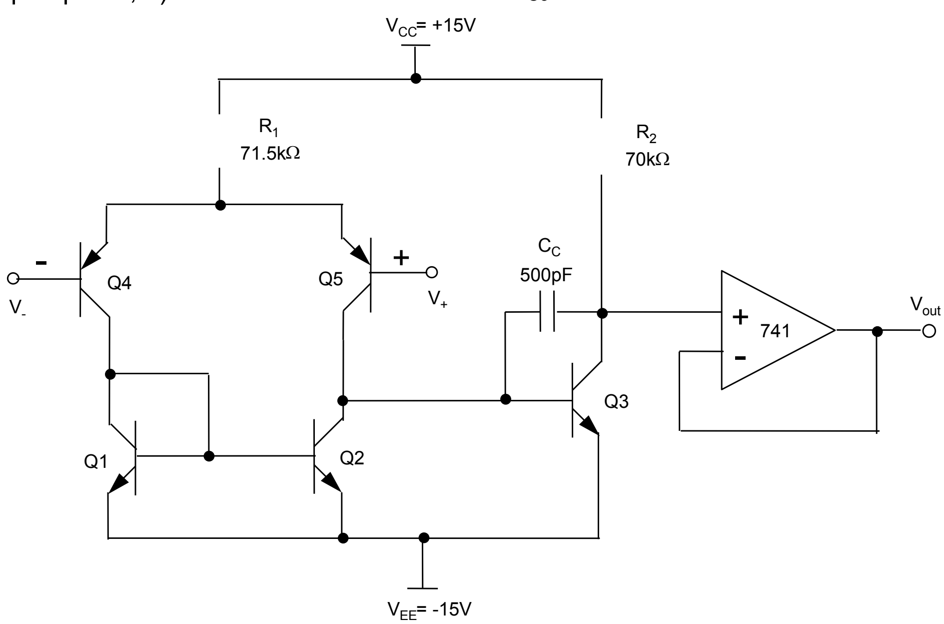
**University of Portland**
**Donald P. Shiley School of Engineering**
**EE371**
**Electronics Laboratory**
**Lab #3**
**BJT Opamp and Feedback**

**Assigned:** Wed, March 25, 2020
**Lab Checkoffs Due:** N/A
**Final Report Due:** Fri, April 17, 2020

1) **Introduction:**

In Lab #3, you will be analyzing the inner workings of an actual BJT opamp. Then you will build and test your opamp in a unique closed-loop 2nd-order circuit configuration.

Consider the BJT opamp circuit and its simple equivalent circuit both shown in Figure 1 below. All five BJT transistors, Q1-Q5, are contained within a single CA3096 chip. The output buffer stage is simply a 741 opamp configured in its unity-gain mode. For hand-calculations: 1) assume $V_{BE-on}$=0.7V for all transistors, 2) assume the 741 is an ideal opamp and, 3) assume that the dc value of $V_{C3}$ = 0V.




Above circuit is equivalent to:

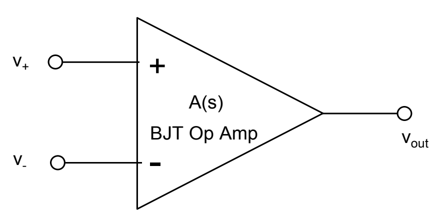



Figure 1.

2) **Pre-Lab Exercises:**

A. Consider the BJT opamp, by itself, in its open-loop configuration as shown in Figure 1.

1. Determine the opamp's transfer function, $A(s) \approx \omega_t/s$, and SR using hand calculations. Record $\omega_t$ and SR in your Summary Table.

B. Next, consider the BJT opamp in the unique closed-loop 2nd-order low pass feedback circuit configuration shown in Figure 2 below. Set $R_1 = R_2 = 1k\Omega$, $C_1 = 1nF$ and $C_2 = 100nF$.

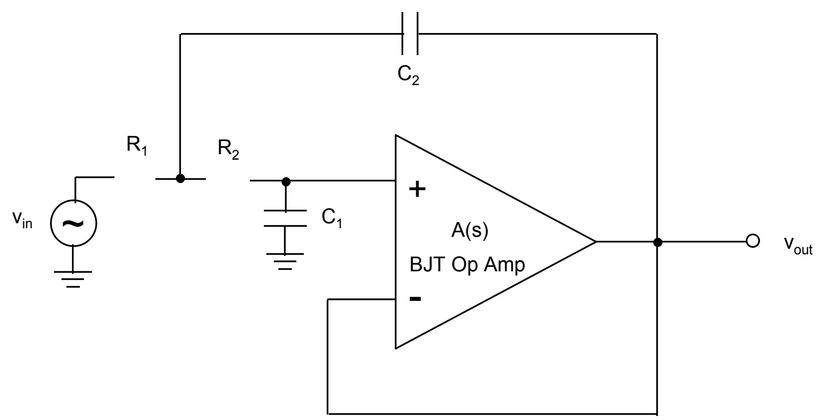



Figure 2.

**BIG HINT: For this circuit…**

$$A(s) = \frac{1}{R_1 R_2 C_1 C_2 s^2 + \left(R_1 C_1 + R_2 C_1 + R_1 C_2\right)s + 1}$$

$$\beta(s) = -R_1 C_2 s$$

1. Sketch the classic feedback diagram of this circuit (use the BIG HINT above). Include in your final report.
2. Determine $A_f(s)$ and LG(s) using hand analysis. Include in your final report. (Remember to state $A_f(s)$ in its most simplified form).
3. Use matlab (i.e., bode(Af)) to plot the $A_f(s)$ Bode Plot. Determine $M_P$, $\omega_p$, and $\omega_H$ using your "Calculator Sheet" and record in your Summary Table.
4. Use matlab (i.e., margin(LG)) to calculate the Gain Margin and Phase Margin and record in your Summary Table.
5. Use matlab (i.e., step(Af)) to plot the Step Response. Determine $t_r$, $t_p$ and $P_0$ using your "Calculator Sheet" and record in your Summary Table.
6. Change $C_2$ to 1nF. Repeat Parts 1 through 5. (**Note that since this is now an overdamped system, you will not need to calculate $M_P$, $\omega_p$, $t_p$ or $P_0$**).
7. Include all your above annotated matlab plots in your final report.

3) **Laboratory Experimentation**

A. ***Make sure to connect Pin #16 on the CA3096 to –15V.*** Using good "Manhattan" layout techniques, build the BJT opamp circuit as shown in Figure 1. Choose standard resistor and capacitor values which are as "close as possible" to those in Figure 1. Use a CA3096 chip for the five BJT transistors. Use a standard 741 opamp for the output buffer as shown. The pin-out diagrams for both the CA3096 and the 741 are attached to this document for your reference. **Remember to use Cursors/V-Bars and H-Bars on your scope, as necessary, to make the measurements in this lab.**

1. Verify the DC functionality of your opamp by casting it into its simple unity-gain configuration and **connect the input to Ground**. Quickly verify the functionality of your opamp circuit by simply checking all DC levels.
2. **Disconnect your input from Ground** and reconnect it to your Function Generator. You will now experimentally determine your opamp's SR. While monitoring the output, set your square wave input such that the output voltage is ±500mV with a frequency of approximately 5kHz and measure SR. Record your SR measurement in your Summary Table.

B. Cast your BJT opamp into the unique 2nd-order low-pass circuit configuration shown in Figure 2. Set $R_1$=$R_2$=1kΩ, $C_1$=1nF and $C_2$=100nF.

1. Again, **with the input Grounded**, quickly verify the functionality of your opamp circuit by simply checking all DC levels.
2. **Disconnect your input from Ground** and reconnect it to your Function Generator. You will now experimentally determine your circuit's Frequency Response. While monitoring the output voltage, set the input sine wave amplitude such that the output voltage is 100mV p-p and vary the frequency from 100Hz to 25kHz. Measure $M_p$, $\omega_p$ and $\omega_H$ and record in your Summary Table.
3. You will now experimentally determine your circuit's Step Response. While monitoring the output voltage, set the input square wave amplitude such that the output voltage is ±250mV with a frequency of approximately 500Hz. Zoom in on a positive edge and measure $t_r$, $t_p$ and $P_0$ using V-Bars and record in your Summary Table.
4. Change $C_2$ to 1nF and repeat Parts 1 through 3. In Part 2, vary your sine wave frequency range from 100Hz to 250kHz, **and note there is no need to measure $M_p$ and $\omega_p$ since this circuit is overdamped.** In Part 3, set your square wave frequency to approximately 25kHz, **and note there is no need to measure $t_p$ and $P_0$ since this circuit is overdamped.**

4) **Lab Notebook and Check-Off:**

As usual, please record all your Pre-Lab Exercise calculations and lab data in your Lab Notebook and Summary Table. Get your lab checked-off by the Instructor, as usual.

5) **Lab Report:**

Please type-up and hand-in your Final Lab Report for this Experiment. Use the same Lab Report format as in Labs 1 and 2. Include your Pre-Lab Exercise hand-calculations (in summarized form), your annotated matlab print-outs, your experimental results, your Summary Table and a Xerox copy of your signed Check-Off page from your Lab Notebook.

## Summary Table

| Section | Parameter | Hand, Calc Sheet, or Matlab | Lab |
|---|---|---|---|
| 2.A.1 | $\omega_t$ | | N/A |
| 2.A.1 & 3.A.2 | SR | | |
| 2.B.3 & 3.B.2 | $M_p$ | | |
| 2.B.3 & 3.B.2 | $\omega_p$ | | |
| 2.B.3 & 3.B.2 | $\omega_H$ | | |
| 2.B.4 | GM | | N/A |
| 2.B.4 | PM | | N/A |
| 2.B.5 & 3.B.3 | $t_r$ | | |
| 2.B.5 & 3.B.3 | $t_p$ | | |
| 2.B.5 & 3.B.3 | $P_0$ | | |
| 2.B.6 & 3.B.4 | $\omega_H$ | | |
| 2.B.6 | GM | | N/A |
| 2.B.6 | PM | | N/A |
| 2.B.6 & 3.B.4 | $t_r$ | | |