CE & CS Amplifiers

	CE w/bypass	CE w/o bypass
A_{v_i}	$-g_m(R_C \| R_L)$ $(-100 \sim -300)$	$\dfrac{-\beta(R_C \| R_L)}{r_\pi + (\beta+1)R_E} \approx \dfrac{-R_C \| R_L}{R_E}$
R_{in}	$r_\pi \| R_1 \| R_2$ (few $k\Omega$)	$r_\pi \| R_1 \| R_2 \| (\beta+1)R_E$
R_{out}	$R_C \| r_o$ (few $k\Omega$)	

	CS	
A_{v_i}	$-g_m(R_D \| R_L)$ $(-10 \sim -30)$	$\approx \dfrac{-R_D \| R_L}{R_{SS}}$
R_{in}	$R_1 \| R_2$ ($M\Omega$)	
R_{out}	$R_D \| r_o$ (few $k\Omega$)	

Design Issues

1. Bias stable

CE : operate over a range of β, V_{BE} temp.

$R_E \cong R_C/4$

$V_{CE} \cong V_{CC}/2$

$R_{TH} = R_1 \| R_2 \cong 0.1(\beta+1)R_E$

$R_2 = 10 \sim 20\, R_E$

R_E s.t. $V_{R_E} = V_{BE(ON)}$

CS : operate over a range of V_{TH}, K_N

$R_{SS} \cong R_D/4$

$V_{DS} \cong V_{DD}/2$

2 Input impedance

CE: $R_{in} = R_1 \| R_2 \| r_\pi$

CS: $R_{in(gate)} = \infty$, $R_{in} = R_1 \| R_2$ chosen to achieve correct V_g.

$$A_{vi} = -g_m (R_C \| R_L)$$

$$= -g_m \frac{R_C R_L}{R_C + R_L} \times \frac{R_{is}}{R_L}$$

$$= -g_m \frac{R_C}{R_C + R_L} R_{is}$$

$$\frac{d A_{vi}}{d R_C} = \frac{d}{dR_C} -K \frac{R_C}{R_C + R_L}$$

$$= \frac{-\cancel{K}}{-\cancel{K}} \quad \frac{R_C}{R_C + R_L}$$

$$\frac{(R_C + R_L) - R_C (1)}{R_L}$$

$$R_L = 0$$

$$R_C = R_L \Rightarrow$$

$$0 \left(\frac{1}{} \right) + -1 \frac{R_C}{()^2}$$

$$\frac{R_C + \cancel{R_L} - R_C}{(R_C + R_L)^2}$$

3. Output impedance

CE: Neglecting r_o. $R_{out} \cong R_C$

$R_L \cong R_{out}$ for max power transfer

4. Transconductance

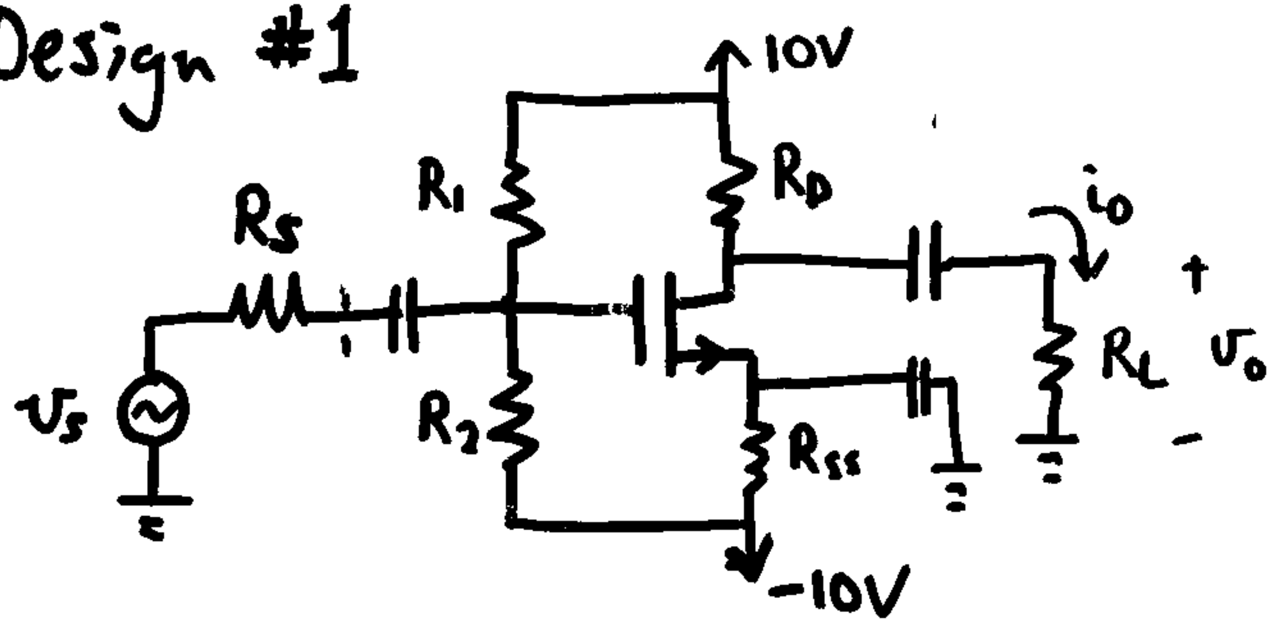
CS: $g_m = 2K_N(V_{GS} - V_{TH})$

$K_N = \frac{\mu C_{ox}}{2} \frac{W}{L}$ ← can be made arbitrarily large

5. Power dissipation

$I_{CC}V_{CC}$
$I_{DD}V_{DD}$ < some specified value.

Design #1



$|V_{TH}| = 2V$

$K_N = 4\frac{mA}{V}$

$\lambda = 0.02V^{-1}$

Design CS amplifier to yield

$A_{v_i} = -10$

$R_{in} > 100k\Omega$

$R_{out} = 2.5k\Omega$

given $R_s = 16\Omega$

$$V_{CE} = V_{CC} - V_{CQ} - V_{EQ}$$

$$= V_{CC} - \left(\frac{V_{CC}}{2} + \frac{V_{CC}}{2}\frac{R_E}{\bigcirc} + \frac{I_C R_E}{\bigcirc} \right)$$

$$= \frac{V_{CC}}{2} + \frac{V_{CC}}{2}\Big($$

$$\frac{R_E}{R_C + R_E}$$

$$V_{max} = V_{CC}$$

$$V_{min} = V_{CC}\frac{R_E}{R_C + R_E}$$

$$V_{CQ} = \frac{V_{CC}}{2}\left(1 + \frac{R_E}{R_C + R_E}\right)$$

$$V_{EQ} \approx \frac{V_{CC}}{2}\left(\frac{R_E}{R_C + R_E}\right)$$

$$\frac{V_{CC}}{2}\left(\frac{R_E}{\cancel{R_E + R_E}}\right. \quad \cancel{V_{CQ}}$$

$$\frac{V_{CC}}{2}\left(\frac{1}{R_C + R_E}\right)$$

$$i_C = \frac{V_{CC} - V_{CQ}}{R_C}$$

$$= \frac{\frac{V_{CC}}{2} - \frac{\frac{V_{CC} R_E}{2}}{R_C + R_E}}{R_C}$$

$$= \frac{\frac{V_{CC}}{2}\left(1 - \frac{R_E}{R_C + R_E}\right)}{R_C}$$

$$R_C + \cancel{R_E - r_o}$$

$$\frac{V_{CC}}{2} + V_{CC}\frac{R_E}{R_C + R_E}$$

$$A_{v_i} = -g_m (R_D \| r_o \| R_L) = -10$$

$$R_{in} = R_1 \| R_2 > 100\,k\Omega$$

$$R_{out} = R_D \| r_o = 2.5\,k\Omega$$

Strategy:

1. A_{v_i} & R_{out} require r_o, g_m

   Have to pick I_{DQ}, V_{DSQ}

   $V_{DSQ} =$

   $\Rightarrow I_{DQ} (R_D + R_{SS}) =$

   $\boxed{\text{Arbitrarily}}$ choose I_{DQ}

   $I_{DQ} = 2\,mA$

   $R_D + R_{SS} =$

$$r_o = \frac{1}{\lambda I_{DQ}} =$$

$$g_m = 2\sqrt{K_N I_{DQ}}$$

$$=$$

2. Solve for R_D, R_{SS}

$$R_{out} = R_D \parallel r_o = 2.5\,k\Omega$$

$$\frac{R_D r_o}{R_D + r_o} = 2.5\,k\Omega$$

$$R_D =$$

$$R_{SS} =$$

3. Solve for R_L

$$A_{v_i} = -g_m (R_D \| r_o \| R_L) = -10$$

$$-g_m (2.5k\Omega \| R_L) = -10$$

$$R_L =$$

4 Solve for R_1 & R_2 (from V_{GS})

$\boxed{\text{Arbitrarily}}$ choose $R_1 \| R_2 = 200k\Omega$

$$V_S = V^- + I_S R_{SS}$$

$$=$$

$$I_{DQ} = K_N (V_{GS} - V_{TH})^2$$

$$V_{GS} = V_G - V_S =$$

$$V_G = V_{GS} + V_S =$$

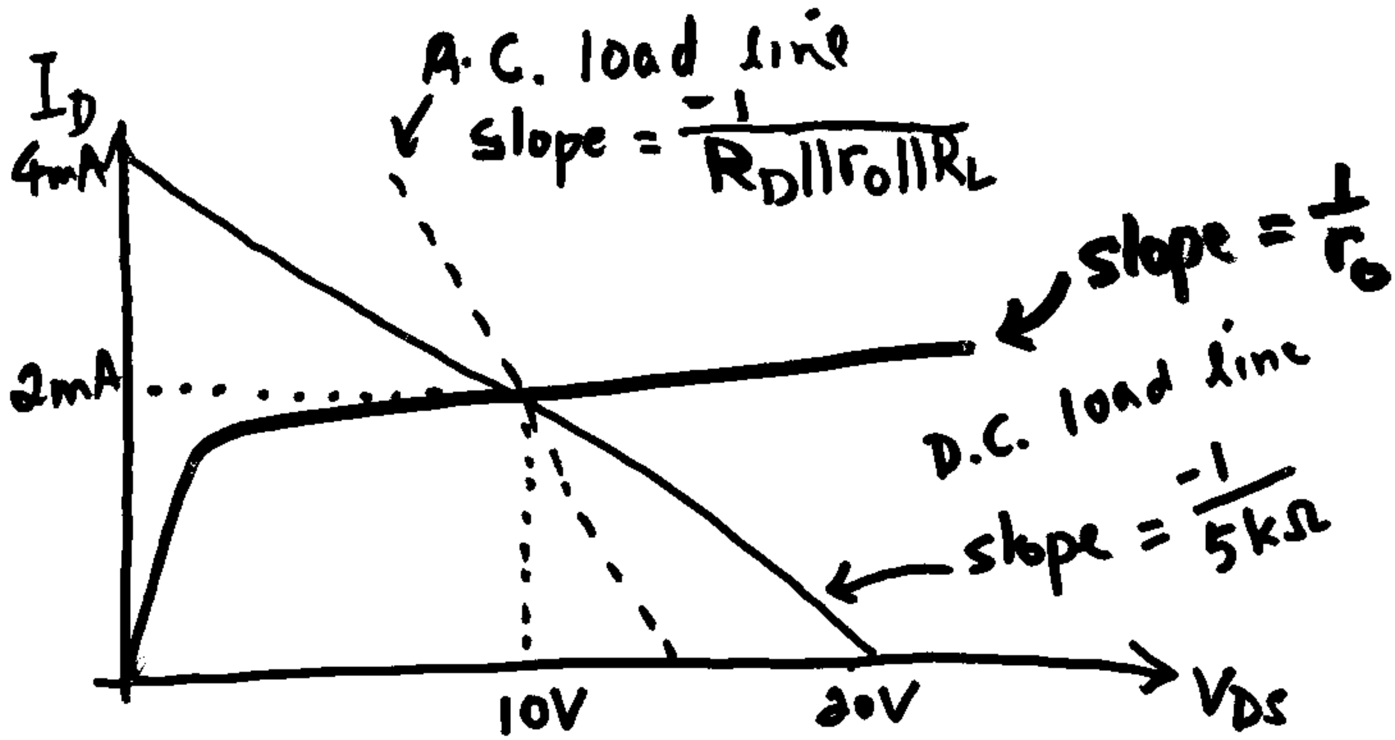
$$\frac{R_2}{R_1 + R_2}\left(V^+ - V^-\right) = V_{R_2} = V_G - V^-$$

$$\frac{R_1 R_2}{R_1 + R_2} = 200\text{k}\Omega$$

$\Rightarrow$

How large can v_s be?

[Maximum symmetric excursion]



$$v_{ds} = -i_d \left(R_D \| r_o \| R_L \right)$$

$$\frac{i_d}{v_{ds}} = \frac{-1}{R_D \| r_o \| R_L} \triangleq \text{slope of A.C. load line}$$

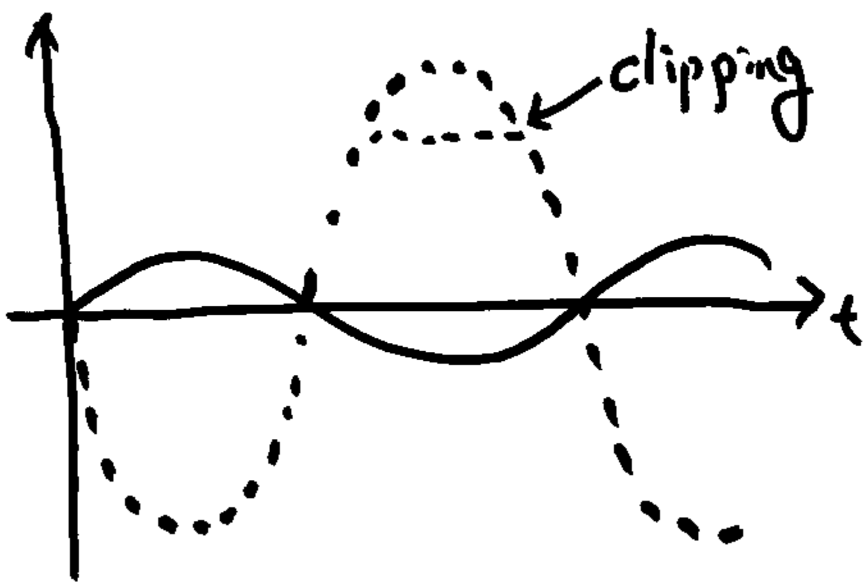
$$v_{ds}(\max) = i_d(\max)\left(R_D \| r_o \| R_L\right) = v_o(\max)$$

$$v_i(\max) = \frac{v_o(\max)}{|A_{v_2}|} \simeq v_s(\max)$$

What if $|v_s| > \dfrac{v_o(\max)}{|A_{v_i}|}$?

FET goes into CUT-OFF

$\Rightarrow$ the output is clipped



SAME V_s

$v_{o,pp}$ use C.E. amplifier

Question: Can we use a gain of $A_{v_i} = -1$

$$A_{v_i} = -g_m (R_C \| R_L \| r_o)$$

$$= -\frac{I_{CQ}}{V_T} (R_C \| R_L \| r_o)$$

$$A_{v_i} V_T = -I_{CQ} (R_C \| R_L \| r_o)$$

$$v_o(max) = i_c(max) (R_{out} \| R_L)$$

$$= |A_{v_i}| V_T$$

$$= 10 \times .026V = 260\,mV$$

$$v_s(max) = 350\,mV \not\ll V_T = 26\,mV$$

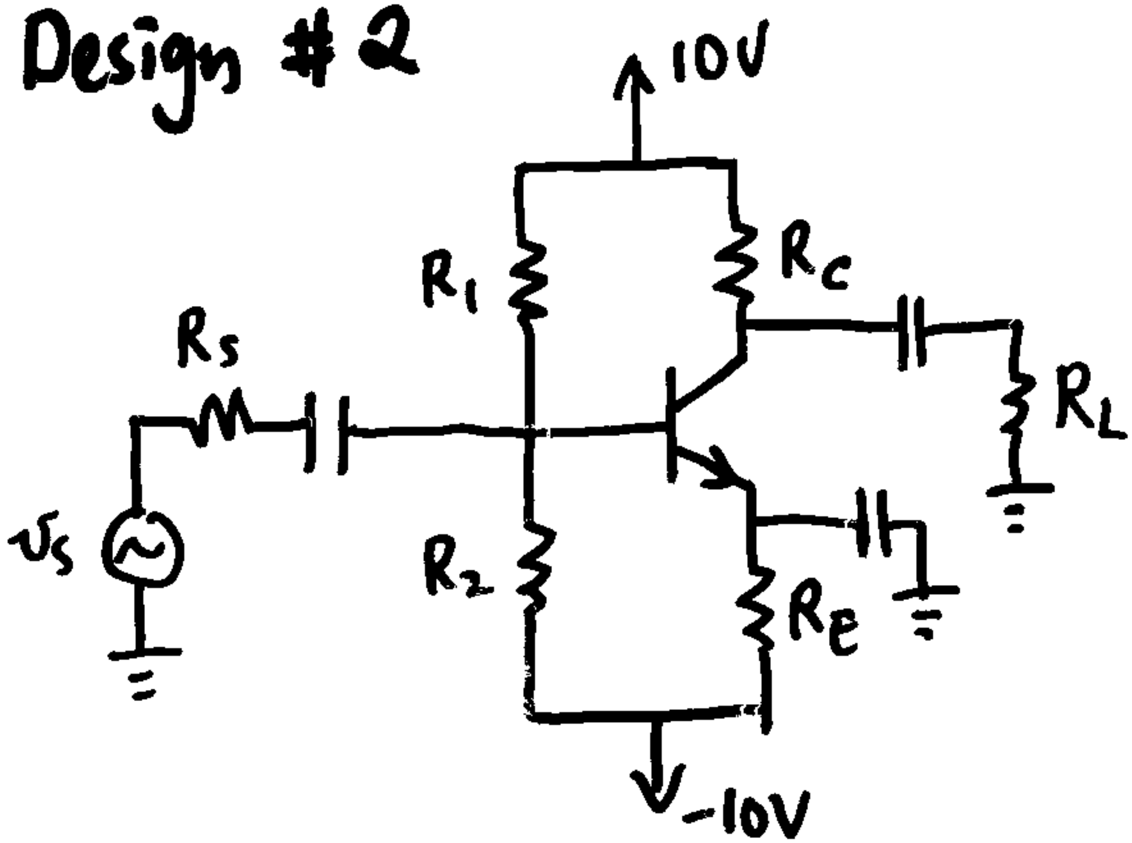
small signal approximations
do not apply

What gain is appropriate?

$$|A_{v_i}| \gg \frac{v_o(max)}{.026}$$

$$|A_{v_i}| \gg \frac{3.5V}{.026V} = 135\ V/V$$

Design #2



$\beta = 120$

$V_A = \infty$

Select the same operating

$(V_{CEQ}, I_{CQ}) = (10V, 2mA)$

$A_{v_i} = 135\ V/V$

1. $I_C R_C + I_E R_E = 10$

$I_C \doteq I_E \Rightarrow R_C + R_E = 5k\Omega$

$R_{out} = 2.5k\Omega \Rightarrow R_C = 2.5k\Omega$

$R_E = 2.5k\Omega$

2. $r_0 = \infty$

$A_{V_i} = -g_m (R_C \| R_L) = -135$

$= -\frac{I_{CQ}}{V_T} (R_C \| R_L)$

$\therefore R_L = 5.9k\Omega$

3. $I_{BQ} = \frac{I_{CQ}}{\beta} = 16.7\mu A$

$V_B = V_{BE} + V_E$

$\doteq 0.7V + 2.5k\Omega\, I_{EQ} - 10V$

$\doteq -4.3V$

$$R_{TH} = 0.1\,(\beta+1)R_E$$

$$R_1 \| R_2 = 30.25\ k\Omega$$

$$20V\frac{R_2}{R_1+R_2} - 10V - V_B = R_{TH} \cdot I_{BQ}$$

$$= 30.25k\Omega \cdot 16.7\mu A$$

$$= 0.505V$$

$$\frac{R_2}{R_1+R_2} = 0.310$$

$$R_1 = 97.6\ k\Omega$$

$$R_2 = 43.8\ k\Omega$$

$$R_{in} = R_1 \| R_2 \| r_\pi$$

$$= 30.25\,k\Omega \,\Big\|\, \frac{V_T}{I_{BQ}}$$

$$= 30.25k\Omega \| 1560\Omega$$

$$= 1.48\ k\Omega$$