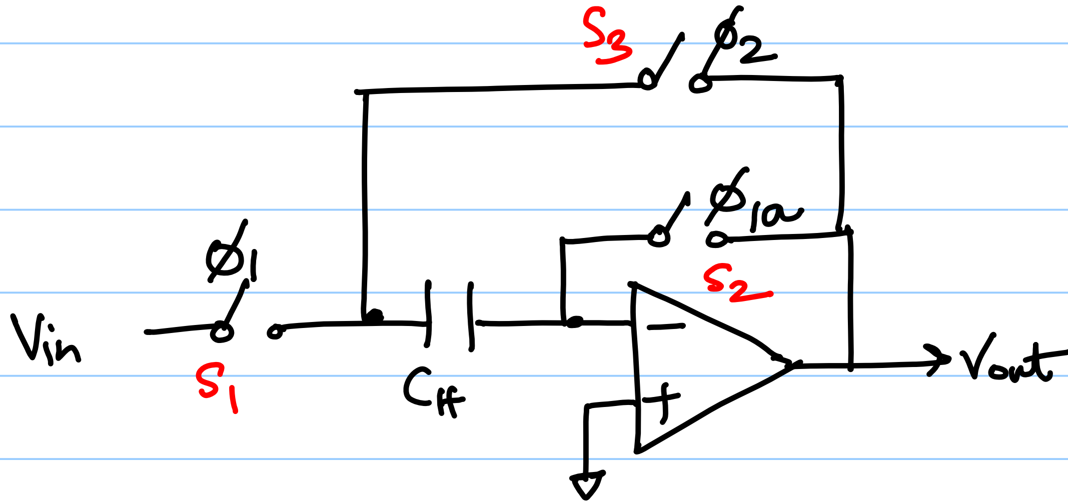
ECE 614 – Lecture 16

Note Title 10/16/2014



$\phi_{1,a} \Rightarrow$ sampling mode

$\phi_2 \Rightarrow$ hold mode

Av

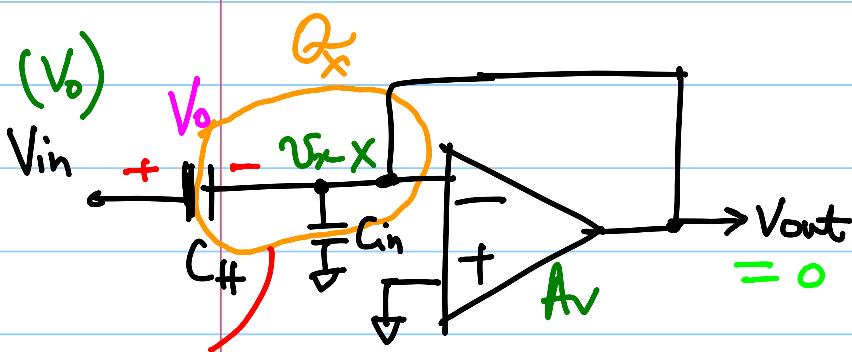
"fun"

in S/C circuits

Single Stage Folded Cascode

Impact of finite A_v ⇐ DC gain

Sampling mode



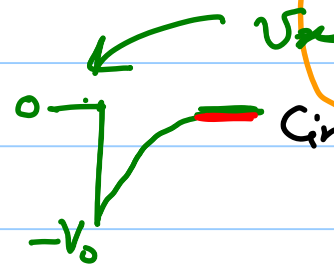
$$Q_x = -C_H V_0$$

$$V_{out} = A_v(0 - V_x)$$

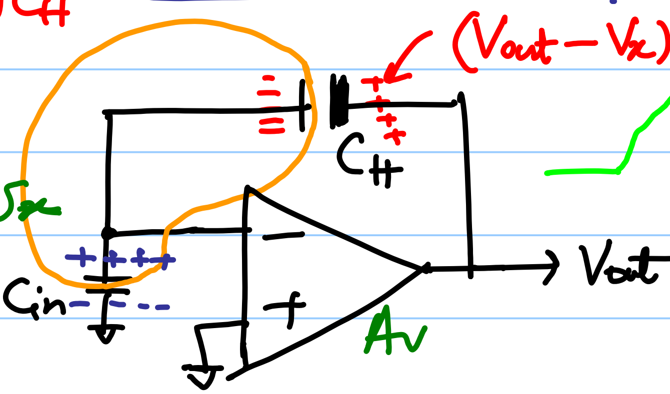
$$V_x = -A_v V_x$$

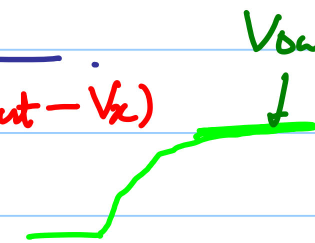
$$V_x = 0$$

$$Q_x = -(V_{out} - V_x)C_H + C_{in}V_x$$



Hold mode





In steady-state, $V_x = ?$

$$V_{out} = A_v(0 - V_x)$$

$$\Rightarrow \quad V_x = -\frac{V_{out}}{A_v} \longrightarrow (1)$$

$$Q_x = -C_H V_0 = -(V_{out} - V_x)C_H + C_{in}V_x$$

$$\Rightarrow \quad V_{out} = \frac{V_x(C_{in} + C_H) + V_0 C_H}{C_H}$$

$\frac{1}{1+x} \simeq 1-x$

$|x| << 1$

$$V_{out} = V_o + \underbrace{V_x\left(1+\frac{C_{in}}{C_H}\right)}_{\text{error}} \longrightarrow (2)$$

$$\Rightarrow V_{out} = V_o - \frac{V_{out}}{A_V}\left(1+\frac{C_{in}}{C_H}\right)$$

$$\Rightarrow V_{out} = \frac{V_o}{1+\frac{1}{A_{V_1}}\left(1+\frac{C_{in}}{C_H}\right)} = V_o\left[1 - \frac{1}{A_{V_1}}\left(1+\frac{C_{in}}{C_H}\right)\right]$$

$$= V_o\left[1 - \frac{1}{A_{V_1}\beta}\right]$$

$$\beta = \frac{C_H}{C_H + C_{in}} \Leftarrow \text{feedback ratio}$$

$A_V\beta \Rightarrow$ loop-gain

Steady-state error $\propto \frac{1}{\text{loop-gain}}$

for precision $\Rightarrow A_V \uparrow$ also $C_{in} << C_H$

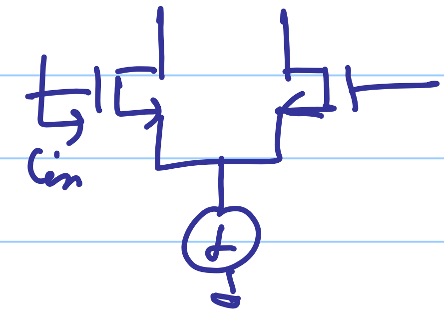
$$V_{in} = V_o$$

$$V_{out} = V_o(1-\varepsilon)$$

$$\varepsilon = \frac{1}{\beta \cdot A_v}$$

<u>Ex</u>. $C_{in} = 0.5\,pF$

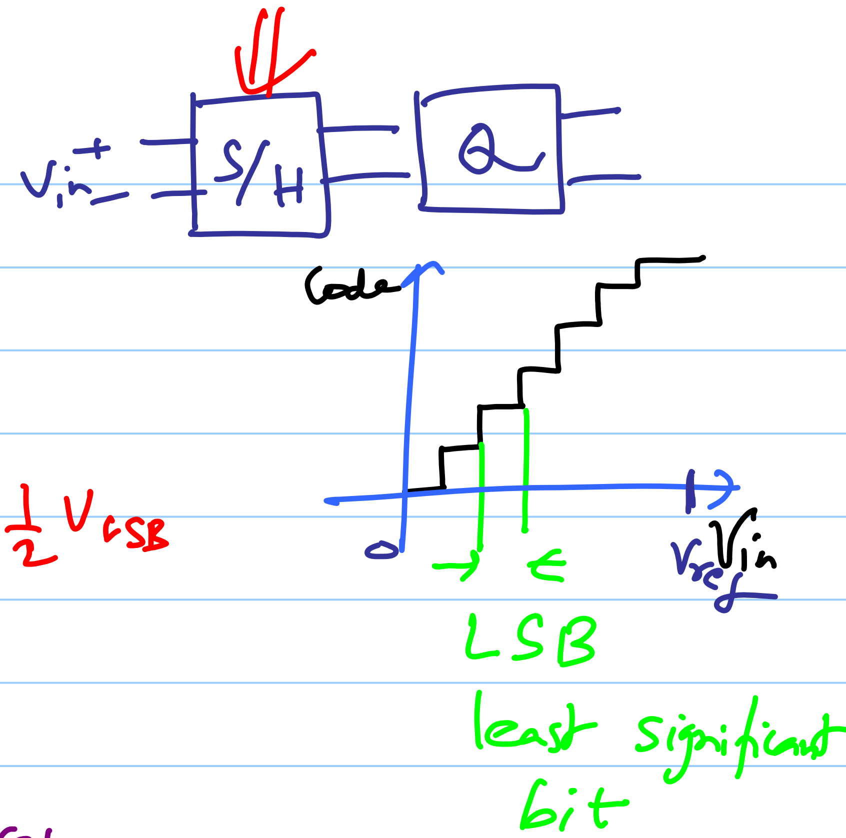
$C_{ff} = 2\,pF$



A_v needed for $\varepsilon \Rightarrow 0.1\%$

$\Rightarrow 10^3 \Rightarrow \underline{\underline{60\text{ dB}}}$

$N = 10$ bit ADC $\Rightarrow$ S/H



$$V_{LSB} = \frac{V_{ref}}{2^N}$$

we want precision better than $\frac{1}{2} V_{LSB}$

$$\frac{1}{2} LSB \Rightarrow \frac{V_{ref}}{2^{N+1}}$$

We want S/H error $< \frac{V_{ref}}{2^{N+1}}$

for $V_o = V_{ref}$

$$\frac{1}{A\beta} = \varepsilon < \frac{1}{2^{N+1}} = \frac{1}{2^{11}}$$

$A\beta > 2^{11}$

Lets say $\beta = 1$ $\Rightarrow$ $A > 2^{11} = 2000$

$\Rightarrow$ 66 dB

$SNR = 6.02\, N_{eff} - 1.76$ full-scale sine wave

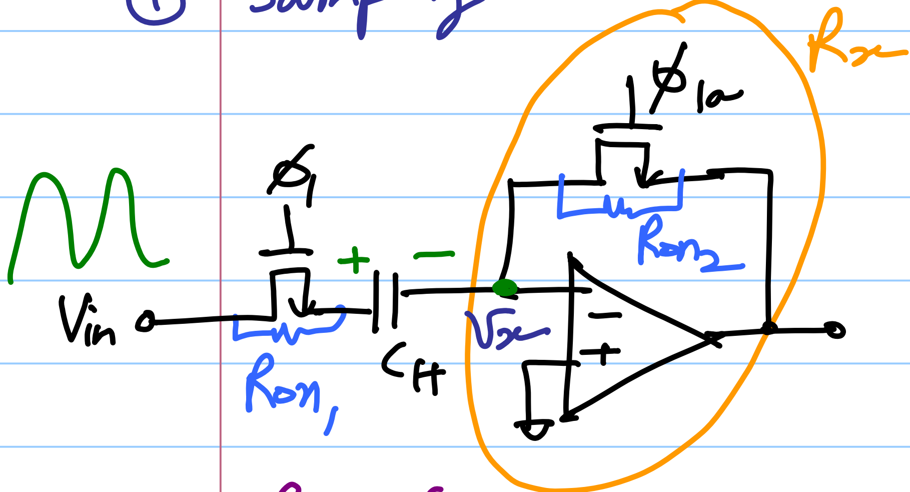
$SNR \simeq 60$ dB for V_{LSB}

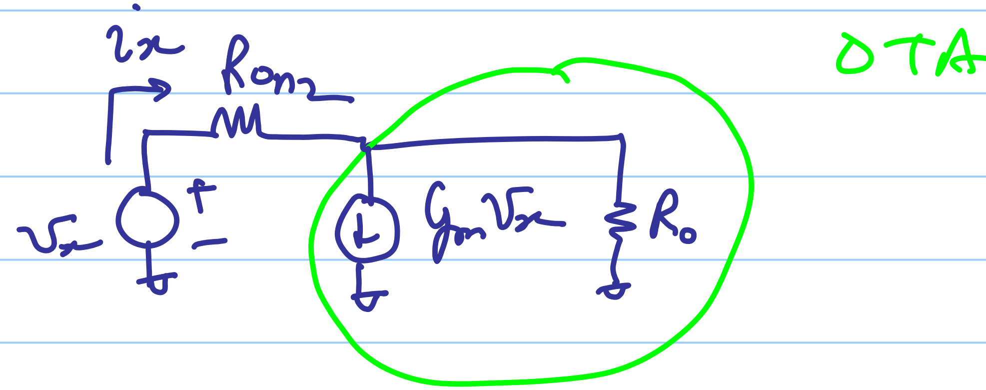
66 dB for $\frac{1}{2} V_{LSB}$ resolution

Speed Considerations

$R_x = ?$

① Sampling mode:





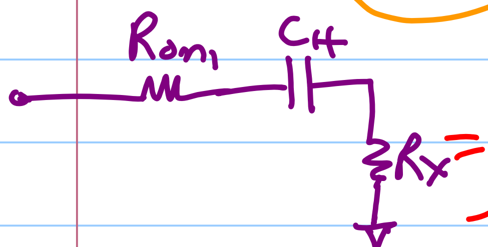
$$(i_x - g_m v_x)R_o + i_x R_{on_2} = v_x$$

$$\Rightarrow R_x = \frac{v_x}{i_x} = \frac{R_o + R_{on_2}}{1 + g_m R_o}$$

$g_m R_o \gg 1$

$R_o \gg R_{on_2}$

$$\simeq \frac{R_o}{g_m R_o} \simeq \frac{1}{g_m}$$

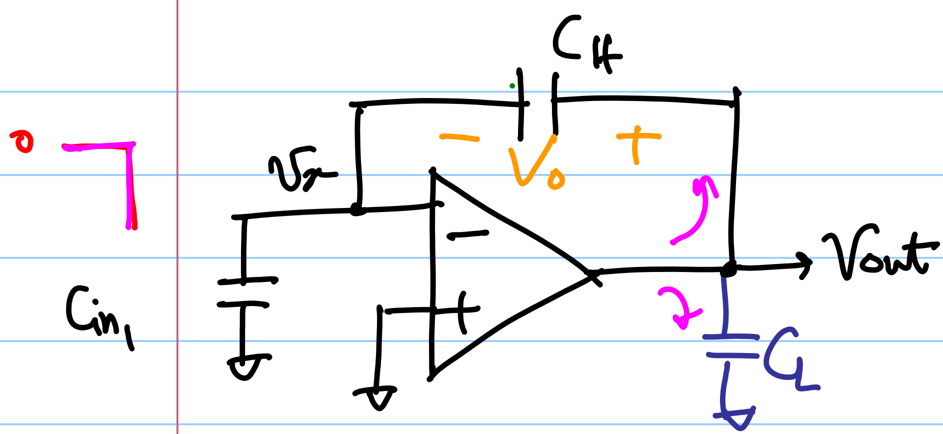


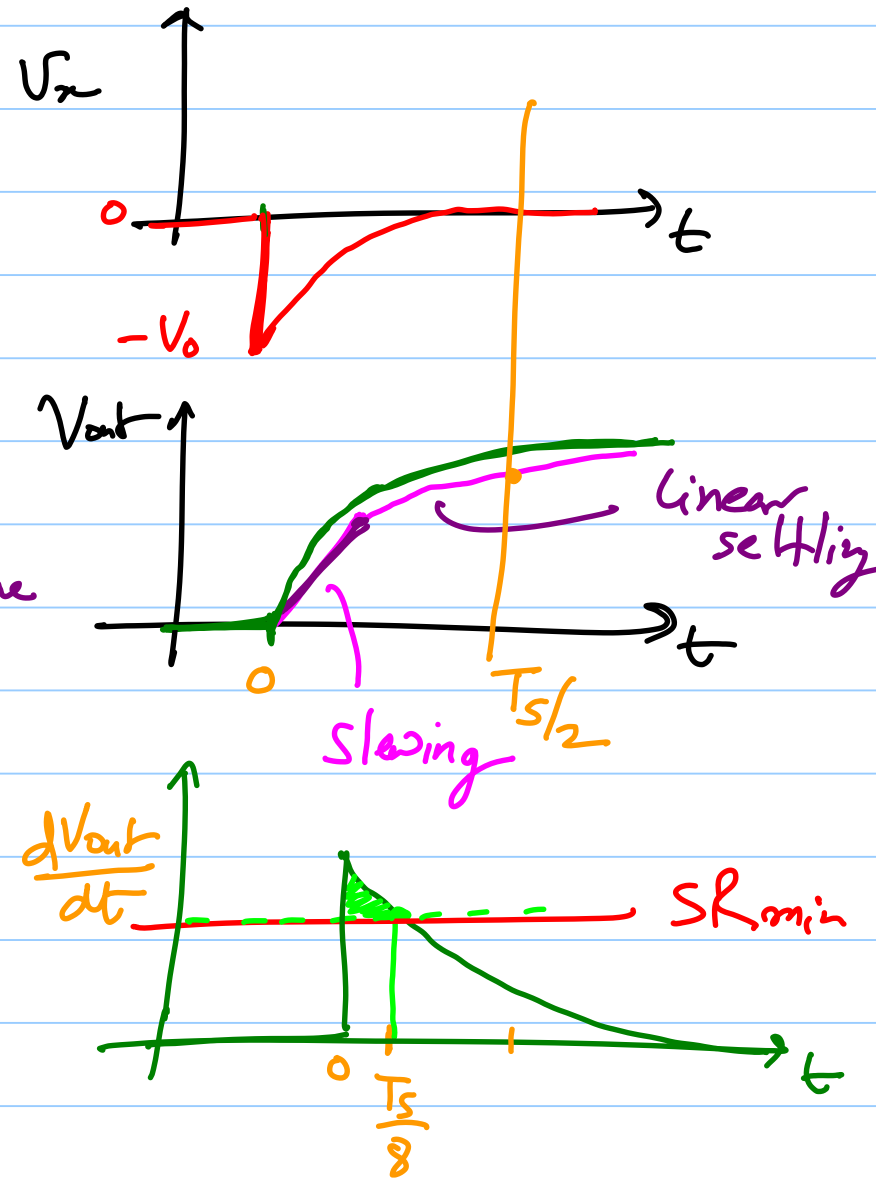
$R_x = \frac{1}{g_m}$

$$\tau_{sampling} = \left(R_{on_1} + \frac{1}{g_m}\right) C_H$$

$$4.7\,\tau_{sampling} < T_s/2$$

Speed considerations in Hold/Amplification mode





Slewing must be limited to at least $\frac{1}{4}$ of the settling time

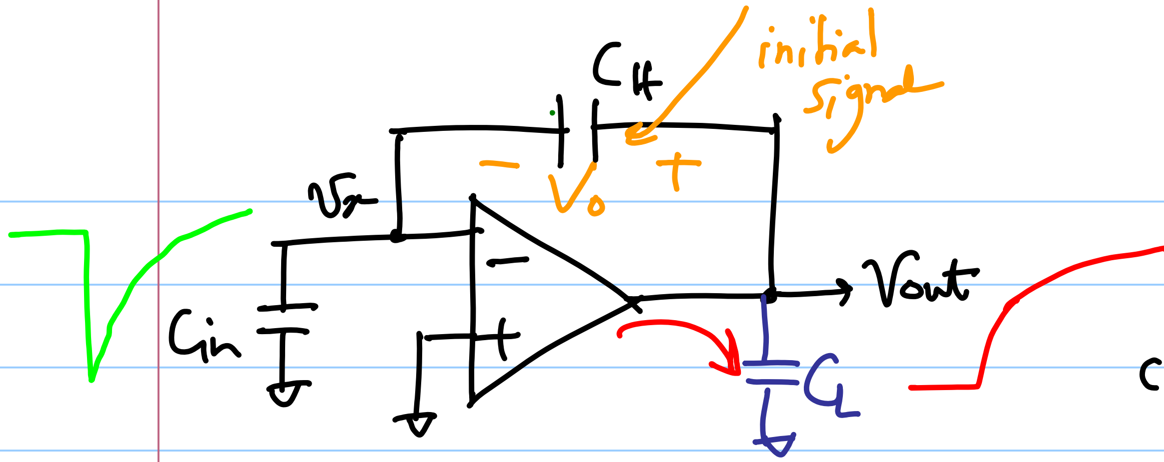
$$T_{slew} < \frac{T_s}{8}$$

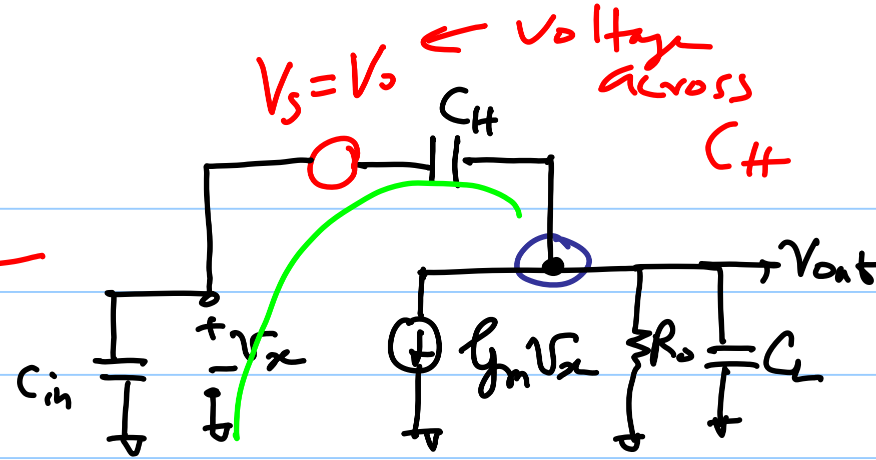
Single-stage $SR \simeq \frac{I_{SS}}{C_{Load}}$

two-stage: $SR \simeq \frac{I_{SS}}{C_c}$

Behavioral Simulation → Simulink   transistor switches

→ Verilog A → A_v, f_m





$$\frac{V_{out}}{V_s}(s)$$

KCL: $V_{out}\left(\frac{1}{R_o}+sC_L\right)+g_m v_x = (V_s+v_x-V_{out})\,sC_H \longrightarrow (1)$

KVL: $V_x\,\frac{sC_{in}}{sC_H} + V_x + V_s = V_{out}$

$V_x sC_{in}$ is the current through C_{in}

$$\frac{V_{out}}{V_s}(s) = \frac{(g_m + sC_{in})C_H}{(C_L C_{in} + C_{in}C_H + C_H C_L)s + g_m C_H}$$

$$\tau_{amp} = \frac{C_L C_{in} + C_{in}C_H + C_H C_L}{g_m C_H}$$

for $C_{in} \ll C_L, C_H \Rightarrow \beta \to 1$

$$\tau_{amp} \simeq \frac{C_L}{g_m}$$

need sufficient loop BW for settling

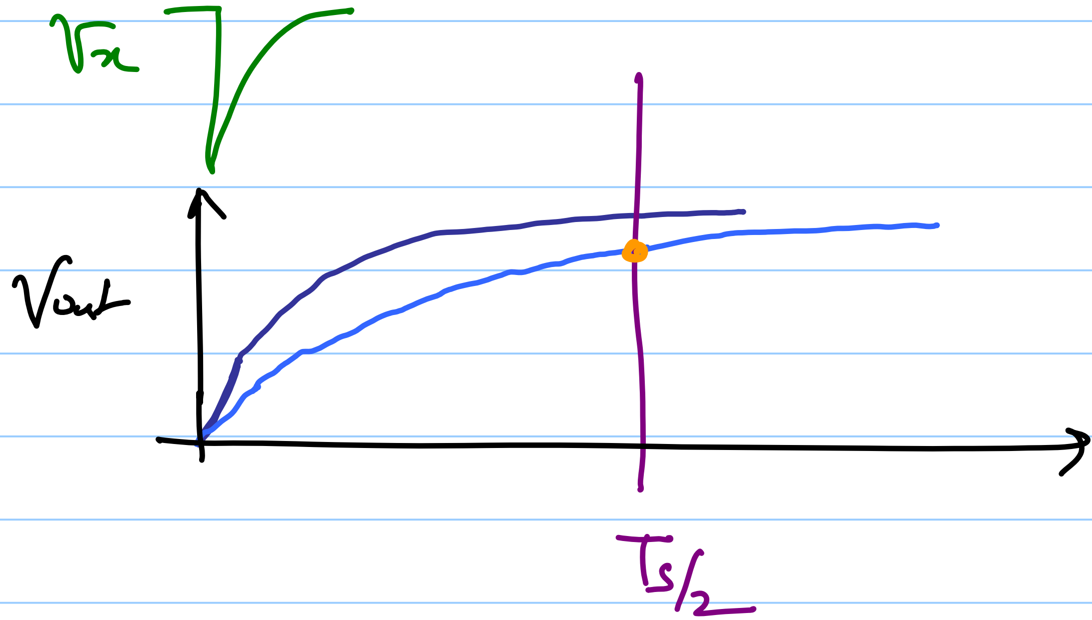
$$\omega_{un} = \frac{g_m}{C_L}$$ for single stage OTA

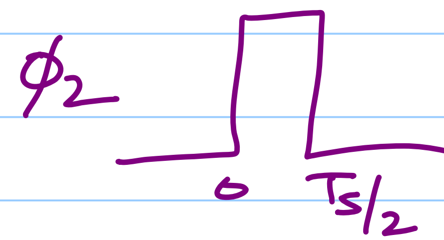
Depending upon the settling precision

$0.1\% \Rightarrow 4.7\tau$

$$4.7\,\tau_{amp} \le \frac{T_s}{2}$$

↳ ⇒ ω_{un} for the opamp





Settling precision ⇒ ω_{un}

$$SR = \frac{I_{ss}}{C_L}$$