Laboratory 4 (3 days):
BJT characteristics, Small Signal Amplifiers

Material covered:

- This laboratory has ***three sessions*** allocated for completion.
  - 1st session: Pre-Lab Exercise 1 and Exercise 1
  - 2nd session: Pre-Lab Exercise 2 and Exercise 2
  - 3rd session: Exercise 3 and Exercise 4
- BJT DC biasing, Forward active, reverse active, saturation
- Small signal models for BJTs
- Common emitter, common base, common collector configurations
- Small signal bandwidth

Overview notes:

PSpice – Setting up DC Sweeps with a secondary sweep

1. Select Simulation Profile and choose Primary Sweep
2. Indicate the source type, source name, start value, end value and increments. Make the increments sufficiently small that your plots look 'smooth'
3. Select Secondary Sweep, checking the box on. Both Primary and Second Sweeps should have check marks in the associated boxes.
4. Again, indicate the source type, source name, start value, end value and increments.
5. After running the simulation, place an appropriate probe on the schematic and you will see plots of the probe type against the Primary Sweep variable. Each plot will correspond to a different Secondary Sweep step value.

Note: The DC biasing circuits for Exercises 4, 5 and 6 are the same. The resistors R_1, R_2, R_C and R_E comprise the DC bias resistors.

Pre-Lab Exercise 1

Note: For the PSpice simulations, the transistors are Q2N2222 and for the experimental portion, the transistors are PN2222.

1. Build the circuit shown in Figure 1 (below) in PSpice. Both sources are of type VDC. Set V_{CE} to 2 V and under the simulation profile set V_{BE} to the Primary Sweep with voltage range $0 < V_{BE} < 0.7$ V. Generate a plot of I_C-versus-V_{BE}.

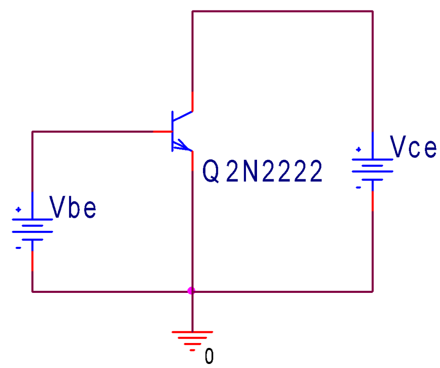

Figure 1: BJT with voltage control

On the plot, indicate the regions where the BJT is OFF and where it is ON.

Approximately, at what base-emitter voltage does the transistor turn ON. Is this consistent with diode characteristics?

2. Change the Primary Sweep to V_{CE}, setting the voltage range $0 < V_{CE} < 2$V. Set V_{BE} to the Secondary Sweep with voltages $V_{BE} \rightarrow \{0.6, 0.62, 0.64, 0.66, 0.68, 0.7 \text{ V}\}$ and plot I_C-versus-V_{CE}.

On the plots, identify the saturation region and the forward active region. Approximately, at what voltage is the transition from saturation to forward active. Is this value approximately consistent with your expectations?

Pre-Lab Exercise 2

1. Implement the Exercise 3 circuit (shown below) in PSpice (common C amplifier), setting V_{CC} = 4 V, R_{Sig} = 10 kΩ and R_L = 1 kΩ. Set the source to a 10 kHz, 0.2 Vpp sinusoidal voltage signal. Identify the passband voltage gain (A_{VOC}).

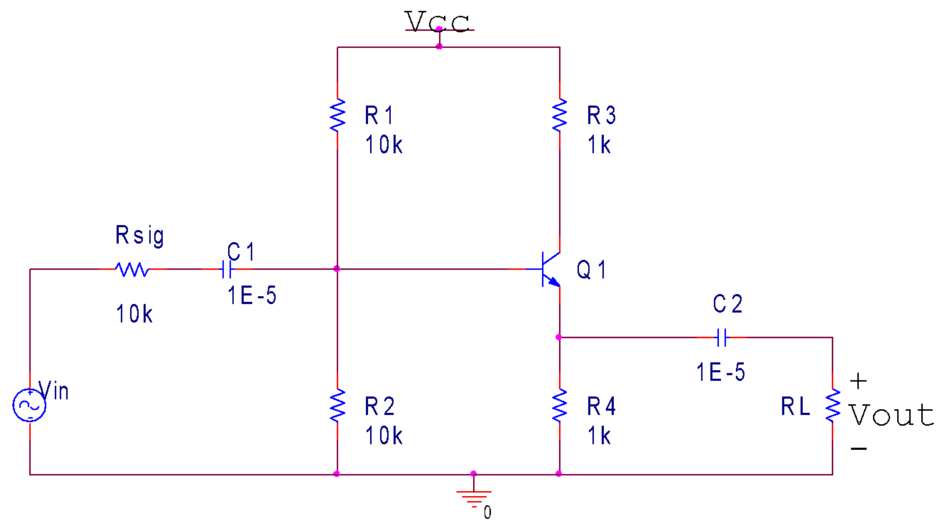

Figure 2: BJT circuit

2. Implement the Exercise 4 circuit (shown below) in PSpice (common E amplifier), setting V_{CC} = 4 V, R_{Sig} = 100 Ω and R_L = 1 kΩ, and run an AC sweep. Identify the passband gain (A_{VOC}) and the low frequency and high frequency cutoff values (–3-dB points).

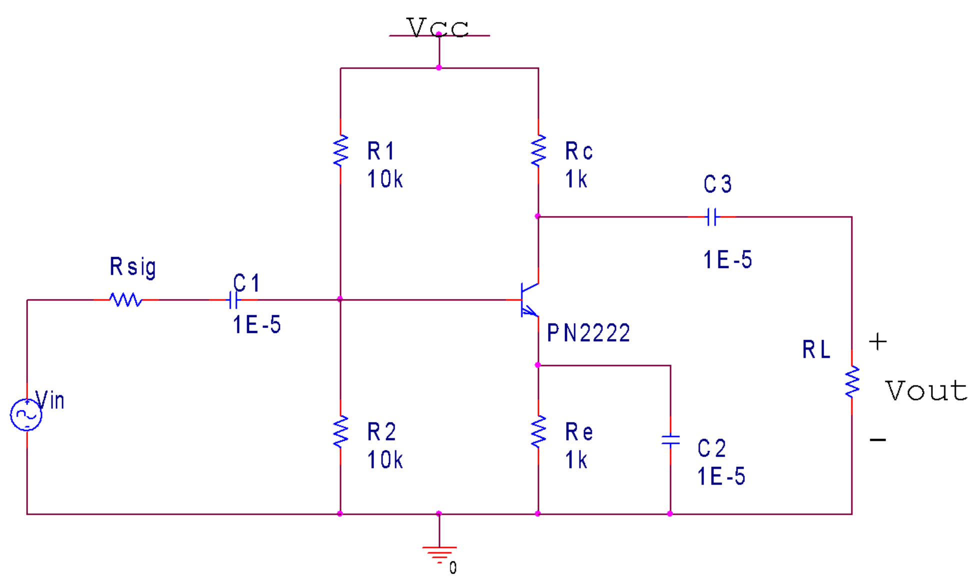

Figure 3: BJT circuit

Exercise 1: Device characteristics

1. Construct the circuit shown in Figure 4 (below) using the +25 V channel on the E3631A power supply for V_1. Set V_1 to the DC voltage of 7 V.

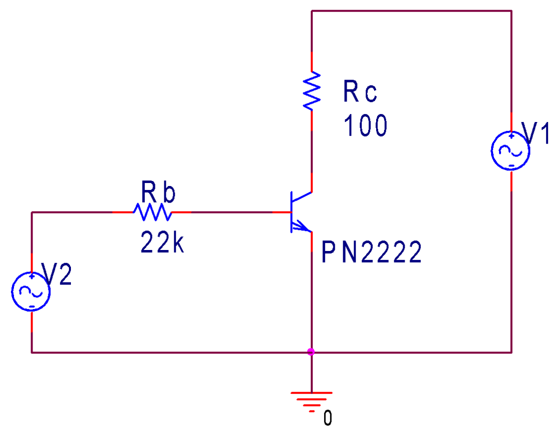

Figure 4: BJT characteristics

In the following, measure the DC voltages across and currents through (using Ohm's law) R_C and R_b. Use the benchtop multimeter to make the DC measurements.

2. Starting at $V_2 \approx 2.0$ V, slowly increase V_2 until the BJT collector current I_C is 20 mA. Determine the base current I_B by measuring the voltage drop across the 22 kΩ base resistor. Measure V_{CE} and verify that the device is in the forward active region. Measure V_{BE}.

   Is the V_{BE} measurement close to our 0.7 V approximation value?

3. At the voltage determined in Part 2 (above), use your I_B and I_C measurements to estimate the common-emitter current gain $\beta = I_C / I_B$.

4. Raise V_1 to 10 V and measure I_C, V_{CE} and V_{BE}.

   Describe the changes you see. Did V_{BE} change significantly?

5. Use the two I_C and V_{CE} measurements to estimate the output resistance, r_{out}, and the Early voltage, V_{Early}. The Early voltage can be calculated from the formula (to be discussed during lecture):

$$Slope = \frac{\Delta I_C}{\Delta V_{CE}} = \frac{1}{r_{out}} = \frac{I_C}{V_{Early} + V_{CE}} \approx \frac{I_C}{V_{Early}}$$

   How do these values compare to the spec sheet values for the PN2222?

   Keep the transistor that you used in this exercise for the remaining exercises. If you lose your transistor, use the above circuit to determine the transistor characteristics for the replacement transistor. You will need the values for the small signal analysis.

Exercise 2: DC biasing and small-signal characteristics.

1. Build the circuit shown below, using V_{CC} = 4.0 V.

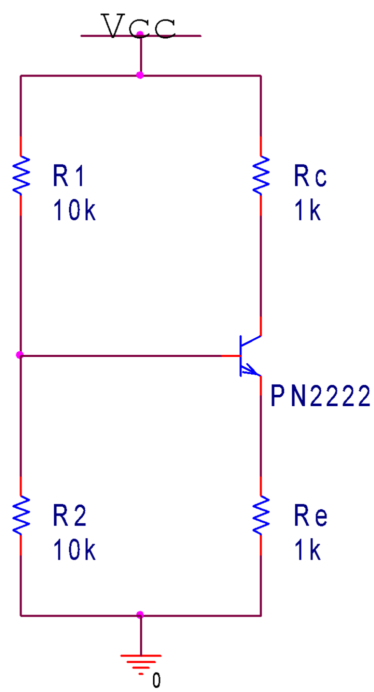

Figure 5: DC bias circuit for amplifier models

2. Measure DC quantities V_{BE}, V_{CE}, I_B, I_C, and I_E using the multimeter on the bench. The bench multimeter has a better input impedance than the Mobile Studio or Discovery Board. To measure I_B, use KCL with regard to I_{R1} and I_{R2}.

3. Verify that the circuit is in the forward active region.

4. For the present DC biasing, determine r_E using the equation $r_E = V_{thermal} / I_E$. Determine the common emitter current gain, $\beta = I_C / I_B$. Is the β value consistent with your previous determination of β (assuming that you are using the same transistor)?

   In your report, draw the small signal equivalent circuit of the DC bias circuit using the T-shaped and π-shaped BJT model.

   Keep this DC bias circuit, you will be using it for the remaining exercises.

Exercise 3: Common collector amplifier.

1. Build the circuit shown in Figure 6 (below) using V_{CC} = 4 V, R_L = 100 kΩ, and R_{Sig} = 100 Ω.

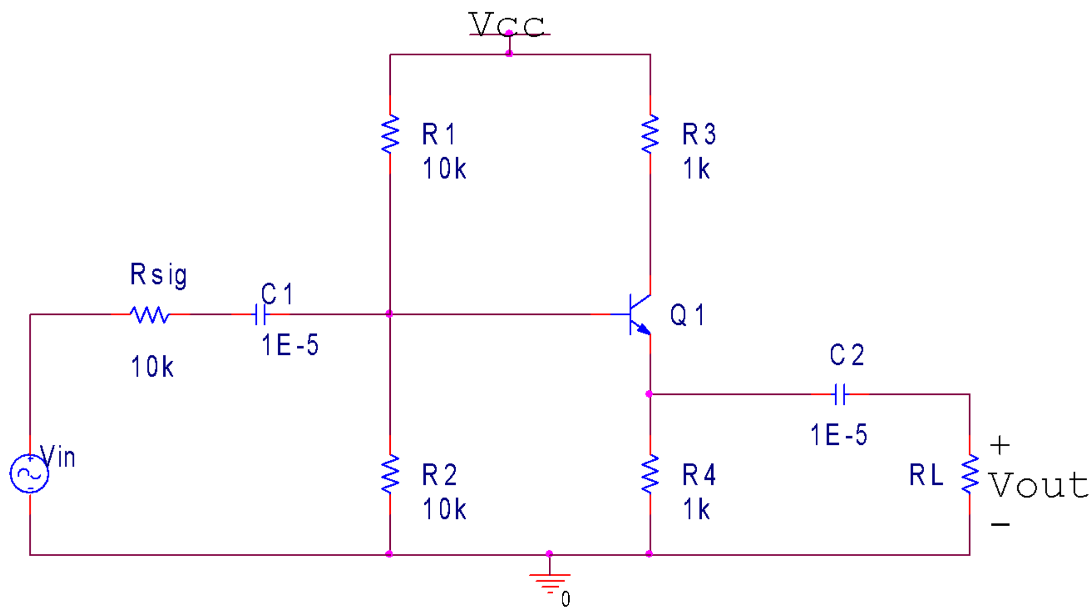

Figure 6: BJT common-collector amplifier

Analytically, using your measured β from Exercise 1 estimate the input resistance, R_{In}, output resistance, R_{Out}, and the open-circuit voltage gain, A_{VOC}.

2. Set R_{Sig} to 100 Ω and R_L to 100 kΩ. Apply an input voltage with DC offset = 0 V, $V_{pk\text{-}pk}$ = 0.2 V, frequency = 1 KHz.

3. Experimentally estimate the open-circuit voltage gain A_{VOC}. Remember to set the V/Div such that the input profile of the measurement does not interfere with the circuit.

4. Change R_{Sig} to 1 kΩ and R_L to 1 kΩ.

5. Experimentally, determine the input resistance, R_{In}. This can be done by measuring the current through R_{Sig} and the voltage on the RHS of R_{Sig} (= v_{in}). Recall: $R_{In} = v_{in} / i_{in}$

6. Experimentally, determine the output resistance, R_{Out}. This can be done by removing R_L, applying a small AC voltage to the amplifier output, and measuring the current into the amplifier. Recall: $R_{Out} = v_{out} / i_{out}$

7. For the same R_{Sig} and R_L, determine the overall voltage gain, A_V.

For all the above values, how do the experimental results compare to the analytic estimates?

Exercise 4: Common emitter amplifier

1. Build the circuit shown in Figure 7 (below) using R_L = 100 kΩ with Vin set to zero. Set V_{CC} to 4 V. Note: when you apply power, the current will increase slowly (why?). Wait until it reaches its final value before making measurements.

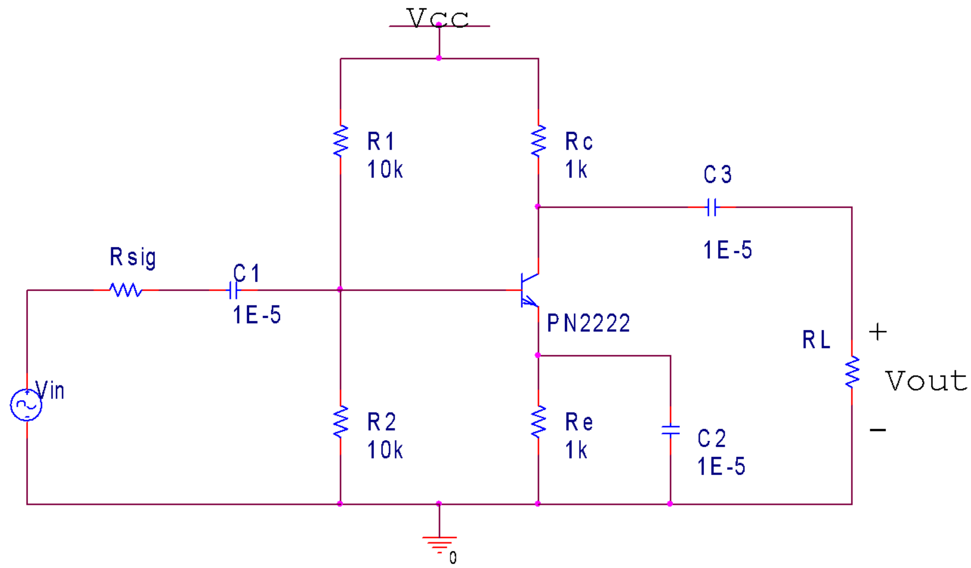

Figure 7: BJT common-emitter amplifier

2. Verify that the DC bias characteristics are consistent with the previous exercise.

   Analytically, using your measured β from Exercise 3.1 estimate the input resistance, R_{In}, output resistance, R_{Out}, and the open-circuit gain, A_{VOC}.

3. Set R_{Sig} to 100 Ω and R_L to 100 kΩ. Apply an input voltage with DC offset = 0 V, $V_{pk\text{-}pk}$ = 0.02 V, frequency = 1 kHz.

4. Experimentally estimate the open-circuit voltage gain A_{VOC}. Remember to set the V/Div such that the input profile of the measurement does not interfere with the circuit.

5. Measure the current through R_{Sig}. Use this measurement to experimentally estimate the input resistance, R_{In}.

6. Replace R_L with a 1 kΩ resistor and the output voltage. Use this measurement to estimate the output resistance, R_{Out}.

7. For the same R_{Sig} and R_L, determine the overall voltage gain, A_V.

   For all the above values, how do the experimental results compare to the analytic estimates?

8. With V_{CC} = 4 V, R_{Sig} = 100 Ω, and R_L = 1 kΩ, do a frequency sweep with $V_{In,pk\text{-}pk}$ = 0.02 V and determine the 3 dB low and high frequency cutoffs.

9. Analytically, estimate the (low-frequency) cutoff frequency associated with each capacitor.

   How do your experimental values compare with an analytic estimate?