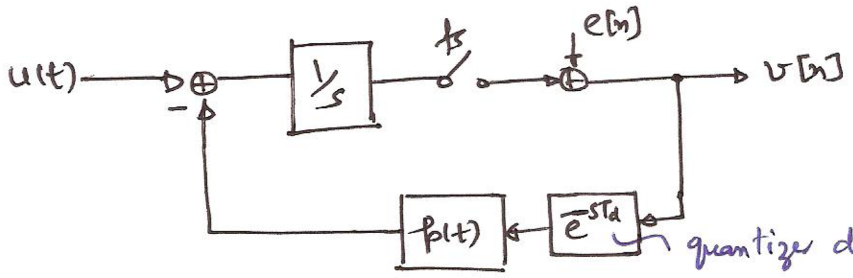
Excess loop-delay in CT-DSMs

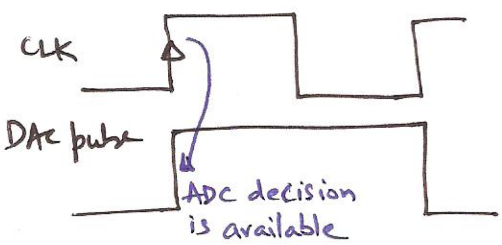
Non-idealities → Quantizer delay



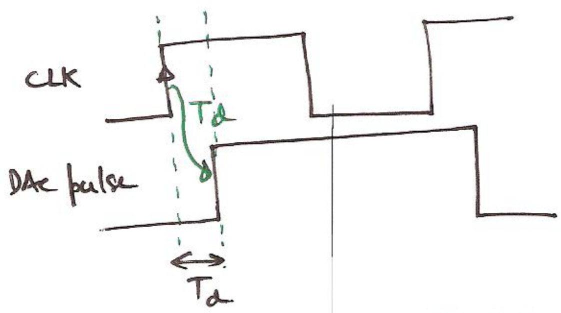
$f_s = 1Hz$

quantizer delay of T_d, $0 < T_d < 1$

Ideal (No delay) case

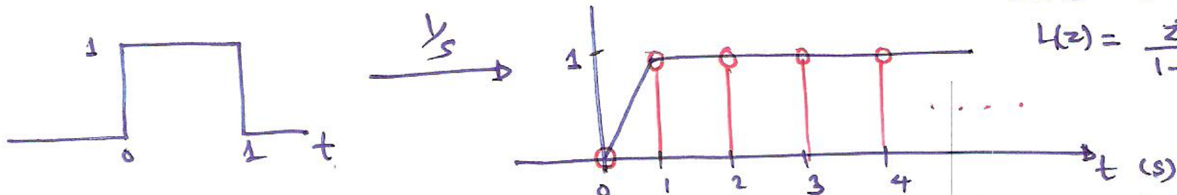


Real case (with quantizer delay)



⇒ More delay in the loop ⇒ NTF will be affected as L(z) changes.

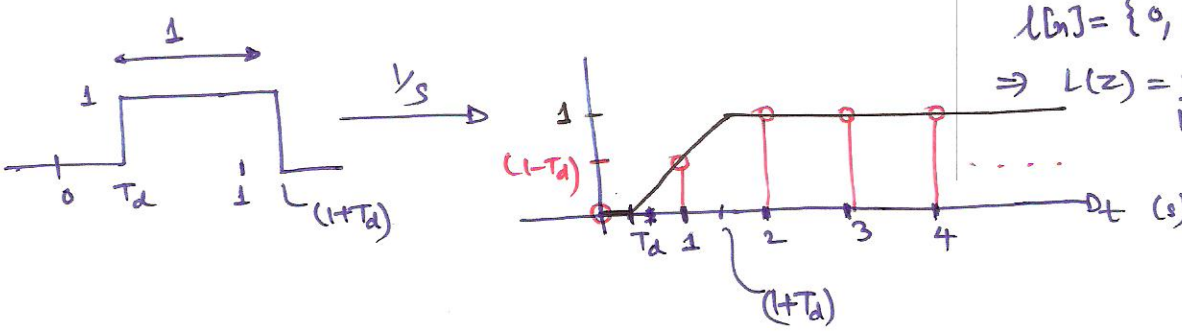
Ideal case:



$l[n] = \{0, 1, 1, \ldots\}$

$L(z) = \frac{z^{-1}}{1-z^{-1}}$

with delay:



$l[n] = \{0, (1-T_d), 1, 1, \ldots\}$

$\Rightarrow L(z) = \frac{z^{-1}}{1-z^{-1}} - T_d z^{-1}$

⇒ first sample after the unit-delay (T_s) is smaller than expected. ($l[0]$ must always be equal to 0).

with ELD:

$$NTF(z) = \frac{1}{1+L(z)} = \frac{1}{1+\frac{z^{-1}}{1-z^{-1}} - T_d z^{-1}}$$

$$= \frac{(1-z^{-1})}{1-T_d z^{-1}(1-z^{-1})} = \frac{(1-z^{-1})}{1-T_d z^{-1}+T_d z^{-2}}$$

for low frequency, $z \simeq 1$, $\Rightarrow NTF(z)\big|_{z=1} \simeq (1-z^{-1})$

$\Rightarrow$ for DC input the NTF is unchanged.

- poles of the NTF are at $\frac{T_d \pm \sqrt{T_d^2 - 4T_d}}{2}$

$\Rightarrow$ As T_d increases, the poles start moving out of the unit circle.

↳ modulator becomes unstable.

↳ too much delay $\Rightarrow$ phase of the loop-response is too high

↳ loop becomes unstable.

$\Rightarrow$ As the order of the filter becomes higher, the excess loop delay (ELD) problem gets worse.

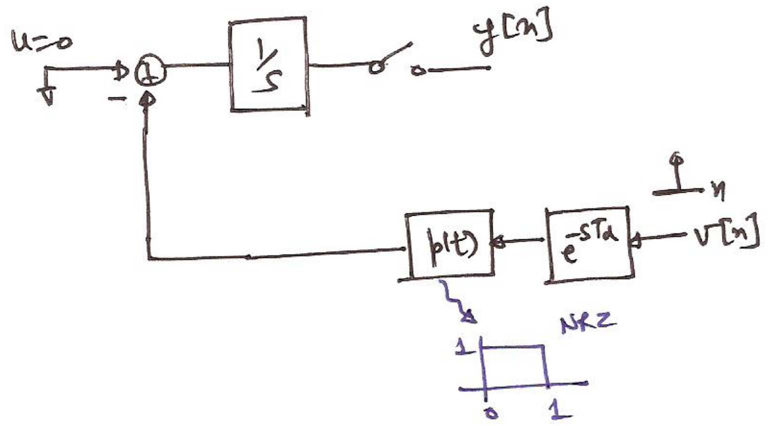
↳ amount of T_d tolerable, as the loop-order increases, decreases.

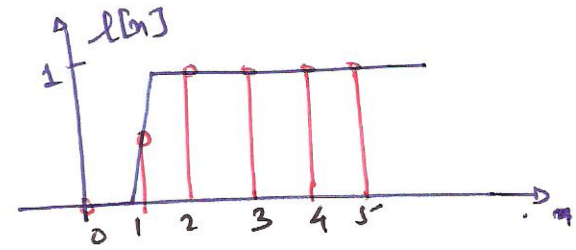
$\Rightarrow$ only one NTF zero.

↳ noise-shaping is not enhanced

↳ but the order of the modulator is increased.

- A simple fix for the first-order CT-DSM
  ↳ more complicated for higher order topologies





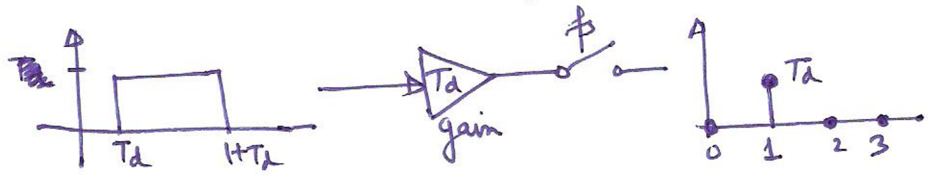
impulse response

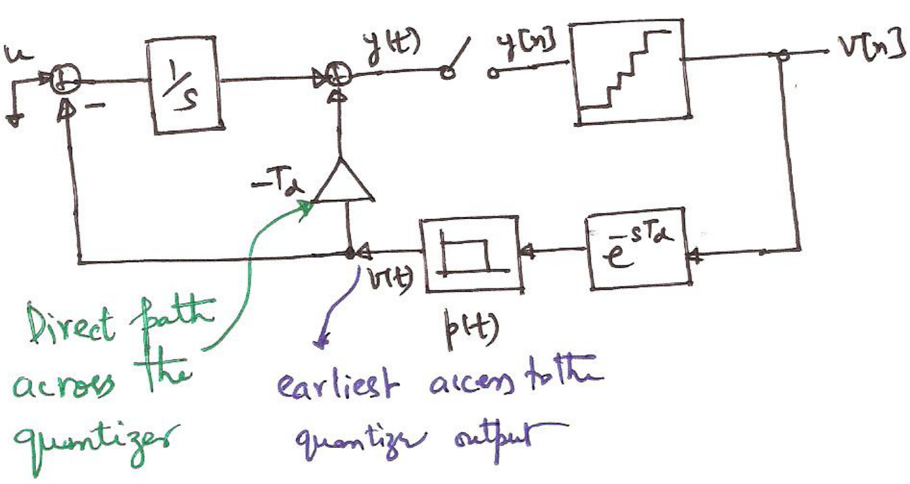
$$\frac{z^{-1}}{1-z^{-1}} - T_d z^{-1}$$

⇒ Somehow need to add $T_d z^{-1}$ to the impulse response.

⇒ Need to add a waveform which after sampling results in $T_d \cdot z^{-1}$

⇒ How about using the DAC pulse itself.
↳ many such solutions possible.

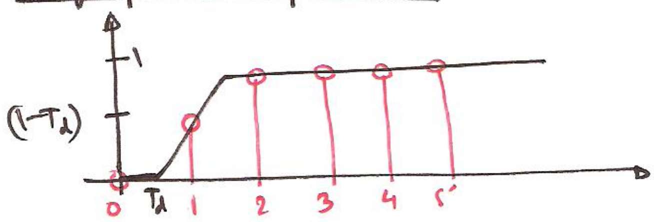




$$\Rightarrow \left(\frac{z^{-1}}{1-z^{-1}} - T_d z^{-1}\right) + T_d z^{-1} = \frac{z^{-1}}{1-z^{-1}}$$

⇒ $L_1(z)$ is fixed.

Graphical explanation:



← $y[n]$ with ELD

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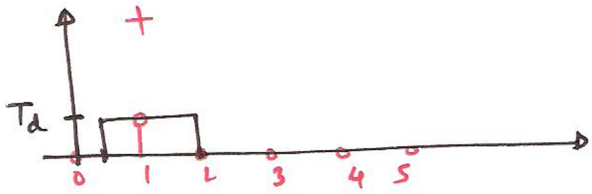

← $y[n]$ only due to the direct path around the quantizer

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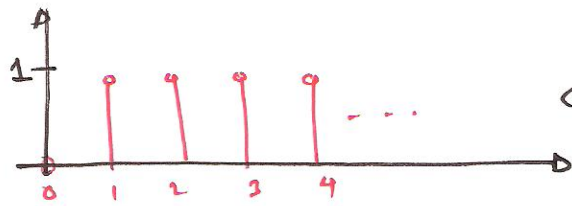

← $y[n]$ after ELD compensation.

⇒ With the excess loop delay, the amount of signal fedback to the quantizer has decreased.

↳ To fix for the delayed feedback, some amount of direct feedback is provided immediately to the quantizer input in order to stabilize the loop.

- Other way to understand the direct path is that, in order to reduce the excess phase, an LHP zero is added (direct path) to provide quick feedback and stabilize the loop.

Summary:

- If T_d becomes significant, NTF changes
  - ↳ feedback is delayed → instability
  - ↳ fix by adding a direct path to provide some quick feedback. (generally $T_d < 60\%$ of T_s)

- Note that when $T_d = 0$, the direct path is unacceptable (⇒ zero delay loop)
- ELD compensation is more complicated for higher-order topologies
  - ↳ (we'll study that later)