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Impact of Oscillator Controllability on System Performance

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Outline of Presentation

- General Model of a Locked Loop
- Digital Signal Processing View of a Locked Loop
- Packet-based Clocks – An Example
- Impact of control granularity on DCO performance
- Concluding Remarks

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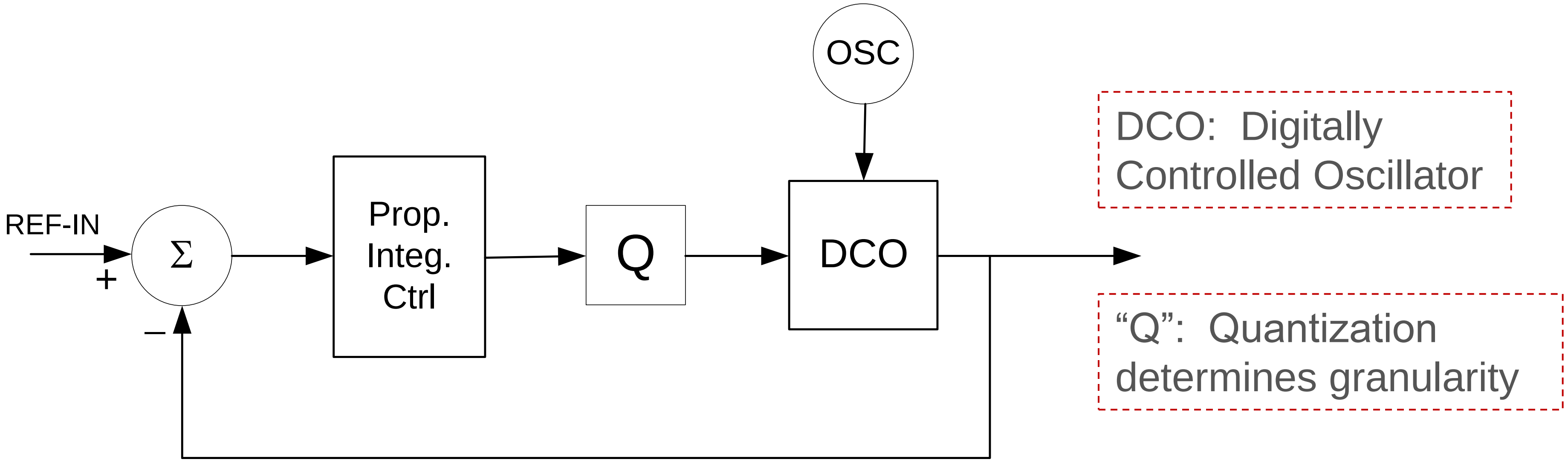
Simplified view of a locked loop



- 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

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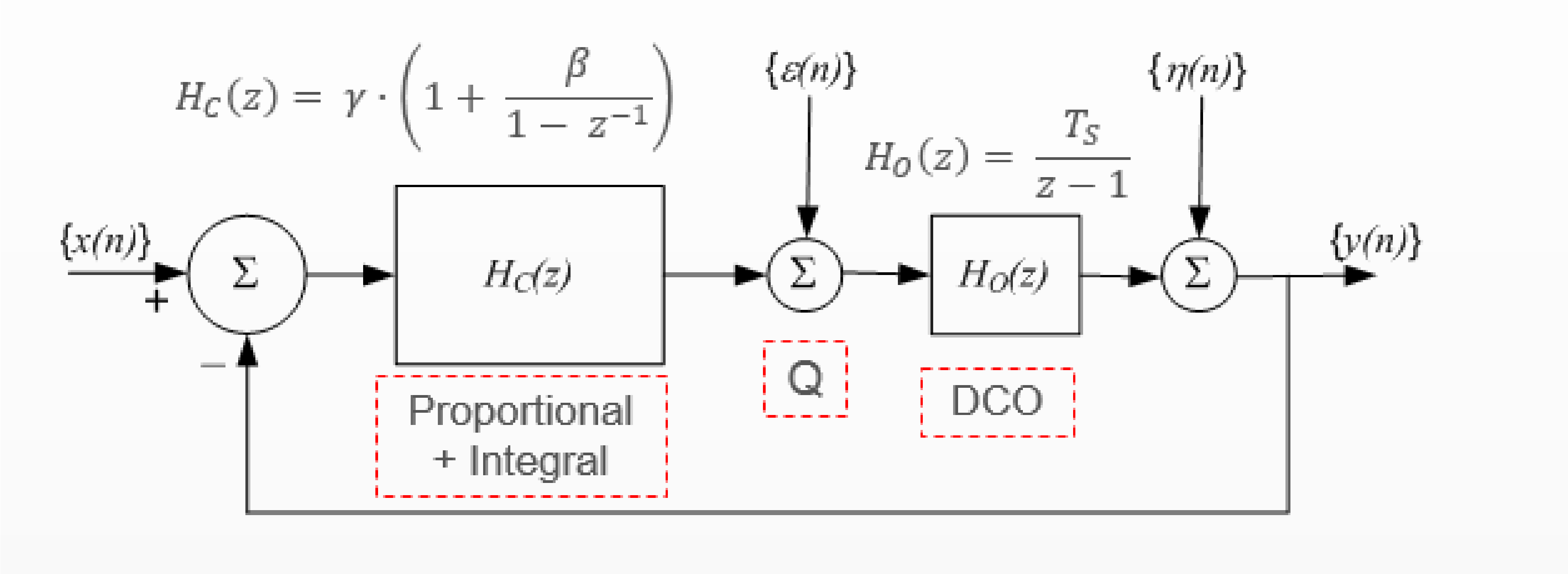
DSP view of a locked loop



- Update interval = T_S is equivalent to sampling interval
- The DCO control is a quantized version of the ideal control value
- Quantization (granularity) manifests itself as a noise sequence $\{\varepsilon(n)\}$
- Oscillator also adds noise $\{\eta(n)\}$ (typically white-FM)

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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) — Low Pass

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

Transfer Function from quantizer (ε) to output (y) — "Bandpass Like"

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

Transfer Function from oscillator (η) to output (y) — High Pass

- Transfer functions determine the behavior of the loop
- From input to output the response is low-pass
- From oscillator to output the response is high-pass
- White quantization noise manifests as white-noise-FM (random-walk phase) in clock output outside the loop bandwidth
- T : sampling interval (loop update interval)

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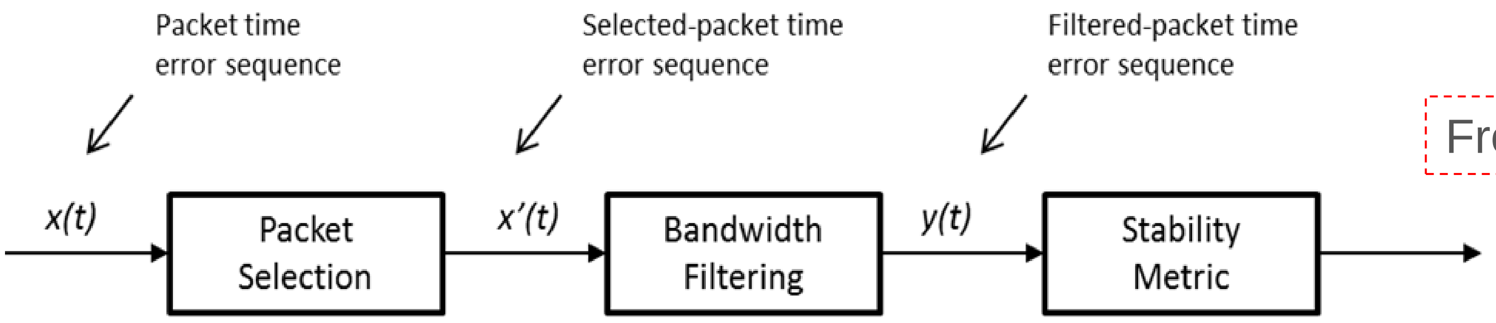
Example – Packet-Based Clock



From G.8260

- “Bandwidth Filtering” achieved with locked loop
- Assume packet selection provides a reference value every 100s (T = 100s)
- With γT = 0.275; β = 0.05; the 3-dB bandwidth is 0.5mHz with 0.2dB gain peaking
- The effective noise-gains for the input reference (noise) and the quantization (noise) are:

$$\sum_k |h_{xy}(k)|^2 = 0.16$$

$$\sum_k |h_{\varepsilon y}(k)|^2 = 2.1 \times 10^4$$

Granularity amplification!

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Granularity Requirement

- Viewpoint #1 (Input Noise)
  - Assume reference input noise (PDV post selection) standard deviation is typically of the order of 1us (1×10^{-6})
  - Assume quantization noise effect is one order of magnitude less than the noise in the reference
  - Then quantization noise standard deviation should be less than 0.28×10^{-9} or **280 ppt**

- Viewpoint #2 (Holdover)
  - In holdover, the granularity of the DCO affects time error in holdover. To hold 1us in 100,000s (~1day) granularity must be less than 1.0×10^{-11} or **10 ppt**

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Granularity Requirement

- Viewpoint #3 (TDEV Performance)
  - Output performance is defined by TDEV mask. Assuming T = 100s and factor of 10 “margin”,

$$\sigma_{\varepsilon} < \left(\frac{1}{10}\right) \cdot \frac{TDEV(\tau = 100s)}{\sqrt{2.1 \times 10^{4}}}$$

  - Example: Fig.2 in G.8262 (EEC Option-1), allowed TDEV at 100s is ~6.4ns. This limits granularity (standard deviation) to ~4.4×10^{-12} or **4.4 ppt**

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Concluding Remarks

- DCO Granularity is important when implementing DSP based locked loops
- An approach to analyzing the constraints on DCO granularity is provided
- Typical granularity requirement is between 200 ppt and 4 ppt

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Questions?

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