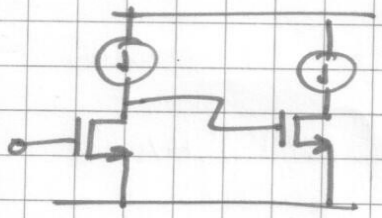
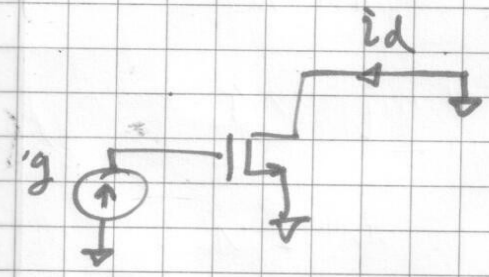
f_T discussion

Transition frequency —



voltage gain = 1

$$\omega_T = \frac{g_m}{C_{gs}}$$



Current gain = 1

$$\omega_T = \frac{g_m}{C_{gs}}$$

Give an idea of Raw speed capability of transistor

Why Transit frequency ?

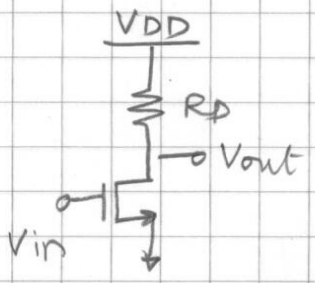
$$\omega_T f_T = \frac{g_m}{C_{gs}} = \frac{\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{TH})}{\frac{2}{3} C_{ox} W \cdot L} = \frac{\left[\frac{3}{2}(V_{GS}-V_{TH})\right]\mu_n}{L}$$

$$= \frac{\mu_n [E_{channel}]}{L} = \frac{v}{L} = \frac{1}{\tau_T}$$

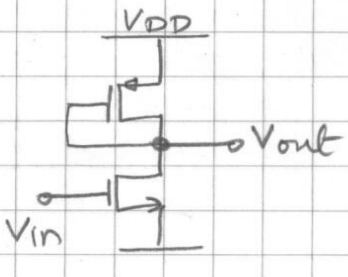
τ_T : Transit Time from source to drain

$f_T \Rightarrow$ gives an idea of intrinsic delay of device.

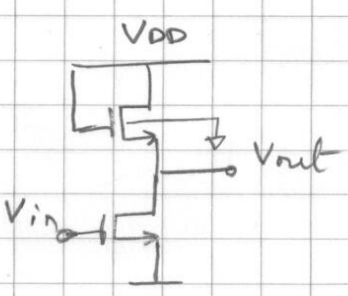
Recap f_T discussion. — Why Transit frequency



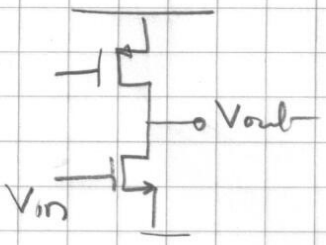
$$\frac{V_{out}}{V_{in}} \cong -g_m (r_o \| R_D)$$



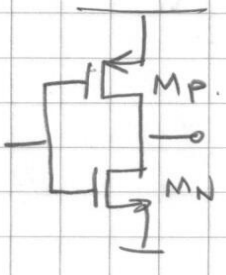
$$\frac{V_{out}}{V_{in}} \cong -\frac{g_{m_1}}{g_{m_2}}$$



$$\frac{V_{out}}{V_{in}} = \frac{-g_{m_1}}{g_{m_2} + g_{mbs_2}}$$

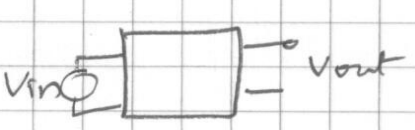


$$\frac{V_{out}}{V_{in}} = -g_{m_1} (r_{o_1} \| r_{o_2})$$



$$\frac{V_{out}}{V_{in}} = -\frac{(g_{mN} + g_{mP})}{(g_{dsN} + g_{dsP})}$$

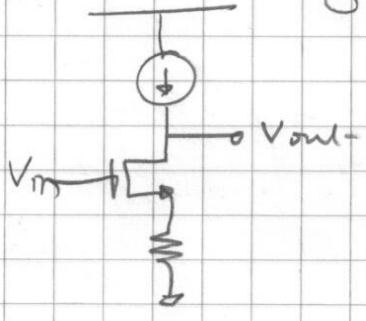
XF Theorem



Short Ckt G_m & R_{out}

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

Source degeneration

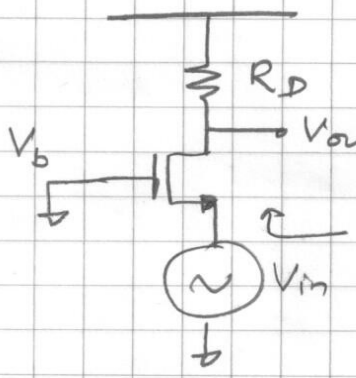


$$G_m \cong \frac{g_m}{1+g_m R_s}$$

$$R_{out} = g_m r_o R_s + r_o$$

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

Common Gate Amplifier

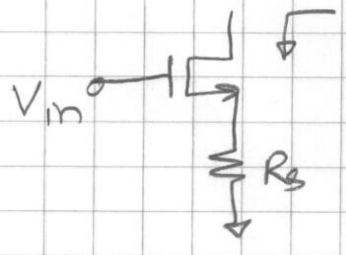


$$\frac{V_{out}}{V_{in}} = \frac{g_m r_o}{(r_o + R_D)} R_D$$

(Body effect ignored)

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

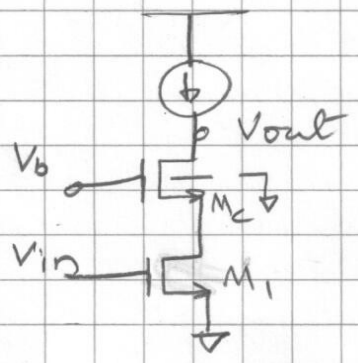
($R_D >>$



$$R_{out} = (g_m r_o) R_s + r_o$$

R_{out} ↑ $(g_m r_o)$ factor

Cascode Common Source Amplifier

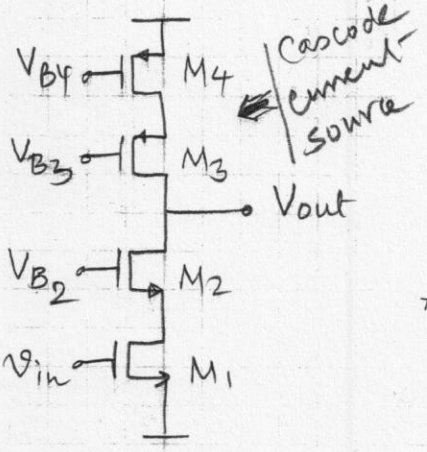


$$A_v = -G_m \cdot R_{out}$$

$$\cong -g_{m_1}\left(g_{m_c} r_{o_c} \cdot r_{o_1}\right)$$

$$\approx -\left(g_{m_1} r_{o_1}\right)\left(g_{m_c} r_{o_c}\right)$$

Cascode Stage with current source



$$G_m = g_{m_1}$$

$$R_{out} = (g_{m_2} r_{o_2}) r_{o_1} \parallel (g_{m_3} r_{o_3}) r_{o_4}$$

Assuming $r_{o_1} = r_{o_2} = r_{o_3} = r_{o_4} = r_o$

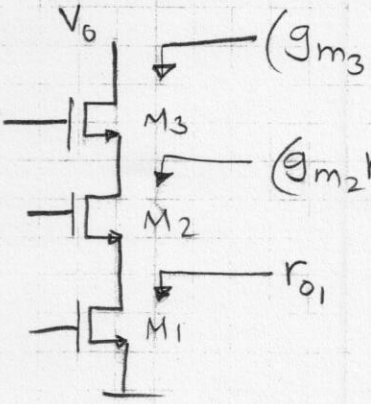
$$g_{m_1} = g_{m_2} = g_{m_3} = g_{m_4} = g_m$$

$$A_v = -\frac{1}{2}(g_m r_o)^2$$

$$V_{out\,min} = V_{dsat_1} + V_{dsat_2}$$

$$V_{out\,max} = V_{dd} - (|V_{dsat_3}| + |V_{dsat_4}|)$$

Tripple Cascode



$(g_{m_3} r_{o_3})(g_{m_2} r_{o_2}) r_{o_1}$ ← Really high o/p impedance

$(g_{m_2} r_{o_2}) r_{o_1}$

r_{o_1}

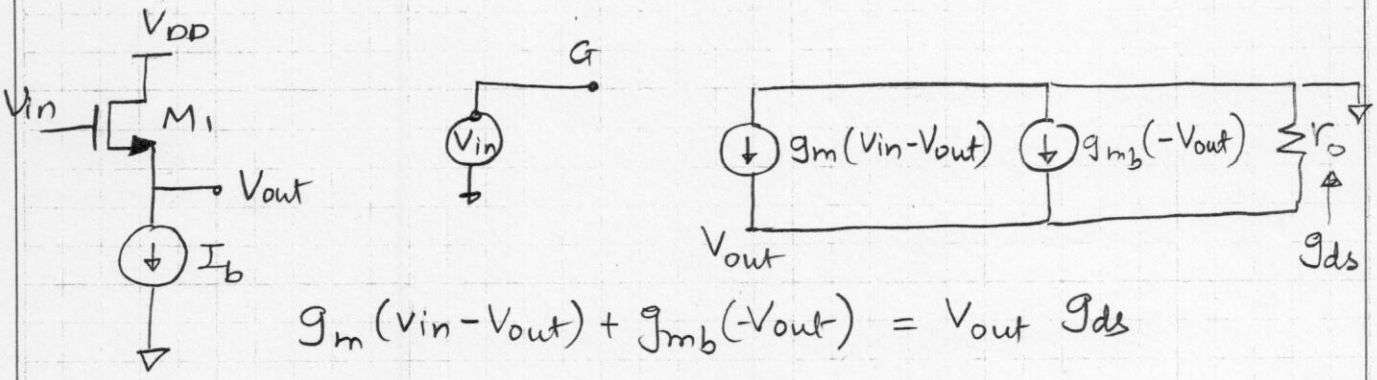
$$V_{o\,min} = V_{dsat_1} + V_{dsat_2} + V_{dsat_3}$$

(with proper biasing.)

Also called

Telescopic Cascode

Common drain Amplifier (Source follower)



$$g_m(V_{in}-V_{out}) + g_{mb}(-V_{out}) = V_{out}\, g_{ds}$$

$$(g_m + g_{mb} + g_{ds})V_{out} = g_m V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{g_m}{g_m + g_{mb} + g_{ds}} \approx \frac{g_m}{g_m + g_{mb}} = \frac{1}{1+\eta} \approx 1$$

→ Non-inverting unity gain. amplifier

$r_{in} = \infty$ $\quad r_{out} = \dfrac{1}{g_m + g_{mb} + g_{ds}} \approx \dfrac{1}{g_m}$ Low imp.

→ O/P DC range

$$V_{out} = V_{in} - (V_{T_1} + V_{dsat_1})$$

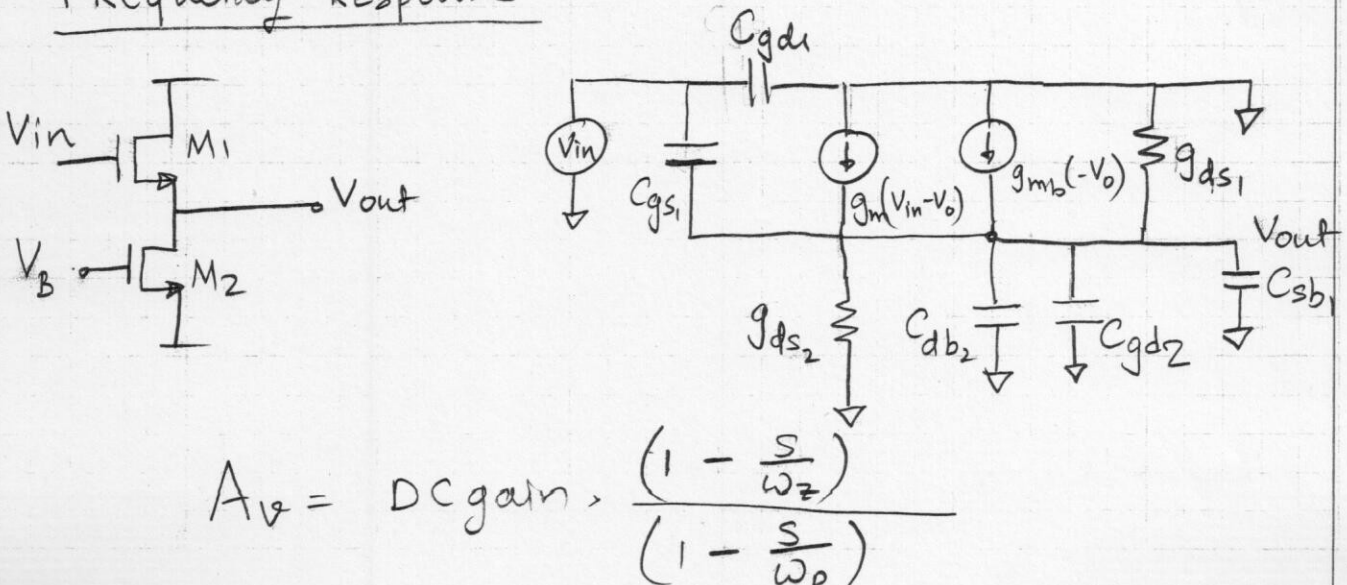
$$V_{out\,max} = V_{DD} - (V_T + V_{dsat})$$

$$V_{in\,max} = V_{DD}$$

$$V_{in\,min} = V_T + V_{dsat} + \underbrace{V_{dsat}}_{cs}$$

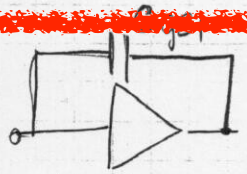
→ DC-level shifter & Buffer. (low O/P imp)

Frequency Response

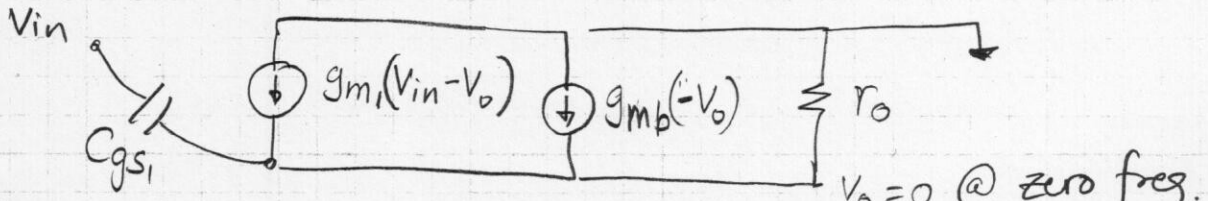


$$A_v = \text{DC gain} \cdot \frac{\left(1 - \frac{s}{\omega_z}\right)}{\left(1 - \frac{s}{\omega_p}\right)}$$

$$\text{LHP} \qquad \omega_p = -\frac{g_{out}}{C_{out}} = -\frac{g_{m_1} + g_{mbs_1} + g_{ds_1} + g_{ds_2}}{C_{gs_1} + C_{sb_1} + C_{db_2} + C_{gd_2}}$$



$\Rightarrow$ LHP zero.

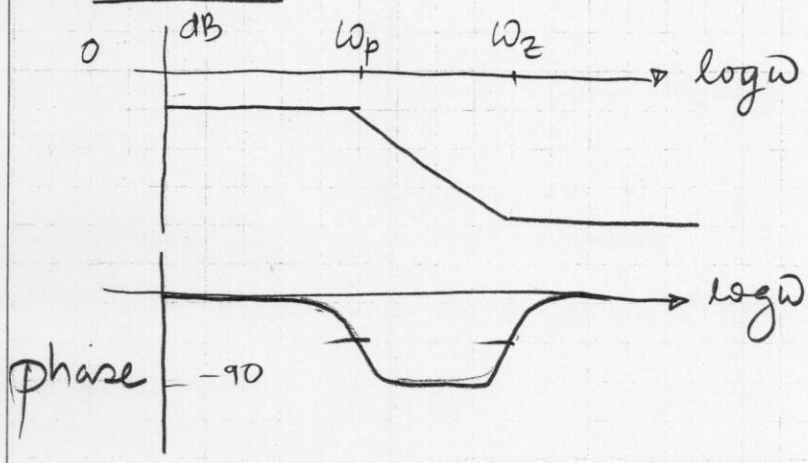


@ Zero frequency ω_z

$$\omega_z C_{gs_1} \cdot V_{in} = -g_{m_1} V_{in} \Rightarrow \boxed{\omega_z = -\frac{g_{m_1}}{C_{gs_1}}}$$

$$A_V = \frac{g_{m_1}}{g_{m_1} + g_{mbs_1} + g_{ds_1} + g_{ds_2}} \cdot \frac{\left(1 + \frac{s}{g_{m_1}/C_{gs_1}}\right)}{\left(1 + \frac{s}{\frac{g_{m_1} + g_{mbs_1} + g_{ds_1} + g_{ds_2}}{C_{gs_1} + C_{sb_1} + C_{db_2} + C_{gd_2}}}\right)}$$

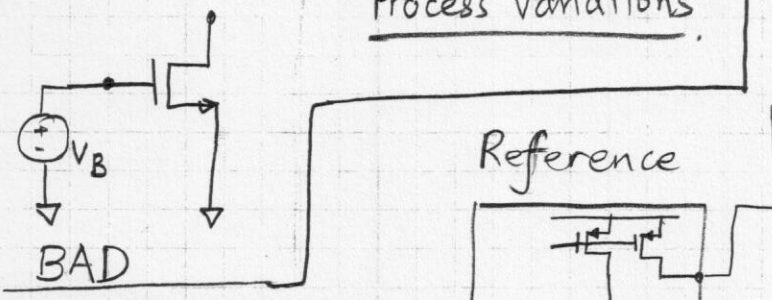
Bode Plot



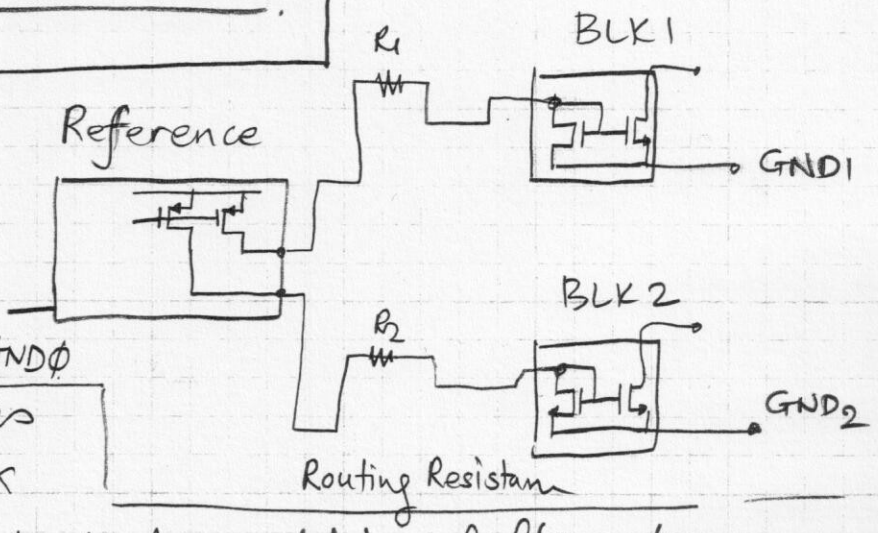
New Topic MOS Current Mirrors / Sources

Novice Biasing

Process variations.



ON CHIP CURRENT DISTRIBUTION



sending voltage as reference XXX

→ Gnd / Vdd potentials could be different

→ transistor properties across the chip change.

Current Sources used for DC biasing,
Active load to get max gain without IR drop.

Specs →
- → Output Resistance
- → voltage compliance (min or max voltage)
- → Accuracy & process independance.
- → DC balance (for mirrors)
- → i/p Resistance (for mirrors)