Modeling Oscillator Performance

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Kishan Shenoi
kshenoi@qulsar.com

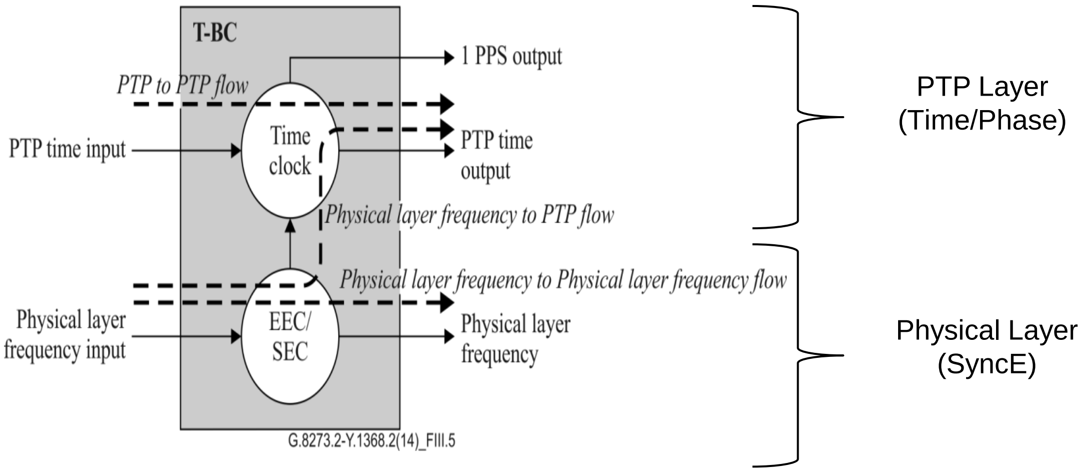
QULSAR

Qulsar, Inc.
90 Great Oaks Blvd, Suite 204
San Jose, CA 95119

Presentation Outline

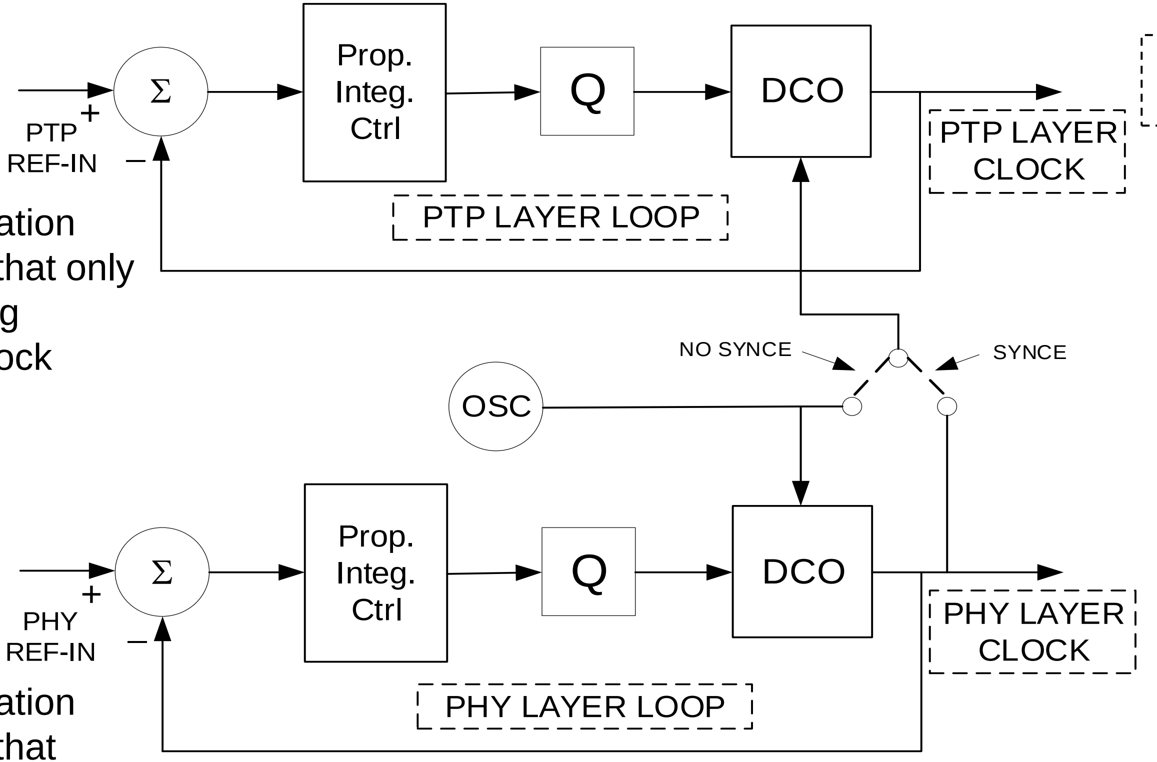
- Simulation and experimental results for the effect of temperature variation on noise generation in a Telecom Boundary Clock (T-BC)
- Hybrid Clock arrangement for a T-BC
  - Dual Loop configuration
  - Simplified Model of the dual loop arrangement
  - DSP models for the dual loop arrangement
- Temperature testing/simulation considerations
  - Temperature variation profile
  - Oscillator behavior (measured): frequency offset versus temperature
- Results of simulation and measurement
- Concluding Remarks

Hybrid Clock (PTP plus SyncE)



- Model of Hybrid clock (G.8273.2) showing the physical layer (SyncE) feeding into the time layer (PTP)

Simplified view of a Hybrid loop for T-BC



Bandwidth:
0.05Hz < BW < 0.1Hz (G.8273.2)

DCO: Digitally Controlled Oscillator

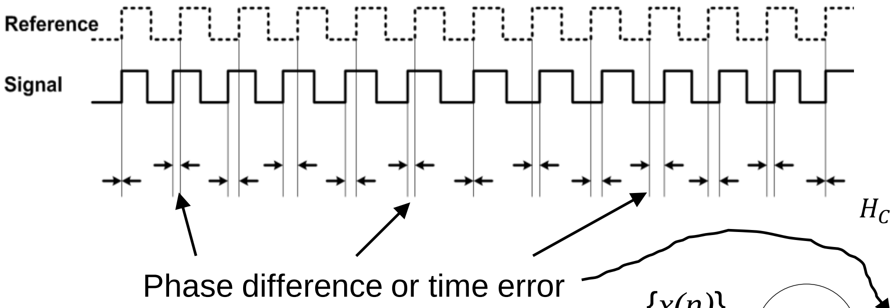
"Q": Quantization determines granularity of DCO control

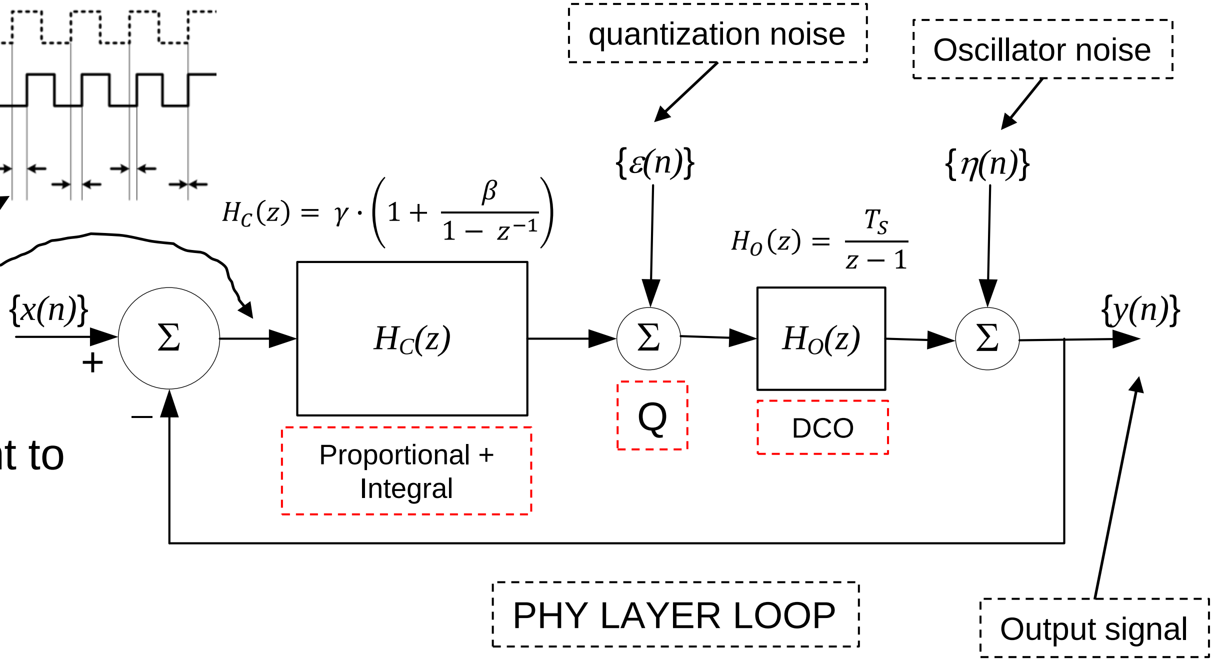
Bandwidth:
1Hz < BW < 3Hz (G.8262.1)
1Hz < BW < 10Hz (G.8262)

Noise Generation Test implies that only time-stamping introduces clock noise

Noise Generation Test implies that there is no input clock noise

DSP view of a locked loop (Time Domain)





Update interval = T_S is equivalent to sampling interval

Oscillator also adds noise $\{\eta(n)\}$ composed of:

- Random component (typically white-FM)
- Effect of aging
- Effect of temperature

PTP LAYER LOOP IS MATHEMATICALLY SIMILAR

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Analysis of the DSP based Locked Loop

$$H_{xy}(z) = \frac{\gamma T \cdot [(1+\beta)z - 1]}{z^2 - [2 - \gamma T \cdot (1+\beta)]z + (1 - \gamma T)}$$

Transfer Function from input (x) to output (y)

$$H_{\varepsilon y}(z) = \frac{T \cdot [z - 1]}{z^2 - [2 - \gamma T \cdot (1+\beta)]z + (1 - \gamma T)}$$

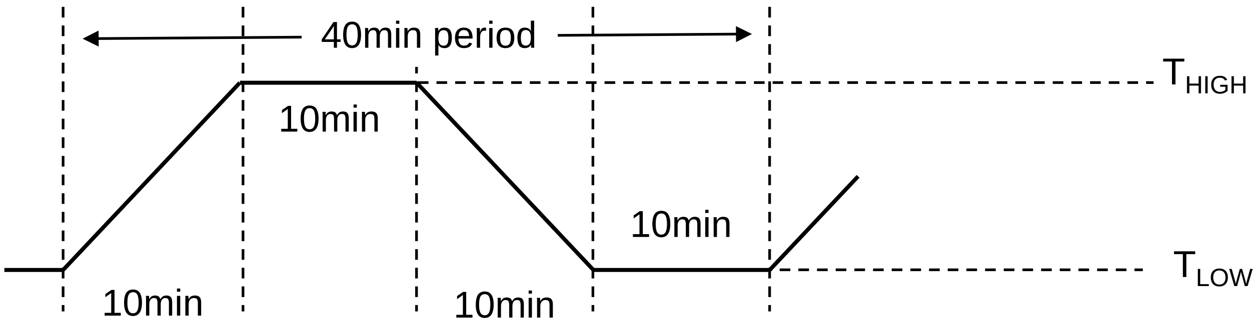
Transfer Function from quantizer (ε) to output (y)

$$H_{\eta y}(z) = \frac{z^2 - 2z + 1}{z^2 - (2 - \gamma T \cdot (1+\beta)) \cdot z + (1 - \gamma T)}$$

Transfer Function from oscillator (η) to output (y)

- From input to output is low-pass; from oscillator to output is high-pass
- T : sampling interval (loop update interval)
- Time-series simulation achieved by:
  - Implementing transfer functions as difference equations
  - Creating suitable excitation signals $\{x(n)\}$ for input and $\{\eta(n)\}$ for oscillator noise and $\{\varepsilon(n)\}$ for quantization noise (if included in simulation)

Temperature Variation Profile



- Temperature is changed in the following periodic pattern:
  - Start at temperature = TLOW
  - 1 deg-C/min positive ramp for 10min
  - Steady at T_{HIGH} for 10min
  - 1 deg-C/min negative ramp for 10min
  - Steady at T_{LOW} for 10min
  - Repeat
- Four temperature ranges considered: (0,10); (10,20); (20,30); (30,40)

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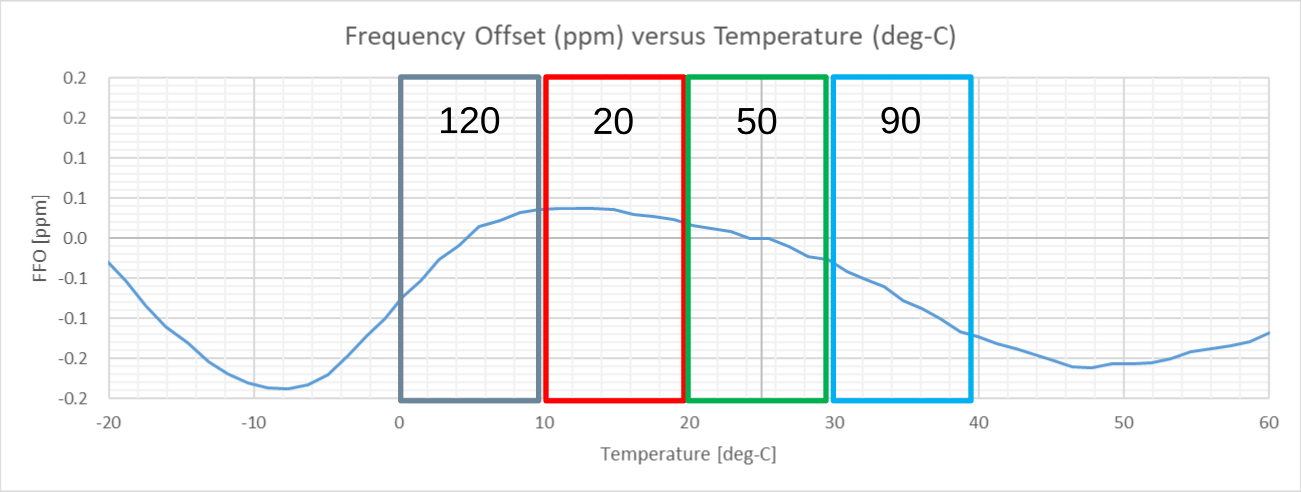
Frequency Offset versus Temperature



- Measured characteristic of oscillator used in the experiments
- Frequency offset normalized to 0 at temperature of 25 deg-C
- Experiments considered 4 zones of 10 deg-C width
- Peak-to-peak FFO in range indicated (in ppb)

Testing Methodology (G.8273)

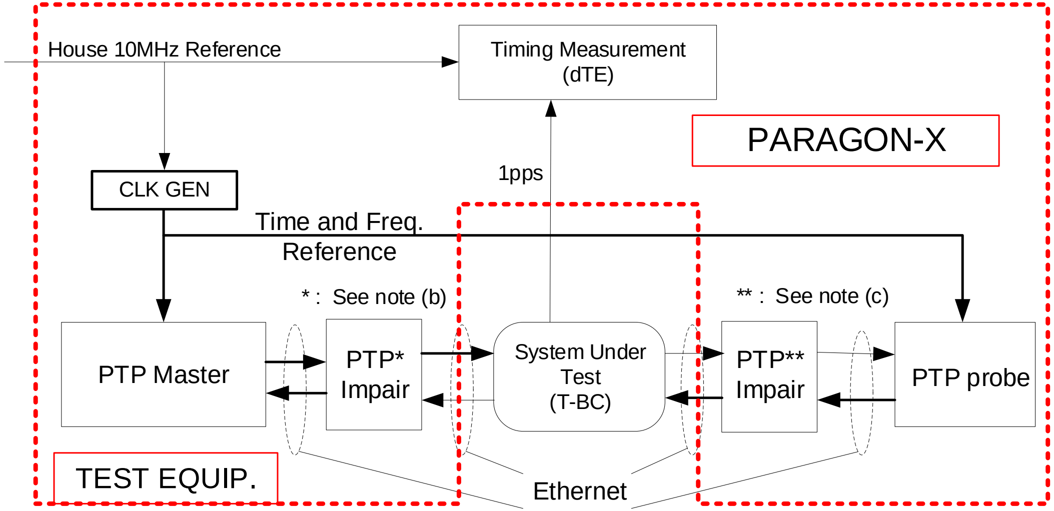


Figure extracted from G.8273

- Timing measurements done entirely with Paragon-X; some analysis done off-line with TimeMonitor Analyzer
- Noise Generation Tests imply no impairment introduced by Paragon-X for either PTP layer or PHY Layer (SyncE)

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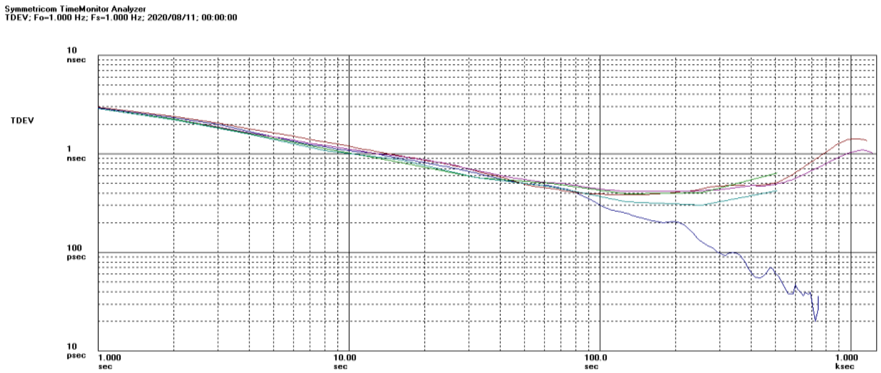
Simulation of Hybrid Loop

PHY BW = 10Hz		PHY BW = 3Hz		
PTP: 0.05Hz	PTP: 0.1Hz	PTP: 0.05Hz	PTP: 0.1Hz	
0.22ns	0.32ns	0.23ns	0.31ns	0 – 10 deg-C
0.23ns	0.31ns	0.23ns	0.31ns	10 – 20 deg-C
0.22ns	0.31ns	0.23ns	0.31ns	20 – 30 deg-C
0.22ns	0.31ns	0.22ns	0.31ns	30 – 40 deg-C
0.22ns	0.32ns	0.22ns	0.32ns	0 – 40 deg-C

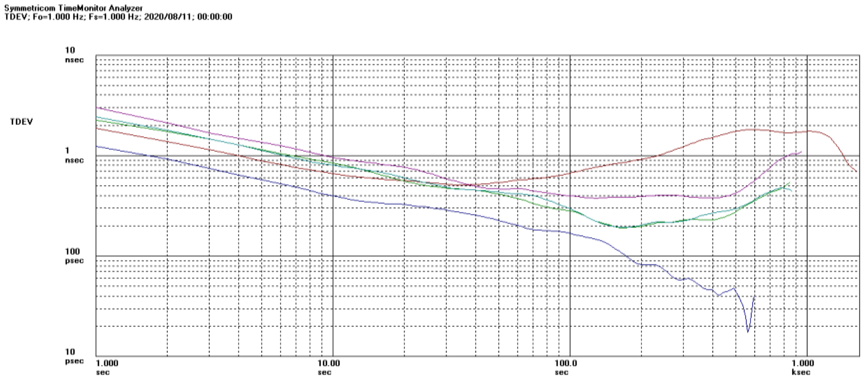
Observation:
The bandwidth of PHY Layer is large enough to render the oscillator temperature variation moot (when SyncE present)

- Bandwidth choices: 3Hz and 8Hz for PHY Layer; 0.05Hz and 0.1Hz for PTP Layer
- Time-stamp granularity (in PTP loop): 8ns
- Oscillator variation derived from measured values of frequency-offset as function of temperature
- ***Calculated parameter*: standard deviation of PTP Layer time error**

Experimental Results



Without SyncE



With SyncE

- Unit Under Test : Class-B T-BC with external oscillator that is in the temperature chamber
- Blue curve is for constant temperature (baseline)
- Without SyncE the behavior is roughly the same with and without temperature variation
- With SyncE we observe the effect of all time-stampers being syntonized

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Concluding Remarks

- Digital Signal Processing (DSP) models are very useful for enabling time-domain simulation – Z-domain transfer functions are very easily converted into difference equations
- Simulation is an effective tool to determine whether temperature related frequency offset of an oscillator will be a significant contributor to noise generation
  - Significantly reduces the time taken to get a result (e.g. 1 minute of compute time versus 2hrs of experiment)
  - Can support “what if” scenarios for variable bandwidths and different time-stamp granularities

Thank You

Questions, comments, suggestions?

kshenoi@qulsar.com