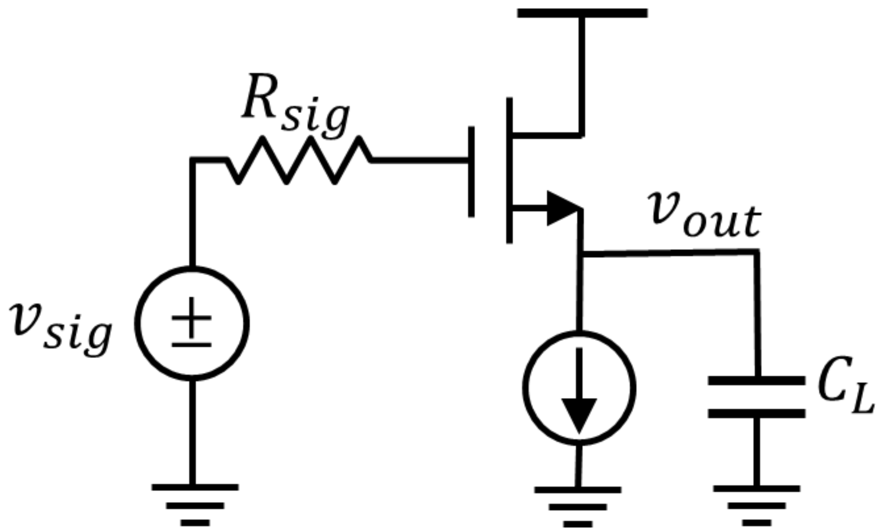
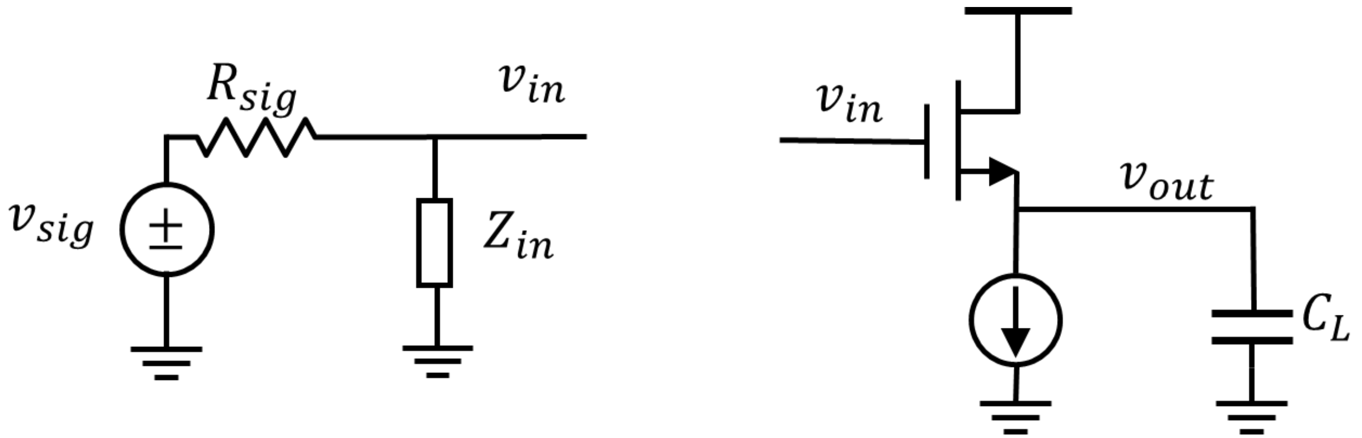
Frequency Response of CD



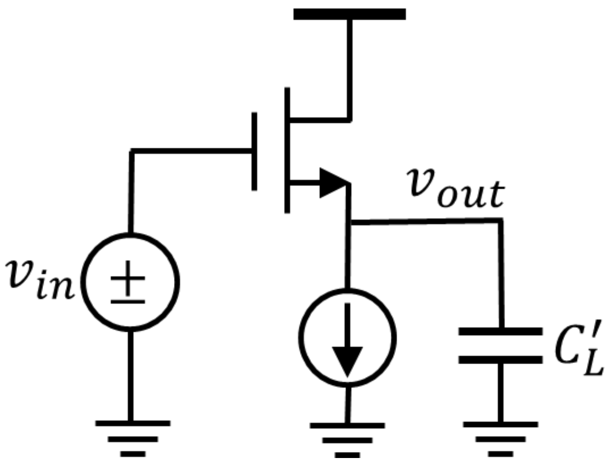
- The circuit has two poles.
- C_{gs} is bootstrapped.
- The two poles are nearby and possibly complex conjugate.
- we can't use the OCTC technique and Miller approximation directly.

divide and conquer



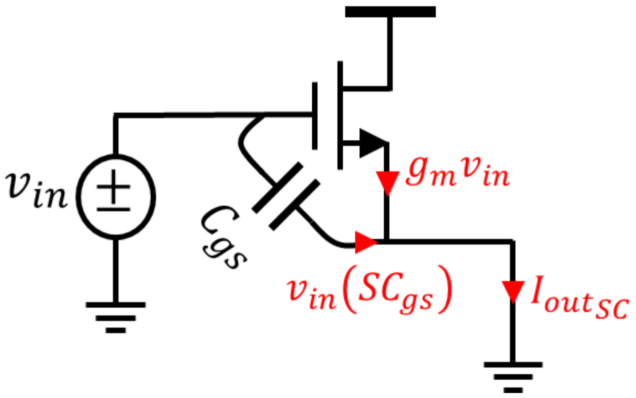
- $\frac{v_{out}}{v_{sig}} = \frac{Z_{in}}{Z_{in}+R_{sig}} \frac{v_{out}}{v_{in}}$
- now all we need is to find v_{out}/v_{in} and Z_{in}

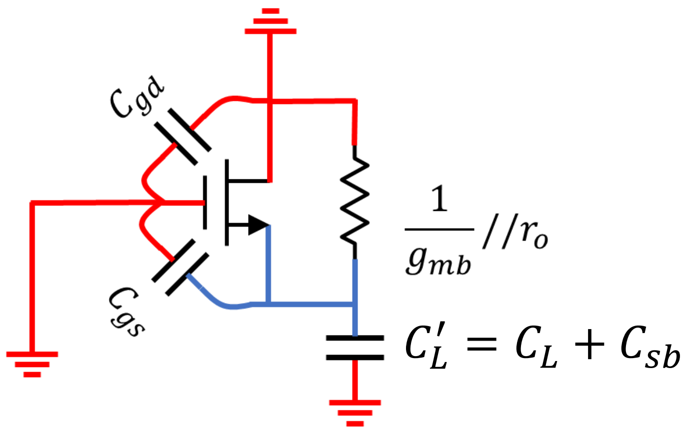
v_{out}/v_{in}(intuitively)



- neglecting r_o and g_{mb} will give us ideal buffer $A_o = 1$
- $A_o = \frac{g_m r_o}{1+(g_m+g_{mb})r_0}$
- C_{gs} has a LHP feedforward zero $S_Z = -g_m/C_{gs}$
- When calculating poles C_{gs} **isn't floating anymore**! (v_{in} is deactivated)
- $C_{out} = C_L'//C_{gs}$ $\qquad R_{out} = 1/g_m$
- $\frac{v_{out}}{v_{in}} = \underbrace{\frac{g_m r_0}{1+(g_m+g_{mb})r_0}}_{A_o} \frac{\overbrace{1+s\frac{C_{gs}}{g_m}}^{\text{(LHP feedforward zero)}}}{\underbrace{1+\frac{s(C_{gs}+C_L')}{g_m}}_{output\ pole}}$

v_{out}/v_{in}(exact)





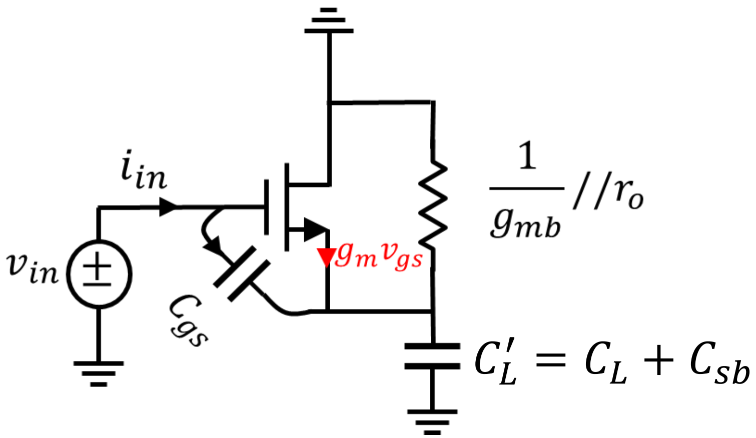
$$I_{out\,SC} = g_m v_{in} + v_{in}(SC_{gs})$$

$$G_m = g_m\left(1 + s\frac{C_{gs}}{g_m}\right)$$

$$Z_{out} = \frac{1}{g_m}//r_0//\frac{1}{g_{mb}}//\frac{1}{s(C_{gs}+C_L')} = \frac{1}{S(C_{gs}+C_L') + g_m + g_{mb} + 1/r_0}$$

$$\frac{v_{out}}{v_{in}} = \frac{g_m r_0}{1 + (g_m + g_{mb})r_0} \times \frac{1 + s\frac{C_{gs}}{g_m}}{1 + \frac{S(C_{gs}+C_L')}{g_m + g_{mb} + 1/r_0}}$$

Z_{in}



$$v_{in} = \frac{i_{in}}{SC_{gs}} + \left(i_{in} + i_{in}\frac{g_m}{SC_{gs}}\right)Z_s = \frac{i_{in}}{SC_{gs}} + \frac{i_{in}\left(1 + \frac{g_m}{SC_{gs}}\right)}{g_{mb} + 1/r_0 + SC_L'}$$

$$Z_{in} = \frac{S\left(C_{gs} + C_L'\right) + g_m + g_{mb} + 1/r_0}{SC_{gs}(g_{mb} + 1/r_0 + SC_L')}$$

- Neglecting CLM and body effect $Z_{in} \approx \dfrac{1+\frac{S\left(C_{gs}+C_L'\right)}{g_m}}{\frac{S^2 C_{gs} C_L'}{g_m}}$
- S^2 indicates negative impedance
- C_{gd} Shunts Z_{in} at high frequency

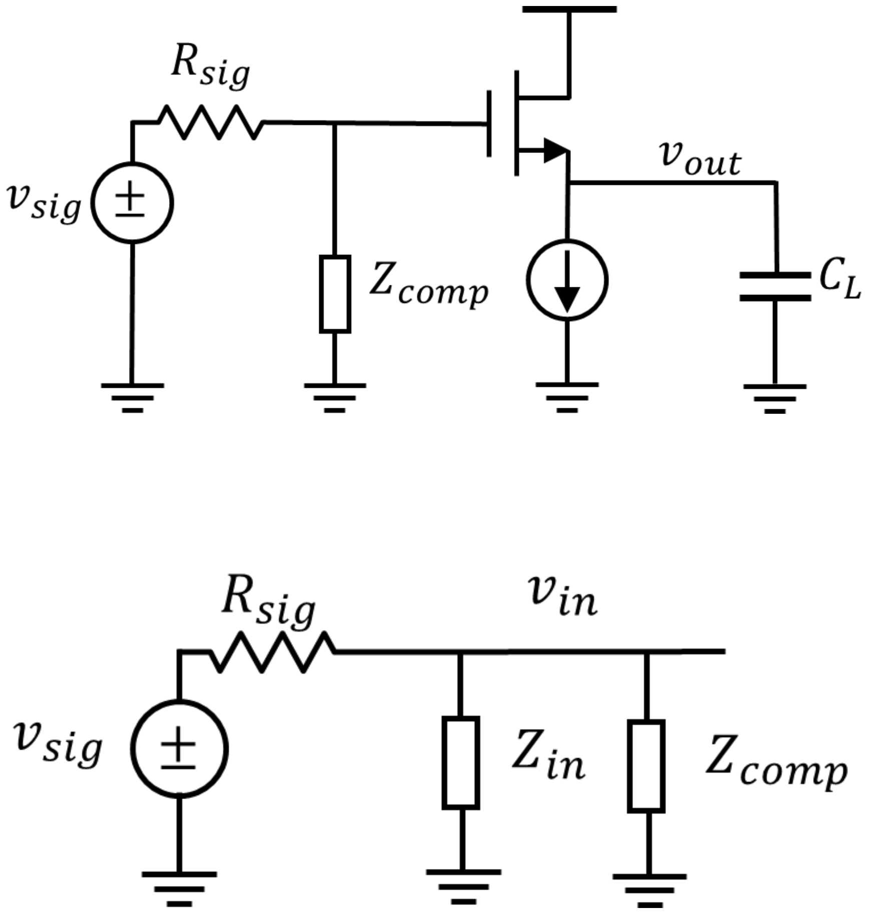
$\frac{\boldsymbol{v_{out}}}{\boldsymbol{v_{sig}}}$

$$\frac{v_{out}}{v_{sig}} = \frac{v_{out}}{v_{in}} \times \frac{Z_{in}}{Z_{in} + R_{sig}} = A_o \frac{1 + s\frac{C_{gs}}{g_m}}{1 + \frac{S(C_{gs} + C_L')}{g_m}} \times \frac{1 + \frac{S(C_{gs} + C_L')}{g_m}}{\frac{S^2 C_{gs} C_L'}{g_m} R_{sig} + \frac{S(C_{gs} + C_L')}{g_m} + 1}$$

$$A(s) = A_0 \frac{1 + s\frac{C_{gs}}{g_m}}{\frac{S^2 C_{gs} C_L'}{g_m} R_{sig} + \frac{S(C_{gs} + C_L')}{g_m} + 1} \equiv \frac{A_0\left(1 + \frac{s}{\omega_z}\right)}{\frac{S^2}{\omega_n^2} + \frac{S}{\omega_n Q} + 1}$$

$$\omega_n = \sqrt{\frac{g_m}{R_{sig} C_{gs} C_L'}} \qquad Q = \frac{\sqrt{g_m R_{sig} C_{gs} C_L'}}{C_{gs} + C_L'} \approx \sqrt{\frac{g_m R_{sig} C_{gs}}{C_L'}}$$

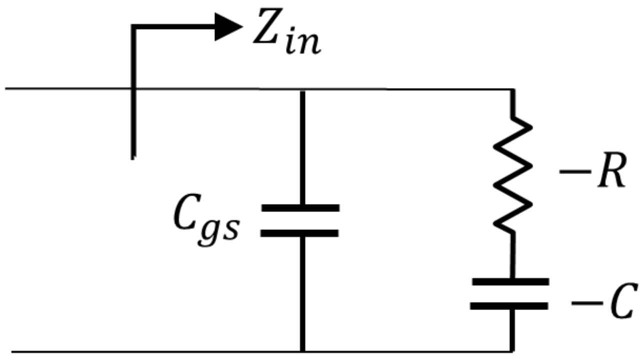
compensation network

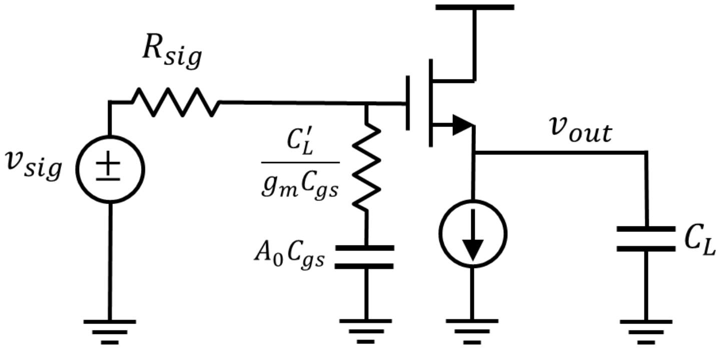


- We can eliminate the negative impedance by adding a compensation network

- $Z_{in_{new}} = Z_{in}//Z_{comp}$

- $Y_{in_{new}} = Y_{in} + Y_{comp}$





$$Z_{in} \approx \frac{SC_L' + g_m + g_{mb} + 1/r_o}{S^2 C_{gs} C_L' + SC_{gs}(g_{mb} + 1/r_o)} \qquad C_L \gg C_{gs}$$

$$Y_{in} \approx \frac{S^2 C_{gs} C_L' + SC_{gs}(g_{mb} + 1/r_o)}{SC_L' + g_m + g_{mb} + 1/r_o} = SC_{gs} - \frac{SC_{gs} g_m}{SC_L' + g_m + g_{mb} + 1/r_o}$$

$$Y_{in} = SC_{gs} - \frac{1}{\frac{C_L'}{g_m C_{gs}} + \frac{g_m + g_{mb} + 1/r_o}{SC_{gs} g_m}} \equiv SC_{gs} - \frac{1}{R + \frac{1}{SC}}$$

- **equivalent to a capacitor // negative impedance**

$$R = \frac{C_L'}{C_{gs}} \times \frac{1}{g_m}$$

$$C = \frac{g_m r_0}{1 + (g_m + g_{mb}) r_0} C_{gs} = A_0 C_{gs}$$