University of California, Davis
Society of Manufacturing Engineers at UC Davis

EEC 110A* Electronics Circuits I Unofficial

Mock Unofficial Practice Midterm Exam Solutions

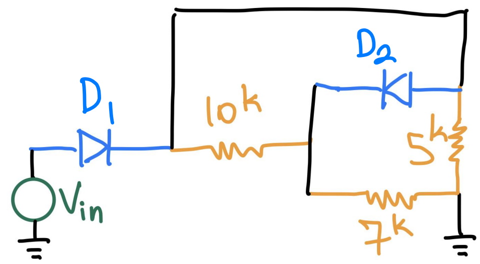
*Disclaimer: This document is a sample final exam of an Electronics Circuits I midterm. It is a mock exam and does not necessarily reflect the format—in the length of the exam, content covered, the protocol, and other aspects—of an actual midterm exam of EEC 110A in University of California, Davis. However, this covers multiple topics that seems to be a halfway agenda of EEC 110A and this document is an attempt to give students extra practice. The problems in this document are written entirely by the author. Any similarity, either in part or in whole, is a complete coincidence. If an error is caught, or if you have any questions and inquiries, please contact the author at mnhyu@ucdavis.edu.

A calculator is not encouraged where not needed. Scoring distribution for each question is not provided as it is not graded and discourages students from judging the importance of a topic over another. Please do not physically print out this document.

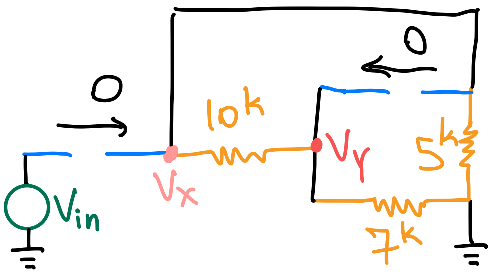
This solution to this examination has eight (8) pages, including this front cover page and the end topology sheet.

Question 1) Diode Circuits	
Question 2) Small Signal Model for BJTs	
Question 3) Amplifier Topology	

1) Plot P_{IN}, the power dissipated by V_{IN}, with respect to V_{IN} using the constant voltage model with $V_{D,ON}$ = 1V. Label your graphs with units and important values.



a) Assume D_1 & D_2 off (V_{in} very negative)



D_1: $V_{D1} = V_{in} - V_x < V_{DON}$

Since no currents are flowing,

$V_x = 0$ & $V_y = 0$

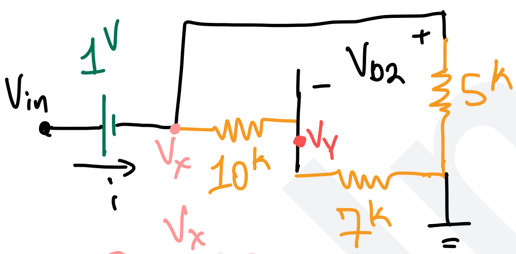
$V_{in} < V_{DON} = 1$ ✓ if V_{in} very negative

D_2: $V_x - V_y < V_{DON}$

$0 < 1$ ✓

$P|_{\text{both off}} = 0$

b) Assume D_1 on & D_2 off ($V_{in} > 1$) and $V_{in} <$ TBD



D_1: $i = \underbrace{(V_{in} - V_{DON})}_{V_x} / (17^k \| 5^k) > 0$

$1^V = V_{in} > V_{DON} = 1^V$ ✓

If V_{in} is just larger than 1^V

Check that P_{in} @ $V_{in} = 1^V$ should be 0^W

$$P_{in} = V_{in}\left(\frac{V_{in}-1}{17^k \| 5^k}\right) = 1\left(\frac{1-1}{17^k \| 5^k}\right) = 0$$

D_2: $V_{D2} < V_{DON}$

$$V_{D2} = \underbrace{(V_{in} - V_{DON})}_{V_x} - \underbrace{(V_{in} - V_{DON})\frac{7^k}{17^k}}_{V_Y}$$

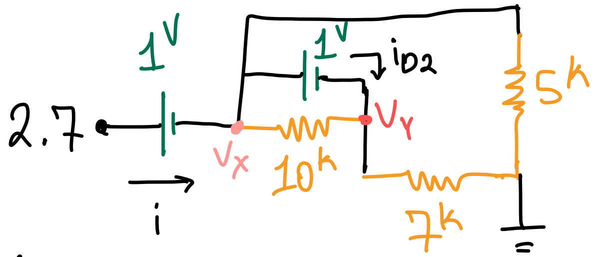
$$\frac{10}{17}(V_{in} - V_{DON}) < V_{DON}$$

$$\frac{10}{17}V_{in} < \frac{27}{17}V_{DON}$$

$$1 < 2.7 \ ✓$$

$$P_{in} = V_{in}\, i\Big|_{D_1 \text{ on},\ D_2 \text{ off}} = V_{in}\left(\frac{V_{in}-1}{17^k \| 5^k}\right)$$

c) **Assume D_1 & D_2 on ($V_{in} < 2.7$)**



D_1: $i = \underbrace{(V_{in} - 2V_{DON})}_{V_Y}/7^k + \underbrace{(V_{in} - V_{DON})}_{V_X}/5^k > 0$

$= \dfrac{5V_{in} - 10 + 7V_{in} - 7}{35^k} = \dfrac{12V_{in} - 17}{35^k} > 0$

$32.4 = 12(2.7) > 17$ ✓

D_2: $i_{D2} = \underbrace{(V_{in} - 2V_{DON})}_{V_Y}/7^k - 1^V/10^k > 0$

$(V_{in} - 2V_{DON})10 > 7$

$2.7 - 2 \times 1 > 0.7$

$0.7 > 0.7$ ✓

$P = V_{in} i \Big|_{\text{both on}} = V_{in} \dfrac{12V_{in} - 17}{35^k}$

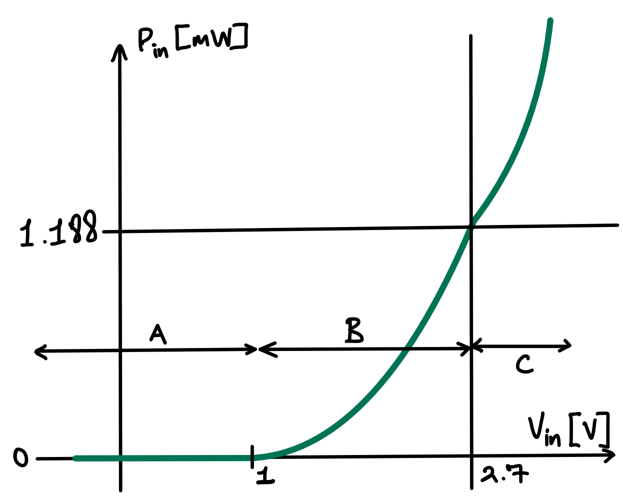
Check P_{in} @ $V_{in} = 2.7$ V — at boundary of condition B and C should equal

b) $P_{in} = V_{in}\left(\dfrac{V_{in} - 1}{17^k \| 5^k}\right) = 2.7\left(\dfrac{2.7 - 1}{17^k \| 5^k}\right) = 1.188^{mW}$

c) $P_{in} = V_{in}\dfrac{12V_{in} - 17}{35^k} = 2.7\left(\dfrac{12(2.7) - 17}{35^k}\right) = 1.188^{mW}$

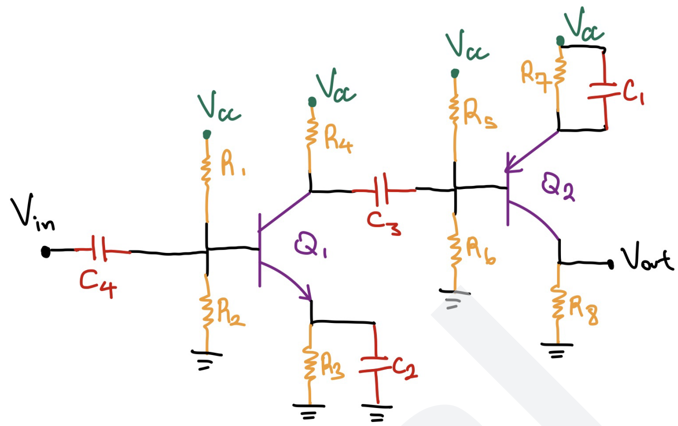
Conclusion:

	D_1	D_2	P
a) $V_{in} \leq 1^V$	off	off	0
b) $1^V < V_{in} \leq 2.7$	on	off	$V_{in}(V_{in} - 1)/(17^k \| 5^k)$
c) $V_{in} > 2.7$	on	on	$V_{in}(12V_{in} - 17)/35^k$



Not drawn to scale

2) You are not allowed to use the topology formula sheet to solve this problem. Given the circuit below with 1 PNP BJT, 1 NPN BJT, 4 capacitors, and 8 resistors, and all transistors operate in the forward active region in the same temperature with $V_A = \infty$,



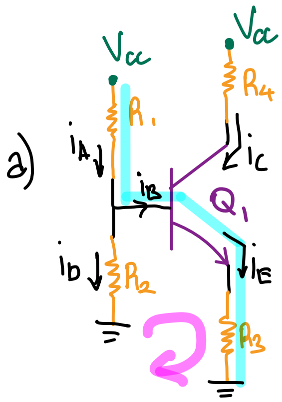
a) Find the transconductance of each BJT in terms of the resistor values, capacitor values, β_1 (current gain of Q_1), β_2 (current gain of Q_2), V_{BE} (for the NPN BJT), V_{EB} (for the PNP BJT), V_T (thermal voltage), and V_{CC}. Do not neglect base currents.

b) Using the small signal model, find V_{OUT}/V_{IN} in terms of g_{m1}, g_{m2}, $r_{\pi1}$, $r_{\pi2}$, and other resistor values in the circuit. You do not have to replace g_{m1} and g_{m2} with results from part a); instead, simply put g_{m1} and g_{m2}. Assume that all capacitors are large enough so that any AC signal would short them.

c) Repeat part b), but instead of gain, find input resistance and output resistance (resistance looking into V_{IN} and V_{OUT}, respectively).

You could use the topology formula sheet to check your work for part b) and c).

a)



(β's below are β_1)

KVLs:

$$V_{CC} - R_1 i_A - V_{BE} - R_3 i_E = 0$$

$$V_{CC} - R_1 (i_B + i_D) - V_{BE} - R_3 i_E = 0$$

$$R_2 i_D = V_{BE} + R_3 i_E$$

$$i_D = \frac{V_{BE} + R_3 i_E}{R_2}$$

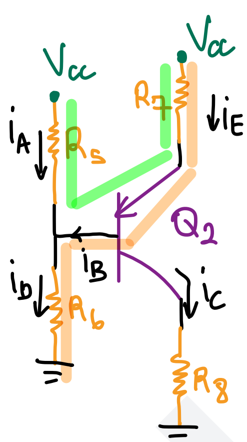
Replace i_D from magenta into cyan $\longrightarrow$ $V_{CC} - R_1\left(i_B + \frac{V_{BE} + R_3 i_E}{R_2}\right) - V_{BE} - R_3 i_E = 0$

Recall $i_E = (\beta+1) i_B \longrightarrow V_{CC} - R_1\left(i_B + \frac{V_{BE}}{R_2} + \frac{R_3}{R_2}(\beta+1) i_B\right) - V_{BE} - R_3(\beta+1) i_B = 0$

Isolate $i_B \rightarrow V_{CC} - R_1 \frac{V_{BE}}{R_2} - i_B\left(R_1\left(1 + \frac{R_3}{R_2}(\beta+1)\right) + R_3(\beta+1)\right) - V_{BE} = 0$

$$i_B = \frac{V_{CC} - V_{BE}\left(\frac{R_1}{R_2} + 1\right)}{R_1\left(1 + \frac{R_3}{R_2}(\beta+1)\right) + R_3(\beta+1)}$$

$$g_{m1} = \frac{\beta_1}{V_T} \frac{V_{CC} - V_{BE}\left(\frac{R_1}{R_2} + 1\right)}{R_1\left(1 + \frac{R_3}{R_2}(\beta_1+1)\right) + R_3(\beta_1+1)}$$



(β's below are β_2)

KVLs:

$$V_{CC} - i_A R_5 = V_{CC} - i_E R_7 - V_{EB}$$

$$V_{CC} - i_E R_7 - V_{EB} - i_D R_6 = 0$$

$$i_A R_5 = i_E R_7 + V_{EB}$$

$$i_D = \frac{V_{CC} - i_E R_7 - V_{EB}}{R_6}$$

$$(-i_B + i_D) R_5 = (\beta+1) i_B R_7 + V_{EB}$$

Replace i_D from tan into green $\rightarrow -i_B R_5 + \frac{R_5}{R_6}\left(V_{CC} - R_7(\beta+1) i_B - V_{EB}\right) = (\beta+1) i_B R_7 + V_{EB}$

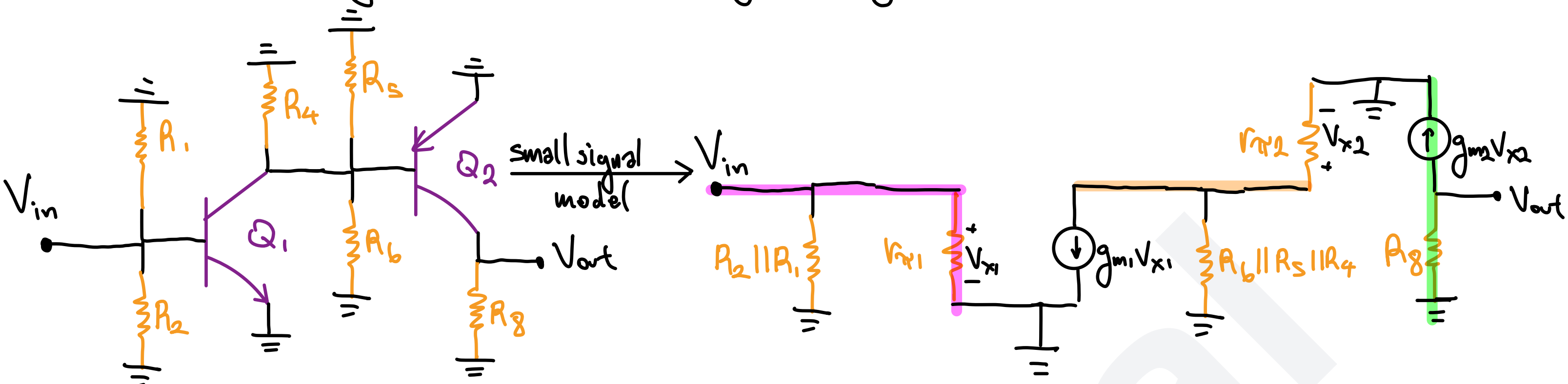
Recall $i_E = (\beta+1) i_B \longrightarrow -i_B R_5 - \frac{R_5}{R_6} R_7 (\beta+1) i_B - (\beta+1) i_B R_7 = V_{EB} - \frac{R_5}{R_6}(V_{CC} - V_{EB})$

(Isolate i_B)

$$i_B = \frac{V_{EB} - \frac{R_5}{R_6}(V_{CC} - V_{EB})}{-R_5 - \frac{R_5}{R_6} R_7(\beta+1) - (\beta+1) R_7} = \frac{\frac{R_5}{R_6} V_{CC} - V_{EB}\left(1 + \frac{R_5}{R_6}\right)}{R_5 + R_7(\beta+1)\left(1 + \frac{R_5}{R_6}\right)}$$

$$g_{m2} = \frac{\beta_2}{V_T} \frac{\frac{R_5}{R_6} V_{CC} - V_{EB}\left(1 + \frac{R_5}{R_6}\right)}{R_5 + R_7(\beta_2+1)\left(1 + \frac{R_5}{R_6}\right)}$$

b) Shorting capacitors and grounding DC sources



KVL: $V_{in} = V_{x1}$

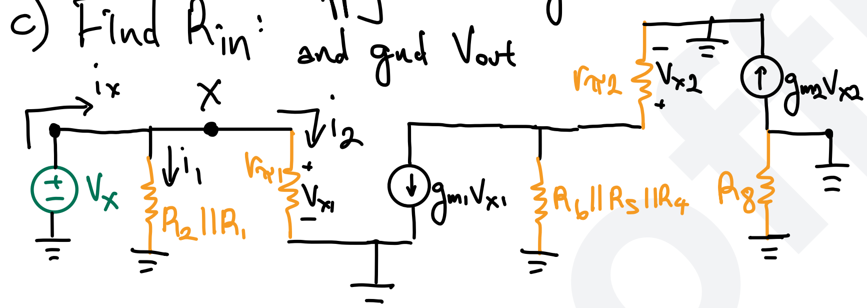
KCL: $g_{m2} V_{x2} = -V_{out}/R_8$

KCL: $g_{m1} V_{x1} = -V_{x2} / (R_6 || R_5 || R_4 || r_{\pi 2})$

$$g_{m1} V_{in} = V_{out} / [(R_6 || R_5 || R_4 || r_{\pi 2}) R_8 g_{m2}]$$

$$\frac{V_{out}}{V_{in}} = (R_6 || R_5 || R_4 || r_{\pi 2}) R_8 g_{m2} g_{m1}$$

c) Find R_{in}: Apply test voltage at V_{in} and gnd V_{out}



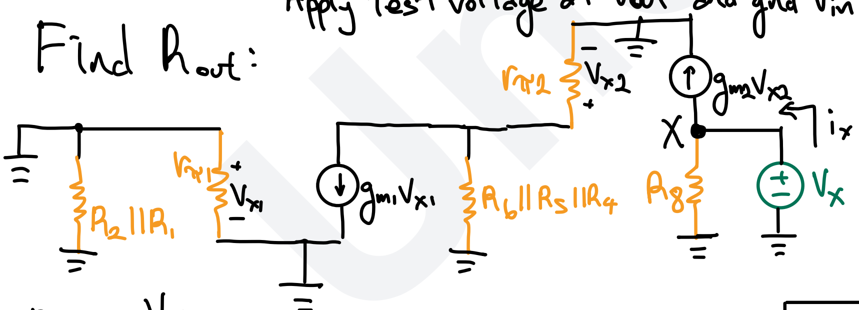
KCL at X:

$$i_x = i_1 + i_2 = \frac{V_x}{R_1 || R_2} + \frac{V_x}{r_{\pi 1}}$$

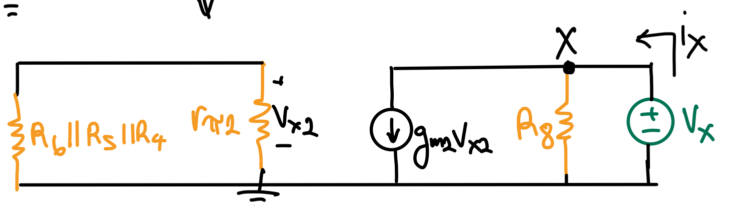
$$R_{in} = \frac{V_x}{i_x} = R_1 || R_2 || r_{\pi 1} = R_{in}$$

If β_1 is very large: $R_{in} \approx R_1 || R_2$

Find R_{out}: Apply test voltage at V_{out} and gnd V_{in}



redrawing, ignoring $R_2 || R_1$ & $r_{\pi 1}$ b/c they are shorted, & therefore $V_{\pi 1} = 0$, so can also ignore $g_{m1} V_{x1}$



$$R_{out} = \frac{V_x}{i_x}$$

KCL at X: $i_x = \cancel{g_{m2} V_{x2}} + V_x / R_8$ ($V_{x2} = 0$)

$$R_{out} = \frac{V_x}{V_x / R_8} = R_8 = R_{out}$$

3) The saturation current of this BJT is 10^{-16} A, current gain is 100. Early voltage is infinite, and thermal voltage is 26 mV. Using the topology formula sheet, find

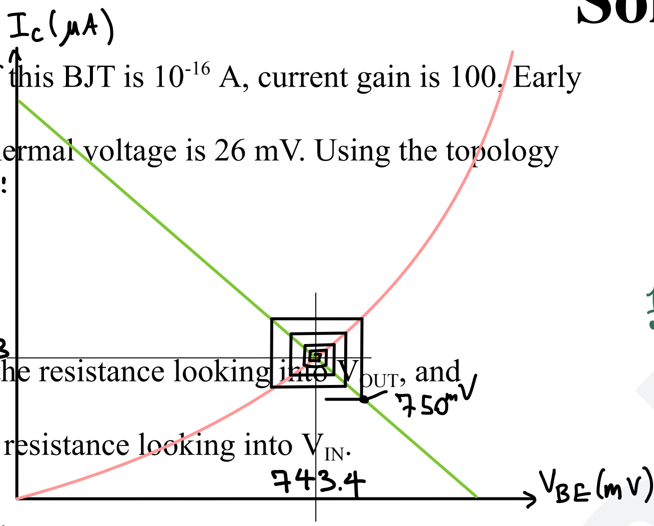
a) $A_V = V_{OUT}/V_{IN}$,

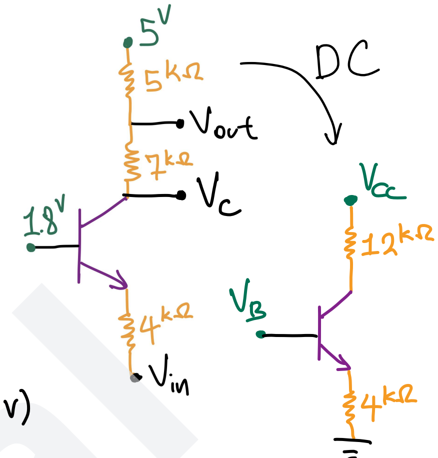
b) output resistance, R_{OUT}, the resistance looking into V_{OUT}, and

c) input resistance, R_{IN}, the resistance looking into V_{IN}.

Do not neglect base currents.

Recursive Visual:





$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \rightarrow {}^{*}V_{BE} = V_T \ln\frac{I_C}{I_S} = 0.026 \ln\frac{I_C}{10^{-16}}$

$\therefore I_C = 261.53\ \mu A$

$V_{BE} = 743.4\ mV$

KVL: $V_B - V_{BE} = I_C\left(\frac{\beta+1}{\beta}\right)4^k$

$\frac{100}{101}\frac{(1.8-V_{BE})}{4000} = {}^{*}I_C = \frac{1.8-V_{BE}}{4040}$

Recursive solving: start w/ $V_{BE} = 750^{mV}$ (typical value)

$I_C^{*} = 259.9\ \mu A$

$V_{BE}^{*}\big|_{I_C = 259.9\mu A} = 0.026 \ln\frac{259.9\ \mu A}{10^{-10}\ \mu A} \simeq 743.24^{mA}$

$I_C^{*}\big|_{V_{BE} = 743.24mA} = 261.57\ \mu A \rightarrow V_{BE}^{*} = 743.41^{mA}$

$I_C^{*}\big|_{V_{BE} = 743.41mA} = 261.53\ \mu A \rightarrow V_{BE}^{*} = 743.40^{mA}$

Close enough! Now... are we in FAR?

FAR?

$V_{BE} < V_{CE} \rightarrow V_B < V_C$

$V_B < V_{CC} - (R_1 + R_2) I_C$

$I_C(R_1 + R_2) < V_{CC} - V_B$

$261.53^{\mu A}(12^{k\Omega}) < 5 - 1.8$

$3.138 < 3.2$ ✓

$g_m = \frac{I_C}{V_T} = \frac{0.26153^{mA}}{26^{mV}} \simeq 0.01\ ℧$ or $\simeq 10\ m℧$

$\frac{V_c}{V_{in}} = \frac{12^{k\Omega}}{\frac{1}{0.01} + 4^k} \simeq 2.927$

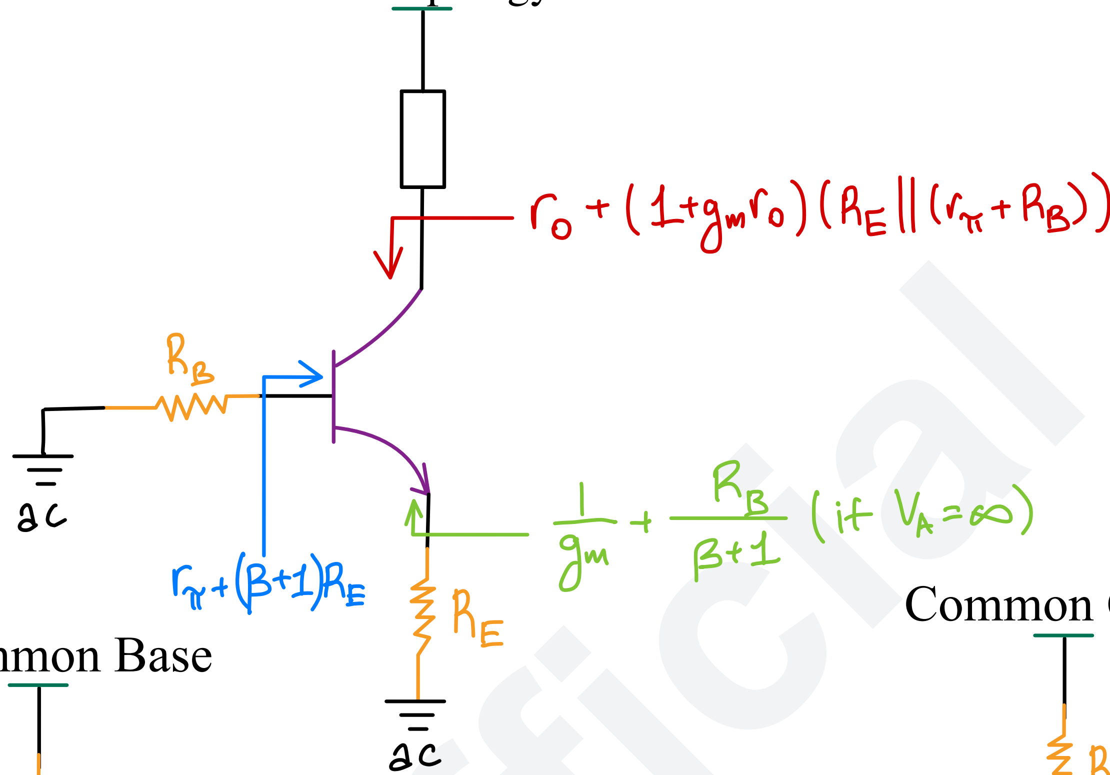
$V_{out} = V_c \frac{R_1}{R_2 + R_1} = V_c \frac{5}{12}$

$\frac{V_{out}}{V_{in}} = \frac{5}{12} 2.927 \simeq 1.220 \simeq A_V$

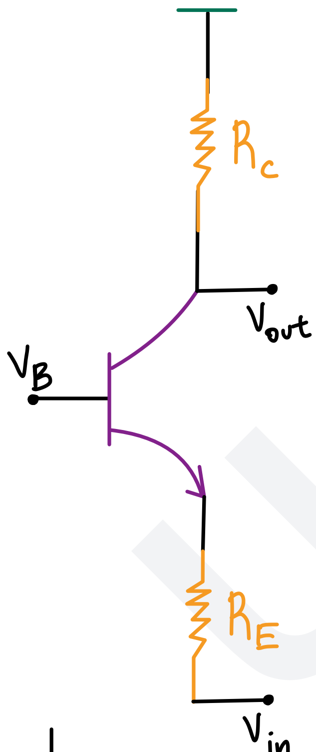
$R_{in} = \frac{1}{g_m} + 4^k \simeq 4099.4^{\Omega} \simeq R_{in}$

$R_{out} = 5^k \,||\, (7^k + \infty) = 5^k \simeq R_{out}$

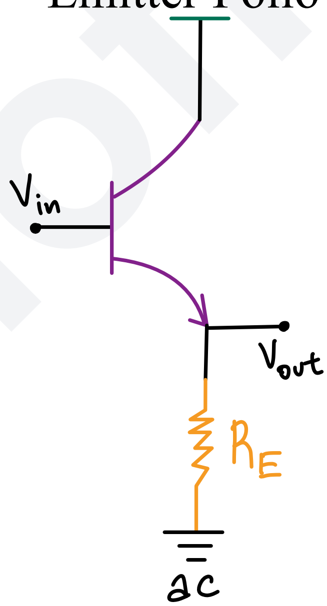
Topology Sheet



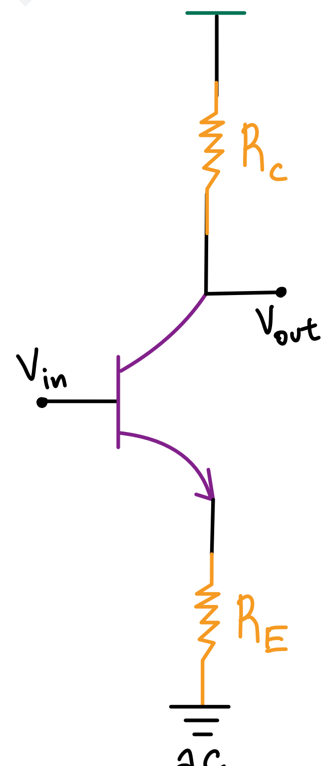
Common Base



Emitter Follower



Common Collector



$$\left. V_{out}/V_{in} \right|_{V_A=\infty} = \frac{R_C}{\frac{1}{g_m} + R_E}$$

$$V_{out}/V_{in} = \frac{R_E \| r_o}{\frac{1}{g_m} + R_E \| r_o}$$

$$\left. V_{out}/V_{in} \right|_{V_A=\infty} = \frac{-R_C}{\frac{1}{g_m} + R_E}$$