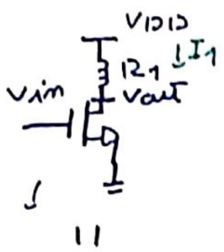
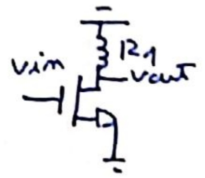
complete analysis

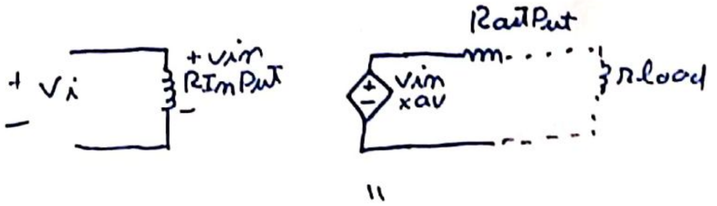
~~stage~~ resistive common source stage

DC



In small signals





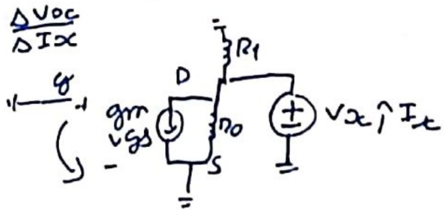
small signal equivalent models

R input

In MOS $R_{in} \simeq 10^{15}\,\Omega$ and a capacitance generally since this is DC, the DC is Ignored

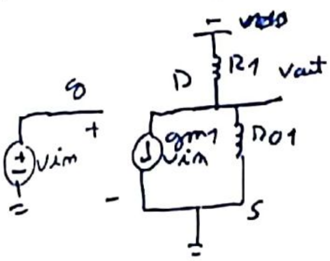
RInput (In DC and low frequencies) $= \infty$

Routput $\frac{\Delta V_{oc}}{\Delta I_x}$



$$\frac{V_x}{I_x} = R_1 \parallel R_o = R_o$$

AV voltage gain $\frac{\Delta V_{out}}{\Delta V_{in}}$



$$\frac{V_{out}}{V_{in}} = \frac{-g_m R_1 R_{o1}}{R_1 + R_{o1}}$$

equivalent current gain

$$\frac{\Delta I_D}{\Delta V_{in}} = g_m$$

The Parameters for The equivalent small frequency circuit

In large signal analysis, Dc simulation assuming level 1 equations

$$V_{out} = V_{DD} - I_D R_D$$

$$\frac{V_{DD} - V_{out}}{R_D} = I_D \text{ saturated}$$

} starting In saturation

$V_{gs} = V_{in}$

$V_{DS} = V_{out}$

$V_{out} = V_{DD} - I_D R_D$

The Transistors enters in the Triode when $V_{gs} - V_{th} > V_{out}$

"longest" with Vout as reference

To make sure The Transistor stays The longest In saturation, we have to make sure The gain is The highest.

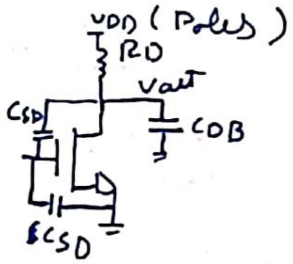
As the result The gain Becomes not linear, creates a lot of distortion

In The ~~xxx~~ Modern Process

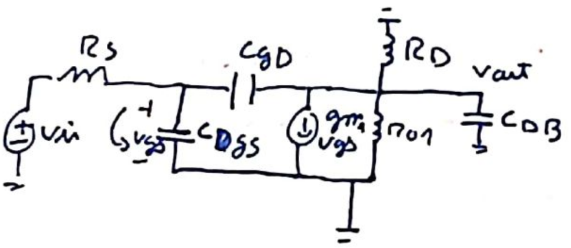
I_D varies not in a a quadratic way with changes In Vin, and its dependencys in Process Parameters are not as linear as They are in level 1 cmos Models

System analysis over frequency

resistive common source stage

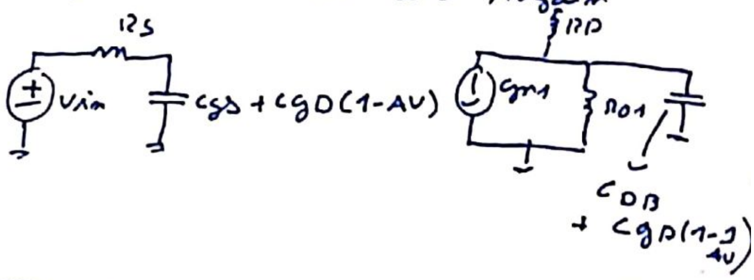


equivalent circuit



=

Using Miller Theorem and Av gain



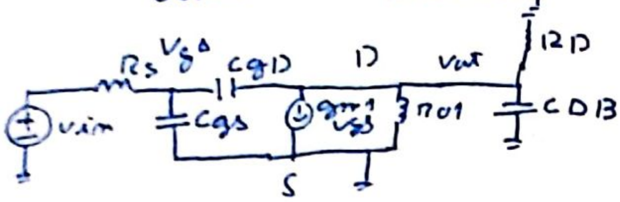
$$\underbrace{w_{in}}_{\text{dominant Pole}} = \frac{1}{R_S \times C_{eq}} = \frac{1}{R_S\left(c_{gs} + c_{gD}\left(1 + g_{m1} \| r_{o1} \| R_D\right)\right)}$$

$$w_{out} = \frac{1}{\underbrace{R_D \| R_{o1}}_{R_{eq}} \times \left(C_{DB} + c_{gs}\left(1 - \frac{1}{A_V}\right)\right)} \qquad A_V \gg 1 \quad \frac{1}{A_V} \approx 0$$

$$A_V(s) = A_V(\text{low frequency}) \times \frac{1}{\left(1 + \frac{s}{w_{in}}\right)\left(1 + \frac{s}{w_{out}}\right)}$$

The "easy way" to calculate

"hard way"



$$Z_{eq1} = R_D \parallel r_{o1} \parallel \frac{1}{C_{DB}s}$$

$$Z_{eq1} = \frac{R_D r_{o1}}{R_D + r_{o1}} \parallel \frac{1}{C_{DB}s}$$

$$Z_{eq1} = \frac{\dfrac{R_D r_{o1}}{(r_D + r_{o1}) C_{DB}s}}{\dfrac{R_D r_{o1}}{R_D + r_{o1}} + \dfrac{1}{C_{DB}s}}$$

$$Z_{eq1} = \frac{\dfrac{R_D r_{o1}}{\cancel{(R_D + r_{o1})} C_{DB}s}}{\dfrac{(r_D r_{o1}) C_{DB}s + (R_D + r_{o1})}{\cancel{(R_D + R_{o1})} C_{DB}s}}$$

$$Z_{eq1} \quad \frac{R_D r_{o1}}{(R_D r_{o1}) C_{DB}s + (r_o + r_{o1})}$$

$$V_{gs}(C_{gs}s) + \frac{V_{gs} - V_{in}}{R_s} + (V_{gs} - V_{out}) C_{gD}s = 0$$

$$\frac{V_{out}}{Z_{eq1}} + g_m V_{gs} + (V_{out} - V_{gs}) C_{gD}s = 0$$

$$-V_{out} \frac{\left(\frac{1}{Z_{eq}} + C_{gD}s\right)}{g_m - C_{gD}s} = V_{gs}$$

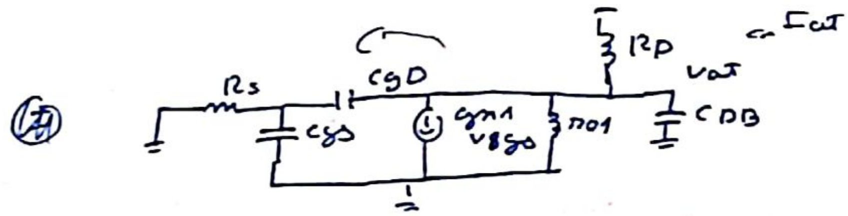
$$-V_{out}\left(C_{gd}s + \left(\frac{\frac{1}{Z_{eq}} + C_{gD}s}{g_m - C_{gD}s}\right)\left(C_{gs}s + \frac{1}{R_s} + C_{gD}s\right)\right) = \frac{V_{in}}{R_s}$$

$$A_V(s) = \frac{+\left(\frac{1}{R_s}\right)(-g_m + C_{gD}s)}{(C_{gs})(g_m - C_{gD}s) + \frac{1}{Z_{eq}} + (C_{gD}s)(\ldots\ldots)}$$

$$A_V(s) = \frac{R_s Z_{eq}(-g_m + C_{gD}s)}{R_s Z_{eq}(C_{gs})(g_m - C_{gD}s) + (1 + C_{gD}s)(1 + R_s(C_{gs}s + C_{gD}s)}$$

↓
continue this will result
in a second order
equation with two poles
+ its hard to solve

outPut Impedance



$$Zeq_1 = RD \,//\, Ro1 \,//\, \frac{1}{CDBD} = \frac{RD\, ro1}{(RD\, ro1) CDBD + (RD + ro1)}$$

$$Vgs = \frac{Rs \,//\, \frac{1}{CgsD}}{Rs \,//\, \frac{1}{CgsD} + \frac{1}{CgDD}} \times Vout$$

$$Rs \,//\, \frac{1}{CgsD} = \frac{RS}{RS\, CgsD + 1}$$

$$\frac{RS\, CgDS}{(RsCgsD + 1)\, CgDS} + (RsCgsD+1)$$

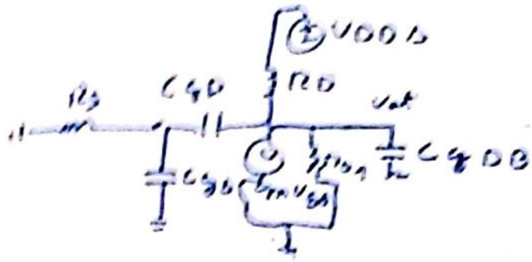
$$Vgs = \frac{RS\, CgDS}{\underbrace{RSgDS + (RSCgSD + 1)}_{Zeq2}} \times Vout$$

$$\frac{Vout}{Zeq1} + gm_1 Vgs + (Vout - Vgs)\, CgDS = Iout$$

$$Vout \left(\frac{1}{Zeq1} + gm_1 Zeq2 + CgDS - Zeq2\, CgDS \right) = Iout$$

$$\frac{Iout}{Vout} = \frac{Zeq1}{(1 + Zeq1\, Zeq2\, gm_1 + CgDS\, Zeq1 - Zeq2\, Zeq1\, CgDS)}$$

At gain



$$A_t = \frac{V_{out}}{V_{DD}}$$

$$V_{gs} = V_{out} Z_{eq2}$$

$$Z_{eq1} = \frac{1}{C_{gDD}} \parallel R_{o1} = \frac{R_{o1}}{R_{o1} C_{gDS} + 1}$$

$$\frac{\frac{R_{o1}}{C_{gRD}}}{\frac{R_{o1} C_{gDS}+1}{C_{gDS}}} = \frac{R_{o1}}{R_{o1} C_{gDS}+1}$$

$$\frac{V_{out} - V_{DD}}{R_D} + \frac{V_{out}}{Z_{eq1}} + g_m V_{gs} + (V_{out} - V_{gs}) C_{gDS} = 0$$

$$V_{out}\left(\frac{1}{R_D} + \frac{1}{Z_{eq1}} + C_{gDD} + Z_{eq}(g_m - C_{gDD})\right) = \frac{V_{DD}}{R_D}$$

$$\frac{V_{out}}{V_{DD}} = A_t = \frac{\frac{1}{R_D}}{\left(\frac{1}{R_D} + \frac{1}{Z_{eq1}} + C_{gDD} + Z_{eq2}(g_m - C_{gDD})\right)}$$

$$\frac{\frac{1}{R_D}}{\frac{1}{R_D} + \frac{1}{r_{o1}}} = \frac{1}{1 + \frac{R_D}{r_{o1}}} = \frac{r_{o1}}{r_{o1} + R_D}$$ → At low frequency

can be obtained by $A_t(s)$

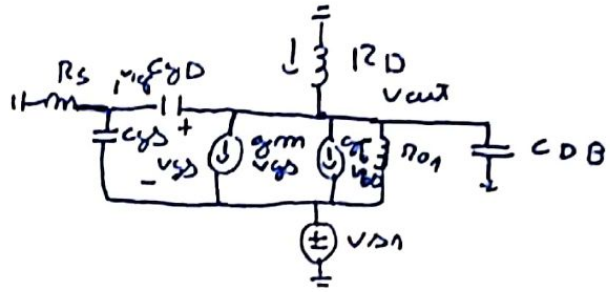
low frequency gain

$$\frac{V_{out} - V_{DD}}{R_D} + \frac{V_{out}}{r_{o1}} = 0$$

$$\frac{-V_{DD}}{R_D} = -V_{out}\left(\frac{1}{R_D} + \frac{1}{r_{o1}}\right)$$

$$\frac{V_{out}}{V_{DD}} = \frac{\frac{1}{R_D}}{\frac{1}{r_{o1}} + \frac{1}{R_D}} = \frac{r_{o1}}{r_{o1} + R_D}$$

A - gain



$$Zeq_1 = RD \parallel \frac{1}{CDBs} = \frac{RD}{RD\,CDBs + 1}$$

$$-\frac{V_{out}}{Zeq_1} = \frac{V_{out} - V_{SS}}{ro_1} + gm\,v_{gs} + (V_{out} - V_g)\,C_{gD}s + gm\,V_{bS}$$

$$V_{bS} = -V_{SS}$$

$$V_{gs} = V_g - V_{SS}$$

$$\frac{V_g}{R_S} + (V_g - V_{out})\,C_{gD}s + (V_g - V_{SS})\,C_{gS}s = 0$$

$$V_g\left(\frac{1}{R_S} + C_{gD}s + C_{gS}s\right) = V_{out}\,C_{gD}s + V_{SS}\,C_{gS}s$$

$$V_g = \frac{V_{out}\,C_{gD}s + V_{SS}\,C_{gS}s}{\left(\frac{1}{R_S} + C_{gD}s + C_{gS}s\right)}$$

$$-\frac{V_{out}}{Zeq_1} = \frac{V_{out} - V_{SS}}{ro_1} + gm(V_g - V_{SS}) + (V_{out} - V_g)\,C_{gD}s) + gmb(-V_{SS})$$

$$+V_{out}\left(\frac{1}{Zeq} + C_{gD}s + \frac{C_{gD}s}{\left(\frac{1}{R_S} + C_{gD}s + C_{gS}s\right)}\left(gm - C_{gD}s\right) + \frac{1}{ro_1}\right)$$

$$= +V_{SS}\left(\frac{1}{ro_1} + gm + \frac{C_{gS}s}{\left(\frac{1}{R_S} + C_{gD}s + C_{gS}s\right)}\left(C_{gD}s - gm\right)\right)$$

$$\frac{V_{out}}{V_{SS}} = \frac{\left(\frac{1}{ro_1} + gm + \frac{C_{gS}s}{\left(\frac{1}{R_S} + C_{gD}s + C_{gS}s\right)}\left(C_{gD}s - gm\right) + gmbs\right)}{\left(\frac{1}{Zeq} + C_{gD}s + \frac{1}{ro_1} + \frac{C_{gD}s}{\left(\frac{1}{R_S} + C_{gS}s + C_{gD}s\right)}\left(C_{gD}s - gm\right)\right)}$$