Lab 3: Multistage Amplifiers

Professor: Dr. Chih-Hung (James) Chen
Name: Erion Keka
Student Number: 400435050
Submission Date: 2024-11-03

1. **(15 Points)** Based on the simulation and measurement data obtained in Steps 1.2 and 1.6, (1) plot the simulated and measured Vo vs. Vsig characteristics and discuss/justify the characteristics. (2) To ensure the circuit works as a common-collector (CC) amplifier, find the DC input range for Vsig and the output voltage range for Vo. (3) Find the Vsig value that results in Vo ≈ 0 V.
    a. The two graphs shown below are very similar. They both feature a similar range for both voltage values and a shape. The two graphs feature a linear relationship between Vo vs. Vsig.

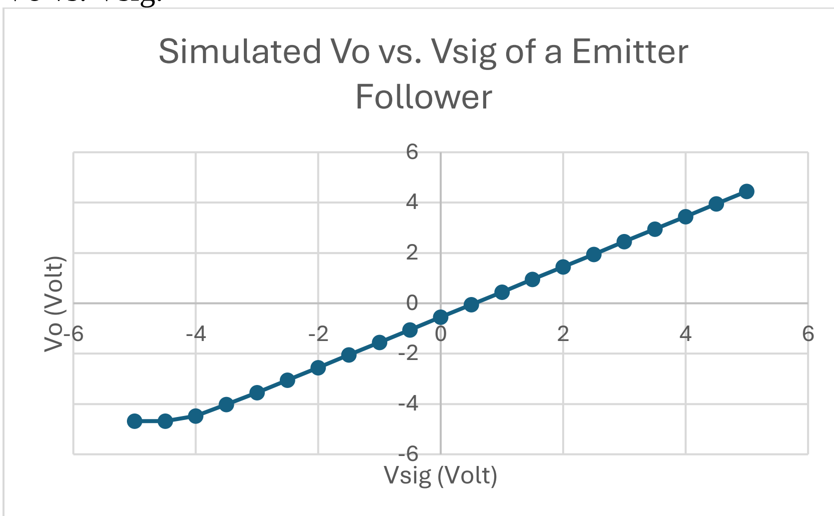


Figure 1: Simulated Vo vs. Vsig of a Emitter Follower (Step 1.2)

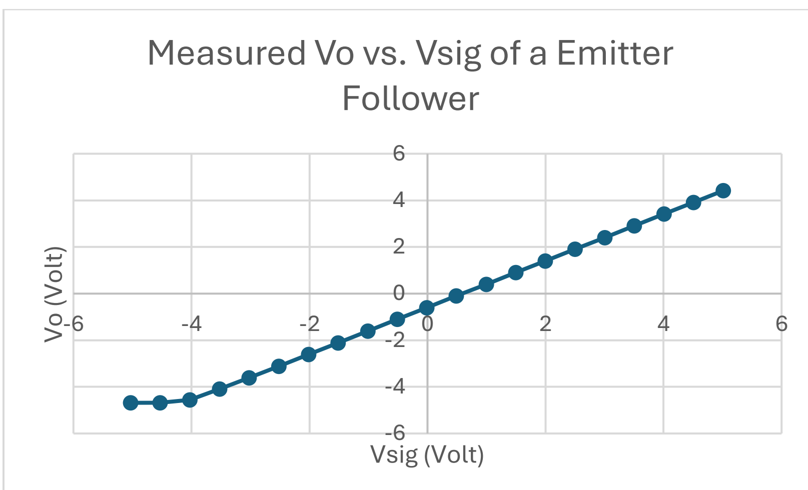


Figure 2: Measured Vo vs. Vsig of a Emitter Follower

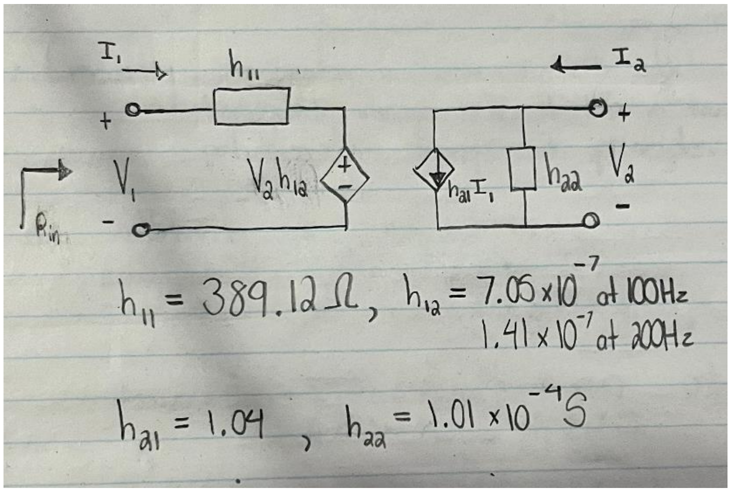
    b. Based on the data obtained, we can estimate that the range of Vsig values that permit the circuit to work as a common collector amplifier is -4.5 V <= Vsig <= 5 V. The corresponding range for the output in the simulation is approximately -4.68322 V <= Vo <= 4.447153 V. Meanwhile, in the measurement, the range is approximately -4.68306 V <= V <= 4.4133 V.

c. By setting Vsig to 0.5 V, we obtain a Vo ≈ 0 V. In the simulation, the Vo is approximately negative 0.052648 V when Vsig = 0.5 V. In the measurement, Vo is approximately -0.0966 V when Vsig = 0.5 V.

2. **(10 Points)** Based on the simulation and measurement data obtained in Steps 1.3 and 1.8, what are the simulated and measured intrinsic voltage gain Avo at low frequency (i.e., 100 Hz) for this CC amplifier? Report its magnitude in dB and phase in degree.
   a. The intrinsic voltage gain Avo at low frequency in Step 1.3 is found to be 0 dB. The intrinsic voltage gain Aco at low frequency in Step 1.8 is found to be 0.1 dB. The phase that these occur at is approximately -8.84×10^{-5} degrees.

3. **(15 Points)** (1) Based on Section 8.2.3 in the textbook, derivate the relationship to express Io as a function of IREF. (2) Based on the simulation data obtained in Step 2.2, when I REF is 0.1 mA, how is Io compared with I REF? When I REF is 1 mA, how is Io compared with I ERF? (3) Justify the observation between the theoretical prediction and the simulated result at I REF is 0.1 mA and 1 mA, respectively.
   a. Based on Section 8.2.3 in the textbook, the relationship between Io and I REF is that Io / I REF. This relationship relates the Io and I REF to the area of the EBJ junction of the transistors. Since the transistors are the same, the area of the junction will also be the same. As a result, Io is the same I REF.
   b. Based on the simulation data obtained in Step 2.2, when I REF is 0.1 mA, Io becomes 0.104 mA. When I REF is 1 mA, Io becomes 0.975 mA.
   c. Based on our theoretical prediction made in the first part of this question, we can see that our results align closely. The prediction made states that in our case, I REF should be the same as Io. This is true in our simulation as when I REF is 0.1 mA, Io became 0.104 mA which can be rounded to 0.1 mA. This is also true for when I REF was selected to be 1 mA as Io become 0.975 mA which can be rounded to 1 mA. The closeness in the I REF value and its respective Io value align with the theoretical prediction.

4. **(15 Points)** (1) Based on the simulation data obtained in Step 2.5, what is the input impedance Rin looking from Vin toward the collector of Q1? What is the current gain Ai of the current mirror? (2) Based on the simulation data obtained in 2.6, what is the output impedance Ro of the current mirror looking into the collector of Q2? (3) Based on the information obtained in (1) and (2), draw the linear two-port network for the current mirror using its h-parameters.
   a. Based on the simulation data obtained in Step 2.5, the input impedance, Rin, looking from Vin forward the collector Q1 is found to be 389.12 Ohms. The current gain, Ai, of the current mirror is found to be 1.04.
   b. Based on the simulation data obtained in Step 2.6, the output resistance, Ro, of the current mirror looking into the collector of Q2 is 1.58×10^{6} Ohms.

c. 

5. **(15 Points)** (1) Based on the simulation data obtained in Step 3.2, what is the voltage gain Ad in dB for the differential-mode signal? (2) Did you observe any mismatch in Step 3.6? If yes, how much offset voltage did you apply at V2 ? (3) Compare your simulated result with the measured result obtained in Step 3.8.
   - **a.** Based on the simulation data obtained in Step 3.2, the voltage gain Ad in dB for the differential-mode signal is found to be 70.07 dB.
   - **b.** The mismatch observed in Step 3.6 is found to be 0.00525 V. This became the offset voltage to be applied.
   - **c.** In Step 3.8, we find the voltage gain to be 55.3 dB. When comparing the simulated result with the measured result in Step 3.8, we can see that the measured result is far lower. This resulted in a percent difference of 23.56%.

6. **(10 Points)** Estimate its upper 3-dB frequency fH (i.e., the frequency at which the amplitude becomes $1\sqrt{2} = 0.707$ of its low-frequency value or the phase changes 45°)
   - **a.** The low-frequency value is found to be 6.3786 V, by multiplying this value by 0.707, we find the upper-3dB-frequency value to be 4.5 V. Upon analyzing the data, we find that this value corresponds to a upper-3dB frequency of approximately 11207.40 Hz**.**

7. **(10 Points)** Compare the upper 3-dB frequency f3dB of this differential amplifier with a current mirror load with that of the differential amplifier using resistive loads obtained in Q8 of Lab 2. Why does the differential amplifier with the current mirror load have a smaller f3dB?
   - **a.** In Q8 from the previous lab, we found the upper-3dB frequency to be 8332821.508 Hz as opposed to the much lower upper-3dB frequency of 11207.40 Hz found in this lab. The differential amplifier with the current mirror load has a smaller upper-3dB frequency based on the Miller Theorem which states that a larger voltage gain will result in a larger Miller Capacitance resulting in a lower upper-3dB frequency.

8. **(10 Points)** What are the gain-bandwidth products (GBW) in Hz of the two differential amplifiers with the current mirror load and the resistive load, respectively?
    a. The gain-bandwidth product in Hz for this lab's differential amplifier is found to be approximately $3.57x10^7$ Hz opposed to the gain-bandwidth product of the previous lab's differential amplifier of $7.98x10^7$ Hz.