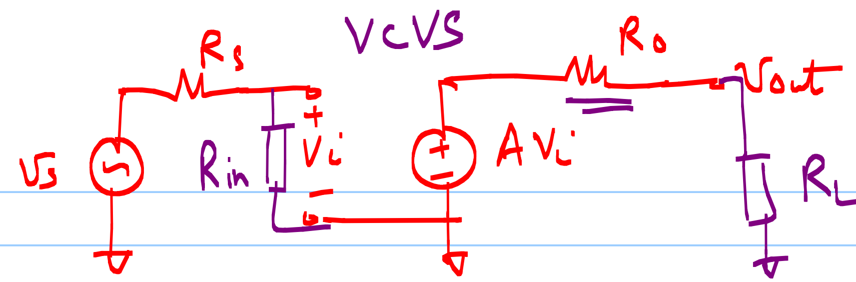
ECE 5411 – Lecture 15.

Note Title 3/16/2011

"Low frequency"

Amplifier Stage	Gain	Z_{in}	Z_{out}	Application
CS	Large	∞	Moderate	Large Gain Amplifier
CS + SD	Moderate	∞	High	Linear, moderate Gain Amplifier (VGA)
CD/"SF"	Low (<1)	∞	Low	Voltage Buffer (V_{o}/V_{s}, $A\approx 1$)
CG	Moderate/High	Low (moderate)	moderate/High	Current Buffer

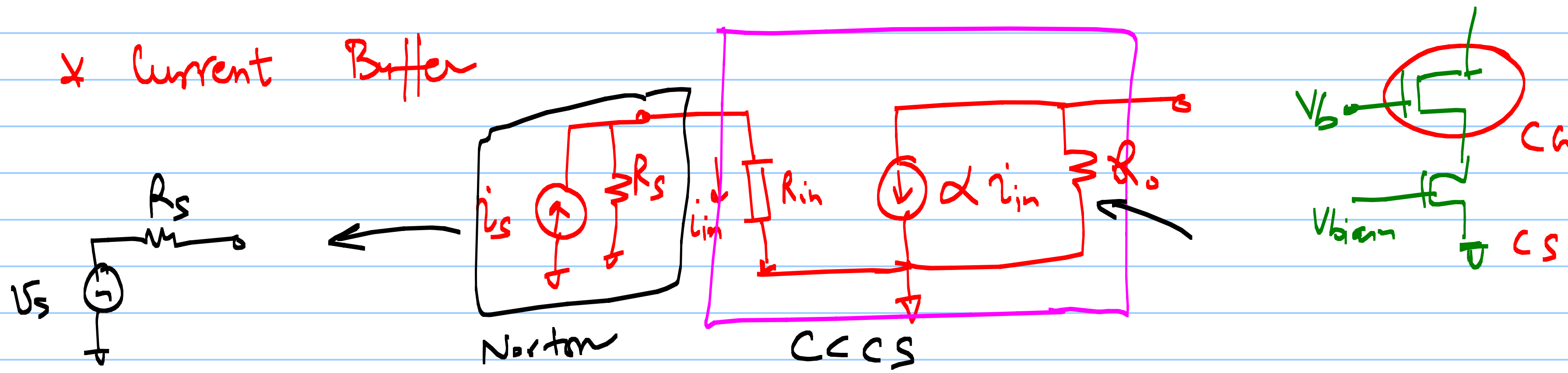
* Voltage Buffer



$R_{in} \to \infty$

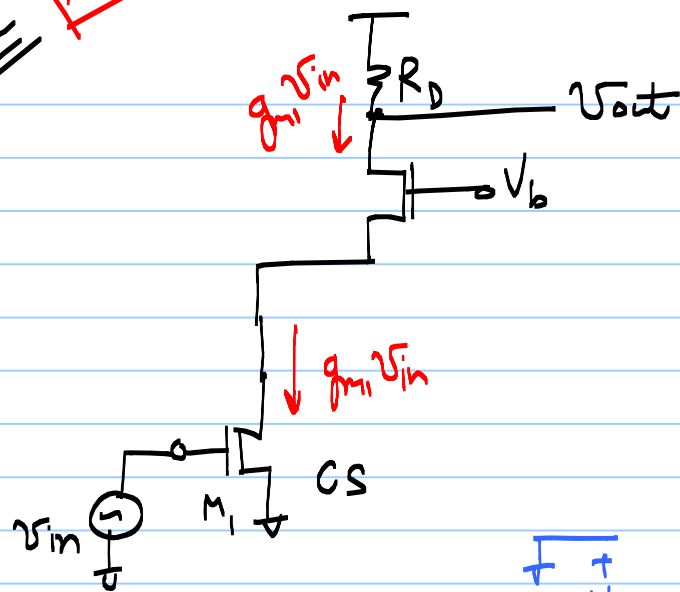
$R_o \to 0$

* Current Buffer



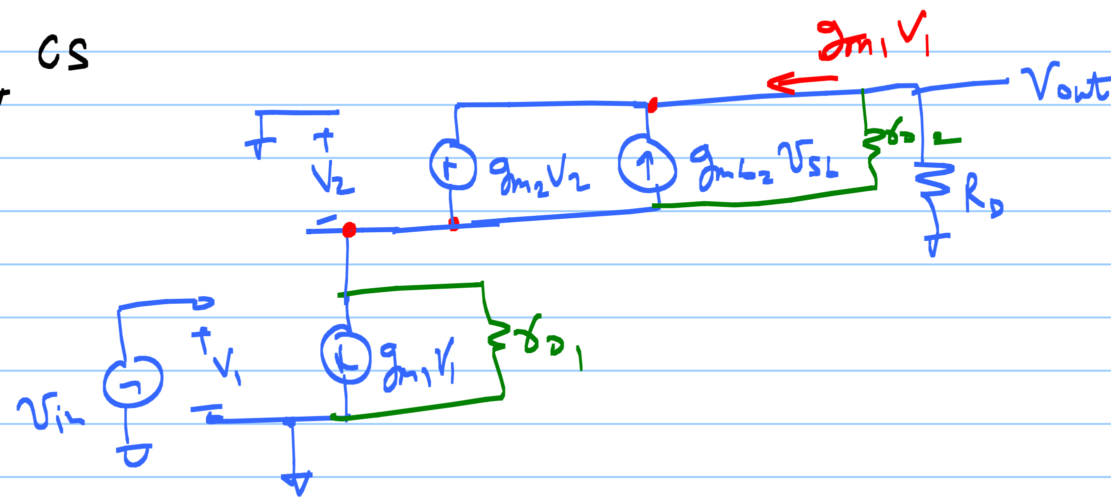
$R_{in} \to 0$, $R_o \to \infty$

Ac $\boxed{\lambda = 0}$



CS ⇒ Converts vin into ac current $g_{m1} v_{in}$

CG ⇒ relaying this current to R_D



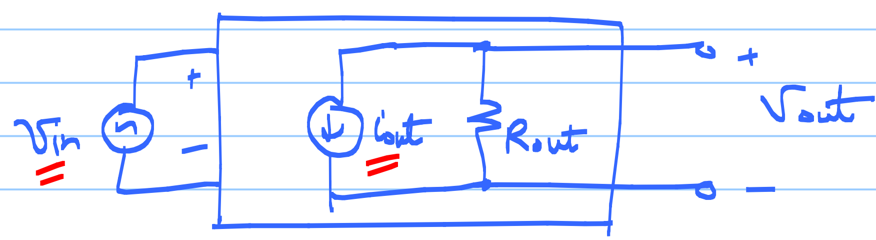
Theorem: In a Linear circuit, voltage gain $= -G_m R_{out}$

where,

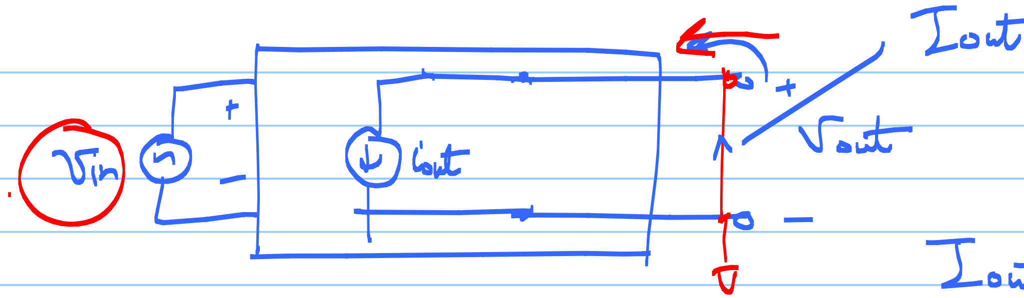
$G_m \rightarrow$ denotes the transconductance of the circuit when the output is shorted to ground.

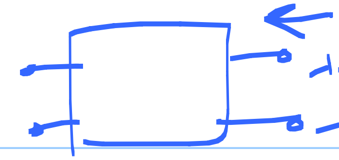
$R_{out} \rightarrow$ output resistance of the circuit when the input is at zero.

~~Proof~~:



g_m:

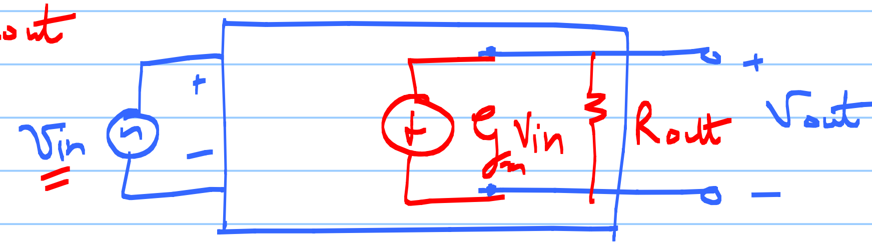




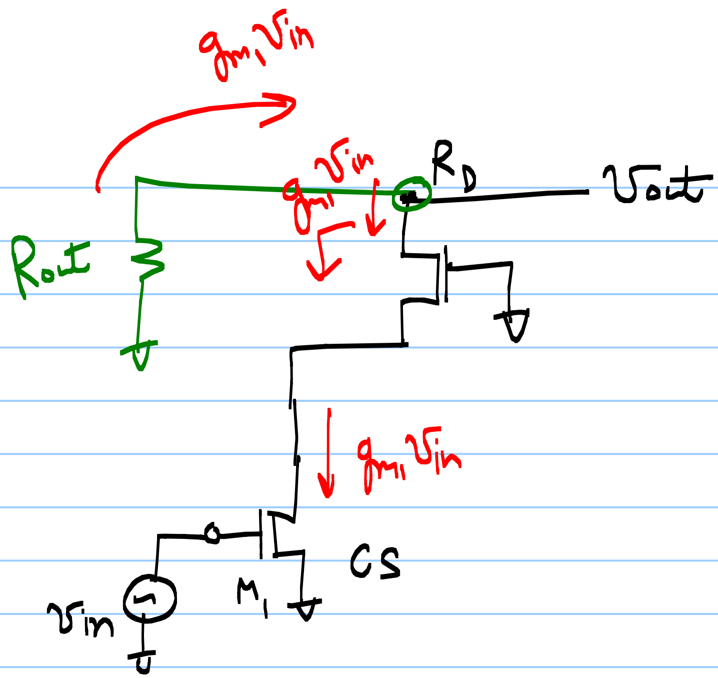
$I_{out} = i_{out}$

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

$$V_{out} = -g_m v_{in} R_{out}$$

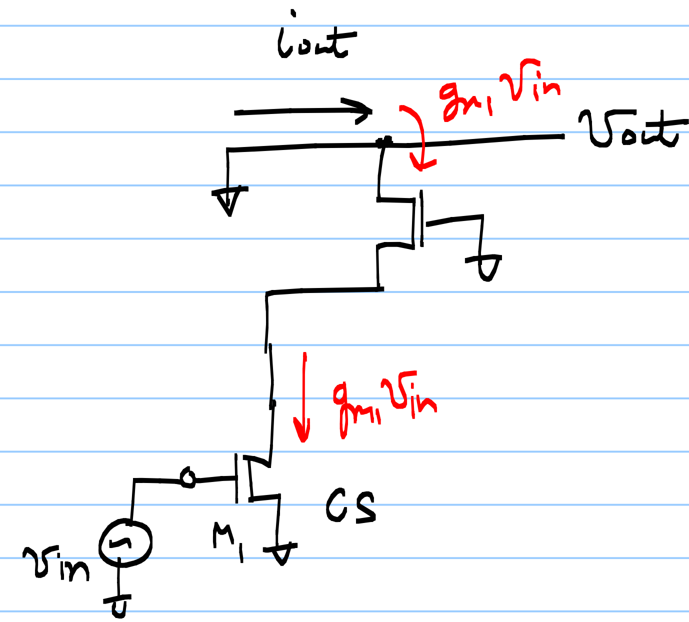


$$A_v = \frac{V_{out}}{V_{in}} = \boxed{-g_m R_{out}}$$



$g_{m1} \rightarrow g_{m1}$

$R_{out} \rightarrow R_D \| (g_m r_o^2)$



$$A_v = -g_{m1} \cdot (R_D \| g_m r_o^2)$$

$$G_m = \frac{g_{m1} r_{o1}\left[r_{o2}(g_{m2}+g_{mb2})+1\right]}{r_{o1}r_{o2}(g_{m2}+g_{m2b})+r_{o1}+r_{o2}}$$

$$g_{m2} r_{o2} \gg 1$$

$$= \frac{g_{m1}\cancel{r_{o1}}\left[\cancel{\frac{g_{m2}r_{o2}+1}{g_{m2}r_{o2}}}\right]^{1}}{\cancel{r_{o1}}+\cancel{\frac{r_{o1}+r_{o2}}{g_{m2}r_{o2}}}^{\,0}} \simeq g_{m1}$$

$$R_{cas} = \left[1+(g_{m2}+g_{m2b})r_{o2}\right]r_{o1} + r_{o2}$$

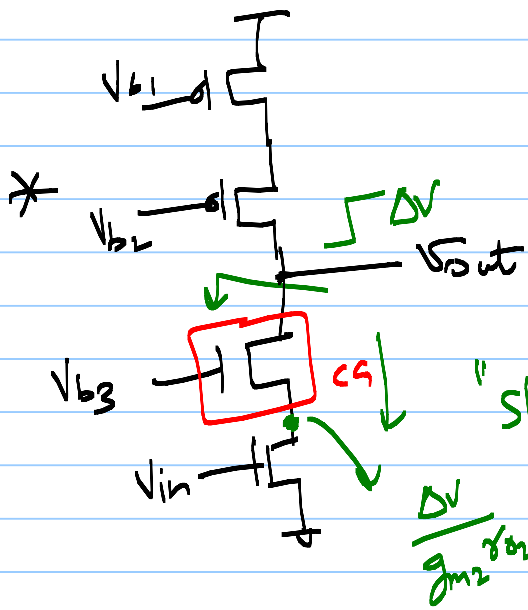
$$\simeq (g_{m2}+g_{m2b})r_{o2}r_{o1} \simeq g_{m2}r_{o2}r_{o1}$$

$\boxed{\begin{array}{l}\text{odd-order harmonics} \\ i_d = g_{m1}v_{gs} + \cancel{g_{m3}v_{gs}^3} \\ \text{Volterra Series} \\ \text{Analysis}\end{array}}$

$$A_v = -g_m R_{out} = -g_{m1}\left(R_{cn} \| R_D\right)$$

$$= -g_{m1}\left(g_{m2} r_{o2} r_{o1}\right) \quad \text{if } R_D \to \infty$$

*



"shielding"

$$A_v = -g_{m1} \cdot R_{con} \| R_{cop}$$

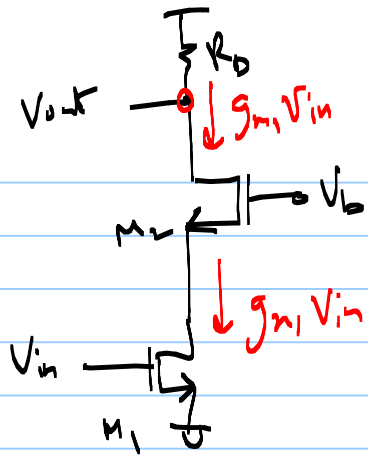
$R_{con} \to g_{mn} r_{on}^2$ $\qquad$ $R_{cop} \to g_{mp} r_{op}^2$

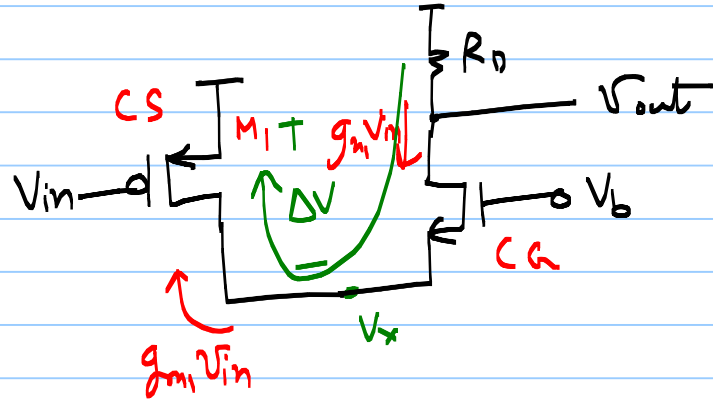
CG shields the drain of CS

↳ large R_{out}

$R_o = (g_{m2} r_{o2}) r_{o1}$

* current steering DAC's

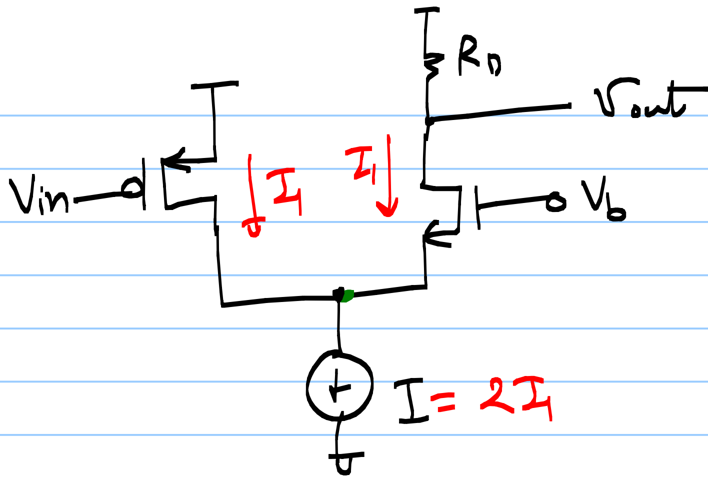




"Folded-Cascode"

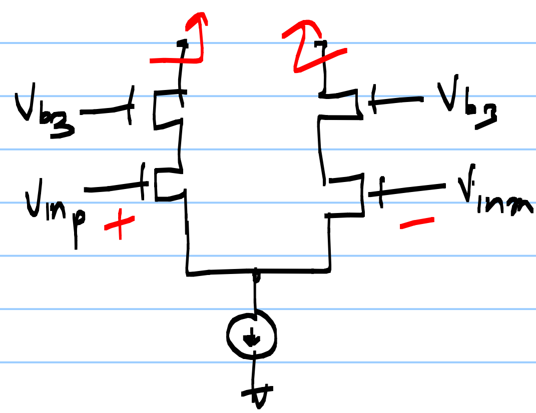
$\left[\begin{array}{l} \text{PMOS} \rightarrow \text{CS} \\ \text{NMOS} \rightarrow \text{CG} \end{array}\right.$

perform the same function as a cascode.



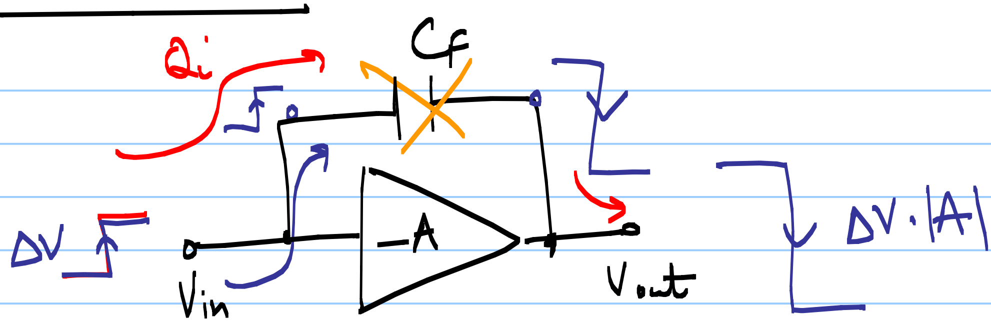
× 2x bias current

× better headroom with cascoded gain



NMOS half ← Telescopic diffamp.

Miller Effect (Capacitance multiplying effect)

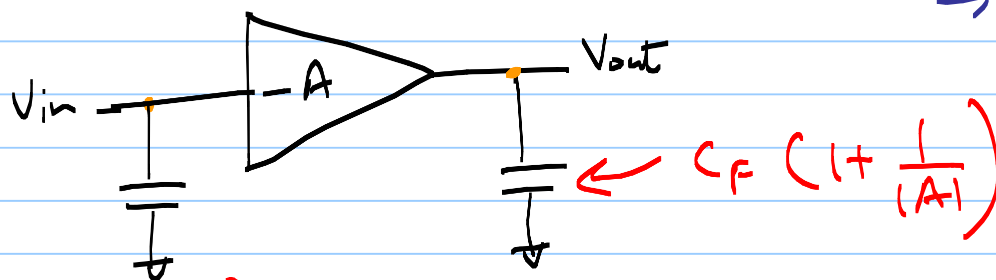


$A >> 1$

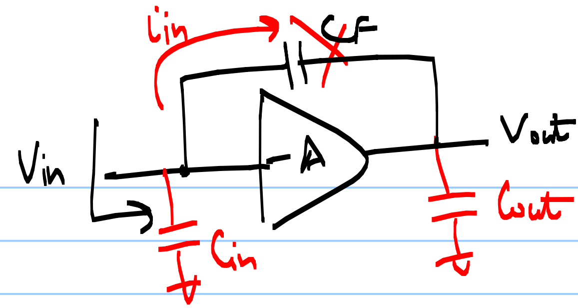
Net voltage change across C_f

$\Rightarrow (1+|A|)\Delta V$

$\Rightarrow Q = \underbrace{C_f(1+|A|)}_{C_{in} = C_f(1+|A|)}\Delta V$



$C_f(1+|A|)$



$$|A| = A > 0$$

$$i_{in} = \frac{v_{in} - V_{out}}{1/sC_F} = sC_F(V_{in} - V_{out})$$

$$= sC_f(V_{in} - (-Av_{in}))$$

$$= sC_f V_{in}(1+A)$$

$$Z_{in} = \frac{v_{in}}{i_{in}} = [sC_F(1+A)]^{-1} = [sC_{in}]^{-1}$$

$$\boxed{C_{in} = C_F(1+|A|)}$$

$$i_{out} = -i_{in} = -sC_f\,(v_{in} - v_{out})$$

$$= sC_f\left(\frac{1}{|A|} + 1\right)v_{out}$$

$$\Rightarrow Z_{out} = \frac{v_{out}}{v_{in}} = \left[\underbrace{sC_f\left(1 + \frac{1}{|A|}\right)}\right]^{-1} = \left[s\,\underbrace{C_{out}}\right]^{-1}$$

$$C_{out} = \left(1 + \frac{1}{|A|}\right)C_f \simeq C_f$$