QULSAR™

Precise time. Synchronized.

Regarding Simulation Models in Clocks

ITSF 2017

Warsaw, November 2017

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Outline of Presentation

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- The underlying premise:
  - Clock Recovery as a Closed Loop System
  - Time-series simulation (allows time-dependent factors)
- Simulating effect of temperature variation of oscillator
  - Oscillator noise sequence as function of temperature gradient (R), temperature coefficient (G), and ramp duration (T_R)
  - Time error for different ramp durations with normalized temperature slope ($G \cdot R = 1$ ppb/s)
- Concluding Remarks

Simplified view of a locked loop

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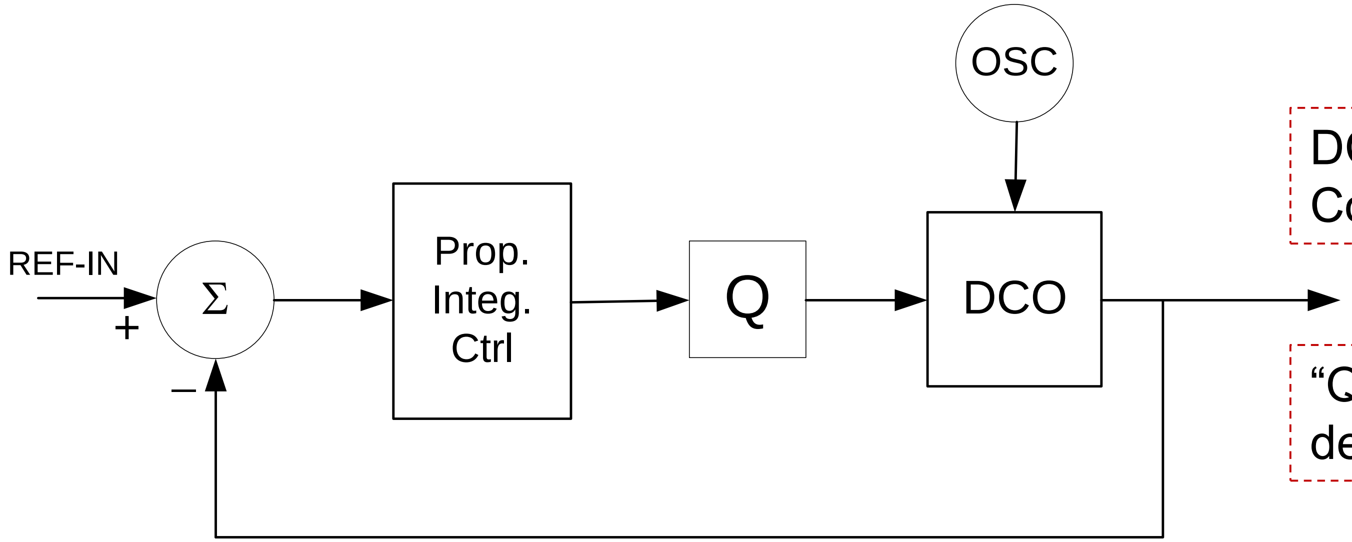
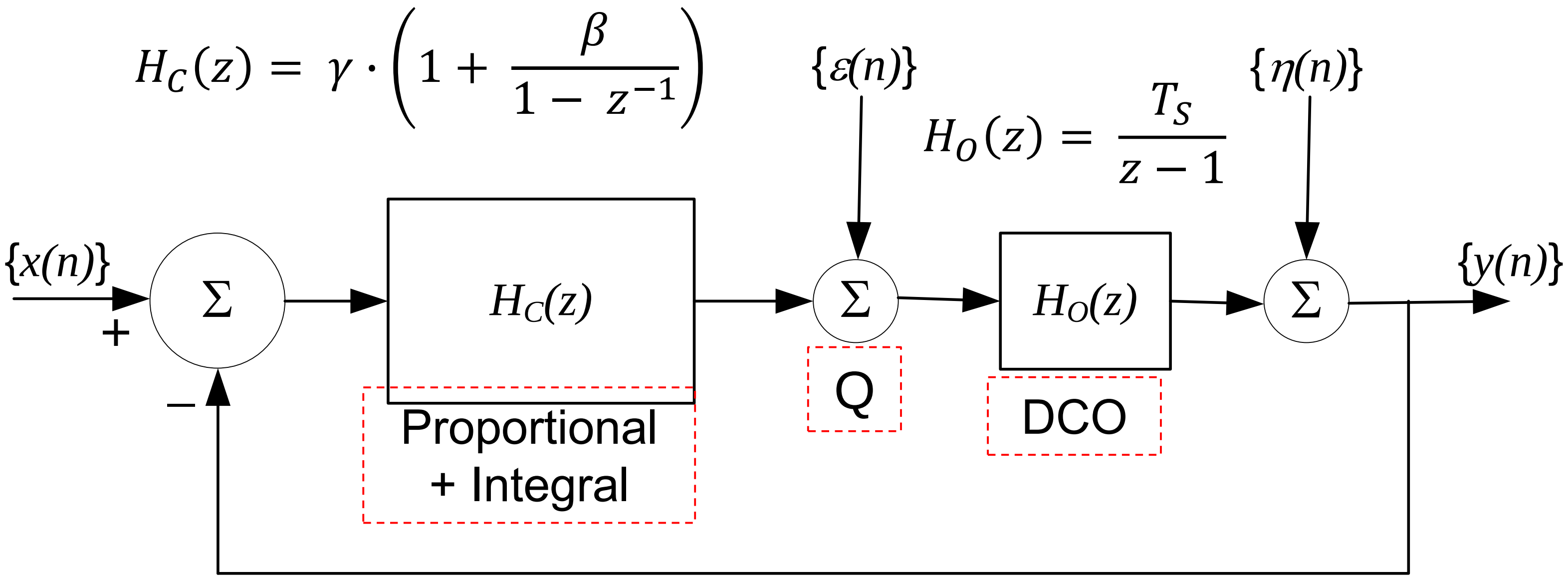


DCO: Digitally Controlled Oscillator

“Q”: Quantization determines granularity

- Locked Loops accept a reference signal
- An error is generated by comparing the output to the reference
- A suitable control algorithm (typically proportional + integral) generates a control value
- The DCO control is a quantized version of the ideal control value

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

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*)

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

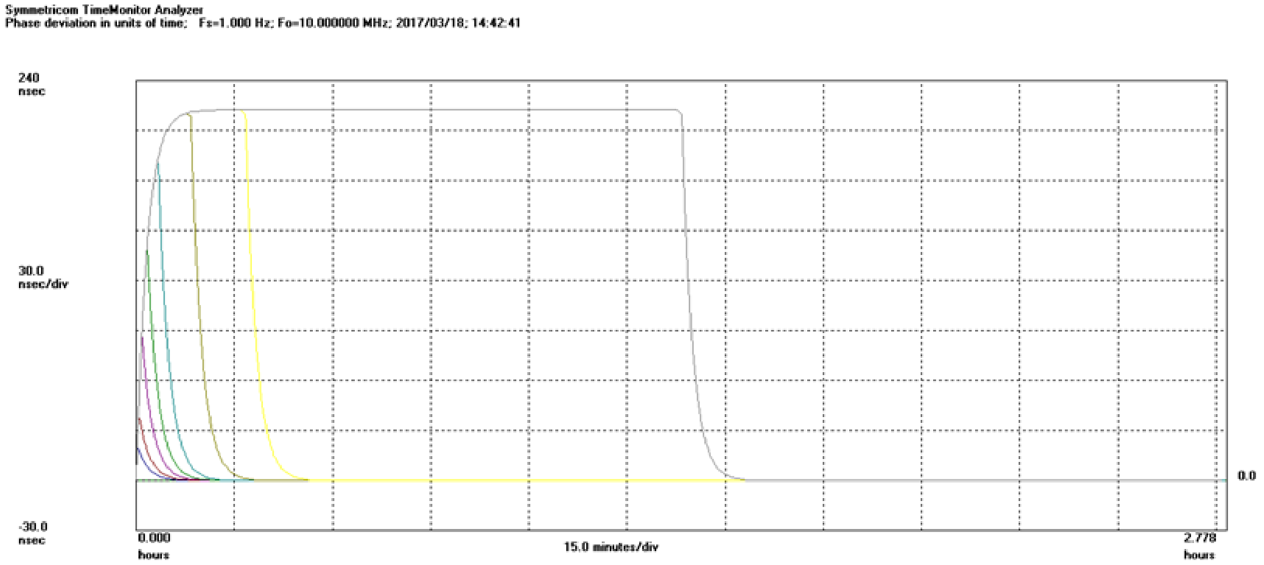
Transfer Function from oscillator (η) to output (*y*)

- 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 {η*(n)*} for oscillator noise and {ε*(n)*} for quantization noise (if included in simulation)

Example of loop parameters

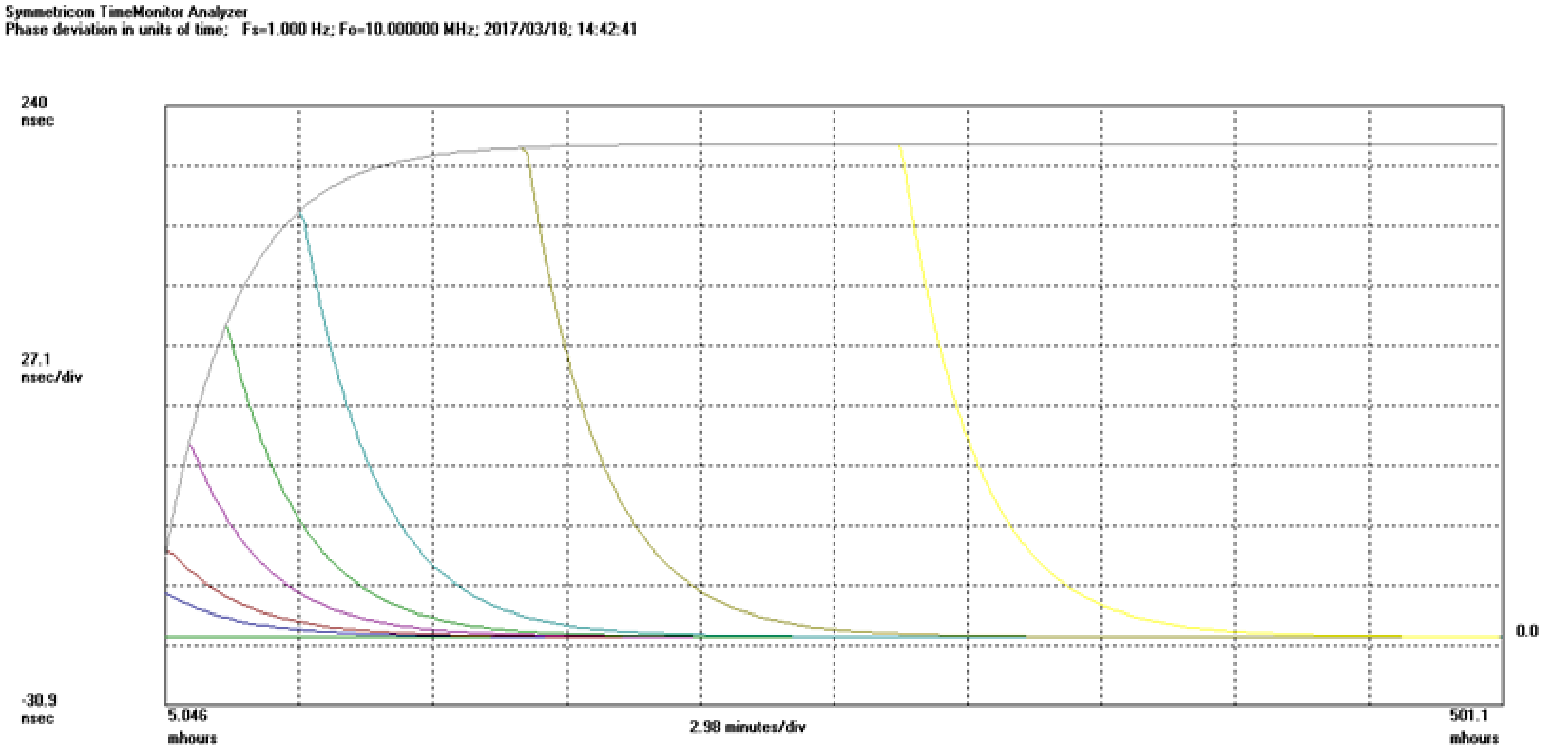
- Typical loop filter:
  - 3dB frequency = 0.1Hz; gain peaking = 0.2dB
  - Sampling frequency = 1Hz
  - $\gamma T = 0.45$; $\beta = 0.01$
- Simulating effect of temperature variation of oscillator
  - Temperature variation : ramp with slope R = 0.5° /min
  - Temperature coefficient : G = 1ppb / ℃
  - Ramp duration : T_R (min)
  - Oscillator frequency is 0ppb prior to ramp start and ($G \cdot R \cdot T_R$)ppb at ramp end and remains constant therefrom
  - For convenience: normalize to $G \cdot R$ = 1ppb/s – time error scales proportionally with $G \cdot R$
- Subsequent results provided for different ramp durations

Time error for different ramp duration



- Ramp duration T_R considered: 10s, 20s, 50s, 100s, 200s, 500s, 1000s, and 5000s.
- NOTE: because the PTP layer is “locked” to its reference, the time error does go back to “zero”
- Worst case time error increases with T_R up to a point. The plateau is proportional to $G \cdot R$
- There is a plateau because of the second-order nature of the (time-layer) loop

Time error for different ramp duration



- Zoom into first ~30min (~2000s)

Example:

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Ramp duration (T_R) (seconds)	Max time error (normalized to $G \cdot R$ = 1ppb/s) in ns	Max. time error for $G \cdot R$ = 0.025 ppb/s) in ns
10	21	0.5
20	40	10
50	87	22
100	141	35
200	193	48
500	221	55
1000	222	55
5000	222	55

- R ~ 0.5 degree_C/min; G ~ 3ppb/degree_C - $G \cdot R$ ~ 0.025ppb/s

Concluding Remarks

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- Time-series simulation is a useful tool for analyzing behavior that has a time-varying aspect (e.g. temperature variation effect on oscillator)
- The second-order nature of the loop limits time-error for temperature ramps (subject to some assumptions)
- Acknowledgement…. Francois Maurice (Nokia) provided several insights as to next steps and suggestions to adapt the method to other situations

Questions?

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