Power Matters.

The Role of Oscillators in the World of Time

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Some Basics

1. Oscillator provide a local source of timekeeping. For example a watch.
2. How well a watch keeps time depends on how often we set the time, how well we set the time.
3. It is also depends of how long we need to go between resetting the time and what environment the watch (and oscillator) needs to tolerate.

Mapping to Our Applications

1. Oscillator provide a local source of timekeeping. For example tuning fork in a watch.
   → Oscillator selection is trade space involving performance, size, power and cost.

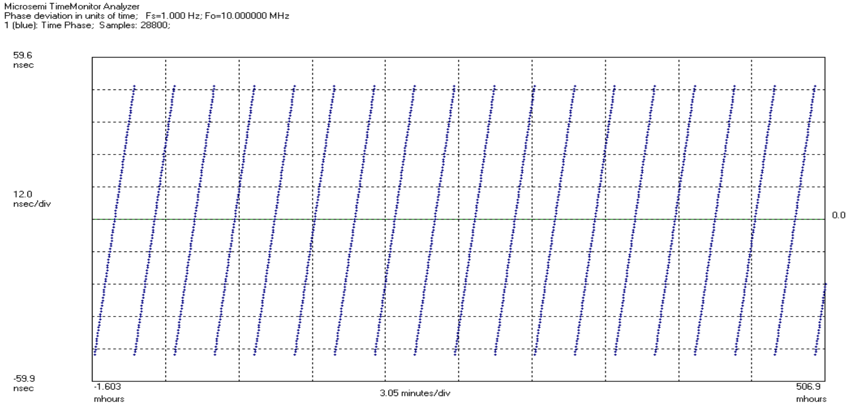
2. How well a watch keeps time depends on how often we set the time, how well we set the time.
   → Setting Time depends on how well we trust the reference(s). Noisy references require longer filtering time.
   Real world reference can be intentionally or unintentionally jammed or spoofed. The more decoupled the local oscillator the better this can be detected.

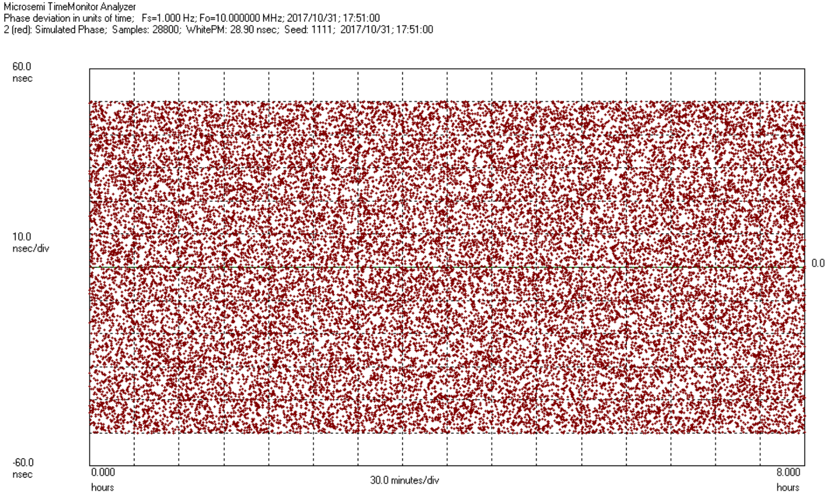
3. It is also depends of how long we need to go between resetting the time and what environment the watch (and oscillator) needs to tolerate.
   → Reference outages need to be accommodated based on issues like time to repair and allowed time error budget.

MTIE Workhorse Specification But Does Not Tell the Whole Story

Consider two cases:

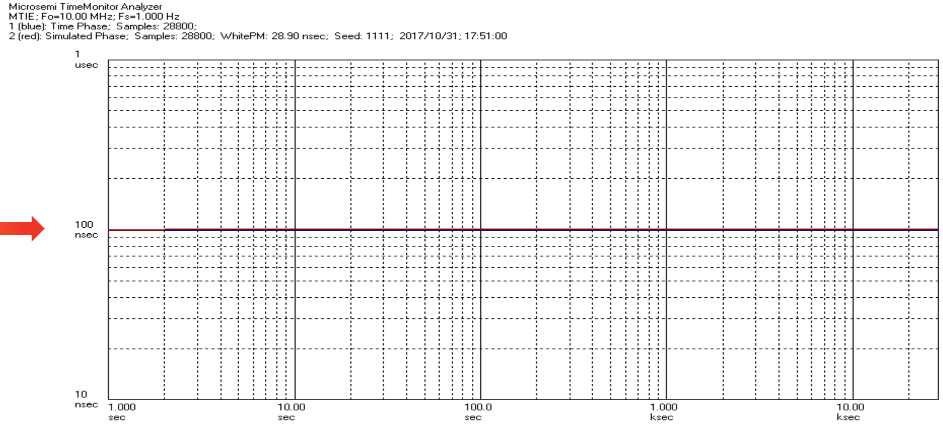
- Periodic 100 second Time Error Ramp (Blue)
- Uniform White Noise Time Error (Red)



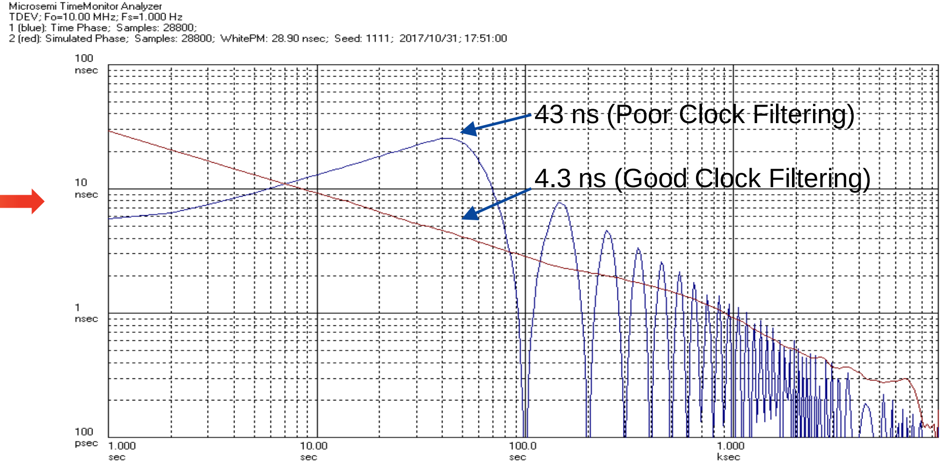


MTIE Does Not Tell the Whole Story

- MTIE for both the periodic sawtooth signal and the uniform white phase noise signal are identical.

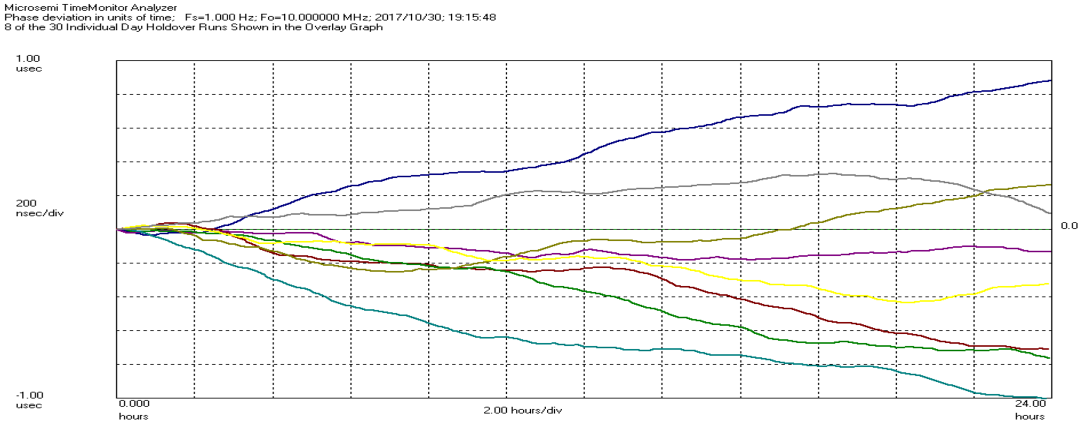


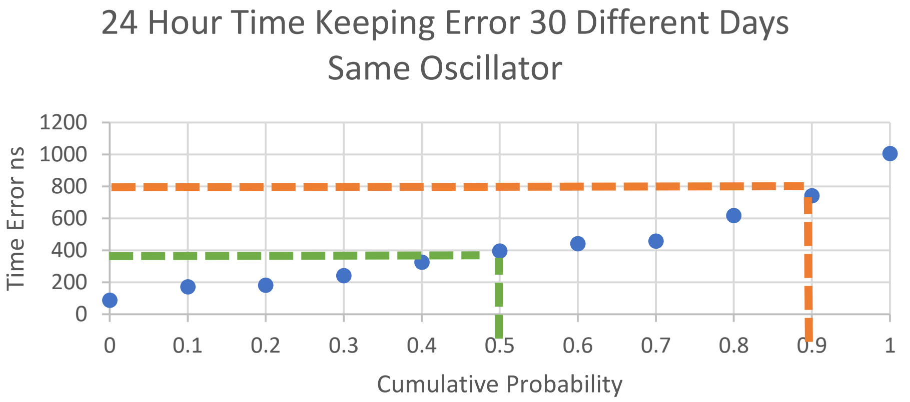
- However the white phase noise signal can be easily filtered by a clock while the periodic signal leaks through.



Be Careful With Time Error in Holdover Specifications

1. Using the Microsemi Timing Analysis Tool we Investigate what 30 individual days of Holdover would look like.
2. For the test we kept everything else at zero:
   - No Initial Clock Estimation Error
   - No Temperature Change
   - No Other External Perturbations
3. A simple mode of a precision oscillator with perfect drift estimation and 5e-12 noise floor was assumed
4. Time Keeping Error for the Same oscillator is random.
5. What should the value be:
   - 400 ns (50% of the time)
   - 750 ns (90% of the time)
   - ????





Need for a Standard Benchmark for Oscillator Time Keeping

1. Classic oscillator datasheet specifications do not provide a direct metric of the time keeping capability
2. What is a needed is a standard benchmark that can properly map oscillator performance to time keeping performance in a world of time applications
3. The next few slides propose a framework for such a metric

Time Keeping Standard Benchmark Framework

The metric is based on the well established clock model.
The general clock model is:

$$X(t) = x_0 + y_0 t + \frac{1}{2} D t^2 + e(t)$$

Where

$X(t)$ is the accumulated time error since t_0

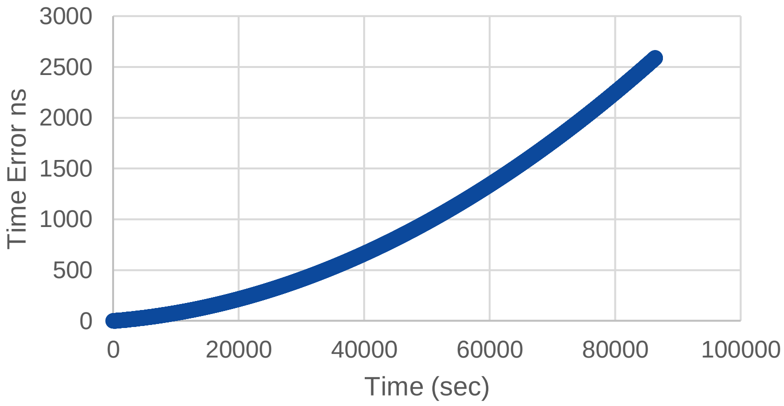
X_0 is the initial time error at time t_0

y_0 is the initial time error at time t_0

D is the frequency drift or aging of the oscillator

e(t) is the accumulated time error associated with random noise processes

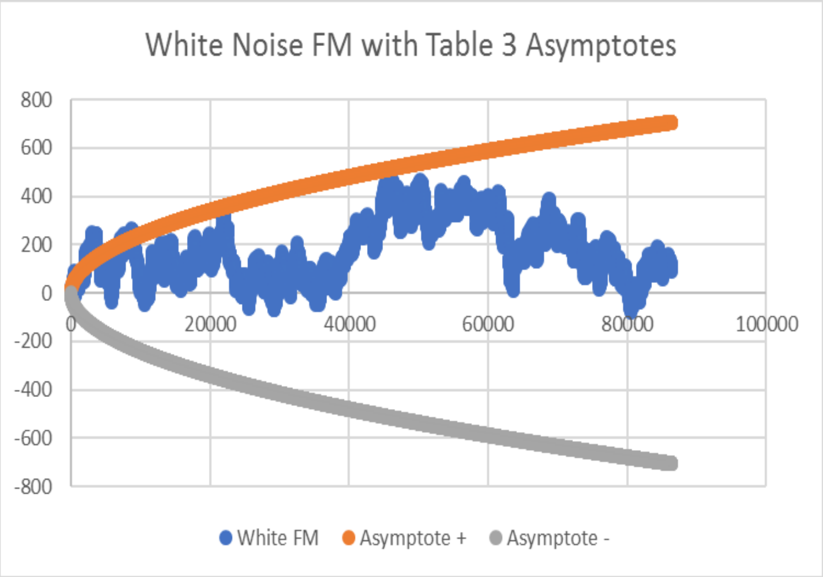
Time Keeping Error
Drift: 5e-11/day
Initial Freq: 5e-12 (noise floor)
Initial Time Offset: 0
e(t) = 0



Time Keeping Standard Benchmark Framework

1. To properly account for the power noise processes in an oscillator we can build on a rigorous foundation[1] Table III provide the asymptotic time accumulation for each noise type.

Noise Type	Time Keeping Error Asymptotic Form
white noise PM	constant
flicker noise PM	$(\log t)^{1/2}$
white noise FM	$(t)^{1/2}$
flicker noise FM	(t)
random walk FM	$(t)^{1.5}$



(1) Time and Frequency Characterization, Estimation, and Prediction of Precision Clocks and Oscillators page 121-128 NIST Technical Note 1337 "Characterization of Clocks and Oscillators"

Time Keeping Standard Benchmark Framework

If we model the time error to include both the systematic effect and the asymptotic power noise contribution the time keeping model takes the form[1]

$$X(t) = x_0 + y_0 t + ½ D_{pe} t^2 + k_0 + k_1 t^{0.5} + k_2 t + k_3 t^{1.5}$$

Where

$X(t)$ is the accumulated time error since t_0

X_0 is the initial time error at time t_0

y_0 is the initial time error at time t_0

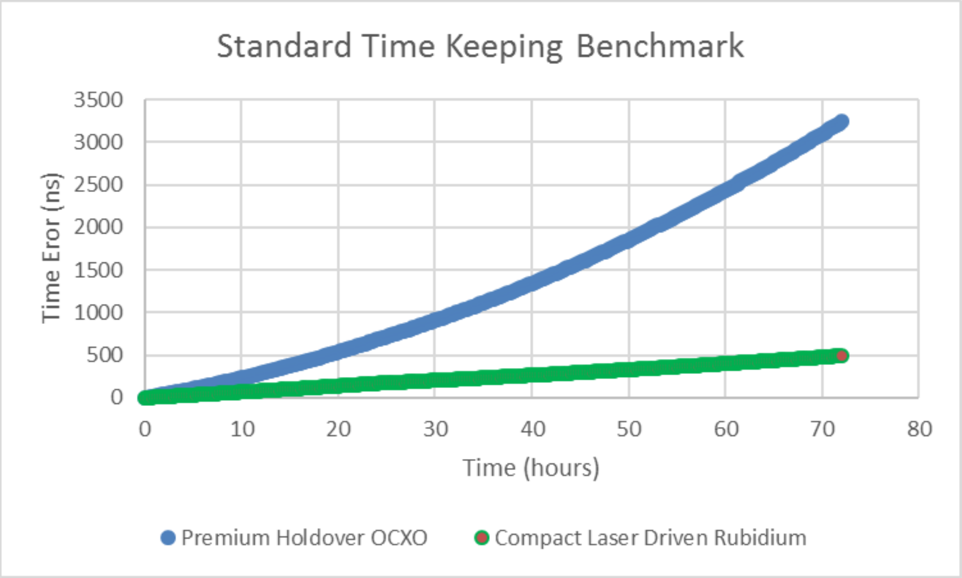
D_{pe} is the frequency drift prediction residual error

k_0 k_1 k_2 k_3 are the coefficients associated with asymptotic noise processes say for the 95% confidence interval

(1) Note Flicker PM noise is not included as it is assumed not significant

Time Keeping Standard Benchmark Framework Example

- The Benchmark Standard is applied to two precision oscillators. The parameters are known for these two oscillators as they are Microsemi components.
- The analysis assumes benign but not constant temperature. The benign environment assumed to have a diurnal temperature variation of 2.8C. Thermals modulate the oscillator output. Thermal sensitivity (ppb/C) maps the thermal environment to frequency.
- For this model the diurnal is assumed to systematic although a fraction will be thermal noise in practice.
- The drift prediction error is a key component and is based on what is achievable based on good reference inputs (such as line of sight) GNSS.



Summary

- Principle role of oscillator is timekeeping during holdover
- Oscillators also play a key role is setting time in a noisy reference environment (with intentional or unintentional jamming/spoofing)
- Traditional oscillator specifications need to be mapped to the timekeeping application.
- The framework for a standard time keeping benchmark based on well established clock models was presented
- Standards work needs to move forward to adopt a technically sound time keeping benchmark