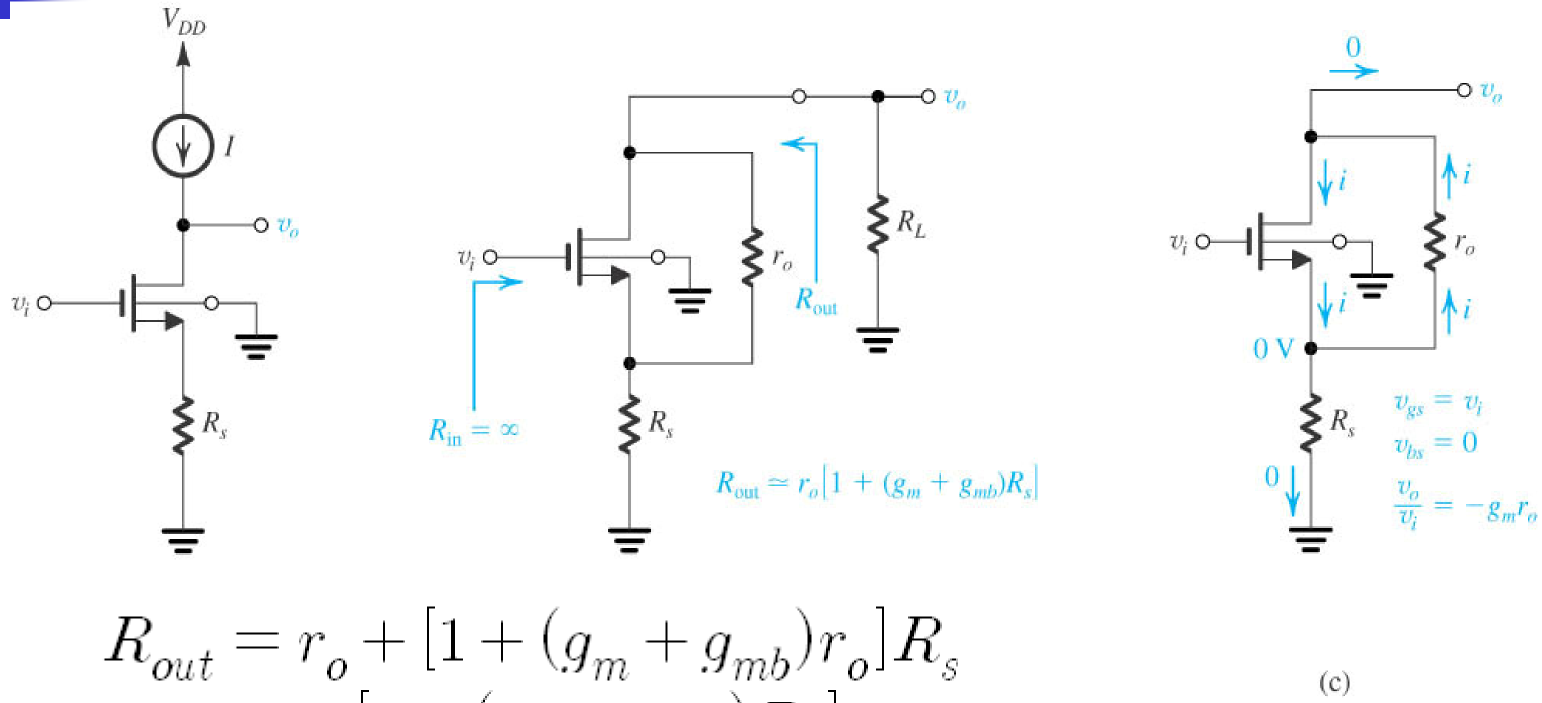
전자 회로 2

Lecture 3 (CS w. Degeneration Resistance, Source Follower)

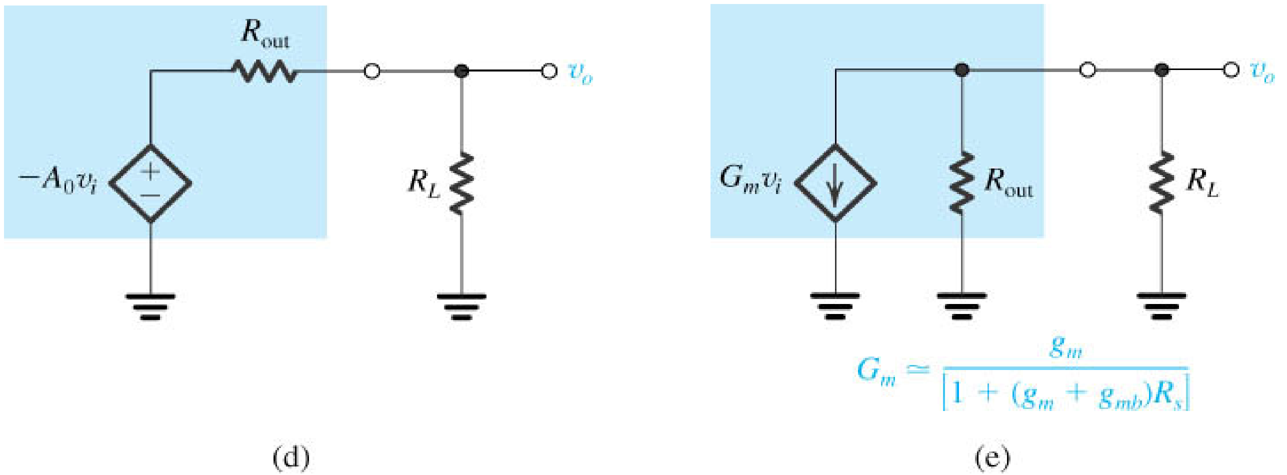
CS with a Source Resistance (Chap. 6.9)



$$R_{out} = r_o + [1 + (g_m + g_{mb})r_o]R_s$$
$$\simeq r_o[1 + (g_m + g_{mb})R_s]$$

$$v_o = -ir_o = -g_m v_i r_o$$
$$A_{vo} = -g_m r_o = -A_0$$

R_S has no effect on A_{vo}



Output equivalent circuits

$$G_m = -\frac{A_{vo}}{R_{out}} = \frac{A_0}{R_{out}}$$

$$= \frac{g_m r_o}{r_o[1 + (g_m + g_{mb})R_s]}$$

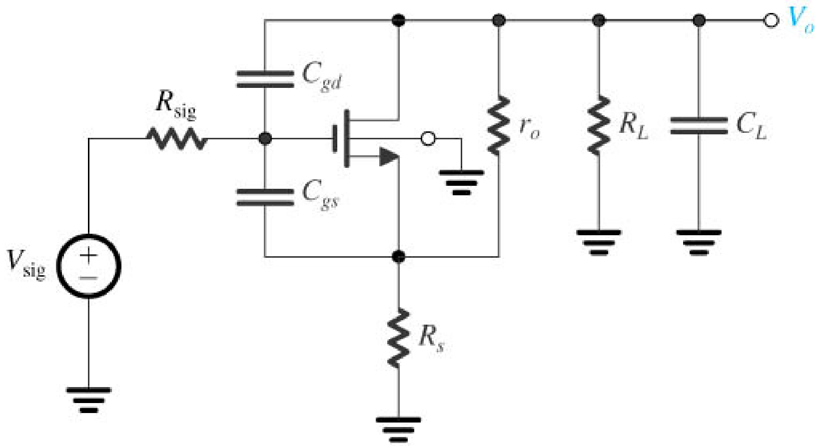
$$= \frac{g_m}{1 + (g_m + g_{mb})R_s}$$

R_S ➔

- Reduces transconductance
- Increases output resistance

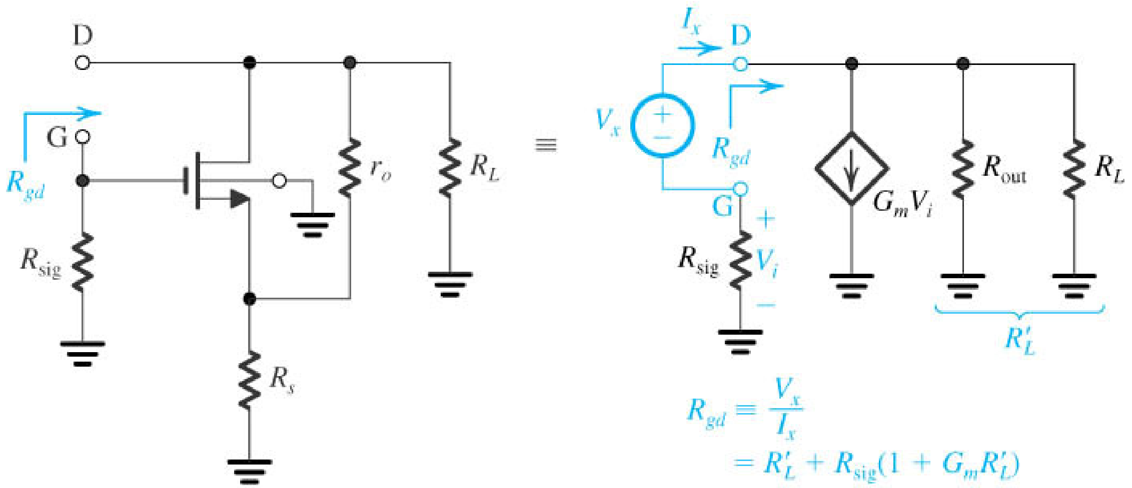
by $1 + (g_m + g_{mb})R_s$

Freq. Response of CS w. R_S



$$R_{C_L} = R_L \| R_{out}$$

$$R_{gs} \simeq \frac{R_{sig} + R_s}{1 + (g_m + g_{mb}) R_s \left(\frac{r_o}{r_o + R_L}\right)}$$

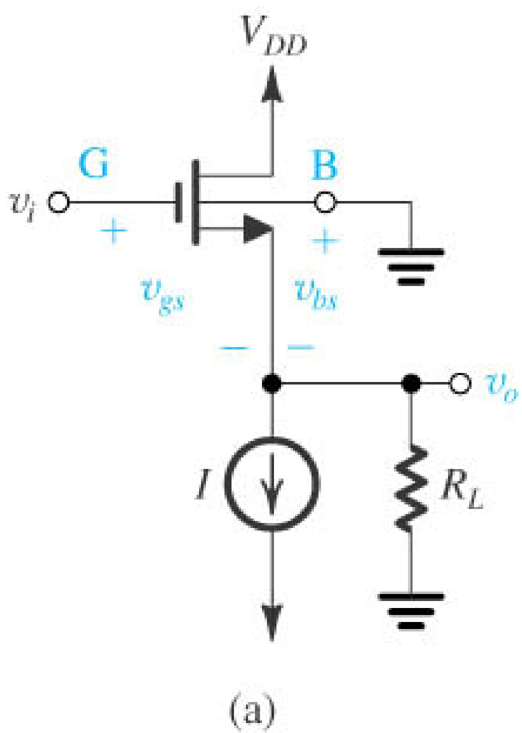


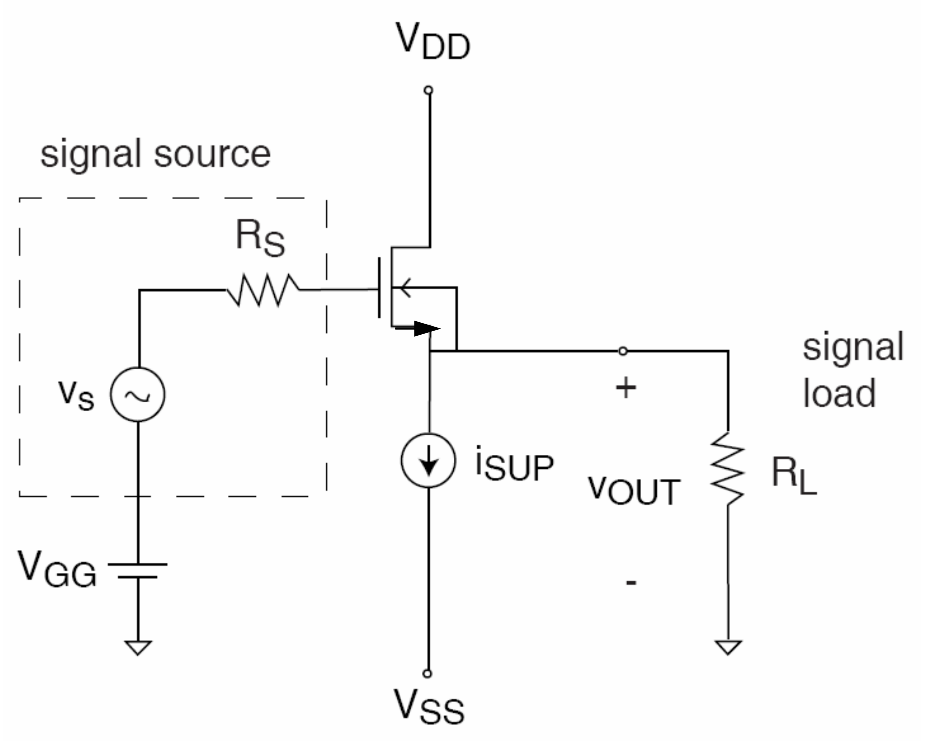
(b)

$$I_x = G_m V_i + (V_i + V_x)/R_L'$$
$$V_i = -I_x R_{sig}$$
$$R_{gd} = R_{sig}(1 + G_m R_L') + R_L'$$

R_{gd} : Decrease
➔ Increased Bandwidth

Source Follower (Common Drain Amp.)

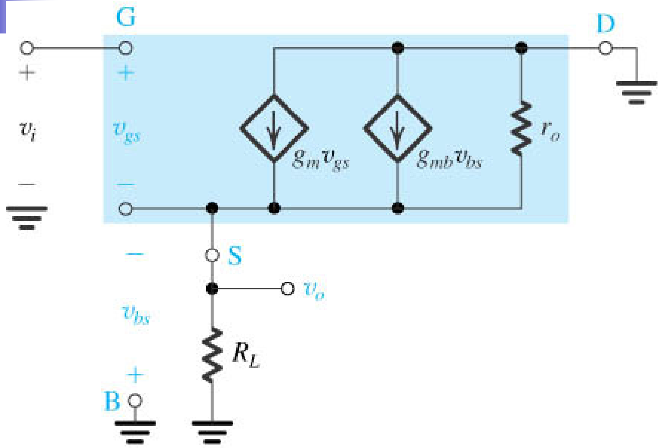




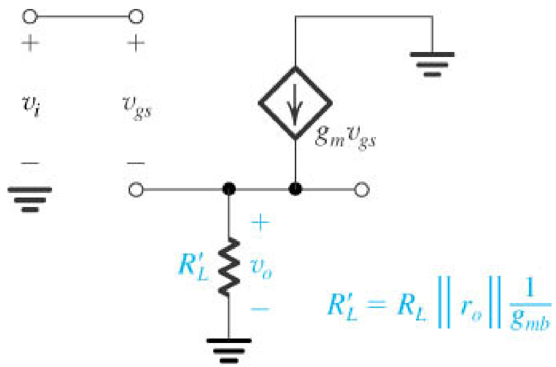
Body = Grounded
➔ Body effect

Body = Source
➔ No body effect (simplified model)

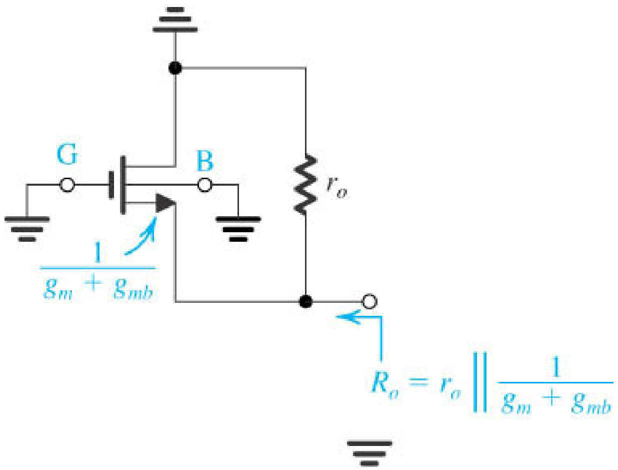
Source Follower (Chap. 6.10)



Small signal model w. BE



Small signal model w. BE
(body = ground)



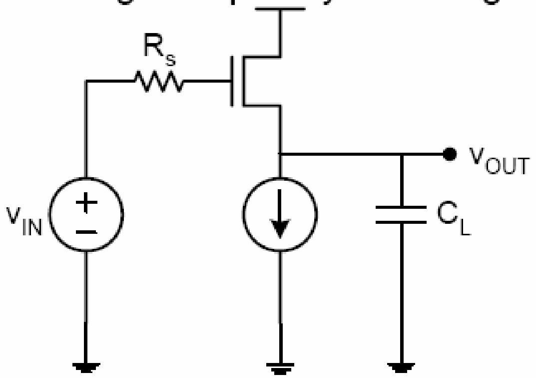
Output resistance

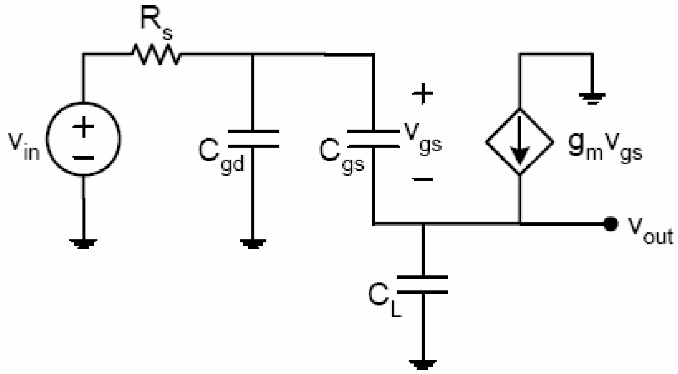
$$v_o = g_m v_{gs} R_L'$$
$$v_{gs} = v_i - v_o$$
$$A_v \equiv \frac{v_o}{v_i} = \frac{g_m R_L'}{1 + g_m R_L'}$$
$$A_{vo} \equiv \left.\frac{v_o}{v_i}\right|_{R_L = \infty}$$
$$= \frac{g_m r_o}{1 + (g_m + g_{mb}) r_o}$$
$$\simeq \frac{g_m}{g_m + g_{mb}} = \frac{1}{1 + \chi}$$

- voltage gain $\simeq$ 1
- high input resistance
- low output resistance
- $\Rightarrow$ good voltage buffer

Freq. Response of Source Follower

- Start with a high-frequency small-signal model of the source follower circuit





- Directly solving for v_{out}/v_{in} yields:

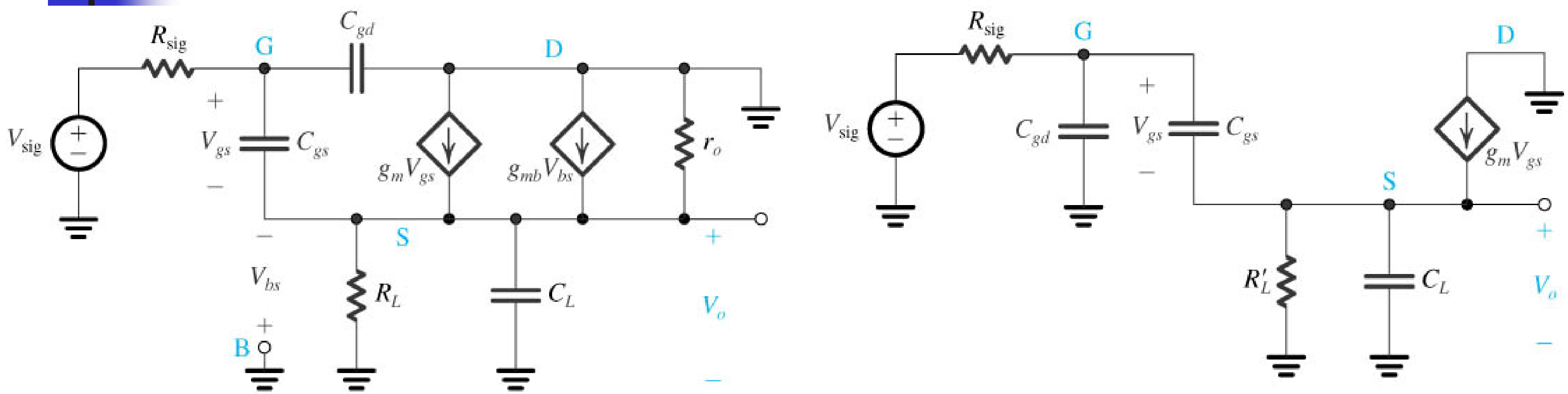
$$\begin{aligned} v_{gs}sC_{gs} + g_m v_{gs} &= v_{out}sC_L \\ v_{gs} &= \frac{sC_L}{g_m + sC_{gs}} v_{out} \\ v_{in} &= R_s\left[v_{in}sC_{gs} + (v_{in} + v_{gs})sC_{gd}\right] + v_{gs} + v_{out} \end{aligned}$$

$$\omega_{P1} \cong \frac{g_m}{g_m R_s C_{gd} + C_L + C_{gs}}$$

$$\frac{v_{out}}{v_{in}}(s) = \frac{g_m + sC_{gs}}{R_s(C_{gs}C_L + C_{gs}C_{gd} + C_{gd}C_L)s^2 + (g_m R_s C_{gd} + C_L + C_{gs})s + g_m}$$

  - The zero is due to C_{gs} that directly couples the signal from the input to the output
- If poles are far apart, then the *s* term represents the dominant pole

Freq. Resp. of Source Follower (OCT)



(a) (b)

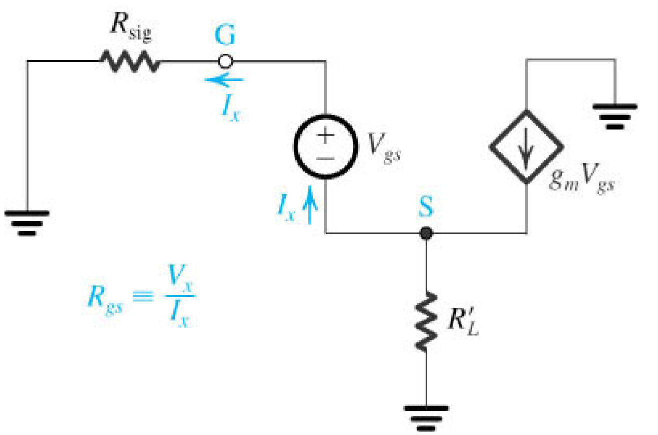
$$g_m V_{gs} + sC_{gs}V_{gs} = \frac{V_o}{R_L{}' \| C_L} = 0$$

$$zero: \; s_z = -\frac{g_m}{C_{gs}} \Rightarrow w_z = \frac{g_m}{C_{gs}}$$

$$R_{gd} = R_{sig}$$

$$R_{gs} = \frac{R_{sig} + R_L{}'}{1 + g_m R_L{}'}$$

$$R_{C_L} = R_L \| R_o = R_L{}' \| \frac{1}{g_m}$$

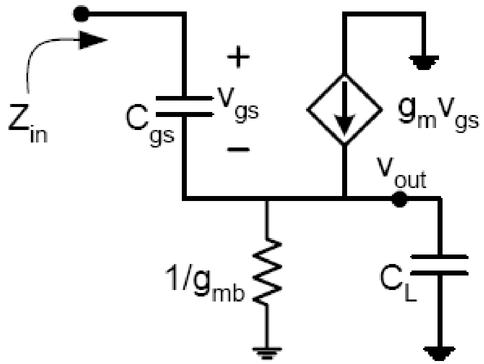


(c)

$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi(C_{gd}R_{sig} + C_{gs}R_{gs} + C_L R_{C_L})}$$

More on Source Follower

- Other important aspects of a source follower are its input and output impedances (since they are often used as buffers)
- Let's calculate the input impedance using the high-freq small-signal models

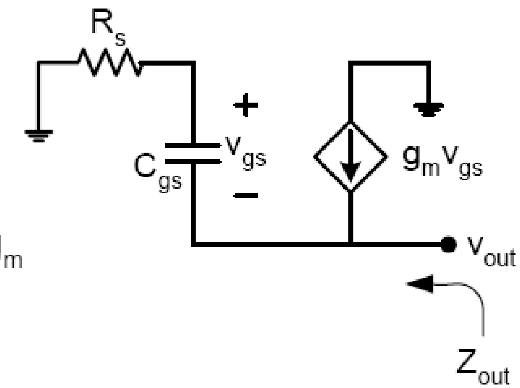


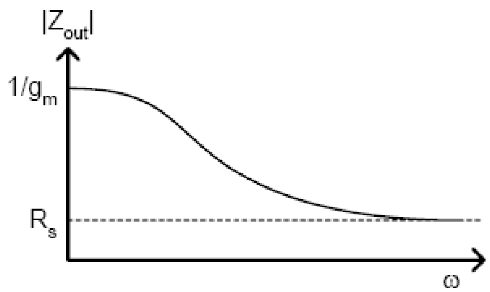
$$Z_{in} = \frac{1}{sC_{gs}} + \left(1 + \frac{g_m}{sC_{gs}}\right)\frac{1}{g_{mb} + sC_L}$$

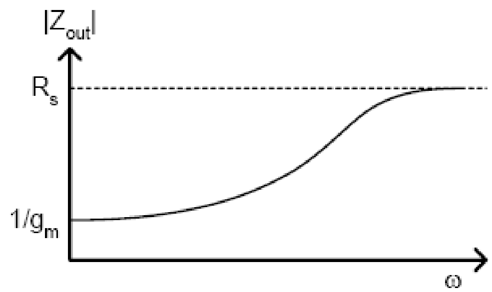
- Now calculate the output impedance (ignoring g_{mb} for simplicity)

$$Z_{out} = \frac{R_s sC_{gs} + 1}{g_m + sC_{gs}}$$

  - At low frequency, $Z_{out} \approx 1/g_m$
  - At high frequency, $Z_{out} \approx R_s$
  - Shape of the response depends on the relative size of R_s and $1/g_m$







Z_{out} can look inductive or capacitive depending on R_s and $1/g_m$