Homework Assignment #7 – due via Moodle at 11:59 pm on Saturday, Mar. 30, 2024 [extended deadline]

***Instructions, notes, and hints*:**

You may make reasonable assumptions and approximations to compensate for missing information, if any. Provide the details of all solutions, including important intermediate steps. You will not receive credit if you do not show your work.

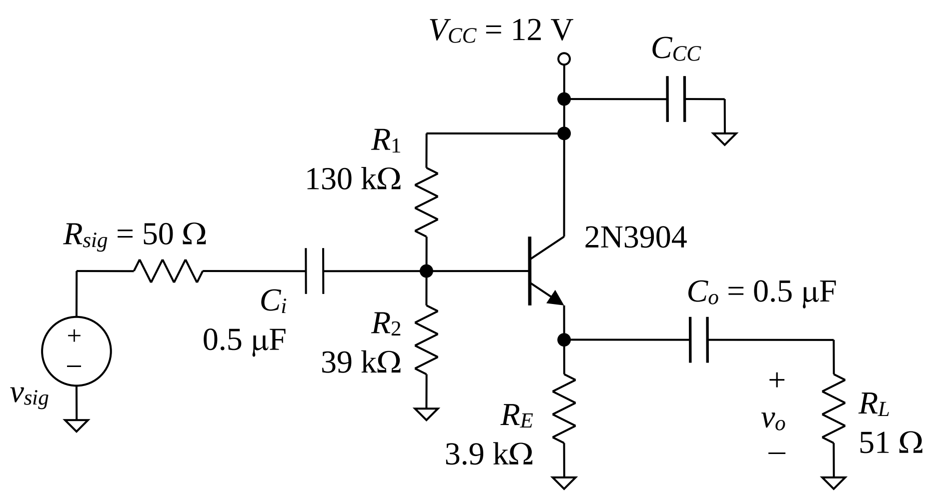
Unless otherwise specified, you may assume that all BJTs are at room temperature, the emission coefficient $\eta = 1$, $V_{BE} = 0.7$ V (quiescent value), and $V_{CE}|_{\text{sat}} = 0.2$ V. If the Early voltage V_A is not specified, you may ignore its effects. For now, unless otherwise specified, capacitors can be assumed to have values large enough that they act as shorts at the operating frequency.

The first set of problems will be graded and the rest will not be graded. Only the graded problems must be submitted by the deadline above. Do not submit the ungraded problems.

***Graded Problems*:**

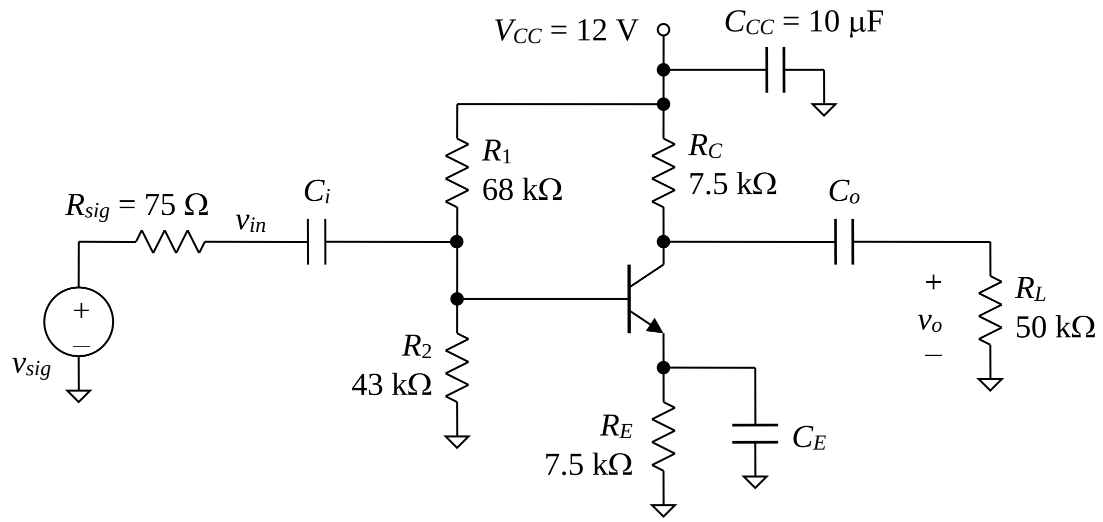
1. The circuit below depicts an emitter follower amplifier. For the BJT, you may assume that $\beta = 150$ and $V_A = 100$ V. The quiescent collector current is around 500 μA.

- **a.** Estimate the lower cut-off frequency f_L of the midband range. You may use the well-known expressions for the input and output resistances of the emitter follower as part of the solution, or you may derive them yourself.
- **b.** Suppose that the quiescent collector current is doubled to 1.0 mA by changing the biasing resistor values to $R_1 = 65$ kΩ, $R_2 = 20$ kΩ, and $R_E = 2$ kΩ. Find the new lower frequency limit f_L that results. Compare the f_L values that you obtain at the two quiescent current levels and briefly discuss some of the implications of the results.

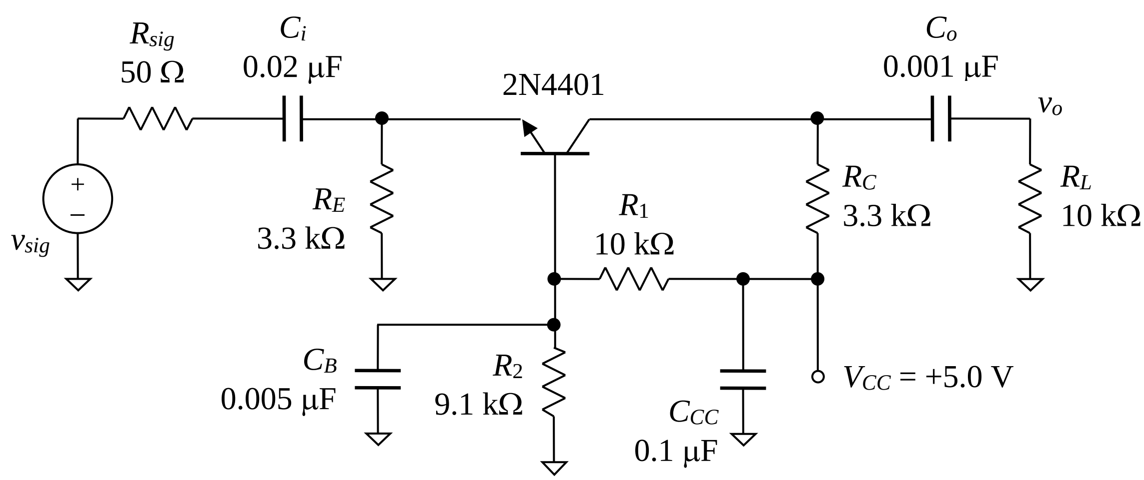


(*continued on next page*)

2. Find the required values for the capacitors C_i, C_o, and C_E in the common-emitter amplifier shown below so that the low end of the midband region is at 200 Hz with the dominant capacitor contributing 90% toward the lower cut-off frequency and the other two each contributing 5% (i.e., the dominant pole contributes 90% of the value of f_L, and the other two poles each contribute 5%). Minimize the total required capacitance. Note that you will first need to find the quiescent point of the amplifier. Also find the mid-band gain $A_v = v_o/v_{in}$. You may assume that $\beta \approx 200$ and $V_A = 100$ V.

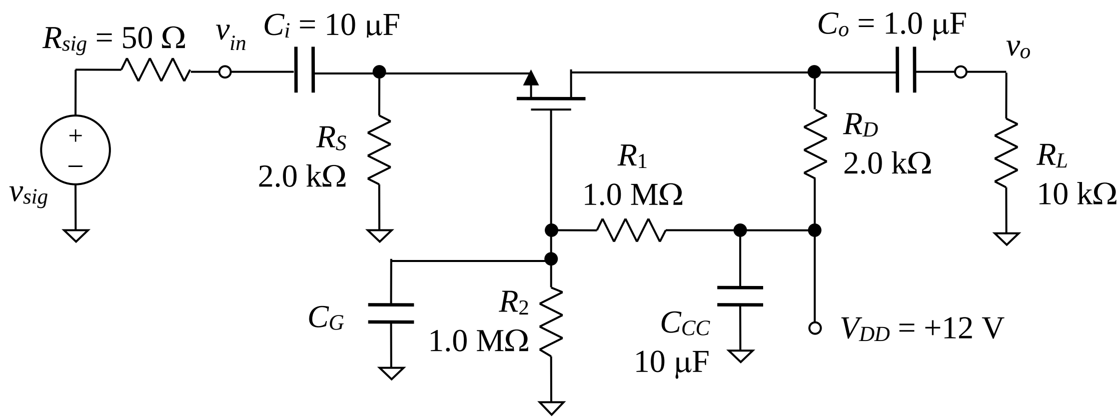


3. Estimate the lower limit f_L of the midband range for the common-base amplifier circuit shown below. Before finding the numerical values of the pole frequencies, first find symbolic expressions for the equivalent resistances seen by each "low-frequency" capacitor in the circuit. Note that you will need to find the quiescent collector current. If you need information from the 2N4401 data sheet, it is available on the Laboratory page at the ECEG 351 course web site. You may ignore the Early effect (so that $r_o \rightarrow \infty$). If necessary, you may assume $\beta \approx 200$.

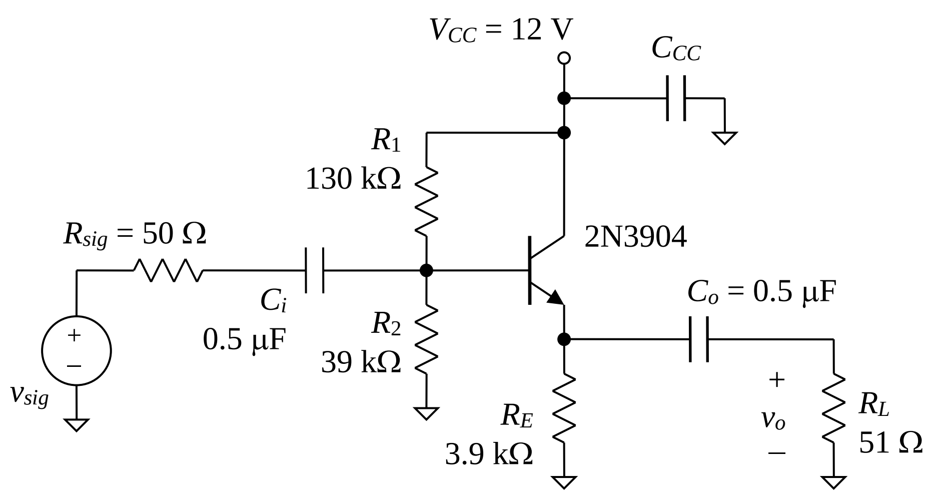


(*continued on next page*)

4. For the common-gate amplifier shown below, determine whether the gate bypass capacitor C_G, if it were present, would significantly affect the lower cut-off frequency f_L of the amplifier's midband range. Briefly explain why or why not. Note that C_G *does* affect the high-frequency response in the sense that if it is large enough, then its reactance is small compared to C_{gs} and C_{gd} at the upper end of the midband range, which grounds those capacitances at their gate ends instead of forming a voltage divider with them (in combination with R_2). In other words, C_G must be large enough to provide a very low impedance path to ground at the upper end of the midband range.



5. Estimate the values of C_π and C_μ for the BJT in the circuit shown below. You will need to obtain some information from the 2N3904 data sheet, which is available on the Laboratory page at the ECEG 351 course web site. The data sheet gives the unity-gain frequency f_T for a collector current of 10 mA; however, that value can be used with reasonable accuracy for the different collector current in the circuit considered here. The variable C_{obo} is used in many data sheets to represent C_μ in the hybrid-pi model. The value of C_μ is mostly independent of the quiescent collector current.

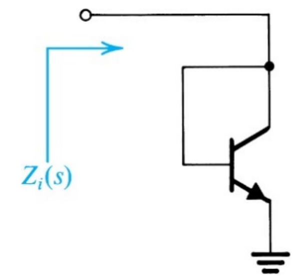


(*continued on next page*)

***Ungraded Problems*:**

The following problems will not be graded. However, you should attempt to solve them on your own and then check the solutions. Try not to give up too quickly if you struggle to solve any of them. Move on to a different problem and then come back to the difficult one after a few hours.

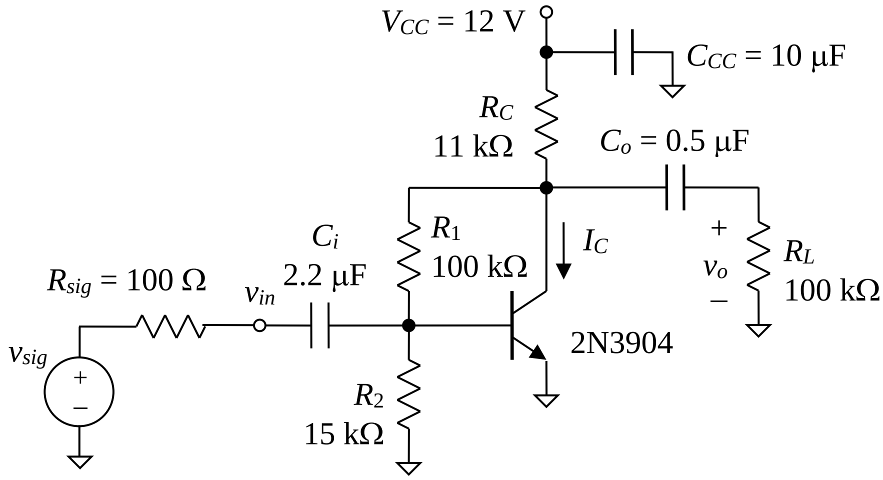
1. [adapted from Prob. 10.45 of Sedra & Smith, 7^{th} ed.] It is possible to determine the unity-gain frequency of a BJT by making careful measurements of the equivalent impedance of the device in the diode-connected configuration as shown below. (The required bias circuit is not shown in the diagram.) Assuming that $\alpha = \beta/(\beta+1) \approx 1$, and using the BJT high-frequency hybrid-π model with $r_x = 0$ and $r_o = \infty$,



a. Derive an expression for $Z_i(\omega)$ as a function of ω, r_e, and C_π (where r_e is given in Table 7.3 of the textbook).
b. Show that the frequency at which the impedance $Z_i(\omega)$ has a phase angle of ±45° is f_T if the quiescent collector current is high enough so that $C_\pi >> C_\mu$.
c. Show that if the quiescent collector current is reduced so that impedance $Z_i(\omega)$ has a phase angle of ±45° at the frequency $2f_T$, then $C_\pi \approx C_\mu$.

2. Suppose that a particular BJT has a unity-gain frequency of 300 MHz and a DC current gain (β_0) of 250. Estimate the highest frequency at which the current gain $\beta(\omega)$ is within 3 dB of its maximum value. To determine whether the "10 log" or "20 log" formula is relevant here, remember that power is proportional to current squared. Also estimate the highest frequency at which β is at least 50, which is a usable amount of current gain for many applications.

3. The common emitter amplifier shown below uses the collector-to-base feedback biasing method. The quiescent collector current is close to 500 µA, and the quiescent collector voltage is close to 6.0 V. Find the small-signal midband voltage gain $A_v = v_o/v_{in}$, and estimate the upper and lower frequency limits of the midband range. If you need a value for β (you shouldn't), you may assume that it is approximately equal to 150. The datasheet for the 2N3904 is available on the Laboratory page at the course web site.



(*continued on next page*)

4. Using the capacitor values from Graded Prob. 2, find the midband gain and lower cut-off frequency for the circuit shown below. The only changes from the circuit considered in the graded problem is that resistor R_D has been added (*D* for "degeneration"), and R_E has been correspondingly reduced. Resistor R_D adds some negative feedback that is active at signal frequencies. By what factors have the gain and cut-off frequency been reduced? Comment on the performance trade-off that this circuit change represents.