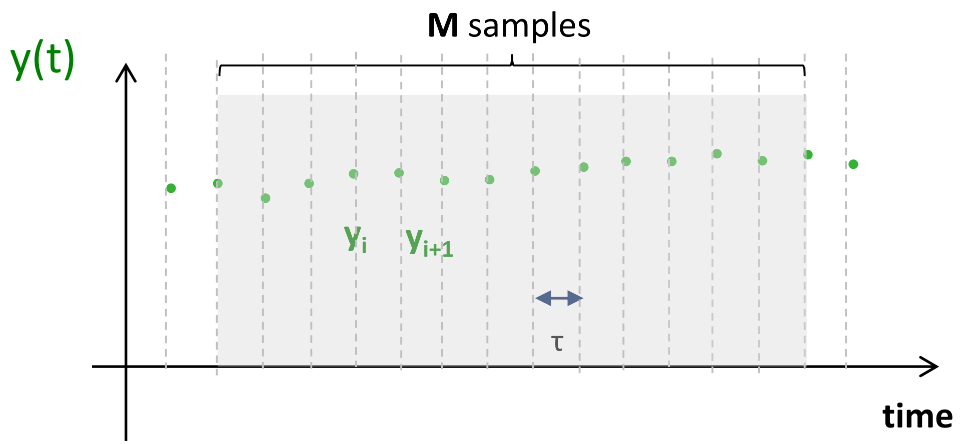
Short/Mid/Long Term Stability

Short/mid/long term stability – mathematical tool

Allan Deviation **ADEV**

τ : counter integration time (frequency sampling)

$$\sigma_y^2(\tau) = \frac{1}{2(M-1)} \sum_{i=1}^{M-1} [y_{i+1} - y_i]^2$$



Most common time domain metric of frequency stability

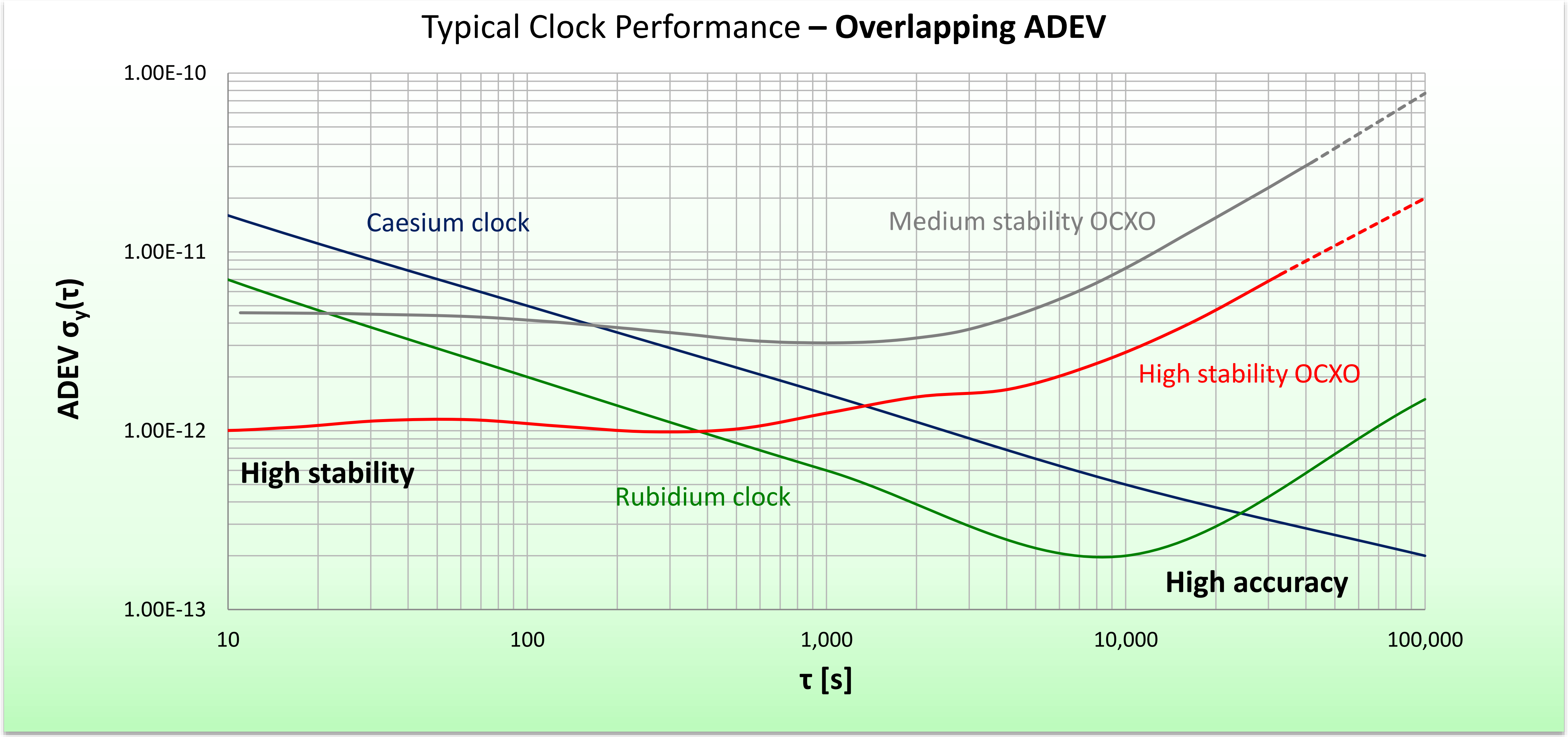
ADEV remains **convergent** for most noise types

Another common metric is the modified Allan deviation **mod $\sigma_y(\tau)$** which may be converted easily to **TDEV**

$$\sigma_y^2(\tau) = \frac{1}{2m^2(M-2m+1)} \sum_{j=1}^{M-2m+1} \sum_{i=j}^{j+m-1} (y_{i+m} - y_i)^2$$

$$TDEV = \sqrt{\left(\frac{\tau^2}{3}\right) mod\ \sigma_y^2(\tau)}$$

Typical clock stability $\sigma_y(\tau)$



10MHz OCXO ADEV Interpretation

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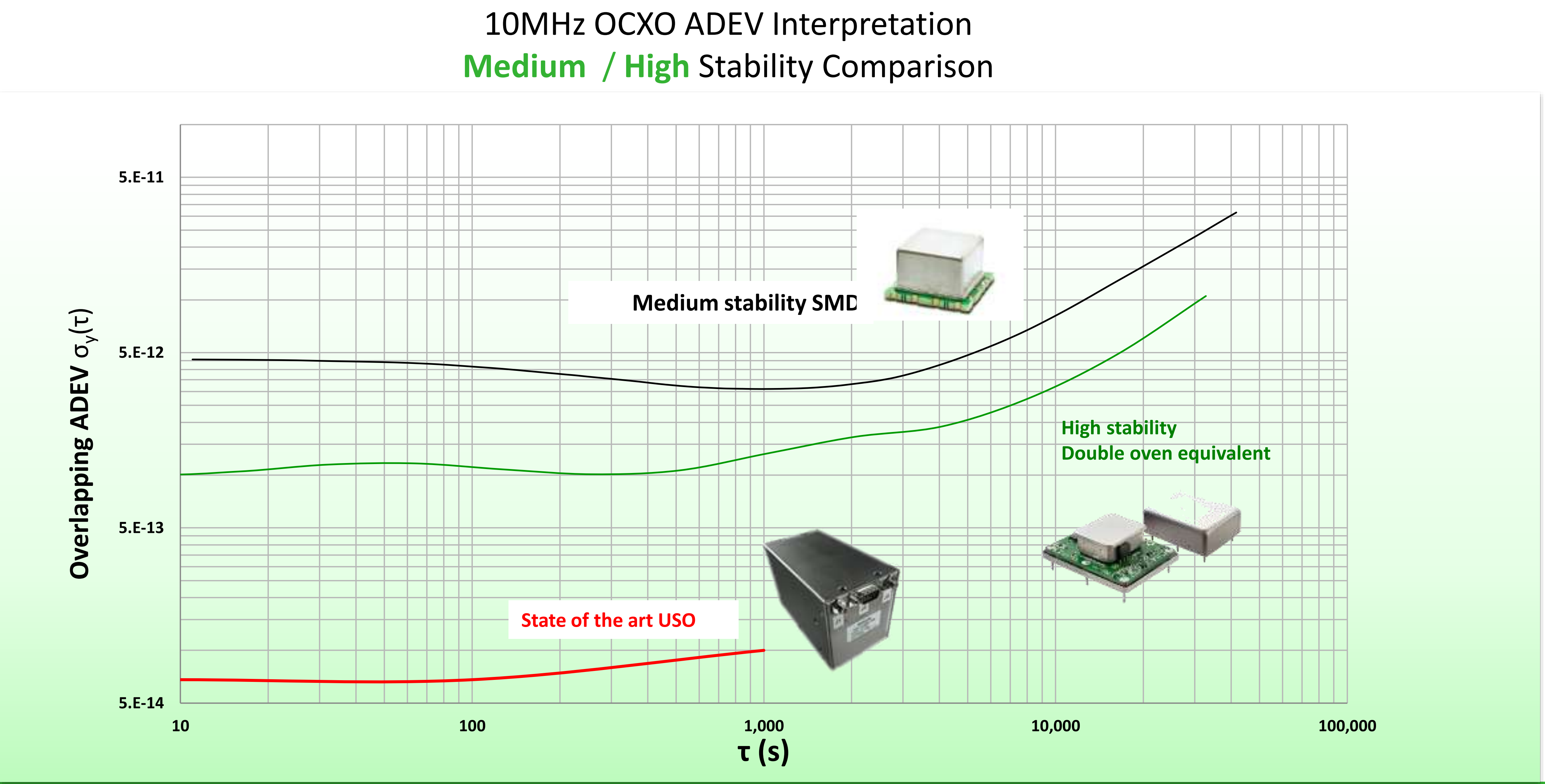
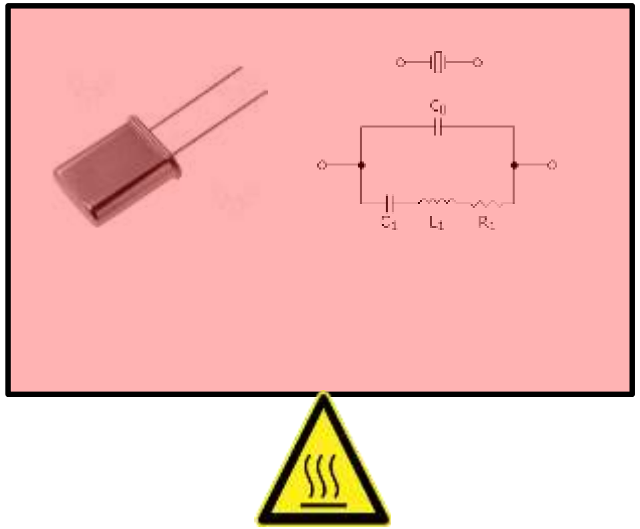


OCXO Fundamentals

Highest Q resonator oscillator (>1000 000)

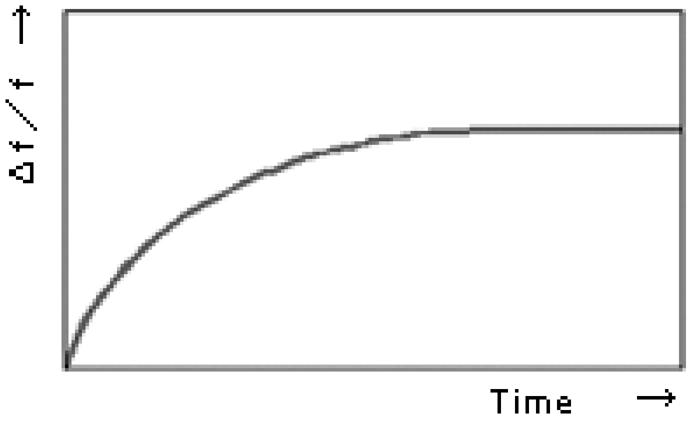
Environmental **insulation** construction

Low transient response **(heating element thermal inertia)**



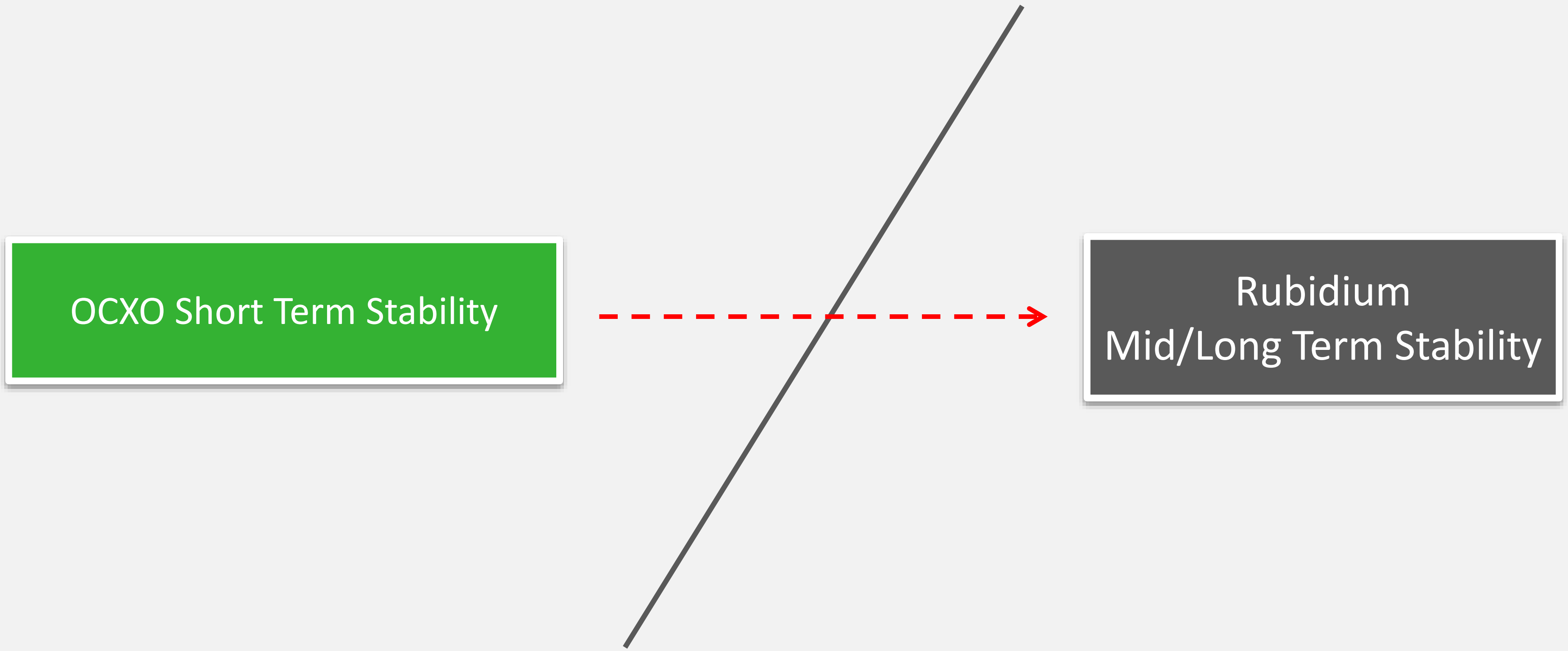
But…

Long term stability limited due to inherent ageing effect…



Telecom System Requirement

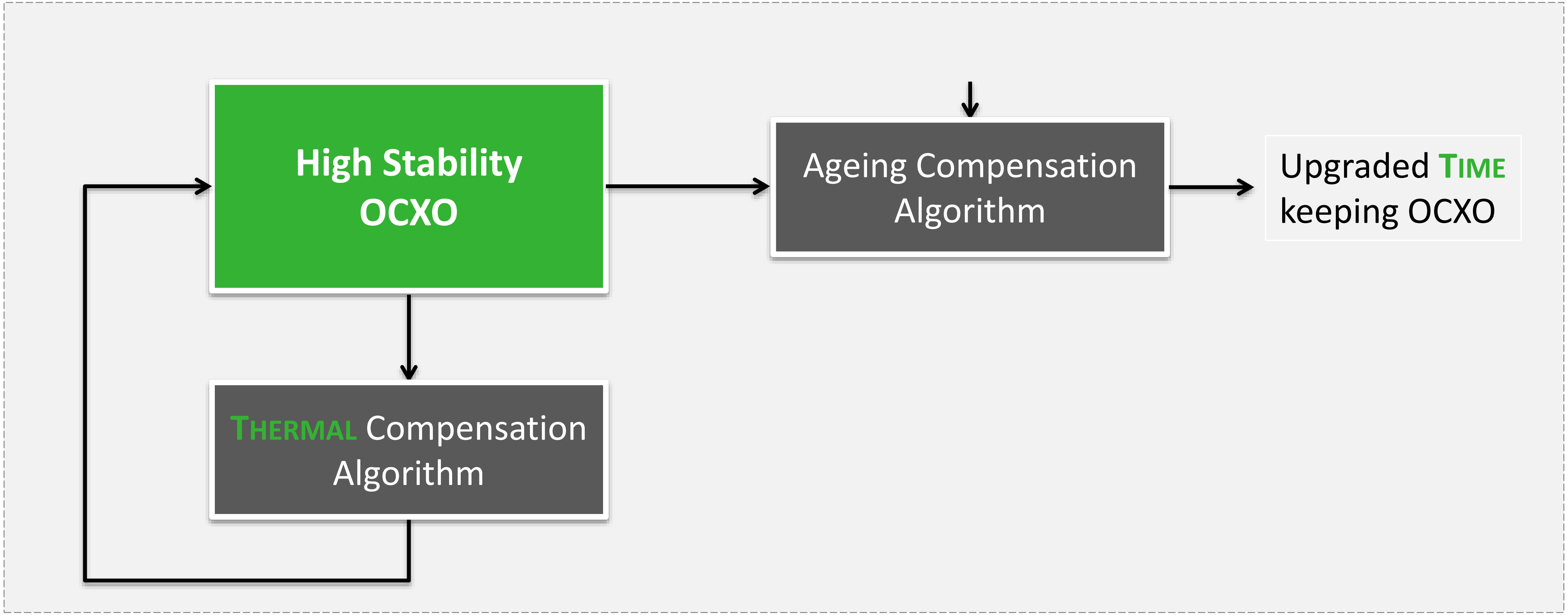
- Good short term stability
- Excellent time keeping ability



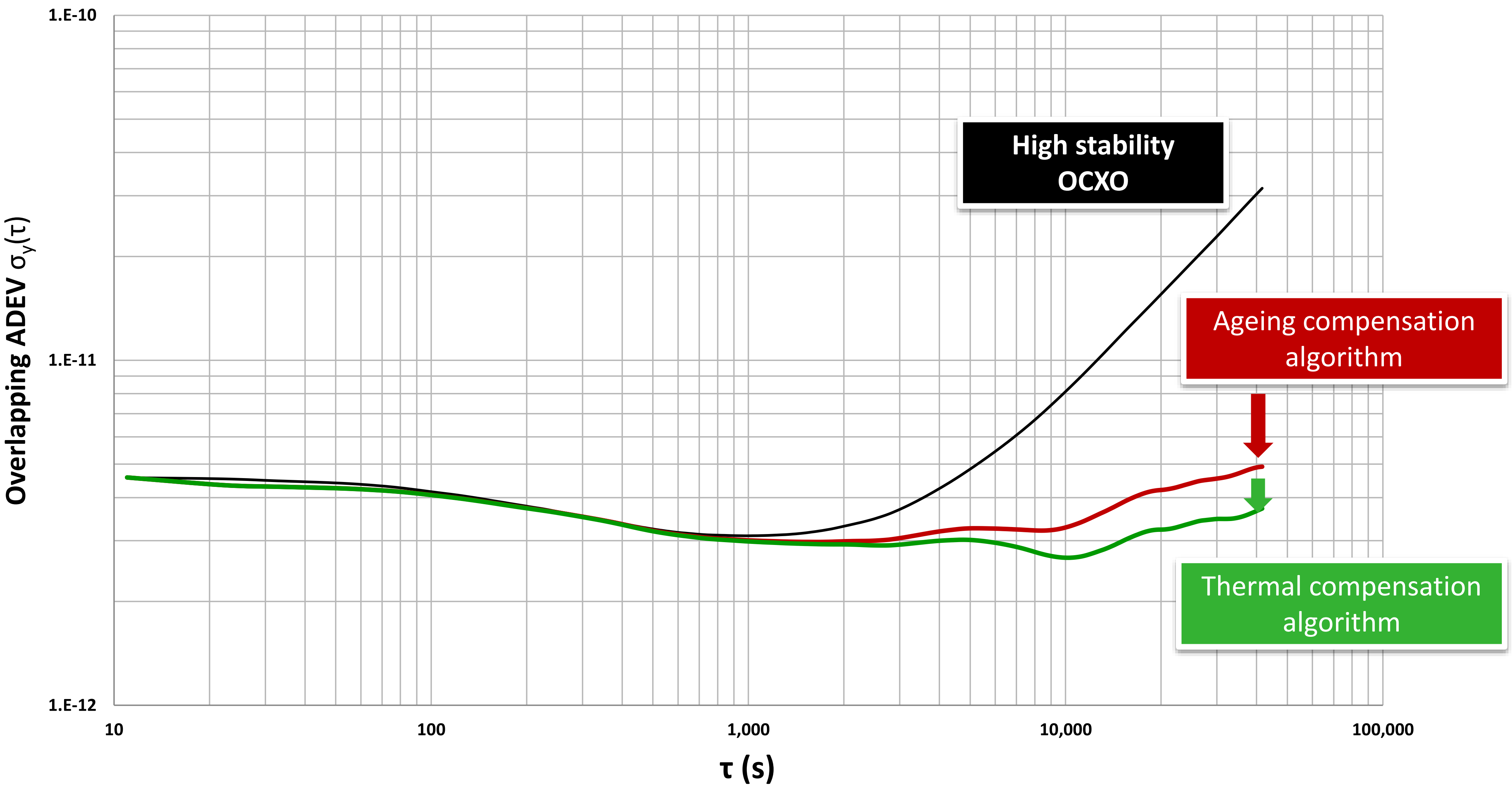
- Need for digital compensation implementation

High End Digital Compensation OCXO Topology

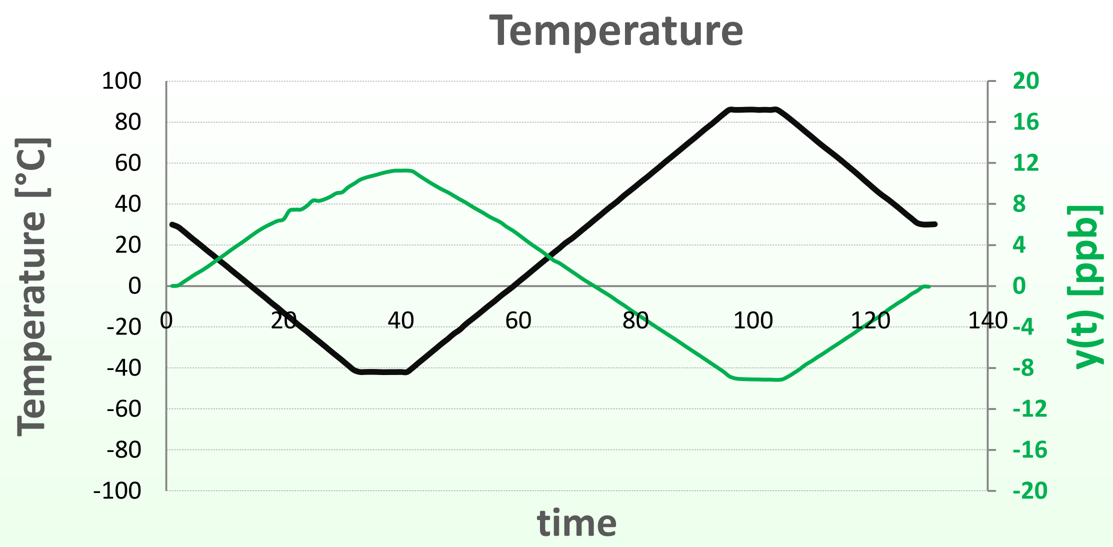
- Keep very short term stability performance
- Overcome unwanted THERMAL and TIME effect



Frequency Instability Contributor ADEV Translation

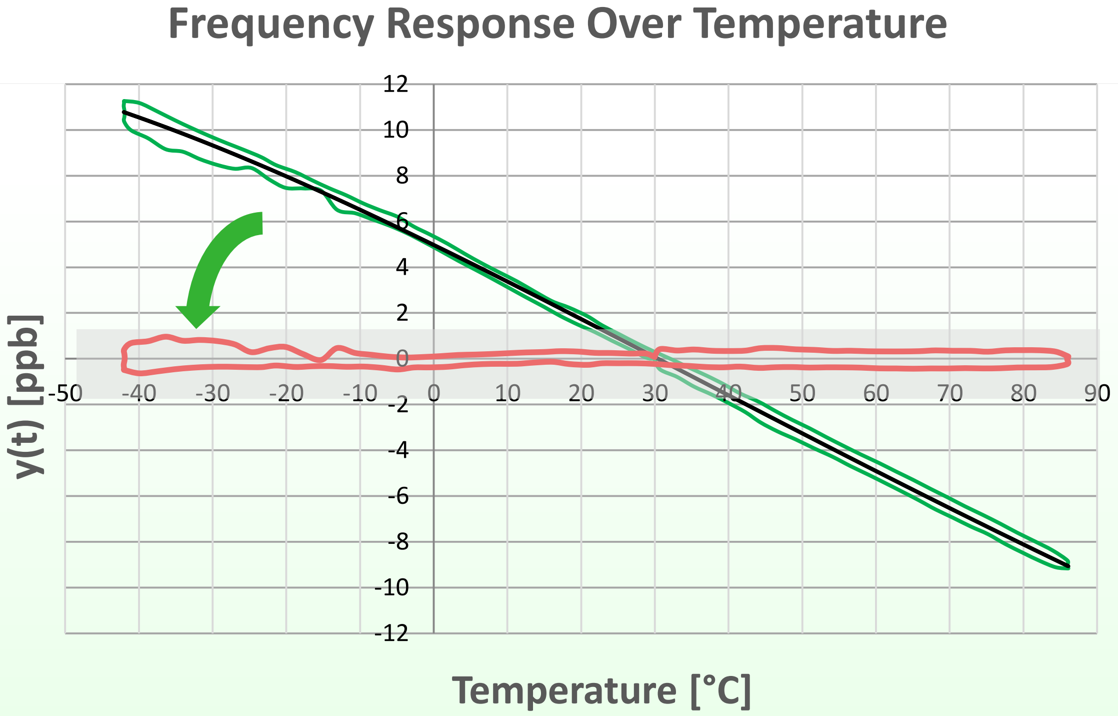


Thermal Compensation Limitation



Apply **temperature** profile

Evaluate **frequency** variation



Frequency vs. Temperature response

Compute the ideal mathematical response

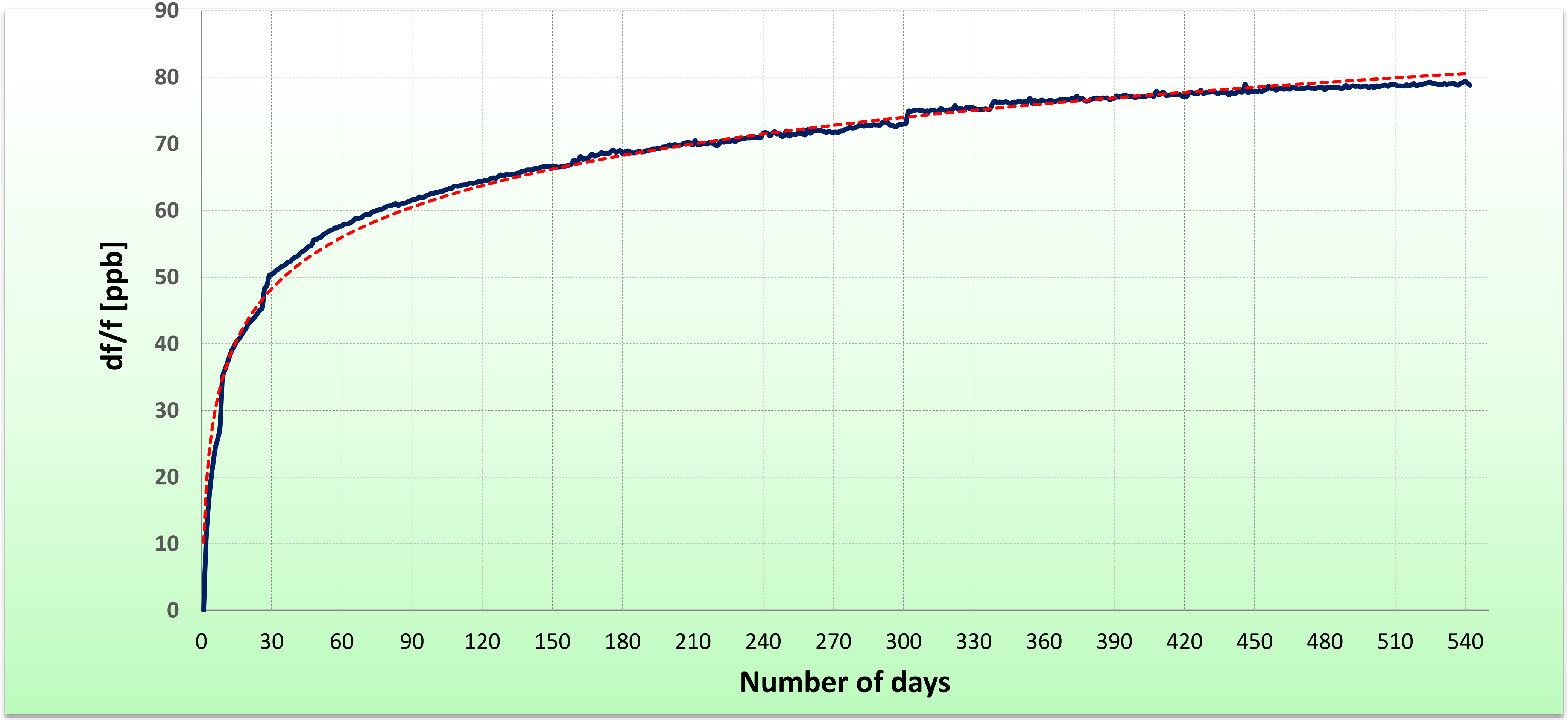
Then apply **compensation** algorithm

But…

Oscillator **hysteresis** limiting residual error

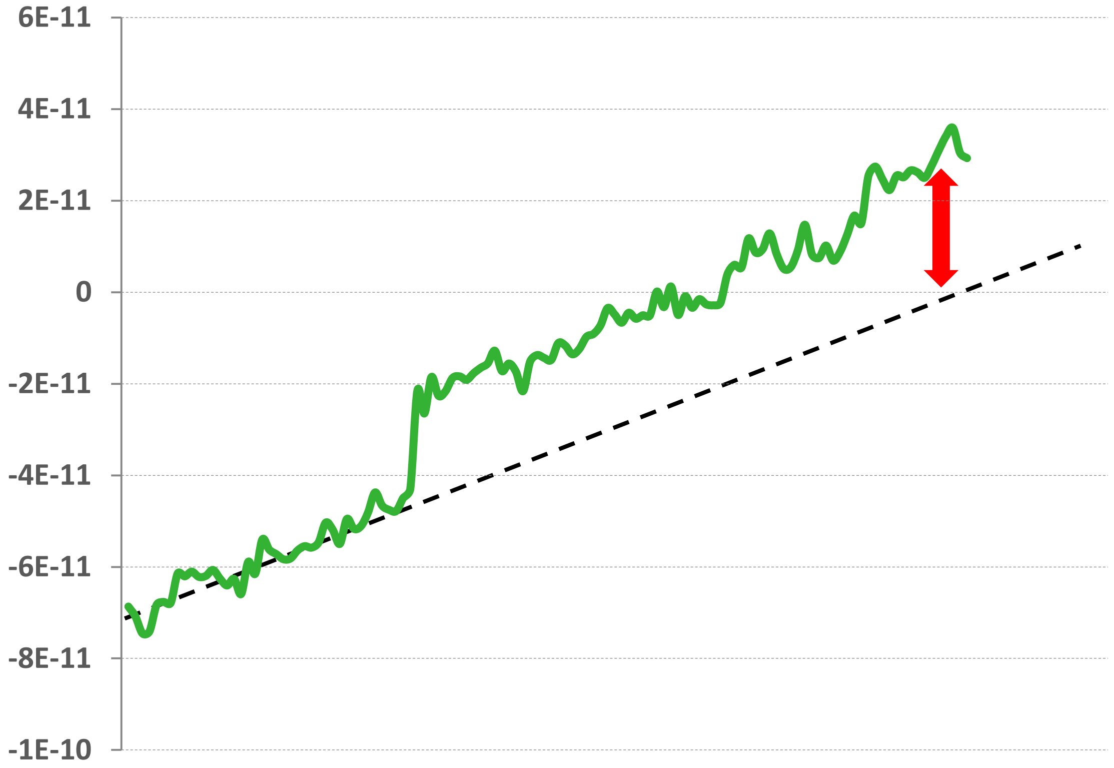
Ageing prediction limitation

- Ideal ageing behaviour is predominantly logarithmic over time
- **The ideal curve fit** may be computed



Ageing prediction limitation

Prediction limited to extrapolation accuracy



Frequency gap between expected and actual ageing response

Summary

- High stability OCXOs are not able (by themselves) to maintain very tight holdover specification such as 1.5 µs over 24 hours
- Additional distinct digital compensation is required to a target specification
- Although mathematically easy to implement, actual OCXO behaviour requires a perfect understanding of Piezoelectric crystal phenomena
- OCXO manufacturers are able to assess each of oscillator’s behaviour by monitoring over significant time periods and environmental conditions

Conclusion

What about the next generation requirement?

Current

- Time keeping is **1.5 µs over 24 hours**
- It means **3,5 x 10^{-11} (35ppt)** stability for all causes over 24 hours
- A wristwatch disciplined by such a stable clock would be off one second after **913 years!**

Tomorrow

- Time keeping is **1.5 µs over 72 hours**
- **Holdover** is not linear
- A clock 3^2 is needed = 9 times more stable to target this specification
- **3,8 x 10^{-12}** stability **(3,8ppt)**
- A wristwatch disciplined by such a stable clock would be off one second after **8219 years!**