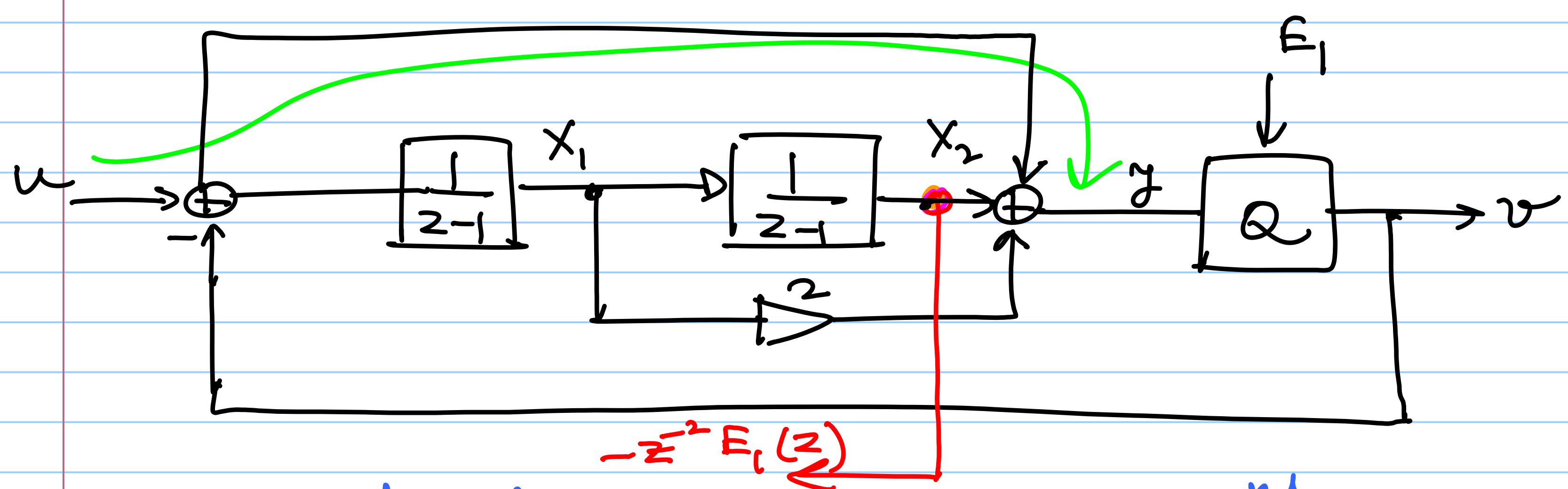
ECE 615 - Lecture 22

Note Title 3/31/2016



feedforward modulator ⇒ 2^{nd} order

$NTF = (1-z^{-1})^2$ $STF = 1$

→ $X_2 = -z^{-2} \cdot E_1(z)$ → low distortion topology

Ex. 2-2 MASH (SoSo)

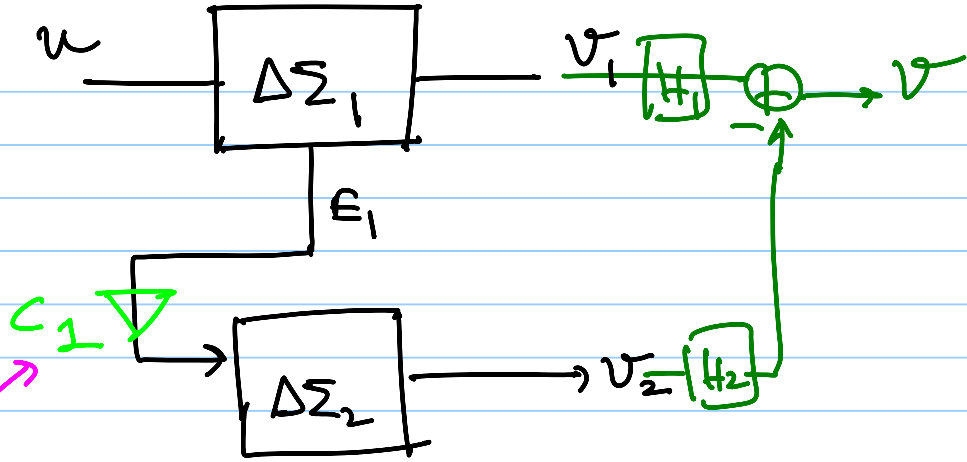
$$STF_1 = STF_2 = z^{-2}, \quad NTF_1 = NTF_2 = (1-z^{-1})^2$$

$$V(z) = z^{-4}U(z) - \boxed{(1-z^{-1})^4} E_2(z)$$

$E_1(z)$ is cancelled (ideally)

$$NTF(z) = (1-z^{-1})^4$$

↳ stability is still governed by OBG = 4.



interstage coupling coeff.

if

$|E_1|_{max} > MSA_2$

↳ instability or SNDR drop

$|E_1|_{max} \ll MSA_2$

↳ low SQNR in the 2nd modulator

* for a 2nd-order "single-bit" first stage ΔΣM, usually $c_1 = \frac{1}{4}$

* for multi-bit quantizer in the first-stage $c_1 \geq 1$

* The inverse of scaling factor (c_1) needs to be included in H_2 to cancel $E_1(z)$

$$H_1 = STF_{2,d}$$

$$H_2 = \frac{1}{c_1} NTF_{1,d}$$

$$V(z) = STF_1 \cdot STF_{2,d}\, U(z) + \underbrace{\boxed{\frac{1}{c_1} NTF_{1,d}\; NTF_2}}_{NTF} \cdot E_2(z)$$

In general:

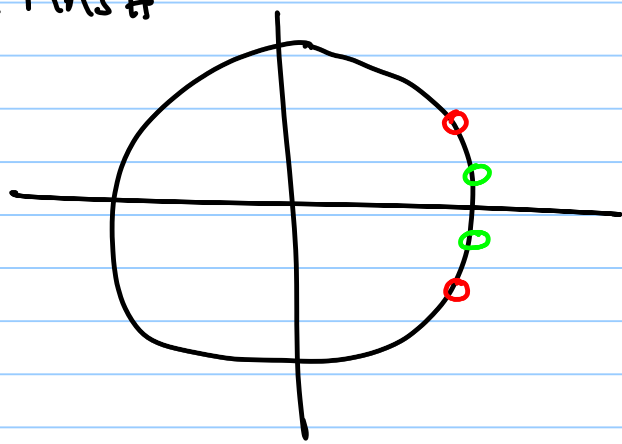
$$NTF_{casc} = \frac{(1-z^{-1})^{N_{casc}}}{\prod_{i=1}^{n} c_i}$$

In band noise

$$IBN = \frac{\sigma_e^2}{\pi}\int_0^{\pi/OSR} \frac{|NTF_1(e^{j\omega})|^2\,|NTF_2(e^{j\omega})|^2\,d\omega}{\prod_i c_i^2} = \frac{IBN_0}{\prod_i c_i^2}$$

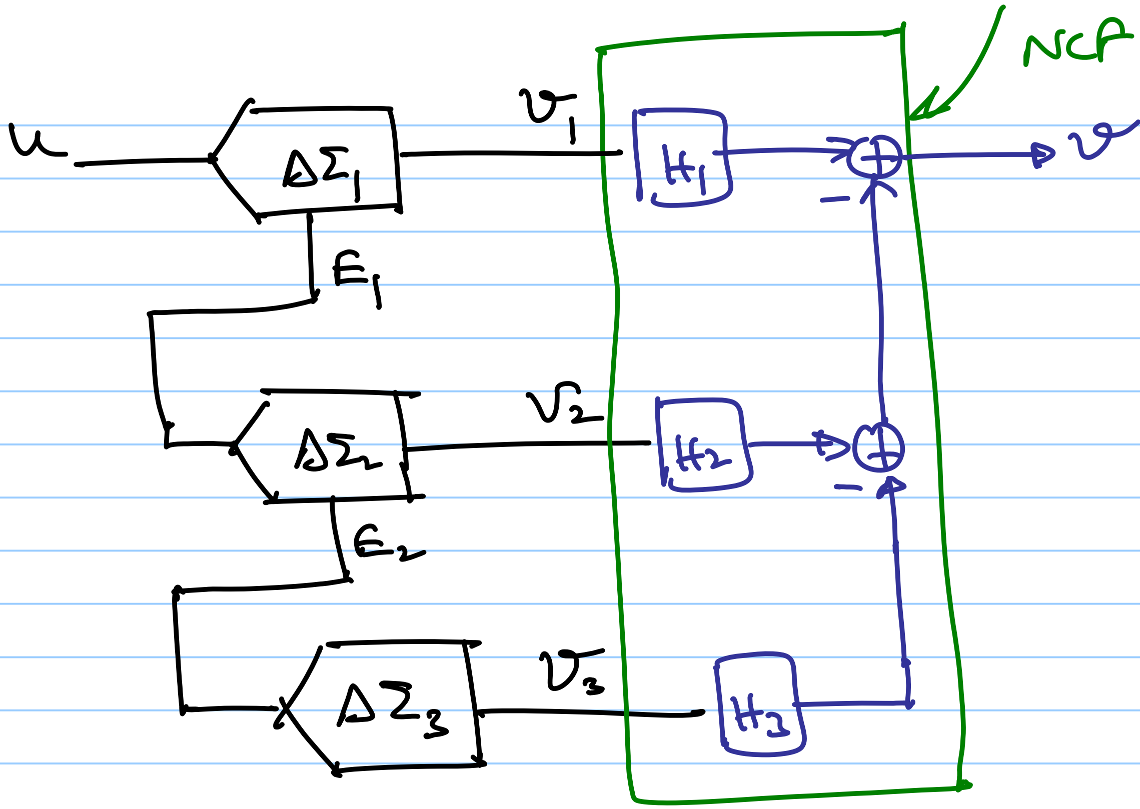
for single-bit MASH $c_i < 1 \Rightarrow IBN \uparrow \Rightarrow SQNR \downarrow$

2-2 MASH



zero pairing in MASH

↳ NCF may be more complicated.



Goal: Cancel E_1 & E_2

$$\left.\begin{aligned} H_1 \cdot NTF_1 - H_2 \cdot STF_2 &= 0 \\ H_2 \cdot NTF_2 - H_3 \cdot STF_3 &= 0 \end{aligned}\right\} \rightarrow (1)$$

If E_1 & E_2 are perfectly cancelled

$$V = STF_1 \cdot H_1 \cdot U + NTF_3 \cdot H_3 \cdot E_3$$

$H_1 = STF_2$, $H_2 = NTF_1$

$$H_3 = \frac{NTF_1 \cdot NTF_2}{STF_3}$$

$STF_3 = z^{-k}$

$$NTF = \frac{NTF_1 \cdot NTF_2 \cdot NTF_3}{STF_3}$$

2-1-1 MASH ← didn't consider c_i's

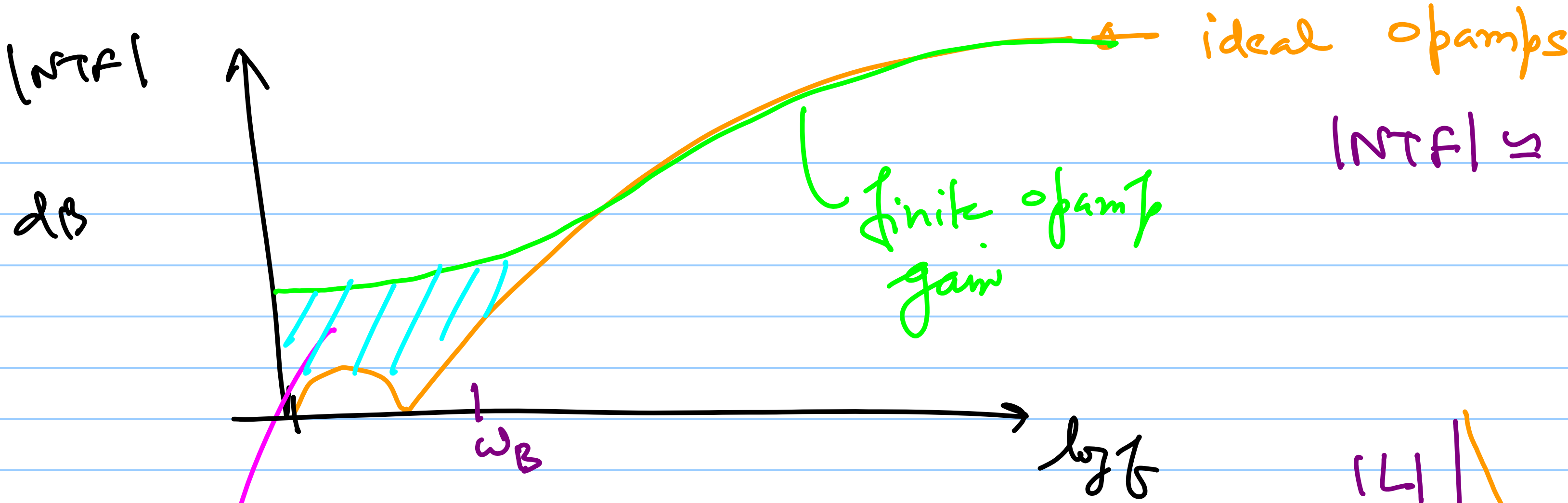
2-2-1 MASH

Analysis of Noise Leakage:

In a single-loop $\Delta\Sigma$ modulator, the issues are:

- ↳ imperfect matching of capacitors (C's)
- ↳ finite-gain of opamps
- ↳ incomplete-settling & slewing in opamps

→ These anomalies change the NTF & STF, and thus the SQNR



$$|NTF| \simeq \frac{1}{|L|}$$

loop gain

"notch filling"

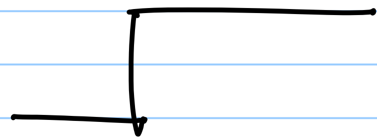
IBN ↑

SQNR ↓

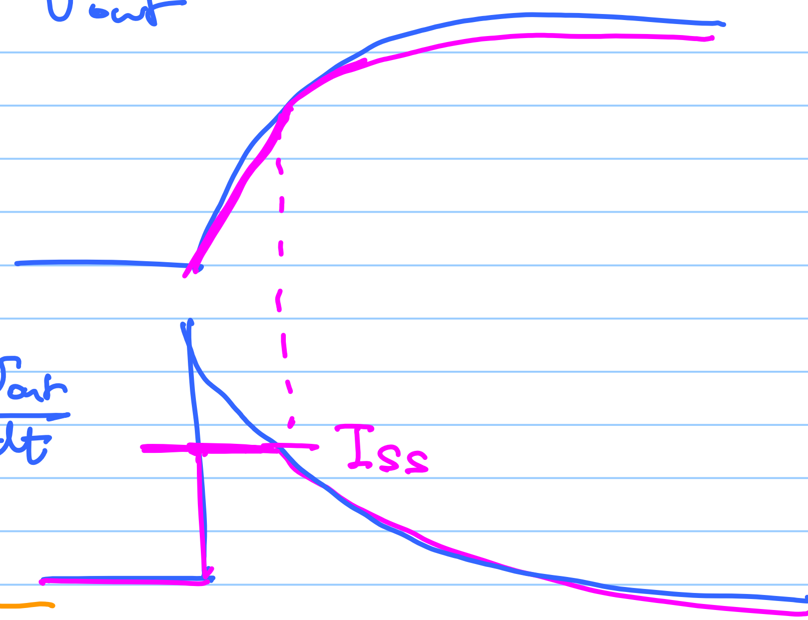
More SQNR ⇒ opamp DC gain ↑

(First order settling)

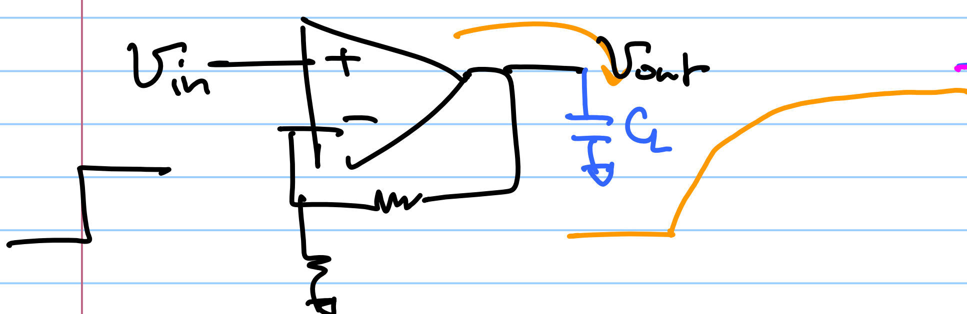
Linear settling.

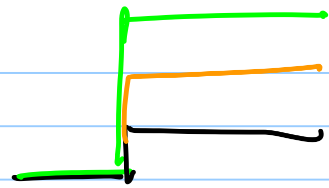


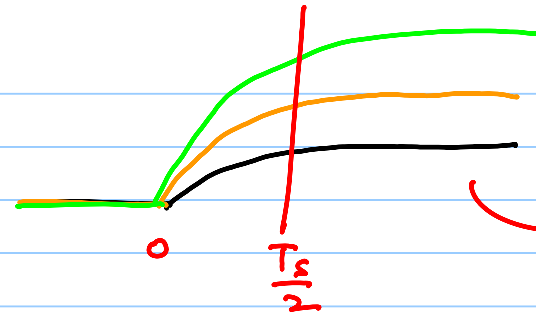
V_{out} $\qquad A_{CL}(1-e^{-t/\tau})u(t)$



$i_{out} = C_L \frac{dV_{out}}{dt}$



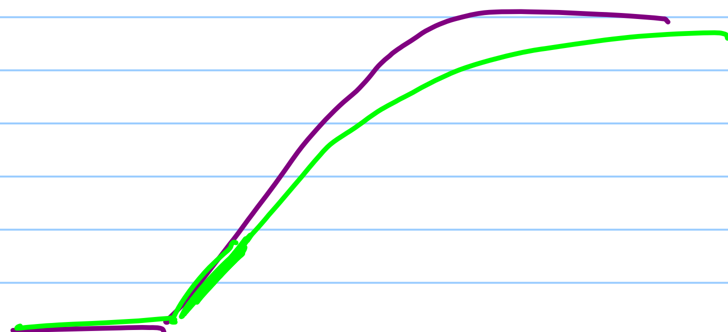


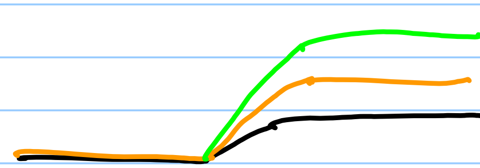


gain = ~~1~~ $1-\epsilon$

$\epsilon = \left(1-e^{-\frac{T_s/2}{\tau}}\right)$

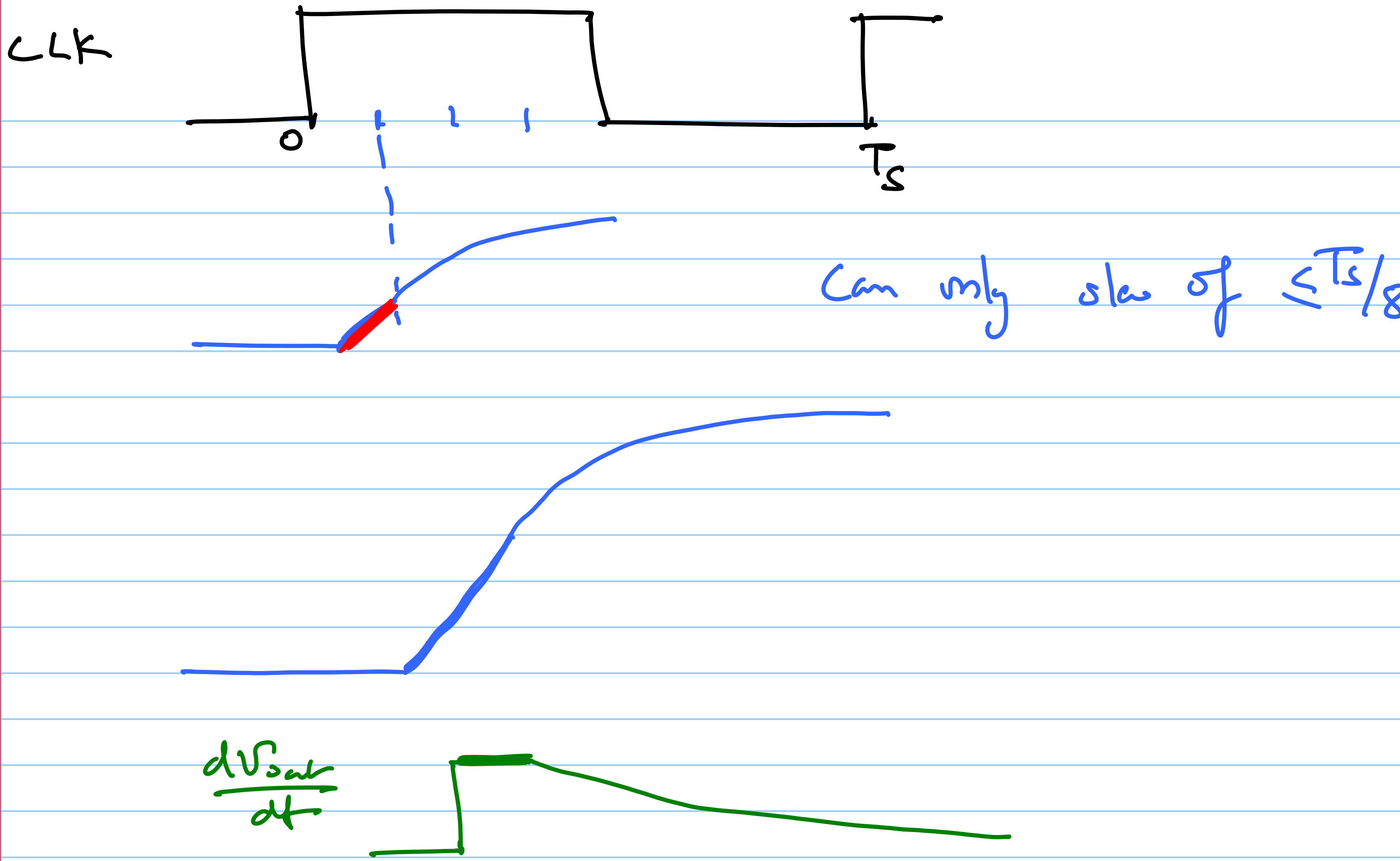
incomplete settling error





Slewing leads to non-linearity

In switched capacitors the opamp shouldn't slew for more than 25% of the settling period!



CLK
0
Ts
Can only slew of ≤ Ts/8
dVout/dt

In a MASH to cancel E_1

$$H_{1i}\, NTF_{1a} - H_{2i}\, STF_{2a} \stackrel{\Delta}{=} 0$$

$$\Rightarrow H_{e_1} = \underline{\underline{H_1}} \cdot NTF_1 - H_2 \cdot \underline{\underline{STF_2}}$$

$H_{e_1} \neq 0$ due to imperfect analog components

$|H_{e_1}| = ?$

$H_1 = STF_2 \leftarrow$ flat in the signal band

$H_2 = NTF_1$

$$|H_{e_1}| \simeq |NTF_1 - H_2| = |NTF_{1a} - NTF_{1i}|$$

ideal

leakage

$$|L_{\ell,1}| \simeq |NTF_{1,a} - NTF_{1,i}|$$

First-stage should be as close to ideal response as possible

$\hookrightarrow$ $\mathcal{E}_1$ leakage

$$I_i(z) = \frac{a}{z-1}$$

integrator gain $= C_1/C_2$

$$I_a(z) = \frac{a'}{z-p'}$$

$\leftarrow$ model for imperfect integrator

$$a' = a(1+D)$$

$$|H_{e_1}| \simeq \frac{1}{A} + z^{-1}(1-z^{-1})\left[\frac{D}{a} + (1+1/a)\frac{1}{A}\right]$$

direct noise feedthrough from E_1 to V

1st-order noise-shaper