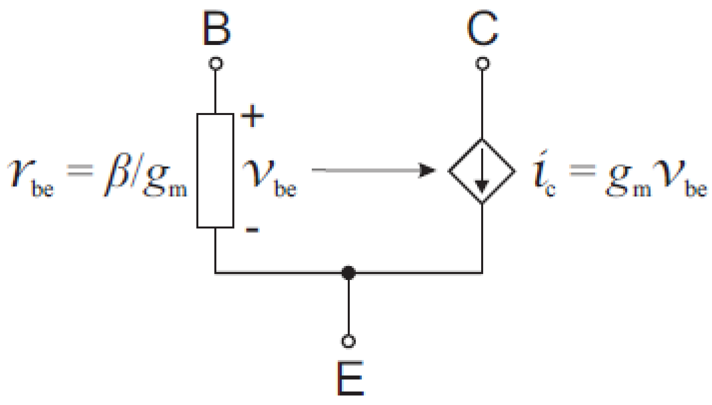
Analogue Electronics Questions

Todd Huffman & Tony Weidberg, MT 2018 (updated 30/10/18).

For the purpose of this problem sheet use the model given in the lecture notes.



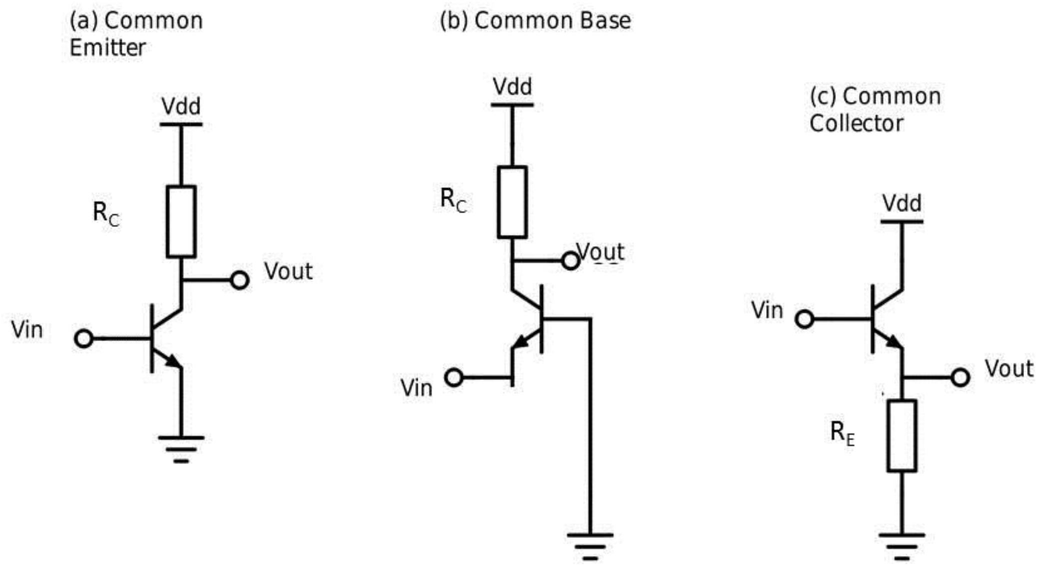
- The current gain is defined by a parameter β, such that $I_c = \beta I_b$
- the transconductance is defined by $I_c = g_m v_{be}$ with $g_m = eI_c/k_BT$ and $I_c = I_0\{\exp(eV_{be}/k_BT)-1\}$.

For the purposes of these questions, assume $\beta >> 10$, i.e. you can assume $\beta \approx \beta + 1$.

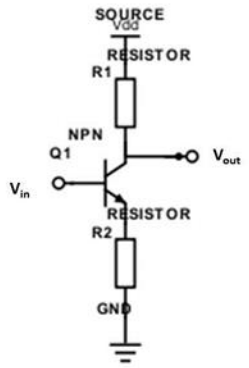
Section A contains standard questions you should attempt. Section B goes far beyond the syllabus and is for enthusiasts only. Please don't worry if you don't have time to look at these or if you get stuck with some of these questions.

Section A Principles (standard questions)

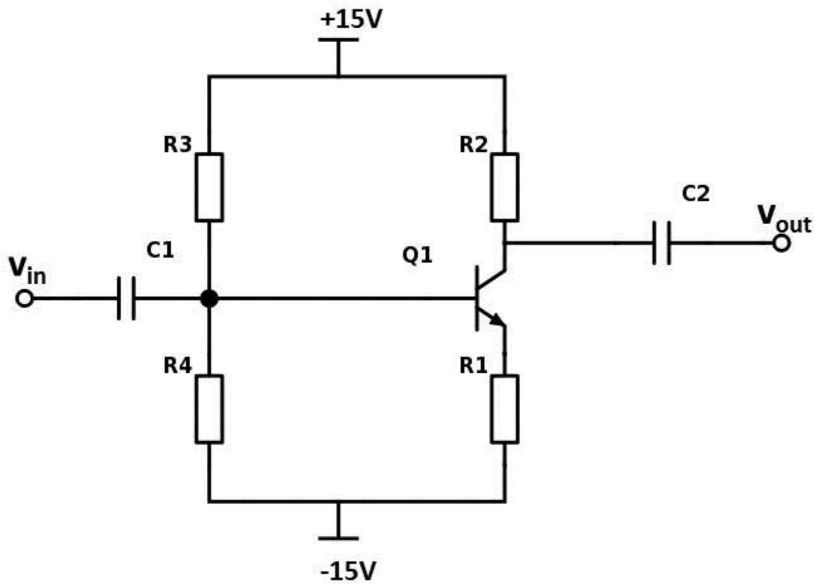
1. Use the small signal model to calculate the voltage gain, input and output resistance for (a) common emitter, (b) common base and (c) common collector configurations. Assume that the transistor is biased in the active region (how to ensure this is the case will be investigated in question 4).



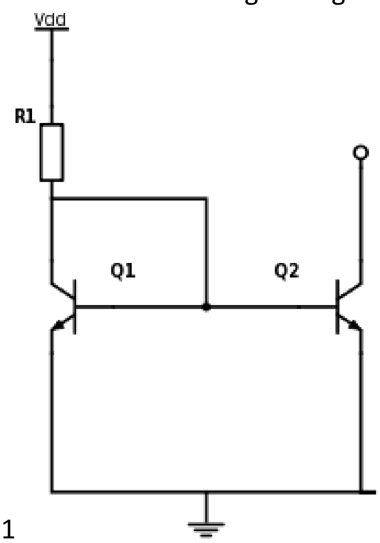
2. (a) Consider a voltage source with a Thevenin voltage V_0 and resistance R_s. The signal is fed into a transistor amplifier with an input resistance r_{int} and voltage gain A_V. Draw an appropriate circuit diagram. Calculate the resulting output voltage.
   (b) Consider a transistor amplifier with an output resistance r_{out} feeding a load with a resistance r_{load}. Draw an appropriate circuit diagram. Calculate the fraction of the amplifier voltage which is seen across the load. Hence explain the use of the common collector ("emitter-follower") transistor.
3. *Common Emitter with emitter resistor*. Consider the simple common emitter circuit of Question 1(a) with the addition of a resistor between the emitter and ground (see figure below). Calculate the voltage gain and discuss the advantages and disadvantages of this circuit compared to that in 1(a).



4. *Potentiometer biasing for common emitter configuration*. Consider the circuit shown below. We want to bias the transistor to be in the active region, so we can assume V_{be}=0.6V.
   (a) Assuming that R1>> $1/g_m$, show that voltage gain A_V=-R2/R1.
   (b) In order to achieve a large output voltage swing we would like the collector voltage to be around 0V. Determine the value of R2 such that the emitter current is 2 mA. You can assume we use +/- 15V power supplies.
   (c) Determine the value of R1 to give a voltage gain of 10.
   (d) Determine the value of the ratio R4/R3 assuming that the base current is negligible compared to the current flowing through R3 and R4.
   (e) Assuming that the minimum value of the current gain β is 50, determine the maximum value of R3 for which the current flowing through R3 and R4 is a factor of 10 greater than the base current.



5. *Current mirror*. For the purposes of this question do not assume $\beta >> 1$. In the circuit shown in the figure assume that the two transistors have identical values of the current gain β. Determine the ratio of the current flowing through the collector of transistor Q2 to that flowing through the



resistor R1

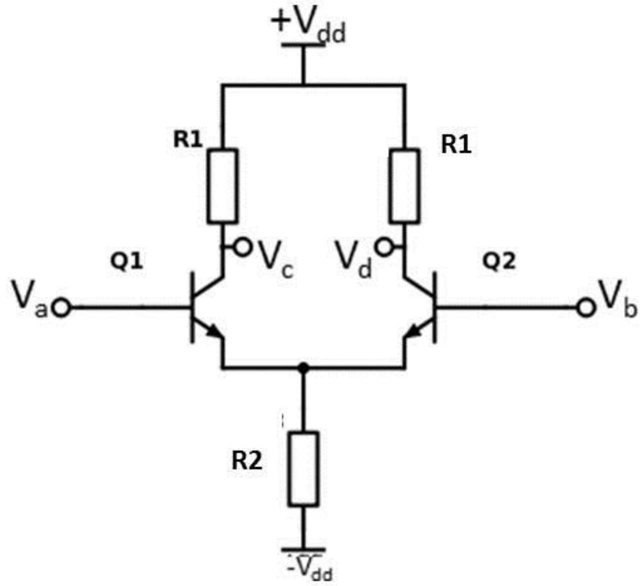
6. *Long Tailed Pair (LTP).* We can define the differential gain of this amplifier as

$$A_{DIFF} = \frac{(v_c \ - v_d)}{(v_a - v_b)}$$

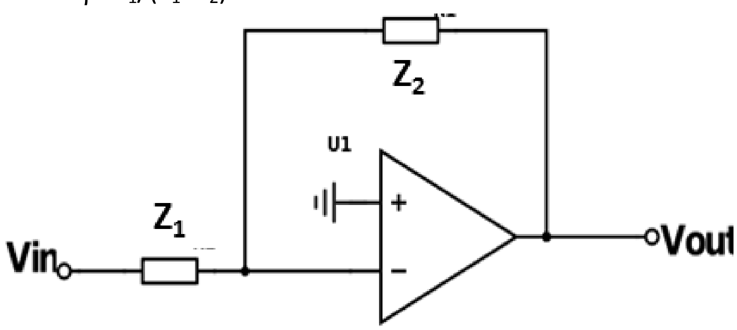
and the common mode gain as (please be aware that alternative definitions of common mode can also be found in the literature) where the voltages are defined in the figure.

$A_{CM} = \frac{v_c}{v_a}$

The common mode rejection ratio is defined by CMRR= A_{DIFF}/A_{CM}.
Determine the differential gain and common mode of a “long-tailed pair” shown in the figure. Define the common mode rejection ration and explain why we want this to be large. For tutorial discussion: What are the key advantages of the (LTP) compared to a single transistor amplifier?



7. (a) Consider an OpAmp which is ideal in all aspects apart from having a finite open loop voltage gain A_{OL}. Determine the closed loop gain (V_{out}/V_{in}) for the voltage feedback configuration shown in the figure (Z1 and Z2 represent general impedances). Assume that the amplifier is ideal in all respects except that it has a finite open loop voltage gain A_{OL}. Show that we can write the closed loop gain as $A_v=-(Z_2/Z_1)/[1+1/(\beta A_{OL})]$ where the feedback factor $\beta=Z_1/(Z_1+Z_2)$.

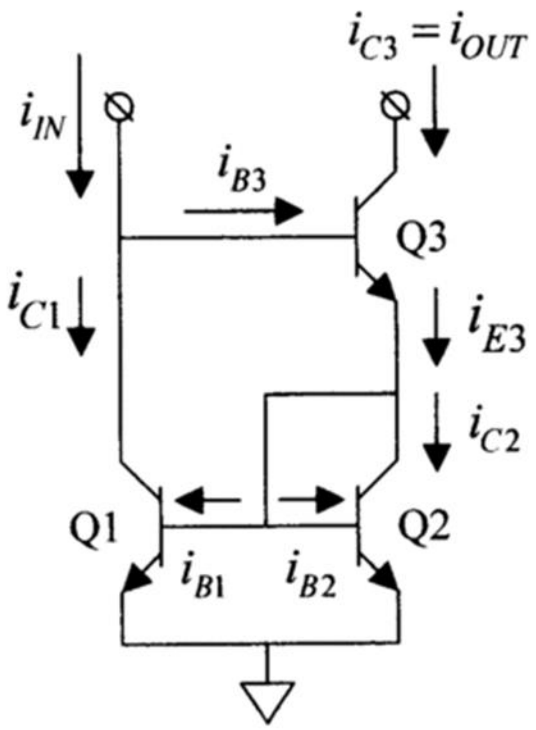


(b) Consider an OpAmp with an open loop gain which varies with frequency as $A_{OL} = A_0 /(1+j\omega/\omega_c)$, with A0=10^6 and fc=$\omega_c/(2\pi)$=10 Hz.

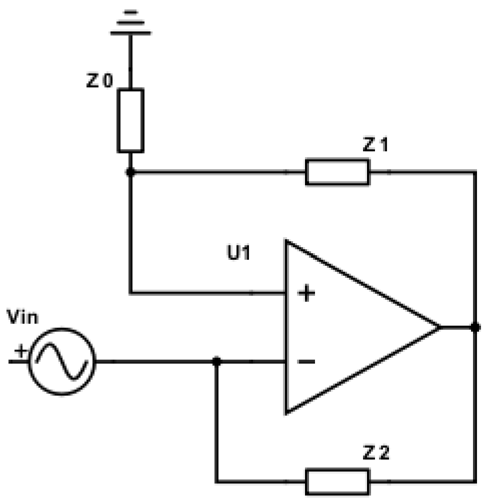
We wish to design an audio amplifier using this OpAmp in the same voltage feedback configuration as in (a), that has the magnitude of the gain that is uniform to a factor of two over the frequency range 10 Hz – 10 kHz. What is the largest closed loop voltage gain at a frequency of 10 Hz that we can have?

Section B Applications (These questions go beyond the syllabus and are for advanced students. However, they do explore interesting and useful topics, so you are invited to try some or all of them.)

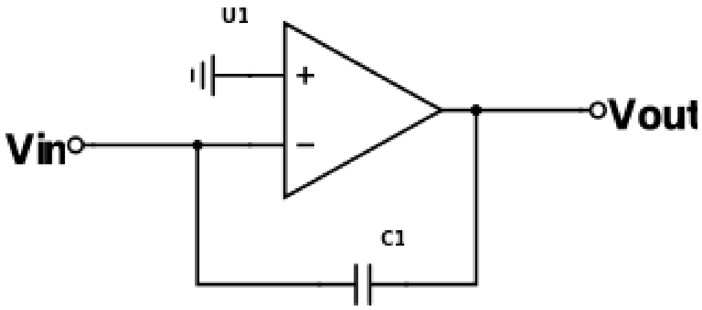
1. An improved version of the simple *current mirror* (see question 5) is given by the *Wilson current mirror* shown in the figure below. Calculate the ratio of the output current (i_{C3}) to input current i_{IN} as a function of β (as in question 5 do not assume β>>1). You may assume that the values of β of all three transistors are identical. Evaluate the ratio of output to input current for values of 50, 100 and 150. Compare this with the equivalent current gain of the simple current mirror of question 5 for the same range of values of β.



2. Consider the OpAmp circuit in the figure. The OpAmp can be considered ideal in that no current flows into the input terminals and the negative feedback ensures that $V_+=V_-$. Determine the input impedance $Z_{in}=V_{in}/I_{in}$ of this circuit. For discussion in tutorials: Why might it be useful to be able to replace an inductor with this circuit when designing integrated circuits?

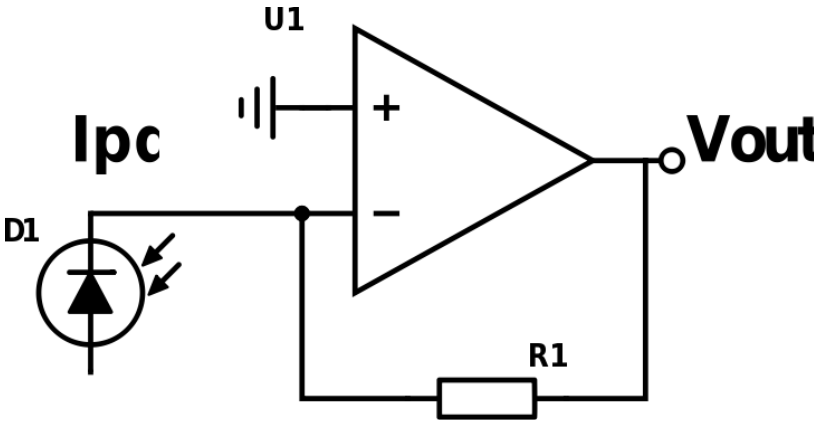


3. *Miller effect*. Consider an OpAmp with a finite voltage gain A_V with a feedback capacitor as shown in the figure. Calculate the input impedance as a function of frequency and hence determine the effective capacitance "seen" by the source. What is the problem if this capacitance is too large?

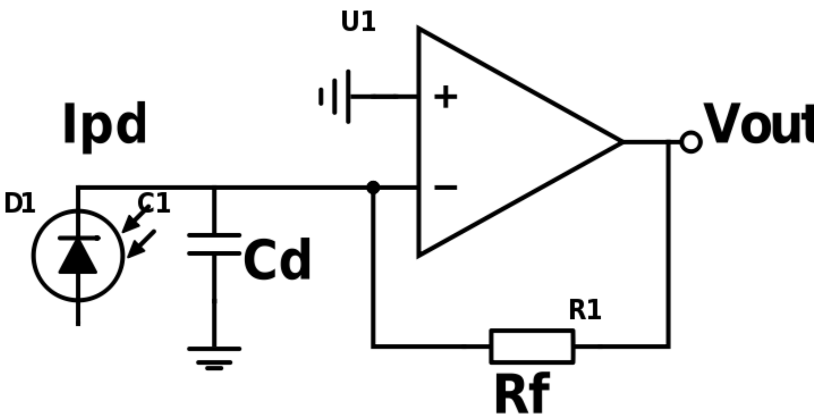


(a) What is the relevance of this result (called the Miller effect) to a common-emitter amplifier?
(b) Determine the magnitude of the Miller effect for a common base configuration. What is the disadvantage of using a common base configuration as an input stage?
(c) Explain how the cascode configuration achieves high input impedance without suffering from the Miller effect. See http://www.allaboutcircuits.com/textbook/semiconductors/chpt-4/cascode-amplifier/#03142L

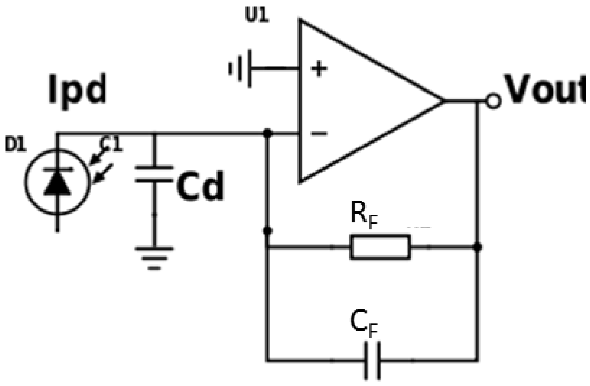
4. *Transimpedance amplifier.* This configuration is very useful if we have a current source and we wish to convert the signal into a voltage. Such a source could be a photodiode, which converts input light to a current. Determine the output voltage for the idealised model shown in the figure. Assume that the OpAmp is ideal in all respects.



A more realistic model includes the parasitic capacitance of the photodiode as shown in the next figure. We now also want to account for the finite open-loop gain A_{OL} of the OpAmp. Calculate the feedback factor β (defined in question A7). Note that although we now have a current source, the OpAmp is still a voltage amplifier so we are justified in using the same formula for the feedback factor. Explain why this circuit can suffer from oscillations.



The stability of the transimpedance amplifier can be improved by the addition of a small feedback capacitor in parallel with the feedback resistors as shown in the figure below.



Calculate the feedback factor β and hence explain how this circuit can be tuned to avoid the problem with oscillations.

For a good explanation see https://en.wikipedia.org/wiki/Transimpedance_amplifier
and http://www.planetanalog.com/document.asp?doc_id=527534

5. For discussion in tutorials. Look up the actual circuit diagram for a real OpAmp such as the 741 and explain the functionality.