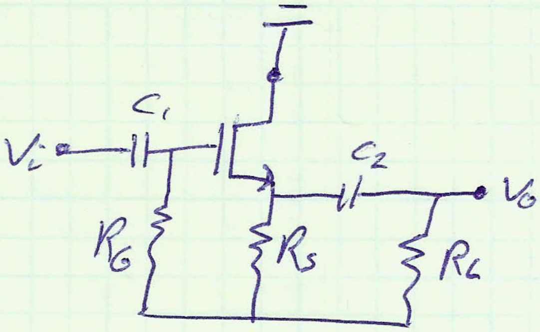
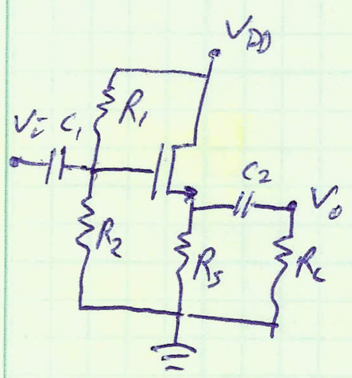
Common Drain and Common Collector Amplifiers

- Common Drain
  (source follower)

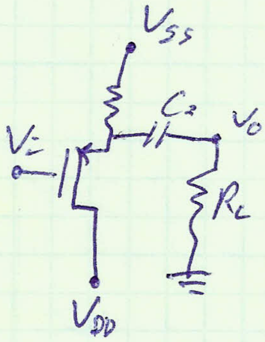


- Note: Drain is grounded for small signals, so it is the "common" terminal of input and output

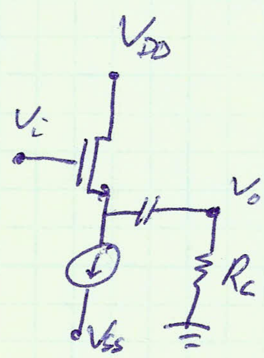
- Several circuits reduce to this form:



$R_G = R_1 \| R_2$

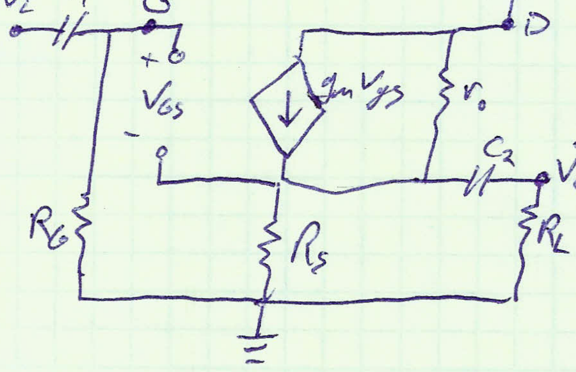


$R_G \to \infty$

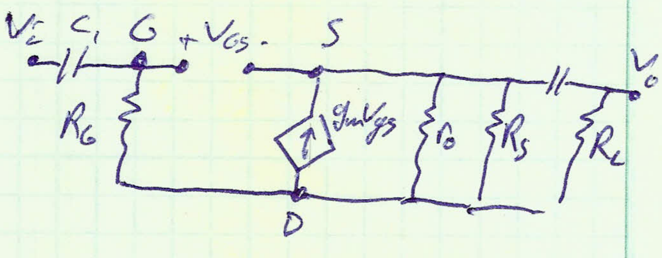


$R_G \to \infty$, $R_S \to \infty$

Replace MOSFET with small signal model



$\Rightarrow$



- Note that R_S parallel to R_L. In practice, R_S often replaced by the load
- define $R_L' = R_S \| R_L$
- open-loop gain found by setting $R_L' \to \infty$

$v_{gs} = v_i - v_o$

$v_o = g_m v_{gs} (r_o \| R_L') = g_m (r_o \| R_L')(v_i - v_o)$

$$A_v = \frac{v_o}{v_i} = \frac{g_m (r_o \| R_L')}{1 + g_m (r_o \| R_L')} = \frac{g_m r_o R_L'}{r_o + R_L' + g_m r_o R_L'} \simeq \frac{g_m R_L'}{1 + g_m R_L'}$$

use $g_m r_o \gg 1$ to drop this term
then divide top + bottom by r_o

to find open-loop gain, set $R_L' \to \infty$. $r_o \| R_L' = r_o$

$$A_{vo} = \frac{g_m r_o}{1 + g_m r_o} \simeq 1$$

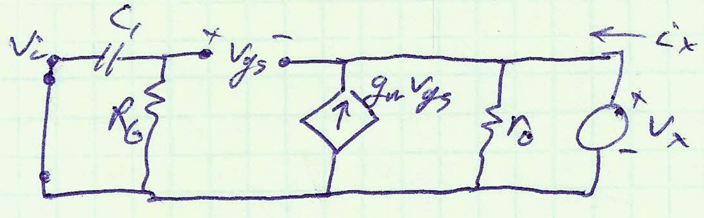
Because $A_{vo} \simeq 1$, $v_o = v_s \simeq v_g = v_i$ → output "follows" input voltage
→ called <u>source follower</u>

<u>Input resistance:</u>

$R_i = R_G$ — no analysis needed

<u>Output resistance:</u>

Zero out v_i, then find Thevenin resistance seen at output



take out R_L'

$v_{gs} = v_i - v_x = -v_x$

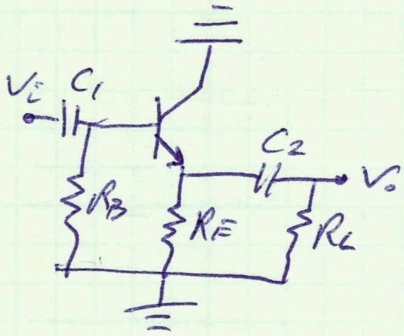
$i_x = -g_m v_{gs} + \frac{v_x}{r_o} = v_x \frac{g_m r_o + 1}{r_o}$

$R_o = \frac{r_o}{1 + g_m r_o} \simeq \frac{1}{g_m}$ → typically small – a few hundred Ω

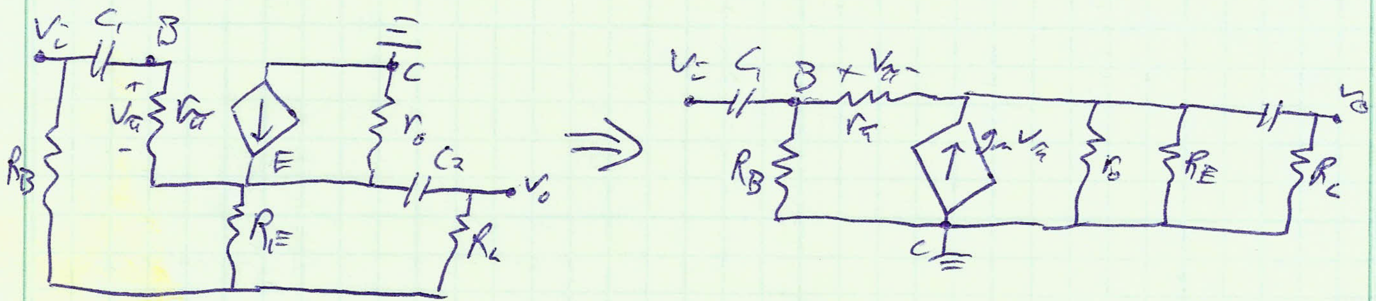
- Source follower has unity gain, but transforms high impedance to low impedance
– often used as a <u>buffer</u> or for the final stage in power amplifiers

Common Collector or Emitter Follower

- Same basic idea as source follower
- Note we have zeroed out the bias sources
- Many circuits can be reduced to this form
- Define $R_L' = R_E \| R_L$



Small signal model:



note $v_\pi = v_i - v_o$

$i_b = v_\pi / r_\pi$

$g_m r_\pi = \beta >> 1$

total current flowing through r_o and R_L' is i_b and $g_m v_\pi$

$$v_o = \left(g_m v_\pi + \frac{v_\pi}{r_\pi}\right)(r_o \| R_L') \simeq g_m v_\pi (r_o \| R_L') = g_m (r_o \| R_L')(v_i - v_o)$$

$$A_v = \frac{v_o}{v_i} \simeq \frac{g_m (r_o \| R_L')}{g_m (r_o \| R_L') + 1} = \cancel{\frac{g_m r_o R_L'}{r_o + R_L' + g_m R_o}} = \frac{g_m r_o R_L'}{r_o + R_L' + g_m r_o R_L'} \simeq \frac{g_m R_L'}{1 + g_m R_L'}$$

use $g_m r_o >> 1$

$$A_v = \frac{R_L'}{R_L' + r_e}$$ where $r_e \equiv \frac{1}{g_m}$, typically a few tens of ohms

$$A_{vo} = \frac{g_m r_o}{1 + g_m r_o} \simeq 1$$ known as Emitter Follower

To find R_i:

$$i_i = \frac{v_i}{R_B} + i_b \quad \text{(KCL)}$$

(KVL)

$$v_i = i_b r_\pi + (i_b + g_m v_\pi)(r_o \| R_L') = i_b[r_\pi + (1+g_m r_\pi)(r_o \| R_L')]$$

$$i_i = \frac{v_i}{R_B} + i_b = \frac{v_i}{R_B} + \frac{v_i}{r_\pi + (1+\beta)(r_o \| R_L')}$$

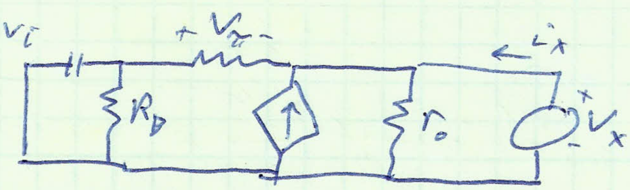
$$\frac{1}{R_i} = \frac{i_i}{v_i} = \frac{1}{R_B} + \frac{1}{r_\pi + (1+\beta)(r_o \| R_L')}$$

$$R_i = R_B \| [r_\pi + (1+\beta)(r_o \| R_L')]$$

- note R_i depends on R_L $\rightarrow$ this amplifier is not unilateral

To find R_o:

Zero out v_i, Remove R_L', attach V_x



$$i_x = -g_m v_\pi + \frac{v_x}{r_o} + \frac{v_x}{r_\pi}$$

note $v_\pi = -v_x$

$$\frac{1}{R_o} = \frac{1}{1/g_m} + \frac{1}{r_o} + \frac{1}{r_\pi} \longrightarrow R_o = (1/g_m) \| r_o \| r_\pi \simeq 1/g_m = r_e$$

since $g_m r_\pi \gg 1$, $g_m r_o \gg 1$

- Unity gain, large input resistance, small output resistance