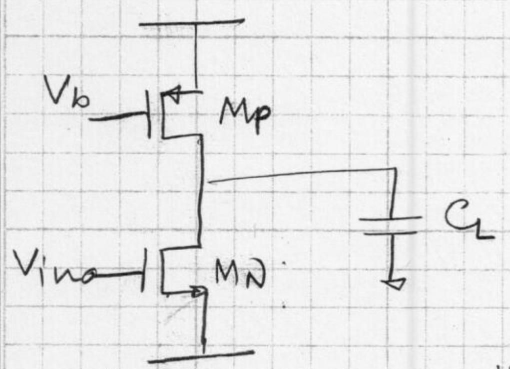
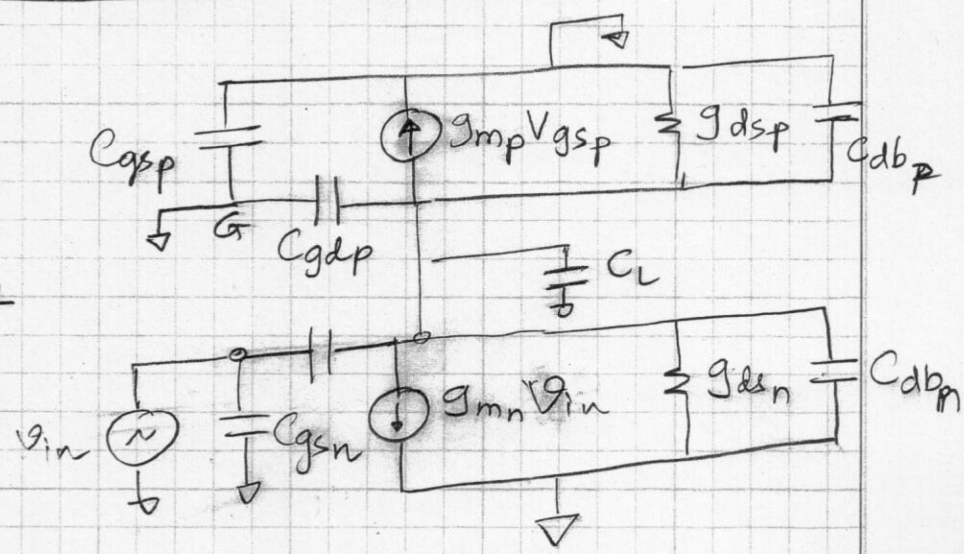
C-S Amplifier with Current source load.

FREQUENCY RESPONSE – Detailed

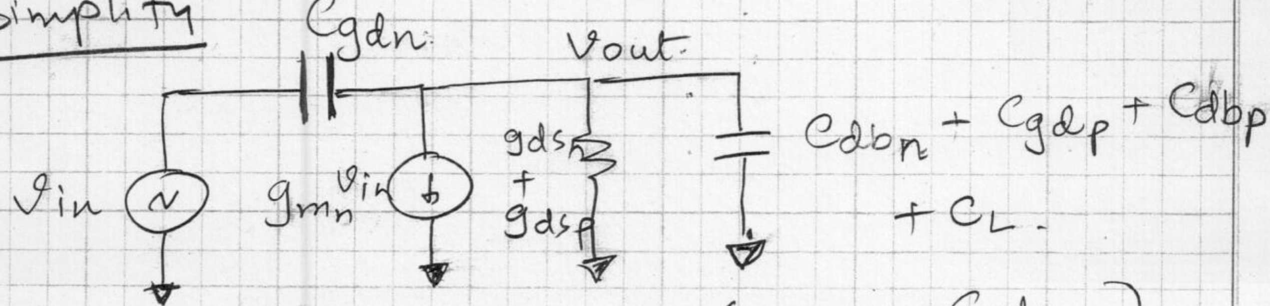




Neglect g_{mp}, g_{mbsn}, g_{mbsp} – No sig.

Neglect C_{gsn}, C_{gsp} – driven by v_{in}

Simplify

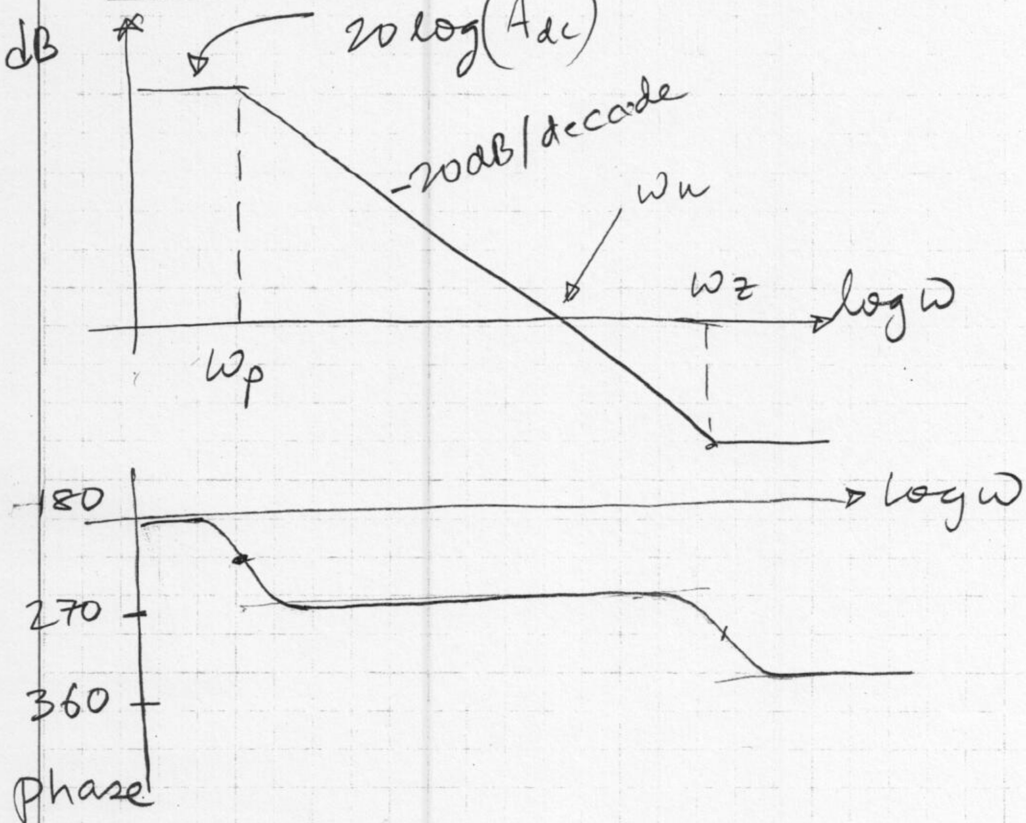


$$A_v = \frac{V_{out}}{v_{in}} = \frac{-g_{mn}}{g_{dsn}+g_{dsp}} \frac{\left(1 - s\frac{C_{gdn}}{g_{mn}}\right)}{\left(1 + s\frac{\left(C_{gdn}+C_{gdp}+C_{dbn}+C_{dbp}+C_{gdp}+C_L\right)}{g_{dsn}+g_{dsp}}\right)}$$

RHP zero $\quad \omega_z = +\frac{g_{mn}}{C_{gdn}}$

LHP pole $\quad \omega_p = -\frac{g_{out}}{C_{out}} = -\frac{g_{dsn}+g_{dsp}}{C_{gdn}+C_{gdp}+C_{dbn}+C_{dbp}+C_L}$

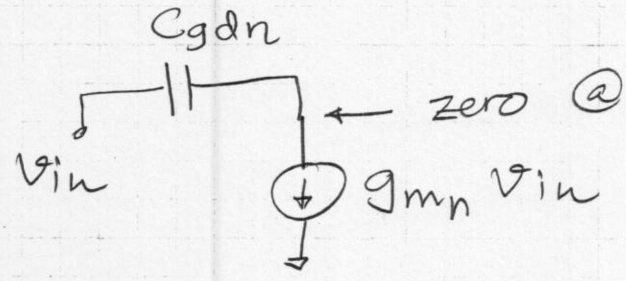
Bode Plots



In Closed-loop feedback system (study later)

RHP Zero

- keeps gain high @ high freq.
- phase shift degrades @ high freq.

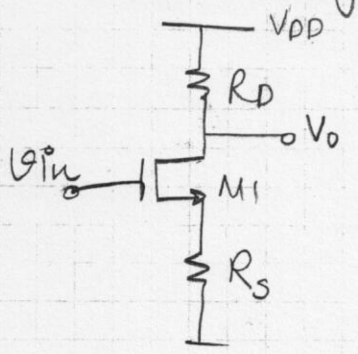


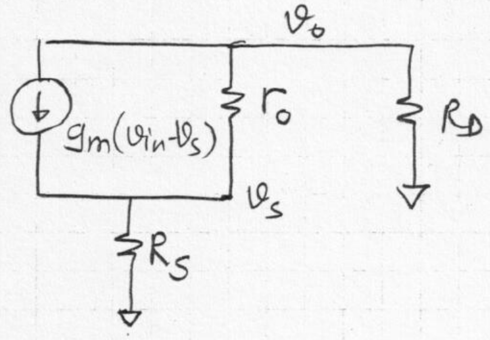
$$s_z C_{gd_n} \cdot v_{in} = g_{m_n} v_{in}$$

$$s_z = \frac{g_{m_n}}{C_{gd_n}}$$ ← Real & +ve RHP.

Quick way to analyse. | cap across inverting stage RHP zero
cap across Non inverting Stage

Source degeneration





$$\underbrace{g_m(v_{in}-v_s) + \frac{v_o-v_s}{r_o} = \frac{v_s}{R_s}}$$

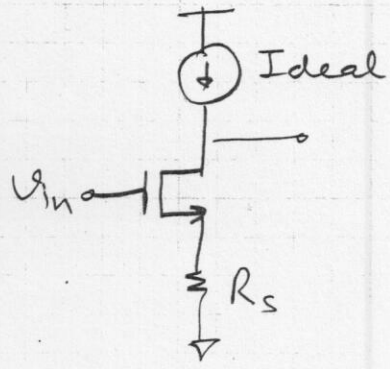
Also $\frac{v_s}{R_s} = -\frac{v_o}{R_D} \Rightarrow v_s = -\frac{R_s}{R_D}v_o$

$$g_m v_{in} - \left[g_m + \frac{1}{r_o} + \frac{1}{R_S}\right]v_s + \frac{v_o}{r_o} = 0$$

$$g_m v_{in} + \left(g_m + \frac{1}{r_o} + \frac{1}{R_S}\right)\frac{R_S}{R_D}v_o + \frac{v_o}{r_o} = 0$$

$$g_m r_o R_D v_{in} + \left[\left(g_m r_o + 1 + \frac{r_o}{R_S}\right)R_S + R_D\right]v_o = 0$$

$$\boxed{\frac{v_{out}}{v_{in}} = \frac{-g_m r_o R_D}{R_D + r_o + R_S(g_m r_o + 1)}}$$



$$\frac{v_{out}}{v_{in}} = -g_m r_o \quad \Big\}\ R_D = \infty$$

Theorem

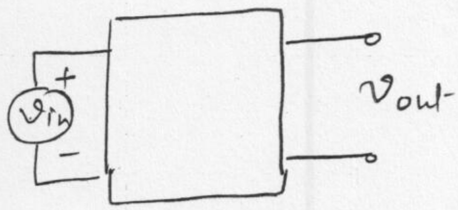
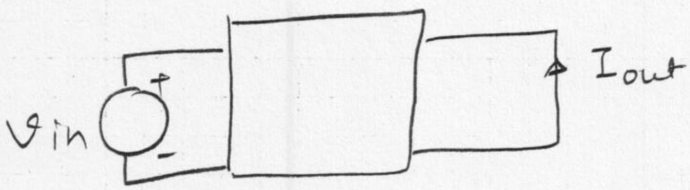


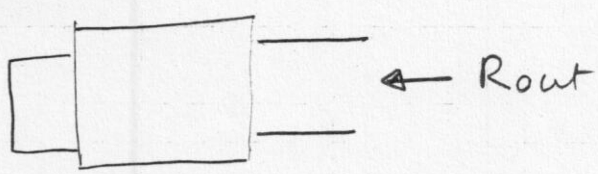
Figure out voltage gain $\frac{v_{out}}{v_{in}}$

① Short ckt Gm.



$$G_m = \frac{I_{out}}{v_{in}}$$

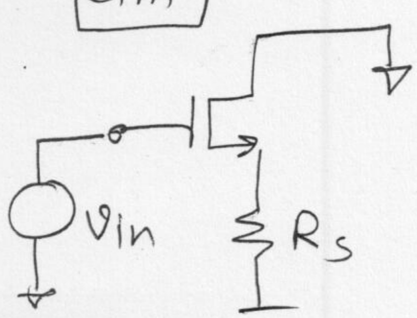
② R_{out} calculation

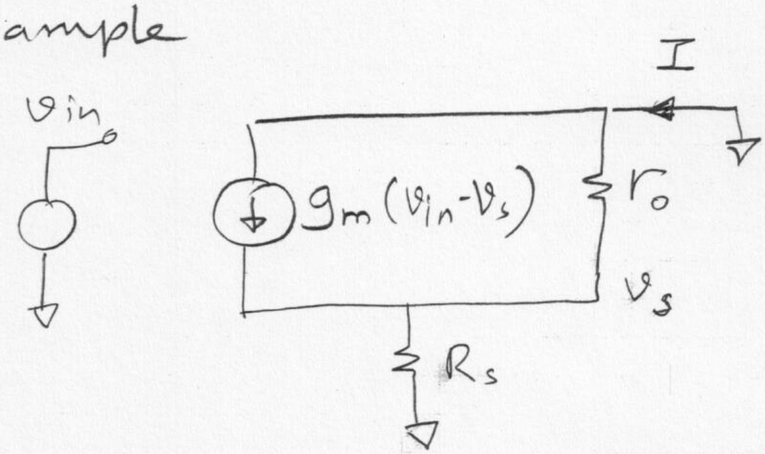


Voltage Gain $\frac{v_{out}}{v_{in}} = - G_m R_{out}$

Source degen Example

$\boxed{G_m}$





$$g_m(v_{in} - v_s) - \frac{v_s}{r_o} - \frac{v_s}{R_s} = 0$$

$$g_m v_{in} = \left(g_m + \frac{1}{r_o} + \frac{1}{R_s}\right) v_s$$

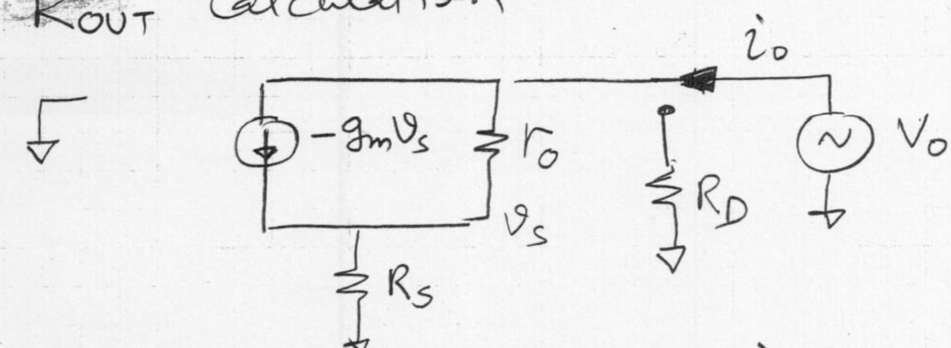
$$I = \frac{v_s}{R_s} = \frac{g_m v_{in}}{R_s\left(g_m + \frac{1}{r_o} + \frac{1}{R_s}\right)}$$

$$G_m = \frac{I}{v_{in}} = \frac{g_m}{g_m R_s + 1 + \frac{R_s}{r_o}}$$

$\Rightarrow$ if r_o is large $\boxed{G_m \approx \frac{g_m}{g_m R_s + 1}}$

$$\boxed{G_m = \frac{g_m r_o}{(g_m r_o + 1) R_s + r_o}}$$

R_{OUT} Calculation



① W/O R_D.

$$v_s = i_o R_s$$

$$g_m v_s + i_o = \frac{v_o - v_s}{r_o}$$

$$(g_m i_o R_s + i_o) r_o = v_o - i_o R_s$$

$$\frac{v_o}{i_o} = \left[(1 + g_m r_o) R_s + r_o\right]$$

$$\left(\approx g_m r_o R_s + r_o\right.$$

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including $\parallel R_D$

$$R_{out} = \frac{[(1+g_m r_o)R_s + r_o]\,R_D}{R_D + r_o + (1+g_m r_o)R_s}$$

$$\frac{V_{out}}{V_{in}} = -G_m R_{out}$$

$$= -\frac{g_m r_o}{\cancel{(g_m r_o+1)R_s + r_o}} \times \frac{\cancel{[(g_m r_o+1)R_s + r_o]}\,R_D}{R_D + r_o + (1+g_m r_o)R_s}$$

$$= -\frac{g_m r_o R_D}{R_D + r_o + (1+g_m r_o)R_s} \leftarrow$$

Same as what we directly derived !!!

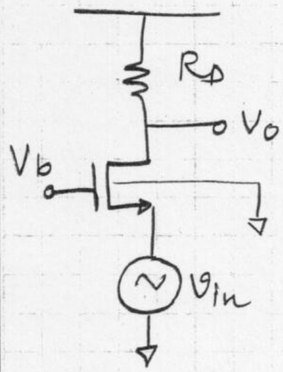
If we ignore r_o

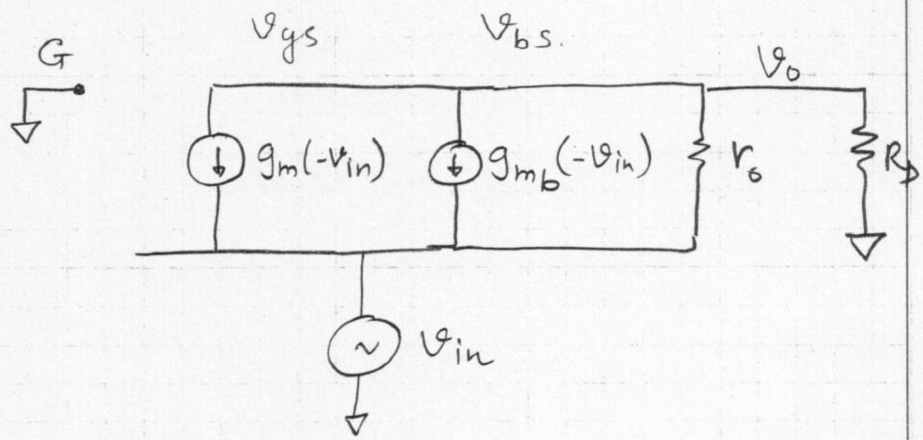
$$G_m = \frac{g_m}{1+g_m R_s} \quad ; \quad R_{out} = R_D$$

$$\frac{V_{out}}{V_{in}} = -\frac{g_m R_D}{1+g_m R_s}$$

(Quick Calculation)

Common Gate amplifier





$$\frac{v_o}{R_D} = g_m v_{in} + g_{mb} v_{in} + \frac{v_{in} - v_o}{r_o}$$

$$v_o\left(\frac{1}{R_D} + \frac{1}{r_o}\right) = (g_m + g_{mb})\, v_{in} + \frac{v_{in}}{r_o}$$

$$\frac{v_o}{v_{in}} = \frac{\left((g_m + g_{mb})\, r_o + 1\right)}{(r_o + R_D)} R_D.$$

If we ignore body effect

$$\frac{v_o}{v_{in}} = \frac{g_m r_o + 1}{(r_o + R_D)} R_D. \longrightarrow \star$$

$$Z_{in} = \frac{v_{in}}{I_{in}} = \frac{v_{in}}{V_o / R_D} = \frac{R_D \cdot (r_o + R_D)}{(g_m r_o + 1) R_D}$$

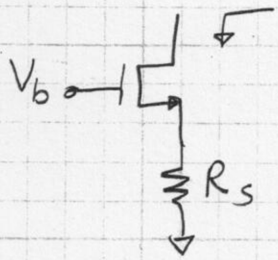
$$Z_{in} = \frac{r_o + R_D}{(g_m r_o + 1)} \approx \frac{r_o + R_D}{g_m r_o}$$

Drain impedance div by $(g_m r_o)$ ↓

ONLY WHEN $R_D \ll r_o$

$Z_{in} \cong$ ro/(gm ro)=1/gm (low impedance)

In case of source degeneration



$$R_{out} \cong (g_m r_o) R_s + r_o$$

$R_{out} \uparrow$ by $(g_m r_o)$

Cascode from Vacuum tubes
1939. - Frederick HUNT
Cascode of two triodes instead of pentode
I guitar amp

Cascode CS Amplifier

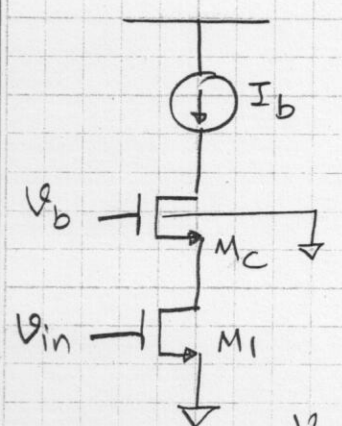
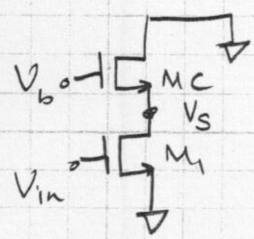


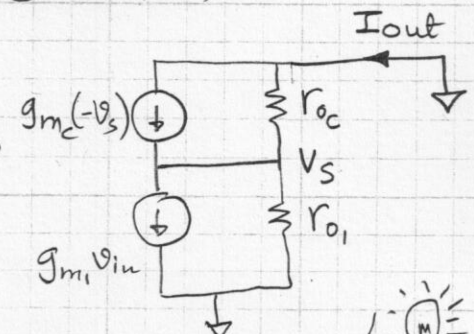
Figure out Gm & Rout

$$A_v = -G_m R_{out}$$

Gm calculation



$\Rightarrow$



Use g_{ds} & r_o interchangeably for convenience

$$g_{m_1} v_{in} + \frac{v_s}{r_{o_1}} + g_{m_c} v_s + \frac{v_s}{r_{o_c}} = 0$$

$$g_{m_1} v_{in} + v_s \Big(\underbrace{\frac{1}{r_{o_1}}}_{g_{ds_1}} + \underbrace{\frac{1}{r_{o_c}}}_{g_{ds_c}} + g_{m_c} \Big) = 0$$

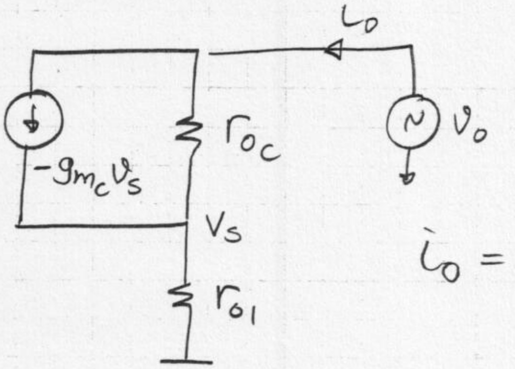
$$v_s = \frac{-g_{m_1} v_{in}}{(g_{ds_1} + g_{ds_c} + g_{m_c})}$$

$$i_{out} = g_{m_1} v_{in} + v_s g_{ds_1} = g_{m_1} v_{in} - \frac{g_{m_1} v_{in} g_{ds_1}}{(g_{ds_1} + g_{ds_c} + g_{m_c})}$$

$$\frac{i_{out}}{v_{in}} = \frac{g_{m1}\left(g_{ds1} + g_{dsc} + g_{mc} - g_{ds1}\right)}{\left(g_{ds1} + g_{dsc} + g_{mc}\right)}$$

$$\boxed{G_M \approx g_{m1}.}$$

Rout Calculation



$$V_s = i_o r_{o1}$$

$$i_o = -g_{mc} v_s + \frac{(v_o - v_s)}{r_{oc}}$$

$$i_o = -g_{mc} i_o r_{o1} + \frac{(v_o - i_o r_{o1})}{r_{oc}}$$

$$i_o r_{oc} = -g_{mc} i_o r_{o1} r_{oc} + v_o - i_o r_{o1}$$

$$R_{out} = \frac{v_o}{i_o} = \left(\underbrace{g_{mc} r_{oc} r_{o1}}_{\text{large}} + \underbrace{r_{o1} + r_{oc}}_{\text{small.}}\right)$$

$$R_{out} \approx (g_{mc} r_{oc}) r_{o1}$$

Cascode self gain multiplier effect

$$\boxed{A_v = (g_{m1} r_{o1})(g_{mc} r_{oc})} \approx (g_m r_o)^2$$

Benefits of cascoding

- (+) Rout → self gain of cascode multiplication
- (+) gain ↑ squared
  - * Can be used for high o/p impedance current source
- (-ve) Headroom Reduced to keep two transistors in saturation

$$V_{out\,min} = V_{dsat1} + V_{dsatc}$$