IEEE 1588 Timing Performance Under Environmental Stress in O-RAN Nodes

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SiTime®

Agenda

- Impact of oscillator performance in PTP time error
- O-RAN O-RU test setup and results
- Oscillator selection

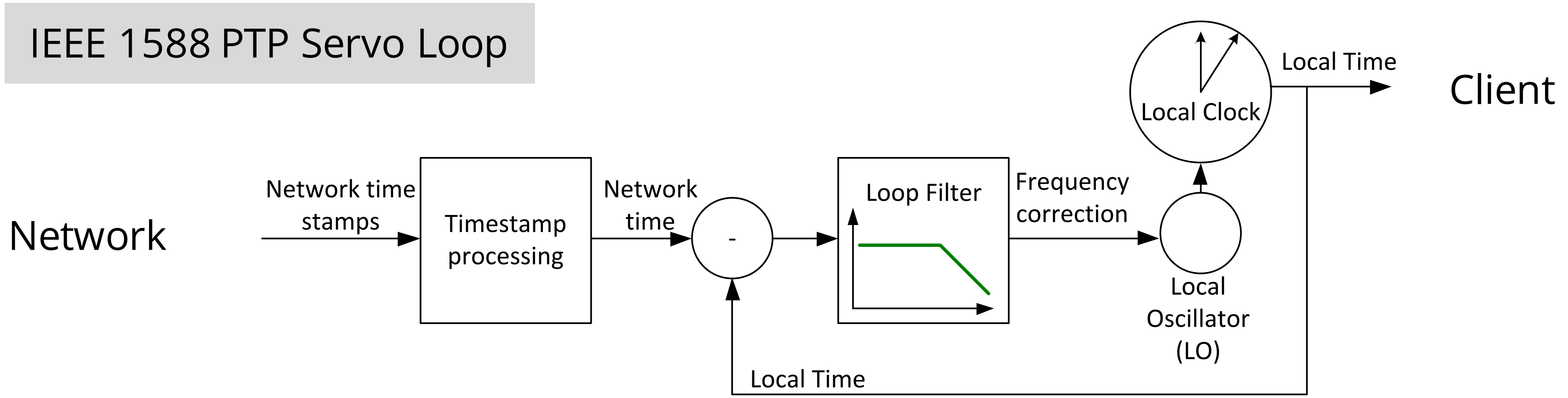
Proper Oscillator Selection is Necessary for Time/Phase Compliance

- Applies to all use cases with tight time/phase requirements
- Ensure quality by-design
  - Oscillator Performance
  - Proper loop filter design
  - Temperature profile
- Avoid over-specifying oscillator
  - OCXO vs TCXO
  - Higher cost, power, size, startup time, etc.

Key Standards Impacted by Oscillator Performance

- Network requirements
  - ITU-T G.8271.1 – Full timing support (FTS)
  - ITU-T G.8271.2 – Partial timing support (PTS)
  - O-RAN-WG4.CUS.0-v08.00 – Open fronthaul interfaces
- Clock specifications
  - ITU-T G.8273.2 – T-BC and T-TSC with FTS, variable temperature
    - dTE_L MTIE = 40, 40, ffs and ffs ns p-p for class A, B, C and D, respectively
  - ITU-T G.8273.4 – T-BC & T-TSC with PTS
    - dTE_L = 50 ns p-p assisted
    - dTE_L = 200 ns p-p unassisted
  - O-RAN Appendix H, O-DU time-error budget analysis
    - $|dTE_{L+H}|$ = ±45 ns and ±57 ns for class A and B, respectively

IEEE 1588 – Lower Oscillator ΔF/ΔT Enables More Accurate Time Stamps



- In locked state, reducing loop-bandwidth…
  - filters more noise from input (network), but
  - increases noise from LO
- The optimal setting balances the two noise contributions.
- Thus, using a **lower-noise LO** enables the bandwidth to reduce, filtering more network noise, enabling
  - **more accurate time stamps**, or
  - **additional hops** in fronthaul network
- dF/dT performance is dominant oscillator noise source

Thermal Profile Greatly Influences PTP Time Error

ITU-T G.8263 – Timing characteristics of packet-based equipment clocks

Where variable temperature testing is required, it should be conducted using the temperature profile shown in Figure IV.1.

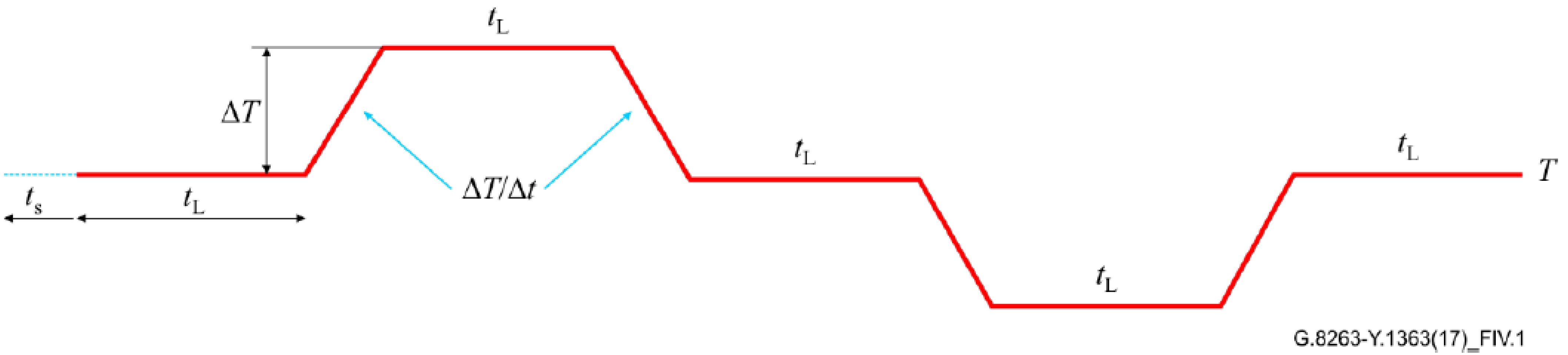
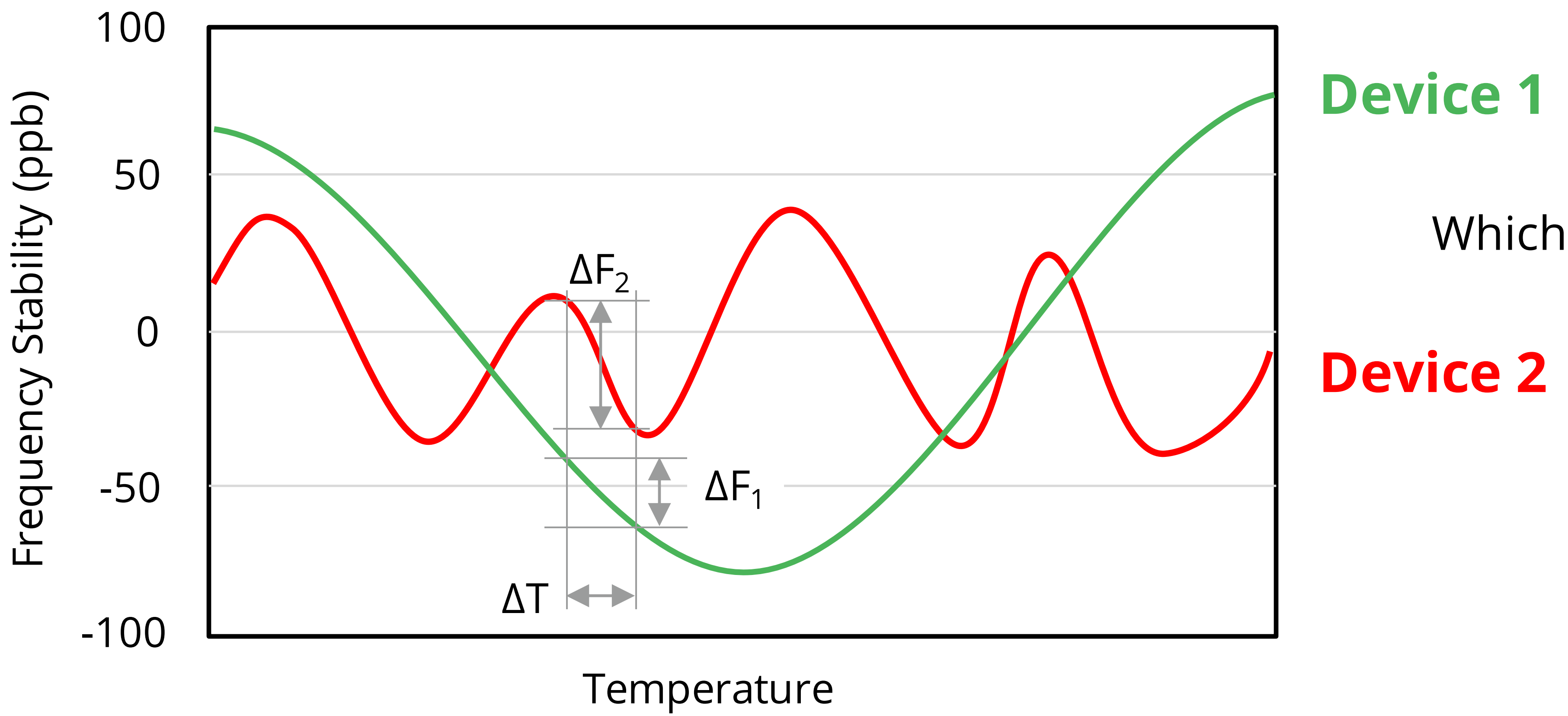


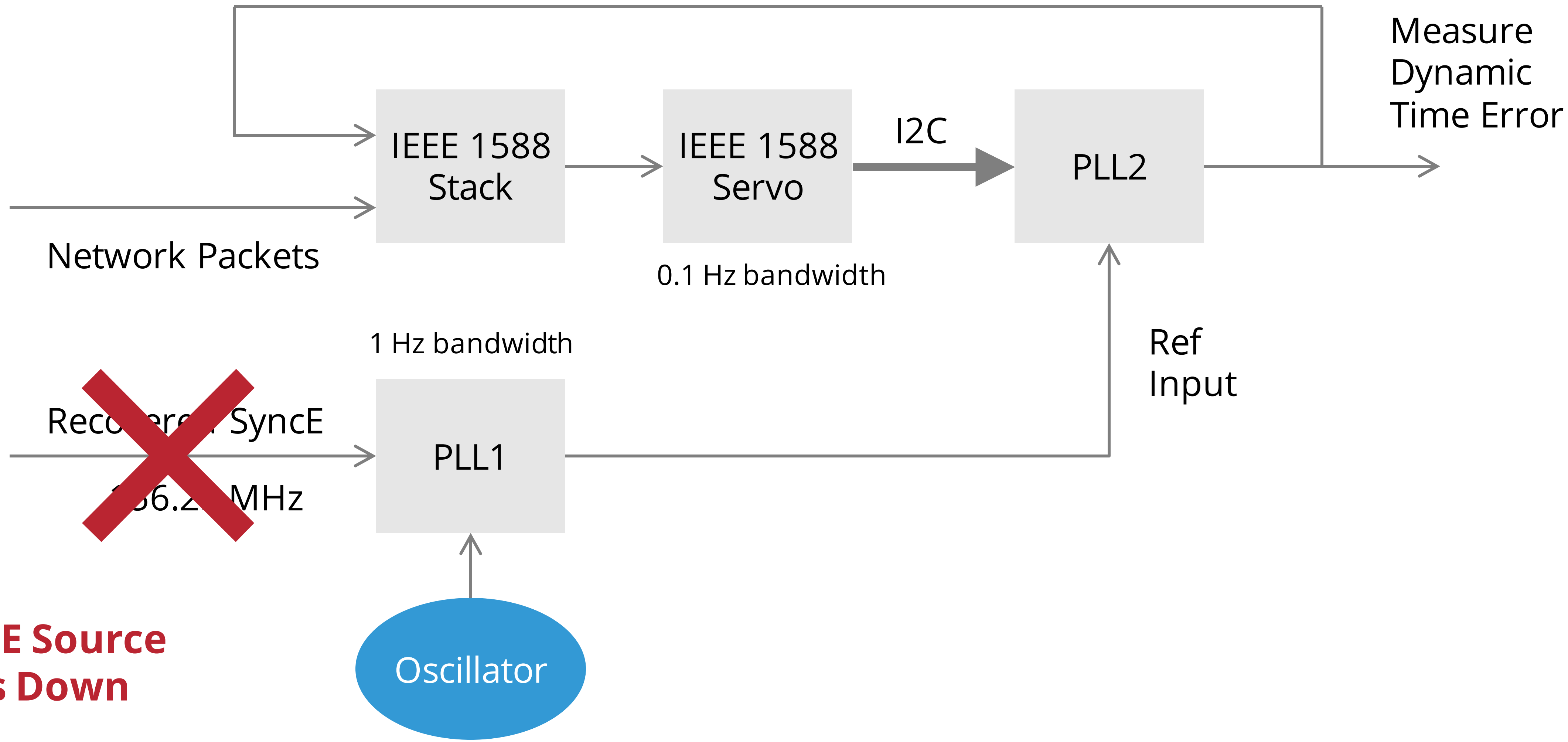
Figure IV.1 – Temperature profile

Smoother Frequency Change Matters More than Rated Lifetime Stability



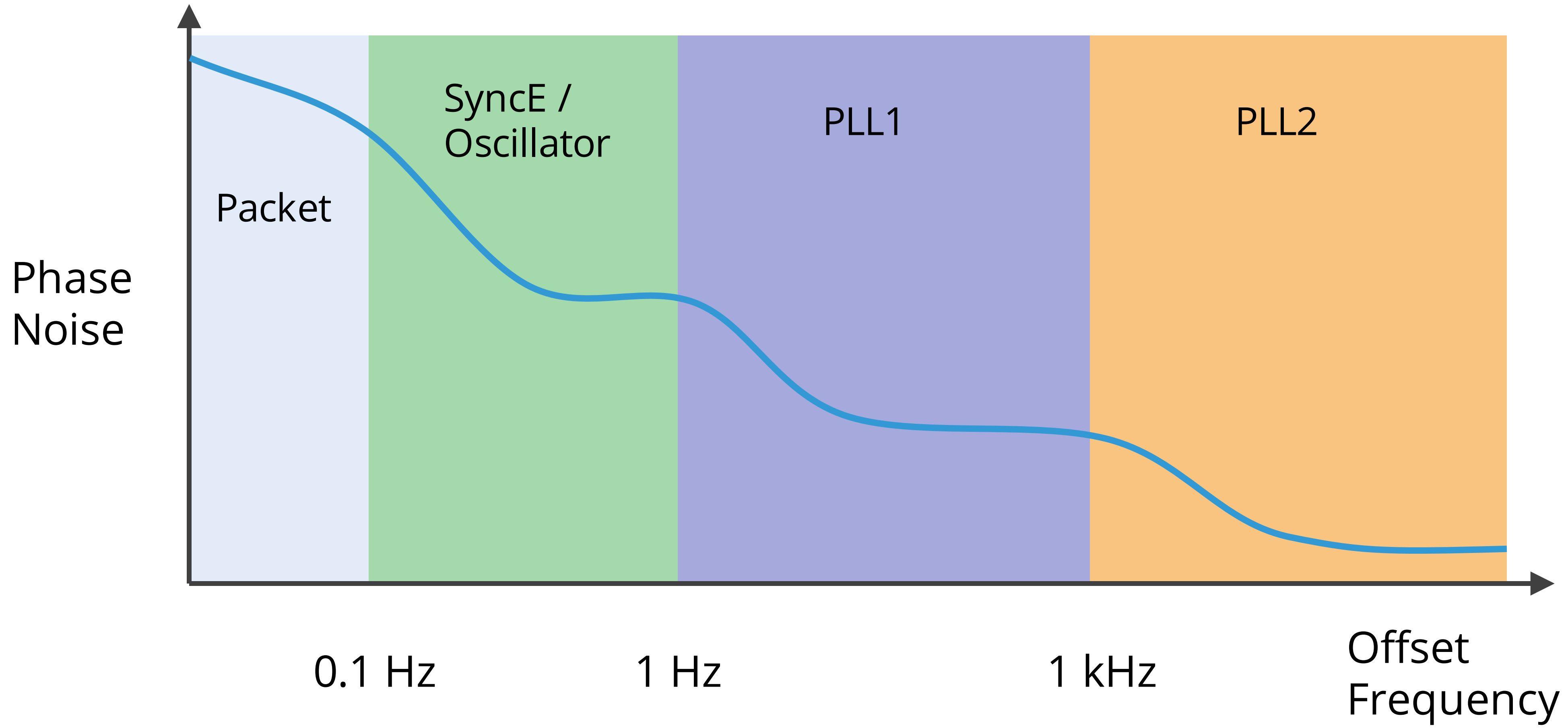
Which device is “better”?

O-RU Test Setup – G.8275.1 Full Timing Support

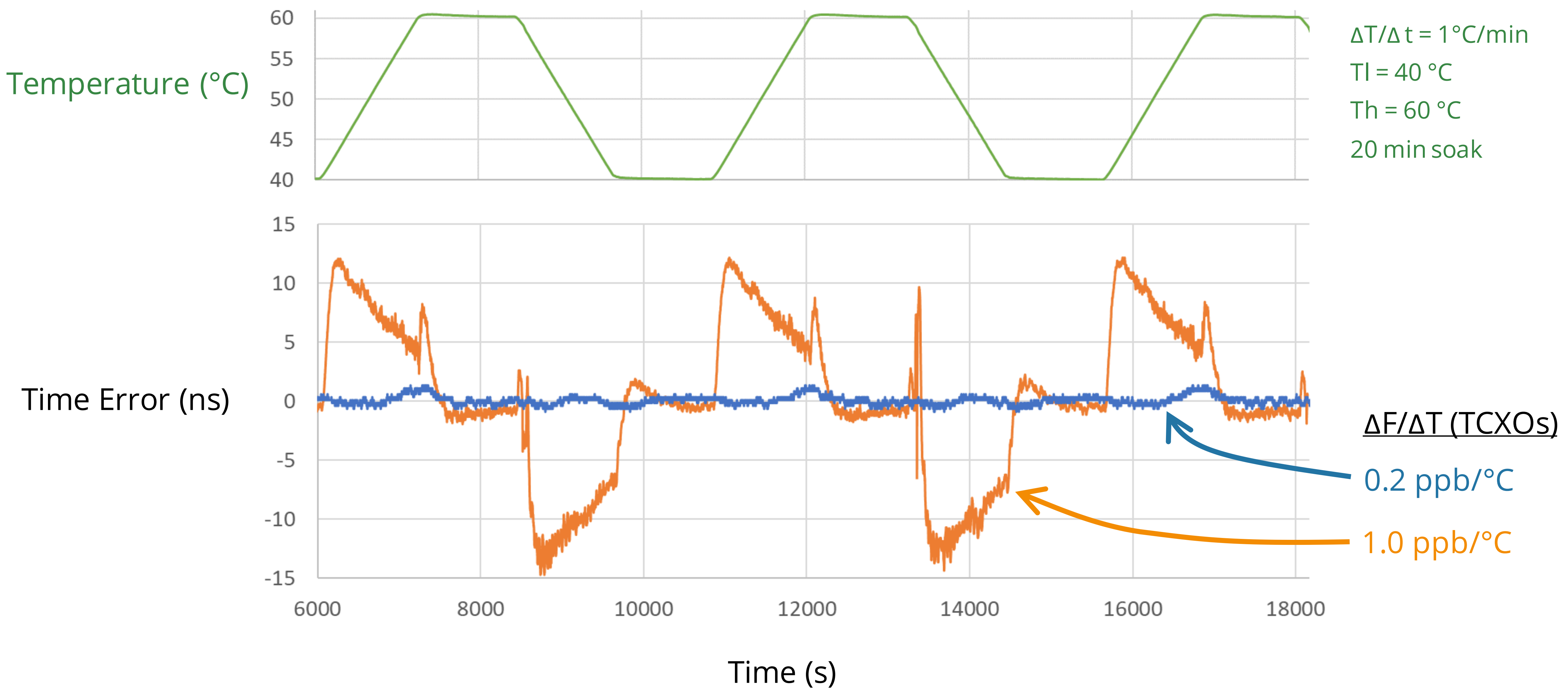


SyncE Source Goes Down

Oscillator Contribution to Phase Noise



Thermal Profile Converts Oscillator ΔF/ΔT to PTP Time Error



Lower Oscillator ΔF/ΔT Increases Network Tolerance to Noise

- O-RAN Appendix H, O-DU frequency/time error budget analysis

Table H.2.1 : O-DU Frequency Error Budget

O-DU class	A	B
• Consider O-DU PTP/SyncE master frequency error budget = …………….. (refer to note 1 in clause 11.3.2.1)	±15 ppb	±5 ppb
• Consider O-RU total frequency error budget based on O-DU frequency error budget taken away from the 3GPP air interface (±50ppb) budget = …………	±35ppb	±45ppb
• Further split the O-RU total frequency error budget as follows as an example of O-RU design:		
○ FFO (O-RU subordinate clock) =………………………………………………… ○ FFO (O-RU internal additive frequency noise) = ………………………	±21ppb ±14ppb.	±27ppb ±18ppb
• With FFO (O-RU subordinate clock) value and filter BW = 75mHz, based on ITU-T SG15 Q13 C1730, Geneva, 5 – 16 December 2011: ***FFO (in ppb) = ±2*π * $\|dTE_{L+H}\|$(in ns)*filter BW(in Hz)*** ⇨ FFO (O-RU subordinate clock) = 2π * $\|dTE_{L+H}\|$ * filter BW ⇨ $\|dTE_{L+H}\|$ = FFO (O-RU subordinate clock)/(2π * filter BW) = ……………………… which is the max allowed network noise limit (between O-DU UNI and O-RU UNI) guaranteeing FFO at the output of the O-RU filter with 75mHz BW. Note that after this network noise limit is agreed in O-RAN spec, it is up to O-RU vendor implementation to select filter BW (not necessarily 75mHz) to trade off the internal budget split between FFO (O-RU subordinate clock) and FFO (O-RU internal additive frequency noise) as long as the O-RU total frequency error budget (±35ppb or ±43ppb) is still met.	±45ns	±57ns

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- $|dTE_{L+H}|$ = ±45 ns and ±57 ns for class A and B, respectively
- Servo loop bw assumed to be 75 mHz, but left to O-RU implementor
- Lower ΔF/ΔT, lower bw → filters more PDV, can increase unfiltered network noise limit

Real-world Conditions Require Environmentally-resilient Oscillators

More Important

Real-world Use Case	Environmental Stressor	Critical Oscillator Parameter
Radio traffic variation, bursts	Thermal gradient (PCB)	Frequency over temperature slope (ΔF/ΔT)
Rain shower, cold front	Thermal gradient (ambient)	
Wind, passing vehicles (train, etc.)	Shock, vibration	*g* (acceleration) sensitivity
Lose upstream frequency ref	-	Allan deviation, holdover

Less Important

Parameter
Banner datasheet spec for Lifetime Freq-over-Temp Stability (e.g. ±100 ppb) – Not applicable

Conclusion – Proper Oscillator Selection Improves Network Performance

- No impact on PTP time error
  - An oscillator's rated lifetime frequency stability
- Great impact on PTP time error
  - Oscillator ΔF/ΔT
  - Loop configuration
  - Thermal profile greatly
- Reduce ΔF/ΔT to
  - increase time accuracy or
  - increase # of fronthaul hops

Thank You