Analog Elektronik IE1202 - Home laboratory 6

Student Name:

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1 Introduction

This laboratory consists of 1 task about bipolar junction transistors (BJT) amplifiers . The objective of this laboratory is that you become familiar with multiple-stage amplifier design at transistor level. The task consists of building a non-inverting amplifier which is composed of an input stage (differential amplifier), an output stage (common emitter amplifier), and resistive negative feedback. You will use different things that you learned throughout the course, so it serves also as a summary. The NPN transistors are BC547C ($\beta \approx 500$ and $V_{AF} = 25V$) and the PNP transistors are BC557C ($\beta \approx 400$ and $V_{AF} = 36V$). Schematic templates for QUCS-S which include spice models for the transistors are available in the course's github repository as F13_LAB2.

2 Non-inverting amplifier, transistor implementation

Fig. 1 shows an amplifier built with BJT transistors. The ampifier is a 2-stage non-inverting amplifier. The first stage (Q1, Q2) is a NPN differential pair. The second stage (Q6) is a PNP common-emmiter stage. Both stages are biased by the current mirror formed by Q3, Q4, and Q5. The amplifier is connected as a non-inverting negative-feedback amplifier by using R8 and R9. Capacitor C3 is a Miller capacitor that loads the output pole of the first stage. It is used to implement dominant pole compensation. Inductor L1 and capacitor C1 are added to the schematic only for simulation purposes. A very large value of L1 effectively disconnects the feedback from the inverting input at AC frequencies while not modifying the DC operating point. Similarly, a very large value of C1 shorts the inverting input to ground at AC frequencies. The addition of L1 and C1 allows to analyze open loop gain, loop gain, phase margin, etc. For close-loop gain simulation, L1 and C1 must be set to 0!

Your task is to dimension all resistors so that the amplifier provides a gain of 3 (9.4 dB) over a bandwidth of 1 MHz. The voltage swing at the output has a maximum peak amplitude $V_{out,MAX} = 1V$. The phase margin must be at least 45 degrees.

2.1 Circuit Theory

1) Find values for the feedback resistores (R8, R9). You can assume that the open loop gain is very high (infinite) and use theory from chapter 2.3 pp 45-47. Then find values for the resistors in the differential pair (R4, R5), and current biasing (R1, R6, R7). Resistor R10 = 100 Ω.
HINTS:
- The feedback resistors R8 and R9 affect the noise performance. Noise is a complex topic that is studied in future courses. You can assume that these resistors will take values between hundreds of Ω to $k\Omega$.
- The biasing current of the first stage affects the noise and input impedance of the whole amplifier. It has also strong effect on the speed (bandwidth). Noise is a complex topic which will be carefully studied in future courses. For this exercise, you can bias the first stage with a tail

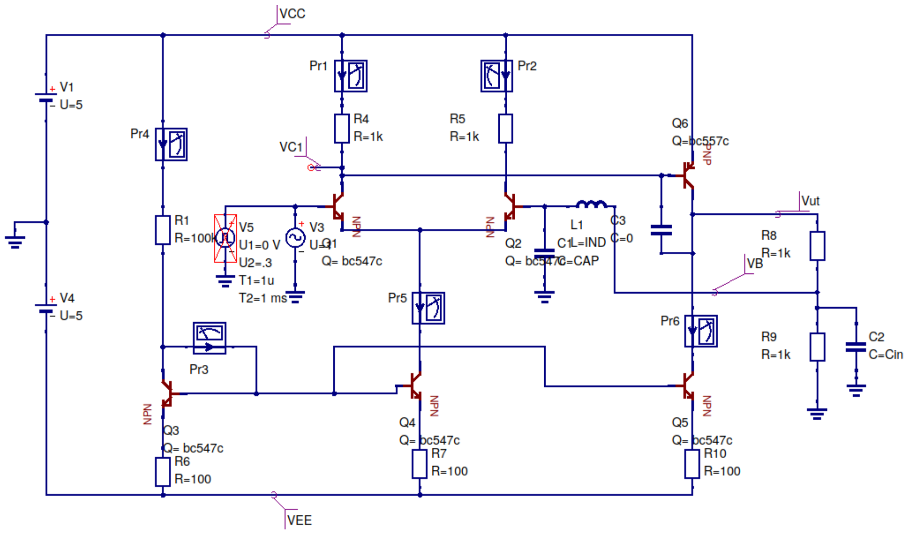

Figure 1: Non-Inverting Amplifier, transistor implementation

current of around 3 mA. Note that once the tail current is fixed, the selection of R4, R5 is not arbitrary since the voltage drop over R4 (V_{R4}) appears in paralell to $V_{BE,6}$ and therefore must have a value be close to 0.7V. Relevant theory for current mirrors is available in chapter 12.5 pp 386-388.

- The biasing current at the second stage must be dimensioned so that the maximum output voltage appears over the load without distortion. In this case the load is only the feedback resistors R8 + R9. Accordingly, the biasing current at the second stage (I_{E5}) should at least be $V_{out,MAX}/(R8 + R9)$. Lower currents will cause clipping of the signal. In practice, a generous margin of no less than 30% should be considered. For protection purposes you will keep R10 = 100 Ω (this will avoid a short-circuit from VCC to VEE in case Q5 and Q6 are driven too strongly). The bias current can be found as $I_{E5} = V_{R10}/R_{10}$. Accordingly, you will have to set V_{R10} by controlling the base voltage of Q5 ($V_{R10} = V_{B,Q5}$ - 0.7V - V_{EE}). This is done by tuning the value of R6 (you will also have to adjust R7 since Q4 at the tail current for the differential pair will be affected).

2) Calculate open loop gain A_0, loop gain βA_0, and closed loop gain A_V by using small-signal analysis. All assumptions must be justified. HINT: find the gain, input impedance, and output of each stage separately and then find a final expression when connecting both stages.

2.2 Circuit Simulation

Replace the resistor values that you calculated in the schematic. Then run a DC operating point simulation. Is the operating point consistent with your calculations? If it is not, you have to troubleshoot the circuit. Then run AC simulations for open and closed loop conditions. Are the low frequency open loop gain, loop gain, and closed loop gain equal to your calculations? What about the stability of the amplifier? Should you need to stabilize the amplifier, increase the value of C3 until the desired phase margin is achieved. You can test the large signal characteristics of the amplifier by running transient simualtions. Change the sinusoidal source's amplitude to 0.33V and check whether the output is amplified correctly. Then disable the sinusoidal source and activate the step source in order to check overshoot/stability. Take a screenshot of the simulations including AC gain, and transient waveforms (input and output signals). Append your screenshots to the end of this lab.

2.3 Circuit Construction and Measurements

Note: the breadboard connections introduce parasitic capacitances and inductances which may result in very different results to what you have simulated, in particular at high frequencies. In general, breadboards are not used to test high frequency circuits. We usually test these circuits mounted on PCBs which are carefully designed for this purpuse. In order to mitigate the problems that arise from using breadboards, try to keep short connections whenever possible and use decoupling capacitors for the power supply very close to your circuits.

Note that inductor L1 and capacitors C1 and C2 only exist for simulation purposes. Do not connect these components to your physical circuit. Mount the circuit of Fig. 1 on the breadboard (use the resistor values that you simulated in the previous subsection). Power the circuit and measure the operating point. If the voltages differ substantially, then you need to troubleshoot your circuit (check that resistor values and connections are correct). Connect the AWG to the input, set up a 0.3 V, 1 kHz sinusoidal signal and measure the output voltage. Is the measurement in agreement with the simulation? Change the sinusoidal signal to a square wave and check the overshoot. Is the amplifier stable? Append a screenshot of your measurement to the end of this lab.

3 Comments on the laboration

Here you can give as much feedback as possible on this lab. How long time did it take you to complete this lab? Did you find this lab useful to reinforce underlying concepts such as differential amplifiers and multiple-stage amplifier?