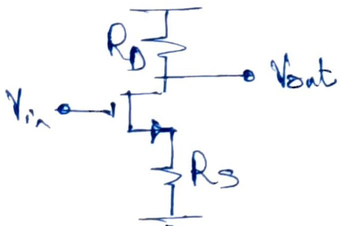
Analog Integrated Circuits.

Lec06: Amplifier topologies.

① Basic Mos topologies.

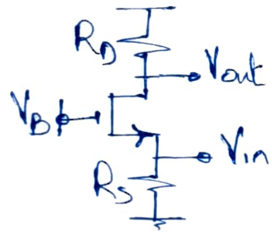
- There are 3 basic topologies of MOS amp. based on Terminal Conditions

Common Source



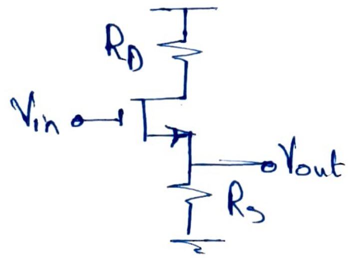
Voltage Amp
Current Amp

Common Gate



Voltage Amp
Current Buffer

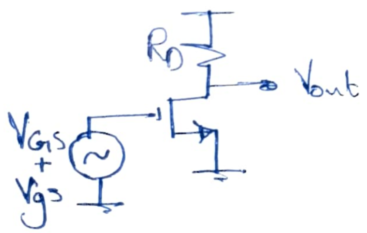
Common Drain

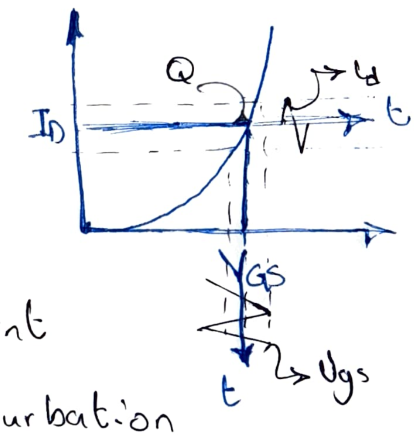


Voltage Buffer
Current Amp

② Basic Amp operation

- The input signal is a Combination of two Component





1 DC Component

a Certain V_{GS} gives a Certain I_D @ Q Point

2 AC Component → where a Small perturbation of Small Signal arround Q Point will result a perturbation around I_D

③ Basic Analysis steps

1. DC analysis
   - → Coupling and bypass Caps → OC
   - → Calculate Q point and define region
2. Calculate Small Signal parameters (g_m r_o)
3. Draw Small Signal equivalent Circuit
   - → DC Voltage → SC
   - → DC Current → OC
   - → Coupling and Bypass → SC
4. Determine the amp parameters
   - → Rin and Rout
   - → Av and Ai

4 Rin / Rout Shortcuts.

- We need to find equivalent impedance looking from Gate, Source, and Drain

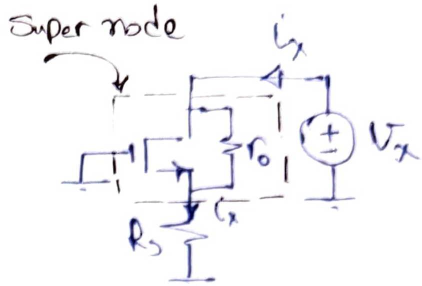
1 looking from Gate.

$R_{LFG} = \infty$ @ low freq

2 looking from Drain

- If G and B are ac connected

$\therefore V_{bs} = V_{gs} \longrightarrow g_m$ and g_{mb} added



Assume Transistor is a Super node

$\therefore V_{gs} = -V_s = -i_x R_s$

Apply KCL @ Drain

$\therefore i_x = (g_m + g_{mb}) V_{gs} + \dfrac{V_x - i_x R_s}{r_o}$

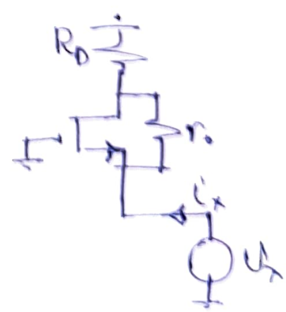
$\therefore i_x = -(g_m + g_{mb}) i_x R_s + \dfrac{V_x}{r_o} - \cancel{\dfrac{i_x R_s}{r_o}} \rightarrow 0$

$\therefore i_x [1 + (g_m + g_{mb}) R_s] = \dfrac{V_x}{r_o}$

$\therefore R_{LFD} = r_o [1 + (g_m + g_{mb}) R_s]$

Active Load
→ If $R_s = 0$ (G and S are ac connected)
$\therefore$ MOS equivalent to r_o

3 looking from Source



Apply KCL @ Source

$\therefore i_x = \dfrac{V_x - V_D}{r_o} - g_m V_{gs} - g_{mb} V_{bs}$

$\therefore i_x = \dfrac{V_x}{r_o} - \dfrac{i_x R_D}{r_o} - (g_m + g_{mb}) V_x$

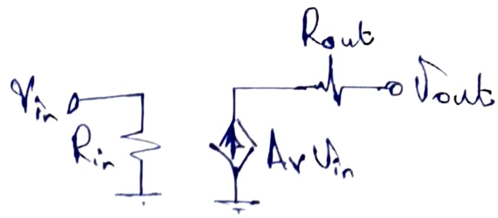
$\therefore i_x \left(1 + \dfrac{R_D}{r_o}\right) = V_x \left[\dfrac{1}{r_o} + (g_m + g_{mb})\right]$

$\therefore \dfrac{V_x}{i_x} = \dfrac{1}{g_m + g_{mb}} \left(1 + \dfrac{R_D}{r_o}\right)$

(5) $G_m R_{out}$ method

1 Thevinin model of Amp

- $R_{in} = \dfrac{V_{in}}{i_{in}}$
- $R_{out} = \dfrac{V_x}{i_x}$ @ $V_{in} = 0$



$\therefore$ OC Voltage gain $\rightarrow V_{Thevinin} = V_{out\,OC} = A_v V_{in}$

$$\therefore A_v = \frac{V_{out\,OC}}{V_{in}}$$

2 Norton model of Amp

- $i_{Norton} = i_{out\,sc} = G_m V_{in}$

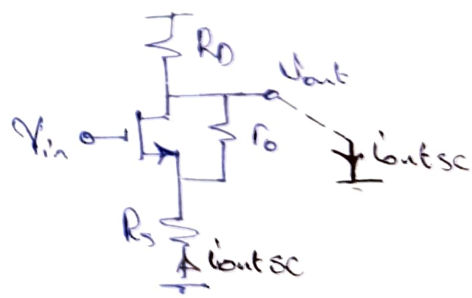
$\rightarrow G_m = \dfrac{i_{out\,sc}}{V_{in}}$

$$\boxed{\therefore A_v = G_m R_{out}}$$

- $A_i = \dfrac{i_{out\,sc}}{i_{in}} = G_m R_{in}$

(6) Common Source (CS)

- Apply KCL @ S where $V_{gs} = V_{in} + i_{out\,sc} R_s$



$$\therefore i_{out\,sc} + g_m (V_{in} + i_{out\,sc} R_s) + g_{mb}(i_{out\,sc} R_s) + \frac{i_{out\,sc} R_s}{r_o} = 0$$

$$\therefore G_m = \frac{i_{out\,sc}}{V_{in}} = \frac{-g_m}{1 + (g_m + g_{mb}) R_s}$$

- $R_{out} \simeq R_D \parallel r_o [1 + (g_m + g_{mb}) R_s]$

$\therefore A_v = G_m R_{out}$

- $\rightarrow$ If R_D is oC OC, $A_v = -g_m r_o$
- $\rightarrow$ If $R_D \ll R_{UD}$: $A_v = \dfrac{-g_m R_D}{1 + (g_m + g_{mb}) R_s}$
- $\rightarrow$ If $R_s = 0$: $A_v = -g_m (R_D \parallel r_o)$

- If S and B are ac connected (for PMOS)

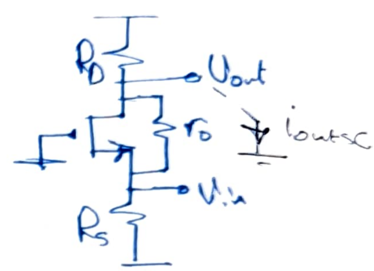
$$A_v = \frac{-R_D \parallel R_{LFD}}{\frac{1}{g_m} + R_S} = -\frac{\text{Drain res}}{\frac{1}{g_m} + \text{Source res}}$$

- If $R_S \gg \frac{1}{g_m}$ and $R_D \ll R_{LFD}$: $A_v \simeq \frac{-R_D}{R_S}$ → linear gain
- R_S reduces G_m (Source Degeneration)

  But improves Linearity

⑦ Common Gate (CG)

- Apply KCL at D where $V_{gs} = V_{bs} = -V_{in}$



$$\therefore I_{outsc} + (g_m + g_{mb})(-V_{in}) - \frac{V_{in}}{r_o} = 0$$

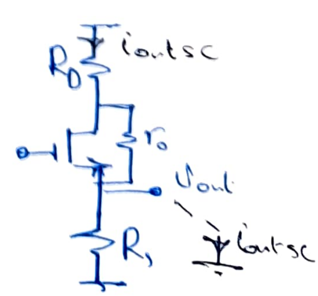
$$\therefore G_m = \frac{i_{outsc}}{V_{in}} \simeq g_m + g_{mb}$$

- $R_{out} \simeq R_D \parallel r_o$ (Why?)

- $A_v = G_m R_{out}$
  - → $A_v = (g_m + g_{mb}) r_o$ → If R_D is ac OC
  - → $A_v \simeq (g_m + g_{mb}) R_D$ → If $R_D \ll r_o$
  - → $A_i = G_m R_{in} <= 1$ (Current Buffer)

⑧ Common Drain (CD)

- Apply KCL at D



$$\therefore i_{outsc} - g_m V_{in} + \frac{i_{outsc} R_D}{r_o} = 0$$

$$\therefore G_m = \frac{g_m}{1 + R_D/r_o}$$

- $R_{out} \simeq R_S \parallel \frac{1}{g_m + g_{mb}}\left(1 + \frac{R_D}{r_o}\right)$
- If $R_S \gg R_{LFS}$: $A_v \simeq \frac{g_m}{g_m + g_{mb}} < 1$

⑨ Quiz

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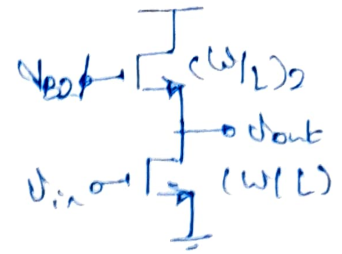
1 find A_v in terms of W/L



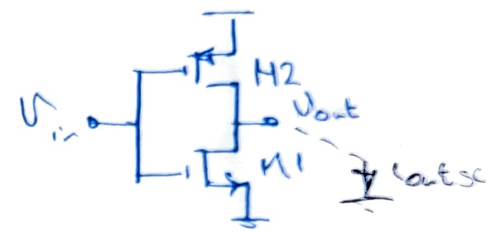
$$A_v = G_m R_{out}$$

$$= g_{m1} \cdot \left(\frac{1}{g_{m2}} \parallel r_{o1}\right)$$

$$\approx \frac{g_{m1}}{g_{m2}} = \sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

2 find A_v using $G_m R_{out}$

apply KCL @ output node



$\therefore$ $i_{outsc} = -g_{m2} V_{in} - g_{m1} V_{in}$

$= -V_{in} (g_{m1} + g_{m2})$

$\therefore$ $G_m = -(g_{m1} + g_{m2})$

$\therefore$ $R_{out} = r_{o2} \parallel r_{o1}$

$\therefore$ $A_v = G_m R_{out}$