Lab 4 – Differential Amplifier

GOAL

The overall goal is to design, build, and test a differential amplifier.

OBJECTIVES

To build, test, simulate, and understand the following:

1) BJT long-tail pair
2) Current source biasing to improve common-mode rejection ratio (CMRR)

GENERAL GUIDELINES

1) Each student builds his/her own circuits.
2) Test stations (e.g. oscilloscope, computer) must be shared.
3) You are allowed (even encouraged) to help each other. Of course, Professor Hedrick will be around to provide assistance as well.
4) **Use neat wiring for your circuits! A messy circuit will cost you 1 pt (out of 10 for the demo).**
5) Each student must turn in his/her own lab report. See the course website for the template.
   Honor Code Compliance: **You must turn in your own work**! Blatant duplication of circuit analysis, design, simulations, and/or lab reports will result in ZERO points and possible reporting to the Honor Council.

   NOTE: There will be one lab exam near the end of the term. The lab exam will test each student's ability to use Simetrix and prototype a circuit.

INTRODUCTION

The overall goal of Lab4 is to design, build, and test a differential amplifier. As an example application, your circuit will amplify the signal from an air pressure sensor. This sensor produces a differential output voltage, hence the need for a differential amplifier! How does the sensor work? In a nutshell, the sensor consists of a very thin silicon membrane with thin film resistors on each side. Air pressure causes the membrane to bend. This stretches resistors on one side but compresses resistors on the other side. These resistors form an electrical bridge network that produces a differential output voltage.

- The sensor properties are the following:

  - The output impedance is 3 kohm (worst case).
  - Responsivity = 0.8 mV/kPa.
  - Max pressure to be sensed is about 20 kPa.
  - Therefore, the max sensor voltage is ΔV_{SENSOR} = (0.8 mV/kPa) x (20 kPa) = 16 mV.

- Based on these sensor properties, your task is to design a BJT long-tail pair with the following properties:

  1) **Input impedance $R_{IN} \geq 60$ kohm**. This ensures that $V_{IN} \geq 0.95 V_{SENSOR}$.

2) **Differential gain $A_d \geq 100$**. This produces a max output voltage $\Delta V_{OUT} \geq 1.6V$, which is easily seen with a scope.

PART 1: LONG-TAIL PAIR

A. Build your differential amplifier based on your PreLab4 design.

- **CONNECT PIN 13 OF THE CHIP TO –10V!**
- Use the matched pair Q_1 and Q_2 for the differential amplifier.
- The pin diagram for the LM3046 transistor array chip is shown below.
- Use the R_E and R_C from your PreLab4 calculations.
- Keep your wiring NEAT!

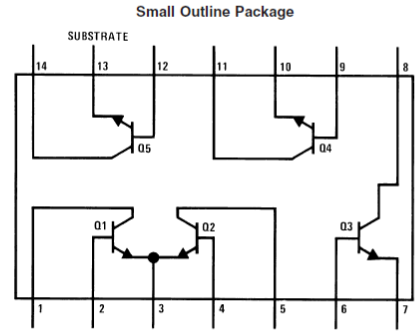

Fig. 1: Remember to connect Pin 13 to -10V!!!

B. Quiescent measurements:

- Ground both V_{IN1} and V_{IN2} (see Fig. 1).
- **Measure the quiescent emitter voltage V_{EQ} with the digital multimeter**.
- Compute the tail current I_T.
- **Measure the quiescent collector voltage V_{CQ} with the multimeter**.
- Do your measured V_{CQ} and I_T agree with your design calculations?

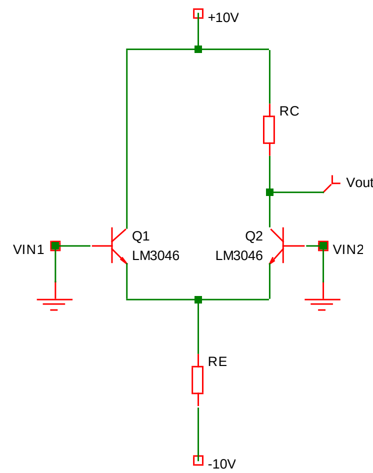

Fig. 2: Quiescent measurement setup.

C. Differential gain measurements:

- Keep V_{IN2} grounded (see Fig. 3).
- Configure the Agilent function generator to High Z output.
- Apply a 20 mV_{PP} sine wave (1 Hz) to V_{IN1}.
- **Use the scope to measure the peak-to-peak output voltage ΔV_{OUT}**.
- Compute the differential gain A_d.
- Does A_d agree with your design calculations?
- If A_d is slightly too low, use the next largest 5% resistor for R_C and repeat the A_d measurement.
- **Record a snapshot of V_{OUT} for your lab report**.

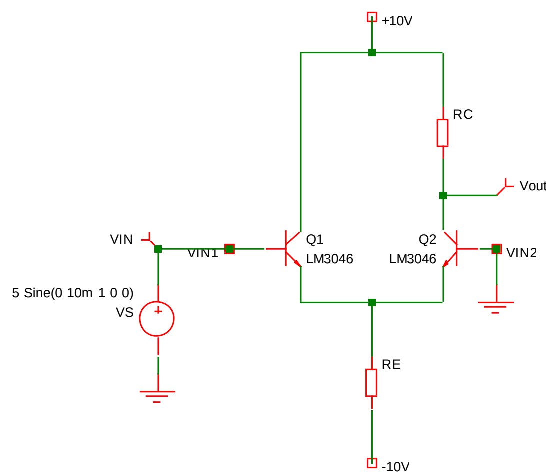

Fig. 3: Differential gain measurement setup.

D. Common mode gain measurement:

- Disconnect V_{IN2} from ground.
- Apply a 1 V_{PP} sine wave (1 Hz) to both V_{IN1} and V_{IN2}.
- **Use the scope to measure the peak-to-peak output voltage ΔV_{OUT}**.
- Compute the common mode gain A_{CM}.
- Compute the CMRR of your amplifier.
  NOTE: It should be around 40 to 50 dB.

E. Input impedance measurement:
   - Connect V_{IN2} to ground.
   - Insert a 100 kohm resistor to the Q1 base (see Fig. 4).
   - Apply a 20 mV_{PP} sine wave (1 Hz).
   - **Measure the peak-to-peak voltage V_{IN1} with the scope**.
   - Compute the input impedance R_{IN}.
   - Does your measured R_{IN} satisfy the design requirement ($\geq$ 60 kohm)?

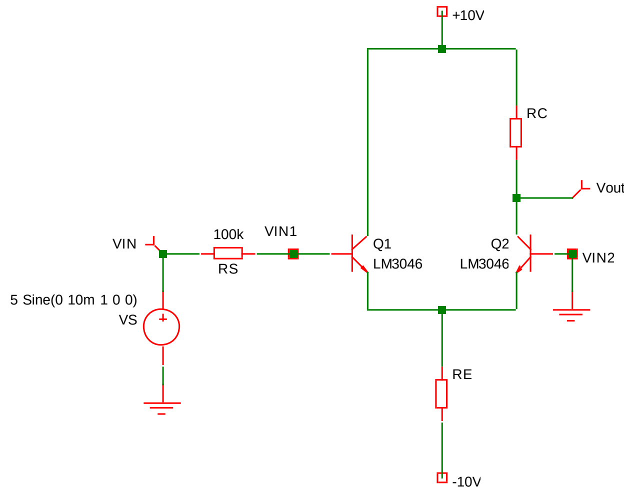

Fig. 4: Input impedance measurement setup.

➢ **Show Professor Hedrick your measured V_{CQ}, A_d, A_{CM}, CMRR, and R_{IN} (3 out of 10 pts of lab demo grade)**.

PART 2: CURRENT SOURCE BIASING

A. Current source design:
   - Use three diodes to bias transistor Q3 (see Fig. 5) with 2.1V.
   - Choose R_2 (5% resistor) to give you approximately the same tail current I_T as Part 1. Use V_{BE} = 0.715V (same as prelab).
   - Compute the base current of Q3 (assume β = 40).
   - Choose R_1 (5% resistor) to establish about 1 mA of current in the biasing diodes.

➢ **Show Professor Hedrick your calculations (3 out of 10 pts of lab demo grade)**

B. Build your current source:
   - Remove the R_E tail resistor from Part 1.
   - Use Q4 in the LM3046 chip for your current source.
   - Attach the Q4 collector to the Q1-Q2 emitter (Pin 3).
   - Keep your wiring neat!

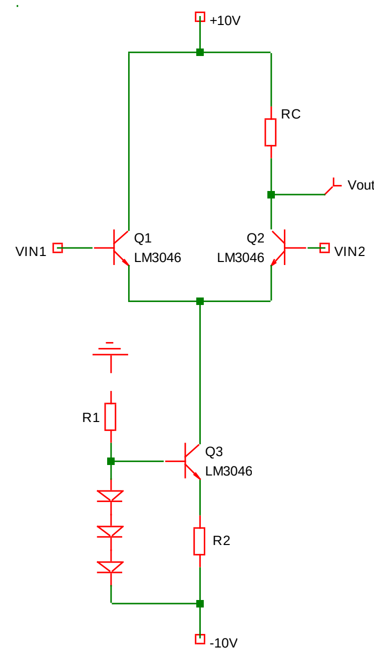

Fig. 5: Current source biasing.

C. Current source testing:
   - Measure the quiescent output V_{CQ}. Use the same technique as in Part 1B.
     NOTE: If V_{CQ} is lower than in Part 1B, then your tail current is slightly too large. Replace R2 in your current source with the next highest value and re-measure V_{CQ}.

D. CMRR measurement:
   - Measure the differential gain A_d. Use the same technique as in Part 1C.
   - Measure the common mode gain A_{CM}. Use the same technique as in Part 1D.
   - Compute the CMRR of your differential amplifier. Hopefully it is at least 20 dB higher than before!

➢ **Show Professor Hedrick your measured V_{CQ}, A_d, A_{CM}, and CMRR (3 out of 10 pts of lab demo grade)**

PART 3: DIFFERENTIAL AMPLIFIER APPLICATION

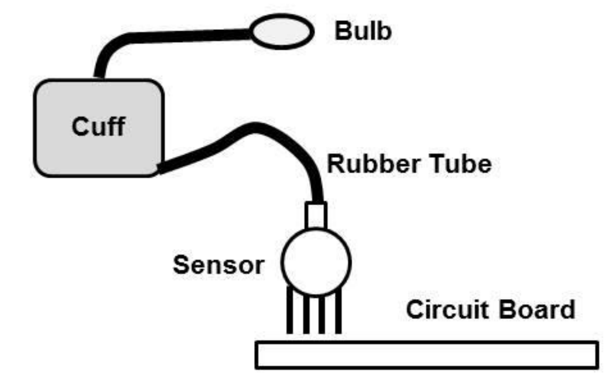

Fig. 6: Schematic of blood pressure measurement system.

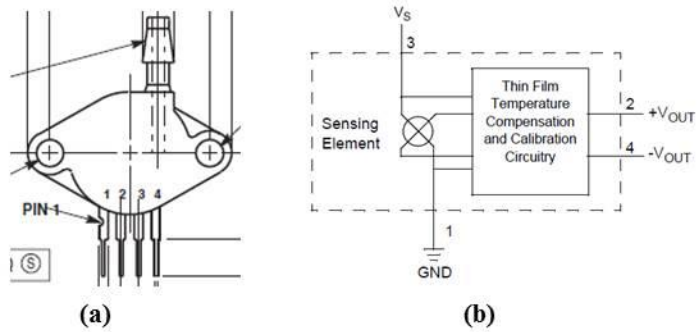

Fig. 7: (a) External appearance of the MPX2050GP pressure sensor (b) Simplified block diagram of the internal electronics of the sensor. Pin 4 is under the nozzle

As an example application, you will use your differential amplifier to measure the pressure in a blood pressure cuff. A sphygmomanometer consists of a pressure cuff and a gage to measure the cuff pressure (see Fig. 6). We will use the MPX2050GP pressure sensor from Freescale Semiconductor, Inc. On the outside, it looks like a circuit component with a plastic nozzle (see Fig. 7a). The sensor output is a differential voltage that is directly proportional to the air pressure inside the cuff. All you need to do is attach a tube, apply power and ground leads, and record the output from the sensor chip! ☺

- You may need to use some tape to secure the sensor to the circuit board.
- Use the +10V supply to power the sensor.
- Connect sensor pin 2 to V_{B1} and sensor pin 4 to V_{B2} of your differential amplifier.
- Use the oscilloscope to measure the quiescent voltage V_Q.
- Inflate the cuff until it feels pretty stiff (probably ten to twenty squeezes of the bulb).
- Record the value of the change in output voltage.
- Press the button on the bulb to release pressure in the cuff.
- The sensitivity of the pressure sensor is 0.8 mV/kPa. Based on your maximum change in output voltage, what do you compute to be the cuff pressure? Hint #1: Remember to include the gain of your amplifier. Hint #2: You should get something in the ball park of 10 kPa.

➢ **Show Professor Hedrick your measured cuff pressure (1 out of 10 pts of lab demo grade)**

(End of Lab 4)