Overview

In this lab assignment, we will study several useful BJT-based amplifier circuits, including a single-stage BJT amplifier and two differential amplifiers.

Before beginning this lab, you should be able to:

- Sketch circuit symbols for npn and pnp BJTs; labeling collector, emitter and base terminals (Module 8.1)
- Sketch typical characteristic curves for npn BJTs, labeling collector-to-emitter voltage, base current, and collector current (Sedra and Smith, section 5.2)
- Identify active and saturation regions on npn BJT characteristic curves (Sedra and Smith, section 5.2)
- State voltage-current relationships for npn BJTs (Module 8.1).

After completing this lab, you should be able to:

- Design and study the performance of BJT amplifiers
- Build and analyze differential amplifiers

This lab exercise requires:

- EE 352 Analog Parts Kit
- Breadboard
- Function Generator, oscilloscope, DC power supplies

Symbol Key:

- Demonstrate circuit operation to teaching assistant; teaching assistant should initial lab notebook and grade sheet, indicating that circuit operation is acceptable.
- Analysis; include principle results of analysis in laboratory report.
- Numerical simulation (using PSPICE or MATLAB as indicated); include results of Matlab numerical analysis and/or simulation in laboratory report.
- Record data in your lab notebook.
I. Single Stage BJT Amplifier

Figure 1 shows a single stage BJT amplifier circuit. We wish to design the circuit to meet the following design specifications:

- Load Resistance: 8.2K Ω
- Input Resistance: > 1.2KΩ
- Mid-band Gain: -100 ± 15%
- Supply Voltage: +12 Volts
- Circuit Capacitors: $C_B = 0.1\,\mu F; C_E = 0.47\,\mu F; C_C = 0.1\,\mu F$

Pre-lab:

Begin your design by choosing an appropriate value for $I_E$. Knowing the small-signal approximations of the input resistance, develop the relationships between $R_{in}$ and $r_\pi$.

$$R_{in} = R_B \parallel r_\pi$$

where

$$r_\pi = \frac{V_T I_B}{V_T (\beta + 1)/I_E}.$$

The mid-band gain of the amplifier is obtained by shorting all the capacitors and is given by

$$A_{vo} = -\left((R_C \parallel R_L)/V_T\right)I_E$$

Once you choose $I_E$ the DC biasing of the transistor can proceed using simple rules of thumb. The voltage $V_B$ should be approximately equal to $V_{CC}/3$ and the current through the biasing resistors $R_1$ and $R_2$ should be roughly equal to $I_E/10$. Since $I_E$ is approximately equal to $I_C$, $R_C$ times $I_E$ should equal $V_{CC}/2$ for maximum symmetrical swing.

Note: $\Delta v_{C_{Emax}} = I_C R_{AC}$  
\hspace{1cm} $R_{AC} = R_C \parallel R_L$
Lab Procedures:

1. Measure all component values and record them. Measure $\beta$ of your transistor at values of $I_C$ and $V_{CE}$ near the Q point in your design on the TEK 571 print out, or on a picture of the TEK 575 screen. Measure all resistor values with your DMM and record them in your lab notebook. Use the RLC meter to measure the exact capacitance values.

2. With no signal applied to the circuit, apply the DC supply voltage and measure and record all DC voltages in the circuit with your DMM. Convince yourself that the circuit is functioning reasonably closely to design values.

3. Apply a sinusoidal input signal at a frequency of about 10 kilohertz. Observe the output with your oscilloscope and reduce the input amplitude until the output shows no distortion. Measure the input and output voltages with your oscilloscope. Compute the mid-band gain (vary frequency for maximum output).

4. Do a rough frequency sweep to locate the lower corner frequency, $f_L$, and record its value. Be sure to always monitor the output for distortion with your scope. Repeat this measurement procedure to determine the upper corner frequency, $f_H$. Then take gain measurements at enough frequencies to enable you to later make a plot of gain versus frequency from mid-band down/up to about two decades below/above the lower/upper corner frequency.

5. Now set the frequency once more to mid-band ($\approx 10$Khz), but switch the input signal to a square wave. Increase the input level until the output no longer increases. The output should be made to have flat tops and bottoms. Measure the two flat levels and record them and their difference. The difference is the maximum peak-to-peak output swing.

6. Switching back to a sinusoidal waveform, reduce the input signal until no output distortion occurs (at $\approx 10$Khz), and measure the input impedance as shown in Figure 2. Be sure to measure and record the exact value of $R$ with your DMM, as well as the values of $V_1$ and $V_2$ measured with your oscilloscope.

![Figure 2. Input Impedance Measurement.](image-url)
7. Leave the part of the emitter resistance $R_E$ un-bypassed as shown in Figure 3 and again measure the gain of the amplifier. $R_{E1}$ un-bypassed should be less than 20Ω. Compute the mid-band gain and measure the input impedance for this case. Compare the results with the case that the emitter resistance is completely bypassed. *Demonstrate your circuit to the TA and have them initial your lab notebook and the lab checklist.*

![Figure 3. Un-bypassed Emitter Resistance Circuit of BJT Amplifier](image)

II. **Differential Amplifier**

*Pre-lab: None.*

*Lab Procedures:*

1. Set up the differential amplifier circuit shown in Figure 4. Use $Q_1$ and $Q_2$ in the SSM2212 array. The objective will be to measure the common mode voltage gain, $A_c$, and the differential mode voltage gain $A_d$.

![Figure 4. Basic Differential Amplifier.](image)
2. Now connect a 1 kilohertz sinusoidal signal of 1 volt peak-to-peak to both inputs, as shown in Figure 5. Note that the differential amplifier has been represented as a block. Check both $v_c$ and $v_o$ with your oscilloscope to insure that there is no distortion. If there is, reduce $v_c$ until the distortion disappears. Then measure $v_o$ and $v_c$ (peak-to-peak values) with your oscilloscope. Record their values and compute $A_c = v_o/v_c$.

![Diagram of differential amplifier with input $v_i = v_c$ and output $v_o$](image)

**Figure 5. Measurement Set-Up for Common Mode Voltage Gain.**

3. In order to measure the differential mode gain, you will ground one input of the differential amplifier and input a small signal (no distortion) to the other input. Measure the voltage out, $v_o$ which is in phase to $v_i$. A diagram indicating the connections is shown in Figure 6. Again the differential amplifier of Figure 4 has been shown as a block.

Note: In reducing $v_i$ until $v_o$ is sinusoidal (no distortion), $v_i$ will be in the range of 10 millivolts. To make the small voltage, add a voltage divider at the input on the circuit board. Measure $v_i$ and $v_o$ with the oscilloscope set to the appropriate scale. The measurement of $v_i$ requires some care because noise can contaminate such a small signal; it should be measured with a x1 probe.

![Diagram of differential amplifier with input $v_i = v_d$ and output $v_o$](image)

**Figure 6. Measurement Set-Up for Differential Mode Voltage Gain.**

Compute the differential mode gain, $v_o/v_i$, and use it and your previously computed common mode gain to calculate CMRR$_{db}$. Demonstrate your circuit to the TA and have them initial your lab notebook and the lab checklist.
III. Improved Differential Amplifier

Pre-lab: None.

Lab Procedures:

1. The circuit shown in Figure 7 uses an emitter current source to improve the CMRR. Note that you will need two SSM2212 chips for this circuit: one SSM2212 will provide Q₁ and Q₂, and the other SSM2212 will provide Q₃ and Q₄. Compute the value of R which will result in the same values of emitter bias for Q₁ and Q₂ as those in the circuit of Figure 6 with \( v_+ = v_- = 0 \). Assume \( \beta = \infty \) and \( r_0 = \infty \) for this calculation. Wire a potentiometer or decade box into the circuit so that the R computed can be accurately placed in the circuit. Then measure the values of common and differential mode voltage gains using the techniques shown in Figures 5 and 6 and compute the CMRR. Demonstrate your circuit to the TA and have them initial your lab notebook and the lab checklist.

![Diagram of Improved Differential Amplifier](image)

Figure 7. Improved Differential Amplifier.

Lab Report:

In your lab report, provide a summary of the results of this lab assignment. You should include, at a minimum, all items indicated on the lab checklist. Append the lab checklist sheet with teaching assistant initials indicating completed lab demos to your report.