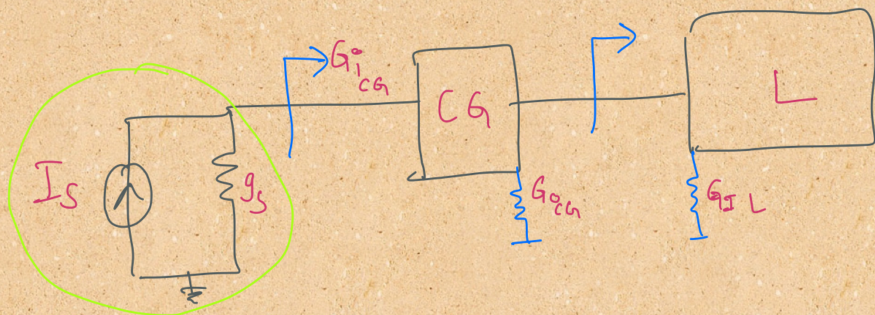
Lecture-8

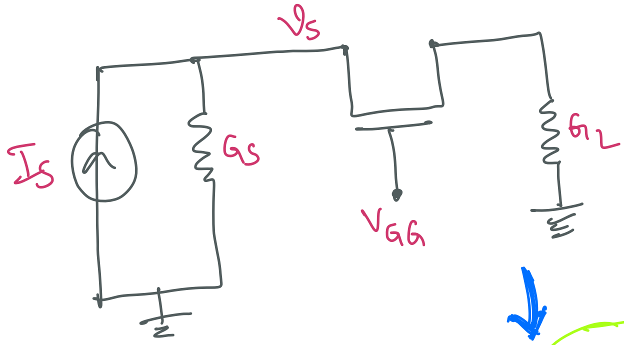
Revanth Reddy Pannala

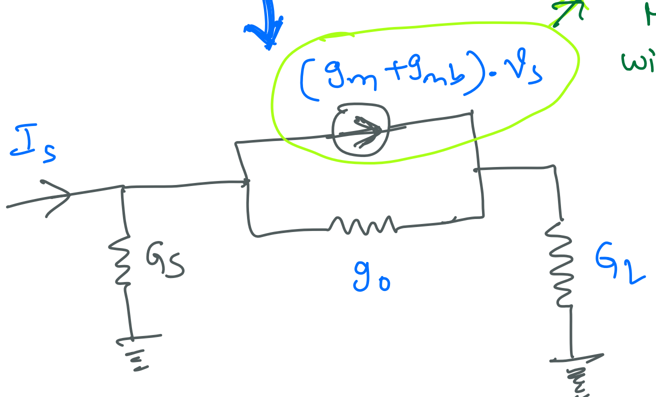
⇒ Continuation of Common Gate Stage



Current Source with Internal Resistance

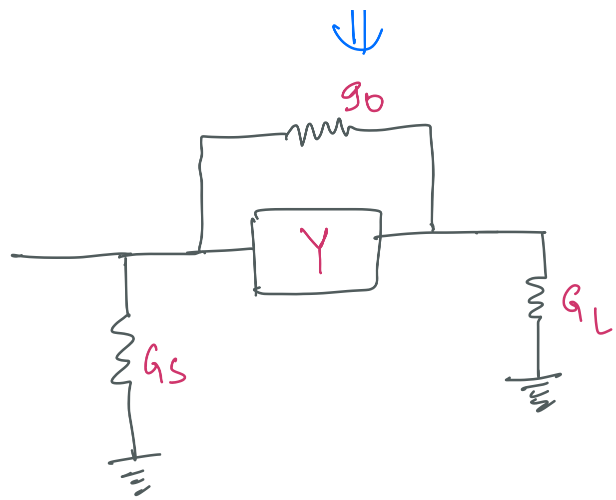
(∴ for maximum current to flow the i/p conductance of CG stage should be High)





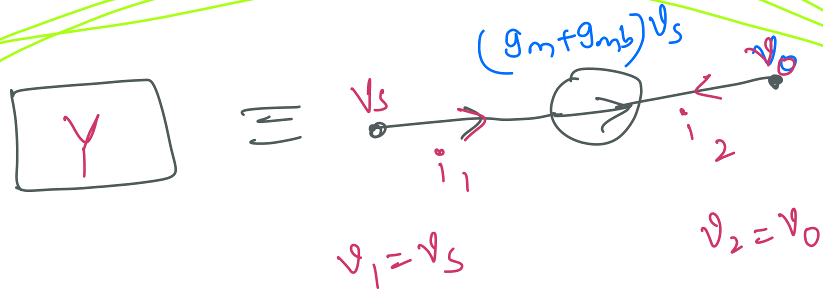
let's try and Model this with Admittance Matrix (Y)

$\Downarrow$



→ For <u>Admittance Matrix</u> (Y)

1) $$\boxed{y_i = \left.\frac{i_1}{v_i}\right|_{v_2=0} = (g_m + g_{mb}) \triangleq g_m'}$$



2) $$\boxed{y_r = \left.\frac{i_1}{v_2}\right|_{v_1=0} = 0}$$

$\because v_1 = v_s$
$\therefore v_s = 0$ $\Rightarrow$ $i_1 = (g_m + g_{mb}) v = 0$

3) $$\boxed{y_f = \left.\frac{i_2}{v_1}\right|_{v_2=0} = -g_m'}$$

4) $$\boxed{y_o = \left.\frac{i_2}{v_2}\right|_{v_1=0} = 0}$$

→ Now we have the elements of the admittance matrix.. what we can do is to apply some of the Rules we have derived for circuit parameters calculation.

They are

$$A_V = \frac{-y_f}{y_o} = \frac{-(-g_m' - g_o)}{g_o + G_L} = \frac{g_m' + g_o}{g_o + G_L} = \frac{G_T}{g_o + G_L}$$

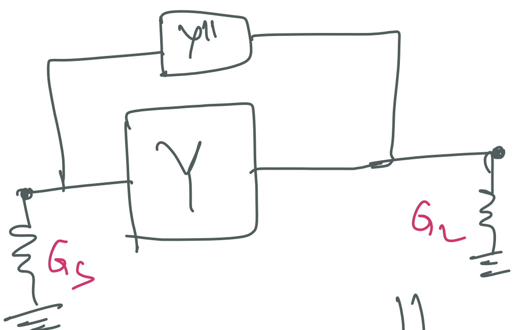
$$Y_i = \frac{\Delta Y}{y_o}$$

$$Y_o = \frac{\Delta Y}{y_i}$$

Similarly other quantities can be found out.

$$A_i = \frac{y_f}{y_i}$$

→ Before writing the values, we need to update our Matrix as the circuit also contains g_o in parallel to Y and G_S & G_L connected to i/p & o/p.



$$\Rightarrow \begin{bmatrix} y_i + Y_{11} & y_r - Y_{11} \\ y_f - Y_{11} & y_o + Y_{11} \end{bmatrix}$$

$$Y_{11} = g_o$$

$$\begin{bmatrix} \underbrace{G_S + g_m' + g_o}_{y_i} & \underbrace{0 - g_o}_{y_r} \\ \underbrace{-g_m' - g_o}_{y_f} & \underbrace{g_o + G_L}_{y_o} \end{bmatrix} \Rightarrow$$

CG

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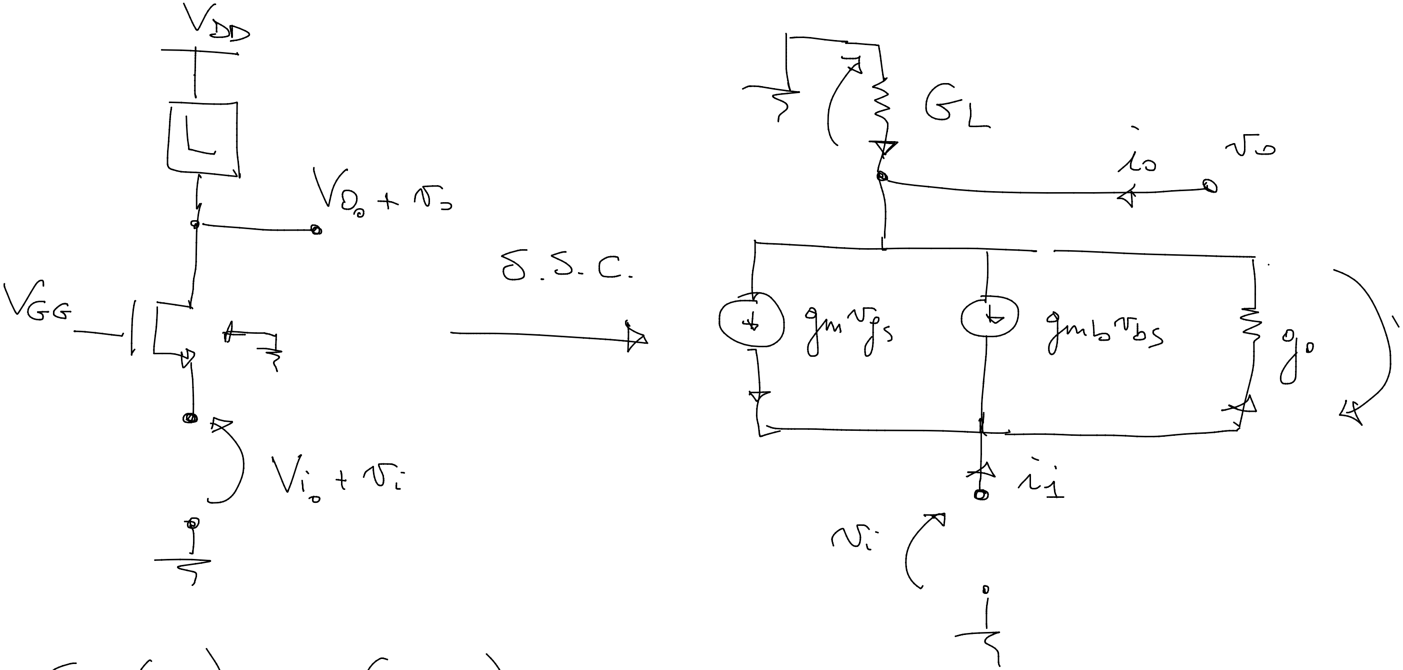


$$G_L \cdot (-v_o) = g_o (v_o - v_i) - g_m \cdot v_i - g_{mb} v_i$$

$$v_o (G_L + g_o) = v_i \underbrace{(g_m + g_{mb} + g_o)}_{G_T} \Rightarrow \frac{v_o}{v_i} = \frac{G_T}{G_L + g_o}$$

$$G_I = \left.\frac{i_i}{v_i}\right|_{i_o=0}$$

$$i_i = g_m v_i + g_{mb} \cdot v_i + g_o (v_i - v_o)$$

$$i_i = G_T \cdot v_i - g_o \cdot v_o$$

$$i_i = G_T \cdot v_i - g_o \frac{v_o}{v_i} \cdot v_i = G_T \cdot v_i - g_o \cdot A_{V_{CG}} \cdot v_i$$

$$A_{VCG} = \frac{G_t}{G_L + g_o}$$

$$\left.\frac{i_i}{v_i}\right|_{i_o=0} = G_I = G_T - g_o \cdot A_{CG} = G_t \left(1 - \frac{g_o}{G_L + g_o}\right)$$

$$G_I = G_t \cdot \frac{G_L + \cancel{g_o} - \cancel{g_o}}{G_L + g_o} = \frac{G_T \cdot G_L}{G_L + g_o}$$

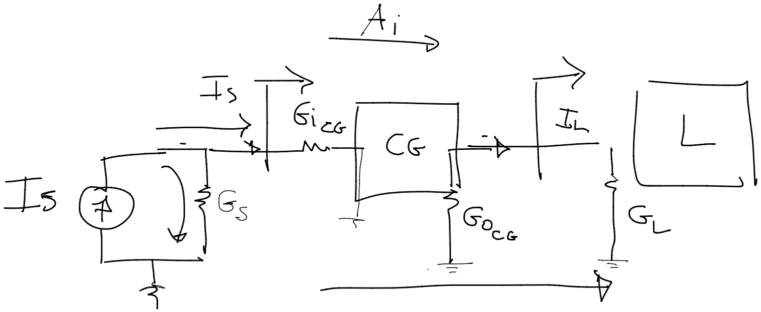
$$\frac{G_T \cdot G_L}{G_L + g_o}$$

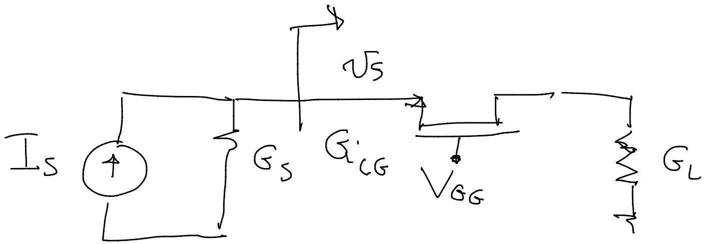
$G_L \gg g_o \quad \simeq G_t$

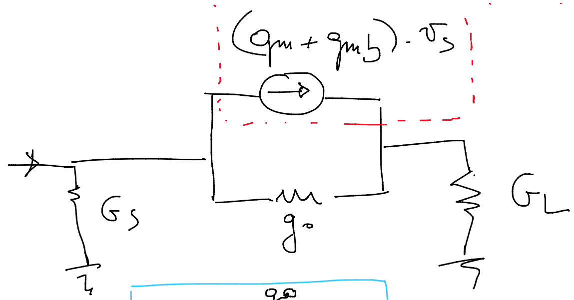
$G_L \sim g_o \quad \simeq \frac{G_t}{2}$

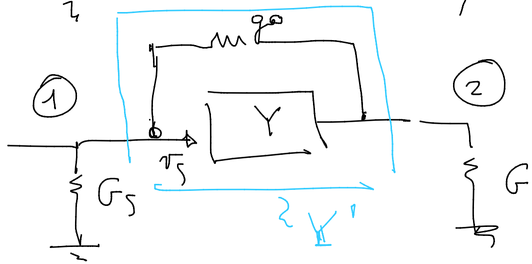
$G_L \ll g_o \quad \simeq \frac{G_t \cdot G_L}{g_o}$

$G_T \uparrow$







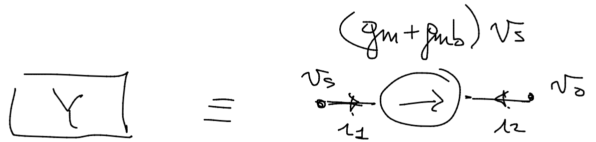


$$y_i = \frac{i_1}{v_1}\Big|_{v_2=0} = (g_m + g_{mb}) \triangleq g_m'$$

$$y_r = \frac{i_1}{v_2}\Big|_{v_1=0} = 0$$

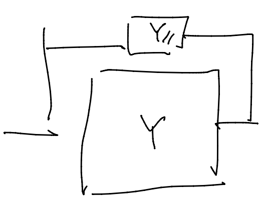
$$y_f = \frac{i_2}{v_1}\Big|_{v_2=0} = -g_m'$$

$$y_o = \frac{i_2}{v_2}\Big|_{v_1=0} = 0$$



$v_S = v_1$ $\qquad$ $v_o = v_2$

$$A_v = -\frac{y_f}{y_o} \qquad Y_i = \frac{\Delta Y}{y_o} \qquad Y_o = \frac{\Delta Y}{y_i} \qquad A_i = \frac{y_f}{y_i}$$



$$\to \begin{bmatrix} y_i + Y_{//} & y_r - Y_{//} \\ y_f - Y_{//} & y_o + Y_{//} \end{bmatrix} \to \begin{bmatrix} G_S + g_m' + g_o & -g_o \\ -g_m' - g_o & +g_o + G_L \end{bmatrix} \sim Y'$$

$$Y' + G_S + G_L \triangleq Y''$$

(i) $$A_v = \frac{g_m' + g_o}{g_o + G_L} = \frac{G_T}{g_o + G_L}$$

(ii) $$Y_i = \frac{(G_S + g_m' + g_o)(g_o + G_L) - g_o(g_m' + g_o)}{g_o + G_L} =$$

$$= \frac{G_S(g_o + G_L) + \cancel{g_m' g_o} + g_m' G_L + \cancel{g_o^2} + g_o G_L - \cancel{g_o g_m'} - \cancel{g_o^2}}{g_o + G_L}$$

$$= G_S + \underbrace{\frac{g_m' G_L + g_o G_L}{g_o + G_L}}_{Y_i}$$

Y_{iCG}

$$Y_{iCG} = \frac{G_L \cdot G_T}{g_o + G_L} = \frac{G_T}{g_o \cdot R_L + 1}$$

$$R_L = \frac{1}{G_L}$$

$g_o R_L \gg 1$

$$Y_{iCG} \simeq \frac{G_T}{g_o \cdot R_L} \simeq \frac{g_m'}{g_o \cdot R_L}$$

~ 100

$$R_{iCG} \simeq \frac{R_L}{100}$$

$g_o R_L \ll 1$

$$Y_{iCG} \simeq g_m'$$

(iii)

$$G_L \,/\!/\, G_{oCG}$$

$$Y_o'' = \frac{\Delta Y''}{y_i''} = \frac{G_L \cdot G_T + G_S(g_o + G_L)}{\underbrace{g_m' + g_o}_{G_T} + G_S} = \frac{G_L(G_T + G_S) + G_S \cdot g_o}{G_T + G_S} = G_L + \frac{G_S \cdot g_o}{G_T + G_S}$$

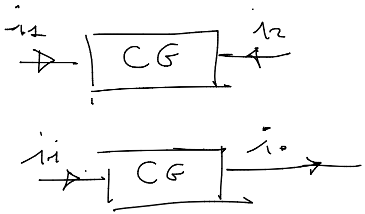
$$\frac{1}{g_o} \triangleq r_{ds}$$

~ 100 g_m

$$Y_{oCG} = \frac{G_S \cdot g_o}{G_T + G_S} \to R_{oCG} = \frac{G_T + G_S}{G_S \cdot g_o} = \frac{1}{g_o} + \frac{1}{g_o}\frac{G_T}{G_S} = \frac{1}{g_o}\left\{1 + \frac{G_T}{G_S}\right\} = r_{ds}\{1 + G_t \cdot R_s\}$$ ** R_o

(iv)

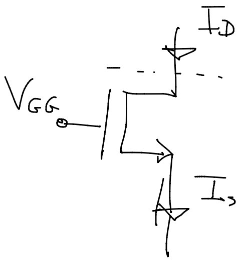
$$A_i = \frac{y_f}{y_i}\Bigg|_{G_S = 0} = \frac{i_2}{i_1} \Rightarrow -\frac{g_o + g_m'}{g_m' + g_o} = -1$$



$$\frac{i_2}{i_1} = -1$$

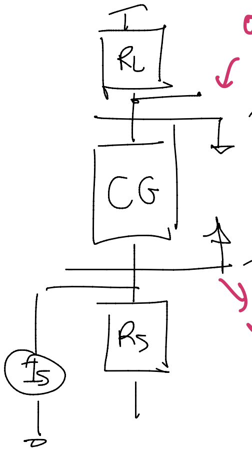
$$i_o = -i_2$$

$$\frac{i_o}{i_1} = 1$$



$$\left[\ \frac{i_o}{i_1} = 1\ \right]$$

Current Gain is Unity



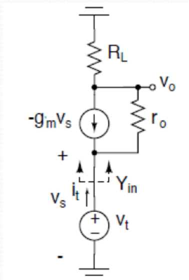
output Resistance seen from o/p

$R_S \cdot 100$

$\frac{R_L}{100}$

i/p Resistance seen from i/p

CG: Input and Output Resistances

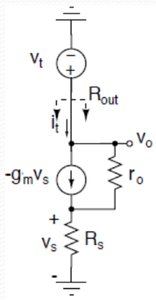


$$Y_{in} = \frac{i_t}{v_t} = \frac{g_m' r_o + 1}{r_o + R_L}$$

ro=1/gd

$$R_L \ll r_o \quad \longrightarrow \quad R_{in} \simeq \frac{1}{g_m'}$$ Well-known result

$$R_L \gg r_o \quad \longrightarrow \quad R_{in} \simeq \frac{R_L}{g_m' r_o}$$ Less-known result but important

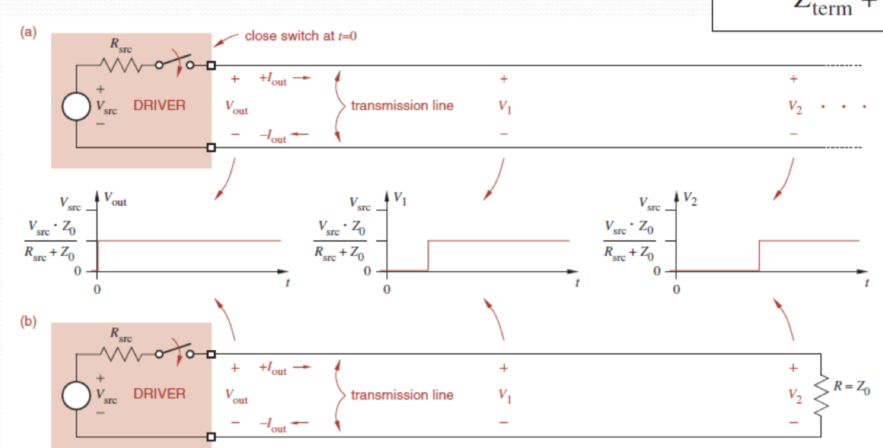


$$\boxed{R_{out} = r_o + R_s + g_m' R_s r_o}$$

Application of CG stage in Transmission lines

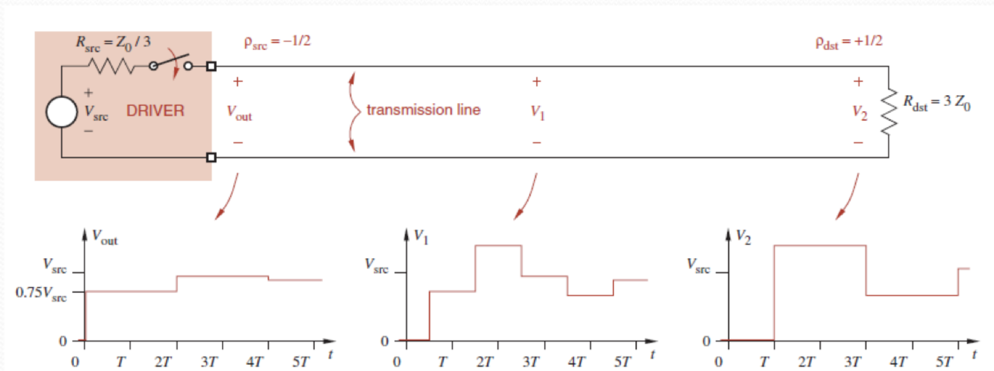
Transmission lines (I)

$$\rho = \frac{Z_{term} - Z_0}{Z_{term} + Z_0}$$



Transmission lines: (a) with infinite length; (b) with finite length, terminated with characteristic impedance.

Transmission lines (II)

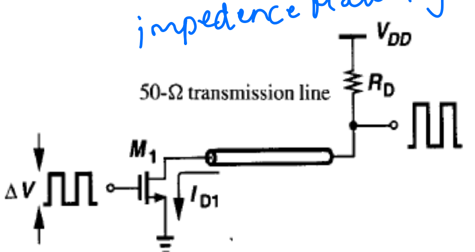


A transmission line that is not matched at either end

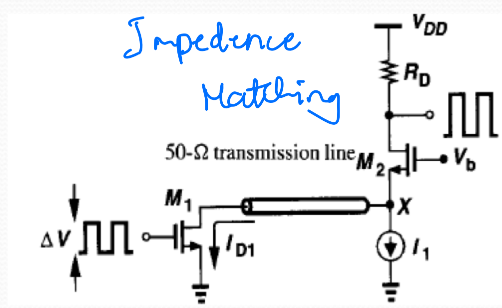
Digital Design Principles and Practices, Fourth Edition, by John F. Wakerly

Intuitive Analysis of CG

Not so much impedance Matching



Impedence Matching

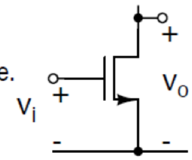


$$1/(g_m + g_{mb}) = 50\ \Omega$$

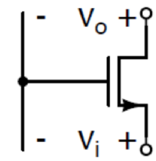
RZ

MOSFET Elementary Stages: Summary

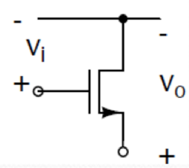
- Common source
  - VCCS.
  - A good voltage amplifier when terminated with a large impedance.



- Common gate
  - Typically low input impedance, high output impedance.
  - Can be used to improve the intrinsic voltage gain of a common source stage:
    - "Cascode" stage → which is widely used in CMOS circuit design.

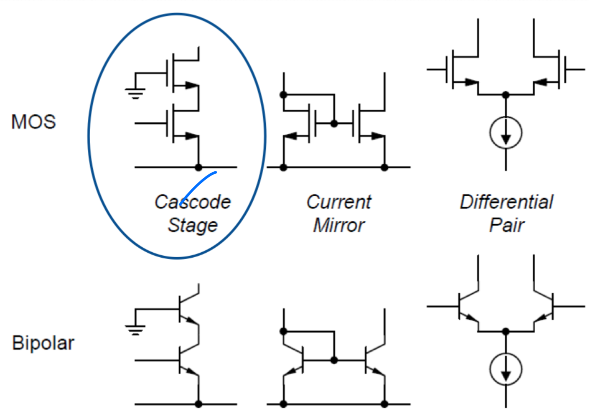


- Common drain
  - Typically high input impedance, low output impedance.
  - Great for shifting the DC operating point of signals.
  - Useful as a voltage buffer when swing and nonlinearity are not an issue.



* Cascode Configuration

Widely Used Two-transistor Circuits



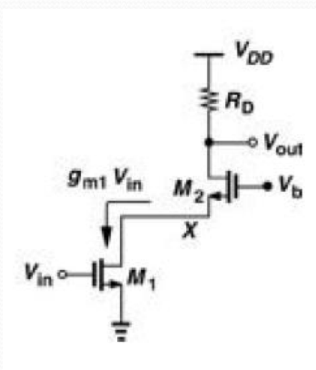
Outline

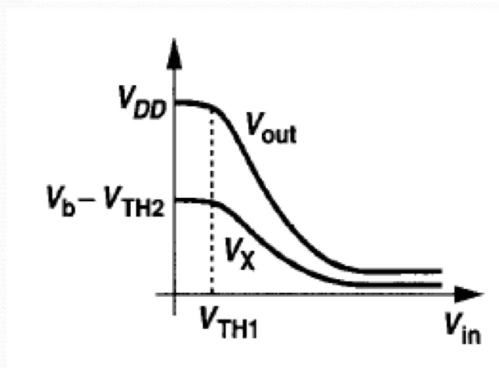
- CMOS cascode diagram
- Small-signal
- The stage as a CS+CG cascade
- Avo
- Transfer charact at the two output nodes

MOSFET Cascode

$$A_V \approx g_{m1}\{[r_{o1}r_{o2}(g_{m2}+g_{mb2})] \parallel R_D\}$$

$$Rout = \{[1+(g_{m2}+g_{mb2})r_{o2}]r_{o1}+r_{o2}\} \parallel R_D$$
$$\approx [r_{o1}r_{o2}(g_{m2}+g_{mb2})] \parallel R_D$$





RZ

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