ECE2280 Examples

1. Assume all transistors are the same and have a finite $\beta$ and an infinite Early voltage. Your expression should include only real resistances ($R_1$, $R_2$, $R_3$, $R_t$, $R_s$, $R_{G1}$, $R_{G2}$ or a subset of these) and possibly $\beta$, $r_e$, or $r_n$.

1. Write an expression for the input resistance $R_{in1}$ in the circuit shown below.
2. Write an expression for the input resistance $R_{in2}$ in the circuit shown below.
2. The transistors below are identical, use $V_{BE}=0.7$, $\beta=100$, $g_m=80 \text{mA/V}$, $r_o=1250\Omega$, $C_1=C_2=100\mu\text{F}$.
(a) Find the complete frequency response for $V_o/V_{\text{sig}}$, ignore $r_o$ and the parasitic capacitors.
(b) Find the low frequency pole values.
Assume the transistors are identical and $\beta = 160, |V_{BE}| = 0.7$.

3. Find $V_{B1}, V_{C1}, V_{E1}, V_{B2}, V_{out}, I_{C1}, I_{1}, I_{B2}, I_{E2},$ and $I_{C2}$. Verify the transistors are acting in the active region.

4. Find the three low frequency pole locations. State the value for $f_p$ in Hz.

5. Draw the hybrid-p small signal equivalent circuit. State the type of 2-stage amplifier configuration this is. (e.g. Common Collector-Common Source, Common Base-Common Collector, etc.).

6. Analyze the circuit for $R_{in}$ and $R_{out}$.

7. Analyze the circuit to determine $V_{out}/V_{sig}$.
8. The input and output curves vs time are shown below. Explain in detail why this circuit is not amplifying the signal and is instead 0V. $V_{CE\text{, SAT}}=0.2\text{V}$, $V_{BE}=0.7\text{V}$, and $\beta=100$. 

![Diagram of the circuit](image)

- Input signal amplitude: VOFF = 0
- VAMPL = 1m
- FREQ = 1k
Example: A BJT Circuit in Saturation

Determine all currents for the BJT in the circuit below.

\[ \beta = 99 \]

Let's see if you are correct! ASSUME it is in active mode and ENFORCE \( V_{CE} = 0.7 \text{ V} \) and \( i_C = \beta i_B \).

The B-E KVL is therefore:

\[ 5.7 - 10 i_B - 0.7 - 2 (99+1) i_B = 0 \]

Therefore \( i_B = 23.8 \mu A \)
See! Base current $i_B = 23.8 \mu A$, just like before. Therefore collector current and emitter current are again $i_C = 99i_B = 2.356$ mA and $i_E = 100i_B = 2.380$ mA. Right?!

Well maybe, but we still need to CHECK to see if our assumption is correct!

We know that $i_B = 23.8 \mu A > 0$.\checkmark
Q: So what do we do now?

A: Change the assumption and try it again!

Let's assume instead that the BJT is in saturation. Thus, we enforce the conditions:

\[ V_{CE} = 0.2 \text{ V} \quad V_{BE} = 0.7 \text{ V} \]

Now let's analyze the circuit!

Note that we cannot directly determine the currents, as we do not know the base voltage, emitter voltage, or collector voltage.

But, we do know the differences in these voltages!

For example, we know that the collector voltage is 0.2 V higher than the emitter voltage, but we do not know what the collector or emitter voltages are!
Q: So, how the heck do we ANALYZE this circuit!?

A: Often, circuits with BJT s in saturation are somewhat more difficult to ANALYZE than circuits with active BJT s. There are often many approaches, but all result from a logical, systematic application of Kirchoff’s Laws!

**ANALYSIS EXAMPLE 1** - Start with KCL

We know that \( i_B + i_C = i_E \) (KCL)

But, what are \( i_B, i_C, \) and \( i_E \)??

Well, from Ohm’s Law:

\[
  i_B = \frac{5.7 - V_B}{10} \quad i_C = \frac{10.7 - V_C}{10} \quad i_E = \frac{V_E - 0}{10}
\]

Therefore, combining with KCL:

\[
  \frac{5.7 - V_B}{10} + \frac{10.7 - V_C}{10} = \frac{V_E}{10}
\]

Look what we have, 1 equation and 3 unknowns.

We need 2 more independent equations involving \( V_B, V_C, \) and \( V_E \)!
**Q:** Two more independent equations!? It looks to me as if we have written all that we can about the circuit using Kirchoff's Laws.

**A:** True! There are no more independent circuit equations that we can write using KVL or KCL! But, recall the hint sheet:

"Make sure you are using all available information".

There is more information available to us - the ENFORCED conditions!

\[ V_{CE} = V_C - V_E = 0.2 \quad \rightarrow \quad V_C = V_E + 0.2 \]

\[ V_{BE} = V_B - V_E = 0.7 \quad \rightarrow \quad V_B = V_E + 0.7 \]

Two more independent equations! Combining with the earlier equation:

\[
\frac{5.7 - (0.7 + V_E)}{10} + \frac{10.7 - (0.2 + V_E)}{10} = \frac{V_E}{10}
\]

One equation and one unknown! Solving, we get \( V_E = 2.2 \) V.

Inserting this answer into the above equations, we get:

\[ V_B = 2.9 \text{ V} \quad V_C = 2.4 \text{ V} \]

\[ i_C = 0.83 \text{ mA} \quad i_B = 0.28 \text{ mA} \quad i_E = 1.11 \text{ mA} \]
First CHECK to see that all currents are **positive**:

\[ i_C = 0.83 \text{ mA} > 0 \checkmark \quad i_B = 0.28 \text{ mA} > 0 \checkmark \quad i_E = 1.11 \text{ mA} > 0 \checkmark \]

Also CHECK **collector current**:

\[ i_C = 0.83 \text{ mA} < \beta \; i_B = 27.7 \text{ mA} \checkmark \]

Our solution is **correct** !!!
Example 9

\[ |V_{BE}| = 0.7, \beta = 100, V_T = 25 \text{mV} \], ignore \( r_o \) and \( r_x \), \( v_{mg} = (2 + 0.1 \sin(\omega t)) \) Volts. Assume that the capacitor acts as an open for DC operation and short for AC operation. Assume saturation for the transistor. Use the attached datasheet.

What is \( \beta_{\text{forced}} \)?
Example 10
Use: ignore $r_o$, $|V_{BE}|=0.7$, $\beta=99$

$$V_{\text{sig}} = 3 + 0.005 \sin(20t)$$

For DC analysis, assume that the capacitors act as an open

(a) Solve for the DC currents:
   a. $I_B$
   b. $I_E$
   c. $I_C$

(b) Solve for the DC voltages:
   a. $V_B$
   b. $V_E$
   c. $V_o$

(c) Prove that the transistor is operating in active mode.

(d) Sketch the TOTAL instantaneous waveform observed for $V_o$ if the AC amplification is $V_o/V_{\text{sig}}=3V/V$. 
Example 11
Use: ignore $r_o, |V_{BE}|=0.7, \beta=100$
$V_I = 7+0.004\sin(500t)$

$r_{\pi 1}=4,000 \quad g_{m2}=100\text{mA/V}, \text{and } I_{B2}=25\mu\text{A} \text{ (DC value)}$

For the following hybrid-$\pi$ equivalent circuit below, find the following values:
(a) $R_{in}$ (input resistance –ignore only the input source, $V_{\text{sig}}$ and include all resistors at the base)
(b) $R_{out}$ (output resistance—include all resistors at the collector {no load is connected}) Hint: A floating resistor does not have a pathway to ground.
(c) midband gain, $\frac{V_o}{V_{\text{sig}}}$

\[
\begin{align*}
\text{Example 11} \\
\text{Use: } & \text{ignore } r_o, |V_{BE}|=0.7, \beta=100 \\
V_I &= 7+0.004\sin(500t) \\
r_{\pi 1} &= 4,000 \quad g_{m2}=100\text{mA/V}, \text{and } I_{B2}=25\mu\text{A} \text{ (DC value)} \\
\text{For the following hybrid-$\pi$ equivalent circuit below, find the following values:} \\
\text{(a) } R_{in} \text{ (input resistance –ignore only the input source, } V_{\text{sig}} \text{ and include all resistors at the base)} \\
\text{(b) } R_{out} \text{ (output resistance—include all resistors at the collector {no load is connected})} \text{ Hint: A floating resistor does not have a pathway to ground.} \\
\text{(c) midband gain, } \frac{V_o}{V_{\text{sig}}} \\
\end{align*}
\]
Example 12
For the circuit shown below, draw the AC small-signal equivalent circuit (use hybrid-\(\pi\) or model T). Make sure that everything is labeled in terms of the transistor number. (e.g. \(g_{m1}, v_{\pi2}\), etc.). Include \(r_o\) for all transistors. \(v_{\text{sig}}=0.001\sin(10t)\) AC. Assume all capacitors are shorted.
Example 13

$|V_{BE}| = 0.7$, $\beta = 100$, ignore $r_o$, $v_{sig}$ is shown in the graph below. Assume that the capacitor acts as an open for DC operation and short for AC operation. Does this circuit operate as a linear AC amplifier? If so, what is the gain, $\frac{V_o}{V_{sig}}$, of the following circuit? If not, explain why.

\[ V_{sig} \]
\[ C_1 \]
\[ 100 \text{m} \]

\[ +4.7V \]
\[ 5k \]
\[ 50 \]

\[ Q_2 \]
\[ +6V \]

\[ Q_2N3904 \]
\[ -2V \]