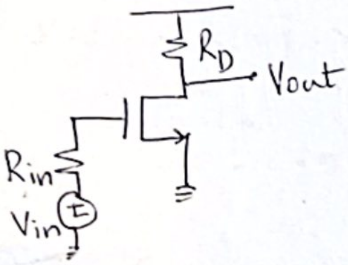
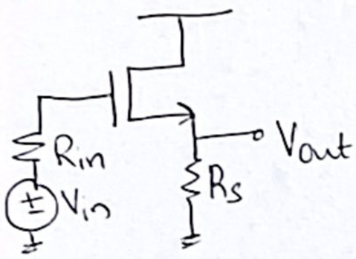
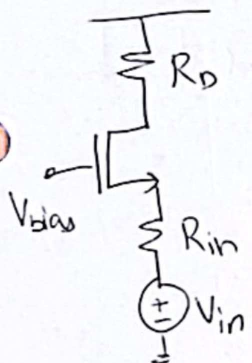
Lec 24

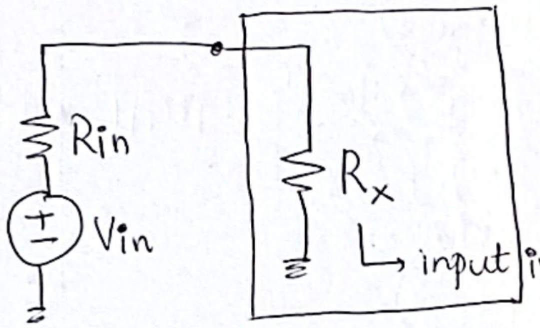
Summary of Single Stage Amplifiers

Type	Small Signal Gain (Low freq.)	Bandwidth	Rin (Low freq.)	Rout (Low freq.)
Common Source 	$-g_m(r_o \parallel R_D)$ HIGH (Inverting)	$\frac{1}{\{R_{in}(1+g_mR_D)C_{gd} + R_{in}(C_{gs}+R_DC_{gd}) + R_DC_{db}\}}$ LOW (Miller)	∞ HIGH	$r_o \parallel R_D$ HIGH (for large gain $\times R_D$)
Common Drain (Source Follower) 	$\frac{g_m(r_o \parallel R_s)}{1+(g_m+g_{mb})(r_o \parallel R_s)}$ $\simeq 1$ (Non inverting)	$\frac{1}{\{R_{in}C_{gd} + \frac{C_{gs}+C_{sb}}{g_m+g_{mb}}\}}$ HIGH (No Miller)	∞ HIGH	$R_s \parallel r_m \parallel r_{mb} \parallel r_o$ $\simeq R_s \parallel r_m$ LOW
Common Gate 	(Assuming $R_{in} \simeq 0$) $(g_m+g_{mb}+r_o^{-1})(r_o \parallel R_D)$ $\simeq (g_m+g_{mb})(r_o \parallel R_D)$; $\frac{(g_m+g_{mb})r_oR_D}{R_D+r_o+R_{in}(1+(g_m+g_{mb})r_o)}$ HIGH (Noninverting)	$\frac{1}{\{(C_{gs}+C_{sb})(R_{in} \parallel \frac{1}{g_m+g_{mb}}) + (C_{gd}+C_{db})R_D\}}$ HIGH (No Miller)	Assuming $R_{in} \simeq 0$: $r_m \parallel r_{mb} \parallel r_o$ $\simeq r_m$ LOW	Assuming $R_{in}=0$: $r_o \parallel R_D$ HIGH

Multistage Amplifiers

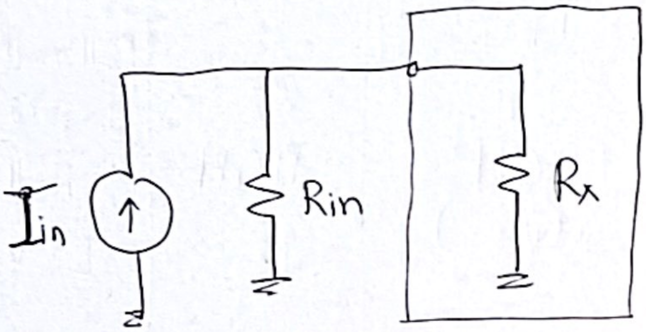
Impedance Viewpoint

Voltage "Sensor"



$R_x \to \infty \Rightarrow$ Good voltage sensor. Since Vin appears across it

Current Sensor



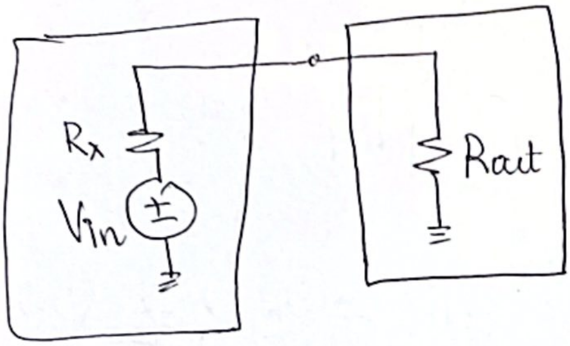
$R_x \to 0 \Rightarrow$ Good curren sensor.

Maximum Power Transfer

> $R_x = R_{in}$ (given Rin).

> Note: Amplifier gain is a function of Rload too!

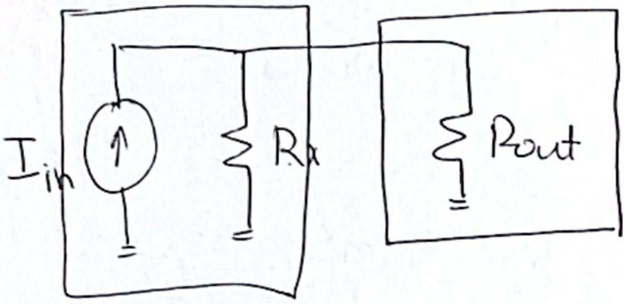
Voltage "driver"



$R_x \to 0$

Note here V_{in} is given!

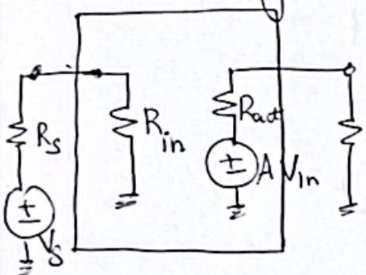
Current "driver"



$R_x \to \infty$

Amplifier Type

Voltage Amp (V sense V drive)

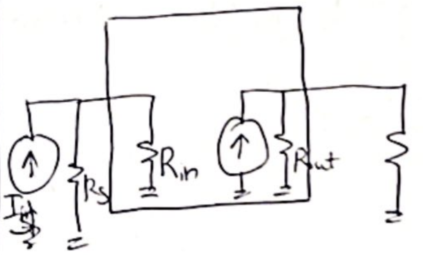


$R_{in} \to \infty$

$R_{out} \to 0$

(Common ~~Gate~~ Drain)

Current Amp (I sense I drive)

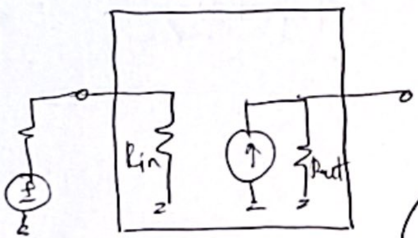


$R_{out} \to \infty$

$R_{in} \to 0$

(Common Gate)

Transconductance Amp (V sense I drive)

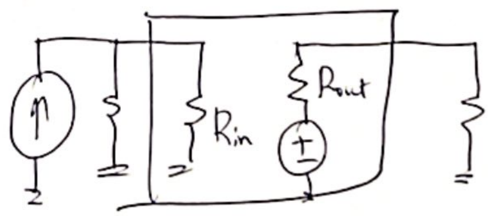


$R_{in} \to \infty$

$R_{out} \to \infty$

(Common Source)

Transimpedance (resistance) Amp (I sense V drive) (TIA)



$R_{in} \to 0$

$R_{out} \to 0$

Design Example

Specs: $|A_v| = 100$

$f_{3dB} =$ ~~20MHz~~ 15MHz

$V_{OD} = 1.8V$

$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_T)^2$

$g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS}-V_T)$

$C_{gs} = W L_{ov} C_{ox} + \frac{2}{3} W L C_{ox}$

$C_{gd} = W L_{ov} C_{ox}$

Parameters: at $I_D = 200\mu A$; $g_m = 5mS$

$r_o = 40K\Omega$

$C_{gs} = 100fF$

$C_{gd} = 20fF$

$C_{db} = C_{sb} = 30fF$

} NMOS.

$g_m = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D}$

W & I_D scaled by $N \Rightarrow g_m \rightarrow N g_m$

Attempt ① Common Source. (Ignoring R_L)

Let $R_D = 5k\Omega$

$\Rightarrow A_v = -g_m(R_D \| r_o) = -5mS(5k\Omega \| 40k\Omega)$

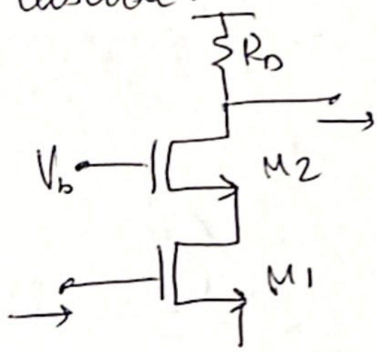
$= -22$

Miller

$$\tau_{gs} = \overbrace{(50k)}^{R_s}\overbrace{\Big(\underbrace{C_{gs}}_{100f} + \underbrace{(1+g_m R_D)}_{23}\underbrace{C_{gd}}_{20f}\Big)}^{C_{in}\;=\;560\,fF} \simeq 28\,nS$$

$$f_{3dB} \simeq \frac{1}{2\pi(\tau)} \simeq 5.6\,MHz.$$

> We need more gain & more BW! ⇒ Cascode.



Attempt ② Cascode (CS + CG)

$$A_v = -g_{m_1}(R_D \,\|\, g_{m_2} r_{o2} r_{o1})$$

$5m \cdot 40K \cdot 40K$

$$\simeq -g_{m_1} R_D$$

$$\simeq -25$$

OCTC: $\tau_{in} = R_s[C_{gs} + 2C_{gd}]$

$= 50K(100f + 40f) = 7nS$

τ_{mid} small since $\frac{1}{g_m}$

τ_{out} small since $(C_{db_2} + C_{gd_2})$ small & R_D is not too large.

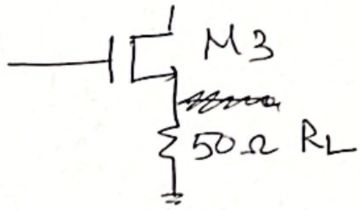
$$\Rightarrow f_{3dB} \simeq \frac{1}{2\pi(7n)} \simeq 21.8\,MHz \rightarrow \text{Good!}$$

> Connecting load 50 Ω

$\Rightarrow A_v = -g_{m1}(R_L \parallel \cancel{R_D} \parallel \cancel{g_{m2} r_{o2} r_{o1}})$

$= -5m \cdot 50 = -0.25$!! BAD!

<u>Attempt 3</u> : Add CD buffer!



CD gain $\simeq \dfrac{g_{m3} R_L}{1 + g_{m3} R_L}$

$g_{m3} R_L = 5m \times 50 = 0.25 \Rightarrow A_{v_3} = \dfrac{0.25}{1.25} = 0.2$

Increase g_{m3} to 50mS $\Rightarrow I_{D_3} = 2\,mA$

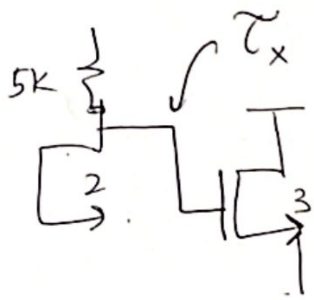
$\Rightarrow N = 10$

$C_{gs_3} = 1pF$

$C_{gd_3} = 200\,fF$

$\rightarrow A_{v_3} = \dfrac{2.5}{3.5} \simeq 0.7$

$\Rightarrow A_v = (-25)(0.7) = -17.8$



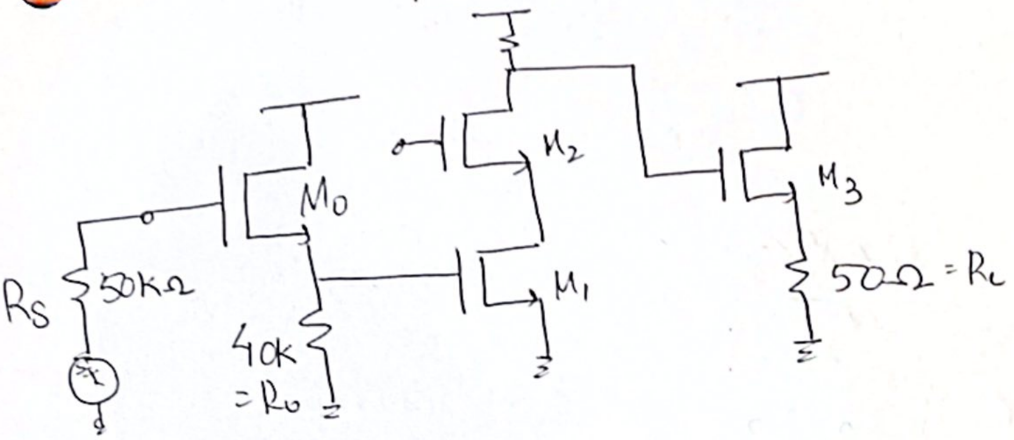
<u>OCTC</u> $\tau_x = 5K \left\{ \underbrace{1000f}_{C_{gs3}} \times 0.3 \rightarrow \text{Bootstrapping} + \underbrace{200f}_{C_{gd3}} \right\} \simeq$ ~~5.5ns~~ ~~3.85ns~~ 2.68nS

$\tau_{out_3} \rightarrow 0 \Rightarrow \tau_{total} = (7n) +$ ~~8.25n~~ ~~3.85~~ 2.68ns $=$ ~~12.5n~~ ~~10.85ns~~ 9.68nS (Problem)

$\Rightarrow f_{3dB} =$ ~~12.7 MHz~~ ~~14.6 MHz~~ 16.4 MHz

Attempt 4 : Isolate Rs from $C_{gs1} + 2C_{gd1}$

Add Common Drain Buffer.



$$A_o = \frac{g_{m0} R_o}{1 + g_m R_o} = \frac{(5m)(40k)}{1 + 5m\ 40k} = \frac{200}{201} \simeq 1$$

OCTC

$$\tau_{in} = \underbrace{(50K)}_{Rs} \underbrace{20\ fF}_{Cgd} = 1\ ns$$

What about C_{gs}? → Bootstrapped since V_{gs} is 0 given that source follows gate.

Miller point of view ⇒ $C_{gs}(1 - A_v) = C_{gs}(1+1) = 0$

⇒ $\tau_{total} \doteq 1\,ns + ~~32.85\,ns~~\ 2.68\,ns$

$= ~~33.8~~\ 3.68\,nS$

f_{3dB} = **43.2 MHz**

$$\text{Gain} = (0.995)(-25)(0.714) = -17.7$$

↑ Bottleneck!

Cascode with PMOS load

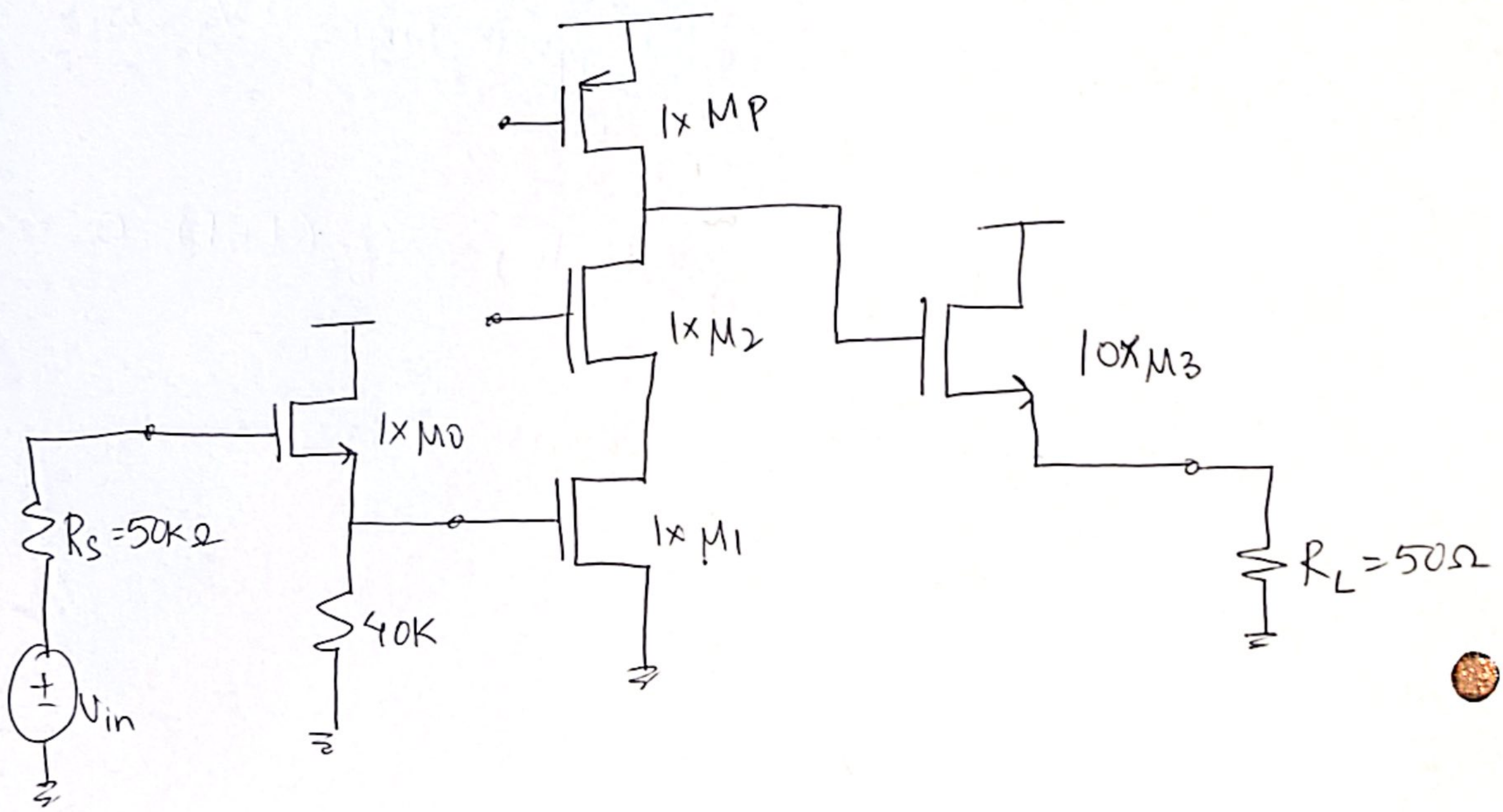
$$A_v = -g_{m1}(r_{op} \| g_{m2} r_{o2} r_{o1}) \simeq -g_{m1} r_{op}$$

$$= 5m \cdot 40k = -200$$

$$\Rightarrow A_{v\,total} = -142$$

BW? $\tau_{mid} \uparrow$ by ×8

$$f_{3dB} = 7\,MHz$$



Redesigning M_3

$\tau_x = 40K\,(100f \times 0.3 + 20f)$

$= \sout{3.8n}\ 2n$

$\Rightarrow f_{3dB} = 53\ MHz$

$$\frac{g_{m_3} R_L}{1 + g_{m_3} R_L} = \frac{1}{2} \Rightarrow g_{m_3} = 20mS$$

$\Rightarrow \boxed{N = 4}$

$\Rightarrow A_v = -200 \times \frac{1}{2} = -100$

$\Rightarrow \tau = 40K\,(400f \times 0.3 + 80f)$

$= 40K\,(200f)$

$= 8nS$

$T = 8n + 1n = 9nS$

$\Rightarrow f_{3dB} = 17.68MHz$