Electrical and Computer Engineering — ELEC 301

MINI PROJECT 4

ACTIVE FILTERS, OSCILLATORS, AND FEEDBACK AMPLIFIERS.

Objectives

To become familiar with and understand the basic operation of active filters and oscillators and to understand some of the characteristics of feedback amplifiers.

Introduction

In this experiment you will "wire up" and "test" a 2^{nd} order active filter, a phase-shift oscillator, and a feedback circuit, using your chosen circuit simulator. The fundamental principles involved in the designs of these circuits are given in the course notes and the reference (you should read the discussions in Sedra and Smith to help you write your report).

References

EECE 356 Course notes.

A. Sedra and K. Smith, "Microelectronic Circuits," 5^{th}, $6^{th,}$ or 7^{th} Ed., Oxford University Press, New York.

Part A - An Active Filter

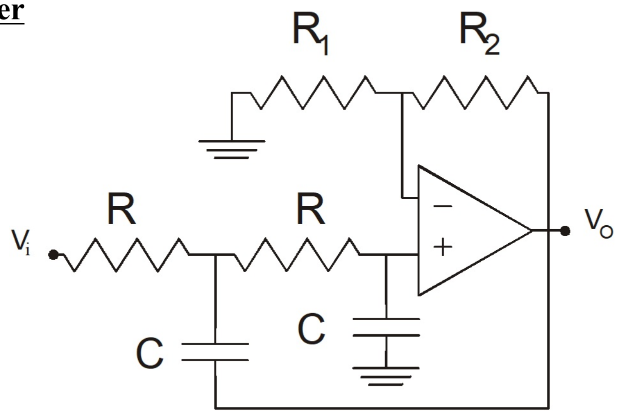

Figure 1. A 2nd order low pass filter.

Part A - Experiment

With the proper selection of the DC gain, the circuit shown in figure 1 is a 2nd order low-pass filter. The transfer function is:

$$H(s)=A_M\frac{1/(RC)^2}{s^2+s\frac{3-A_M}{RC}+\frac{1}{(RC)^2}}$$

where A_M is the pass-band gain (also the DC gain) and is given by $A_M = 1+R_2 / R_1$. This transfer function has two poles. By varying A_M, you can control the damping ratio, and hence the poles can be made complex. This low pass filter can be made into a 2nd order Butterworth filter by placing the poles at specific locations on a circle, centred at the origin, in the s-plane (see the notes).

Using an UA741 as the op-amp and a ±15V power supply, "wire-up" the circuit for the active 2nd order low-pass filter setting R and $R_1 + R_2$ equal to 10kΩ.

1. Calculate the values of C and A_M that will turn the filter into a 2nd order Butterworth filter and give the filter a 3dB frequency of 10kHz.
2. Keeping $R_1 + R_2 = 10$ kΩ, change R_1 and R_2 slowly to increase A_M. At what value of A_M does your circuit start to oscillate (you can check for oscillations by removing the source and grounding the input).

Part A - Report

Report the values of C and A_M that will turn the filter into a 2nd order Butterworth filter and give the filter a 3dB frequency of 10kHz. Plot the Bode plots for both the magnitude and phase of circuit with these values and show where your poles are located in the s-plane. Plot the output of your circuit when it starts to oscillate, report the values of R_1 and R_2 at this point. At what value of A_M did you expect your circuit to start to oscillate? Why? Measure and report the oscillation frequency. Describe what is happening to your poles in the s-plane when you change A_M (i.e., draw the root locus for your filter and explain what is happening).

Part B - A Phase Shift Oscillator

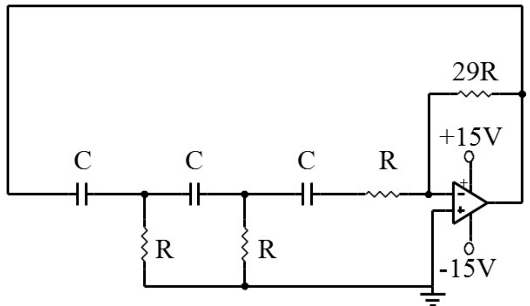

Figure 2. A phase shift oscillator.

Part B - Experiment

The circuit shown in figure 2 is a phase shift oscillator. “Wire-up” this circuit using a UA741and 1k resistors for all of the resistors, R, 1μF for all of the capacitors, C. You may have to adjust (increase) the value of the 29R resistor slightly, but this circuit will oscillate, though, depending on how much you increase the 29R resistor, you may have to give it time to stabilize. Once you have a good value for the 29R resistor, increase R and C by factors of 2 and then decrease them by factors of 2 (from their original values) and plot the oscillating frequency for your chosen values of R and C.

Part B - Report

Explain how a phase-shift oscillator works and why you had to increase the 29R resistor. Show that the oscillating frequency for the circuit shown in figure 2 can be calculated using the equations given in the course note handouts (i.e., find an equation that predicts the oscillating frequency of the circuit shown in figure 2 and compare it to the equations given in the handout) and discuss any discrepancies that you observed between your calculated values and those either measured or given.

Part C - A Feedback Circuit

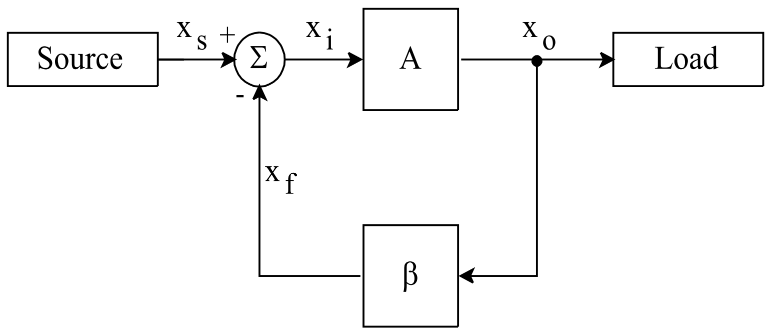

Figure 3. A Basic Feedback Network.

A basic feedback network is shown in figure 3. The operation of a feedback network can be described as "feeding back" a sample of the output of the network to the input of the basic amplifier so that it can be subtracted (negative feedback) from the input signal, the difference signal then being used to drive the basic amplifier. Two important aspects of the feedback network are how the signal is mixed (subtracted) at the input and how it is sensed at the output. Only four basic mixing and sensing schemes are possible since both mixing and sensing are done either in series or in shunt. The naming convention for the feedback network is based on the type of mixing and sensing. For example, the combination of series-mixing and shunt-sensing is termed "series-shunt" feedback. The other three possible combinations are covered in the course notes.

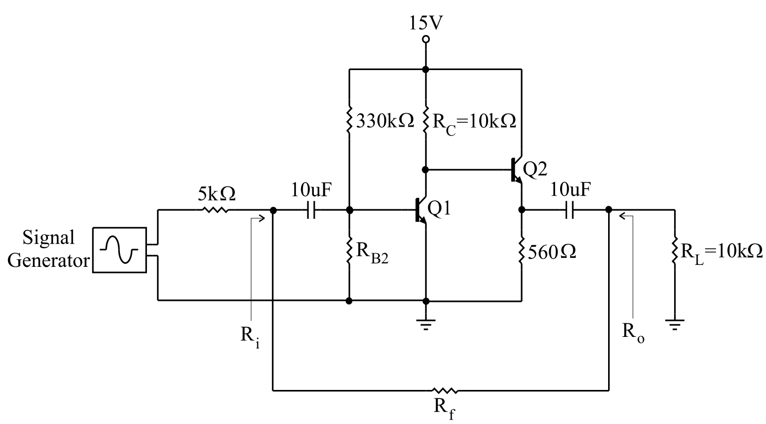

Figure 4. The Feedback Circuit.

Part C - Experiment

In this experiment you will "wire-up" and "test" a feedback circuit using your chosen circuit simulator. A schematic of the circuit is shown in figure 4. A two-stage cascaded transistor amplifier, a common-emitter amplifier in cascade with a common-collector amplifier, is used as the basic amplifier and a resistive network, R_f, is used as the feedback network. In the basic amplifier the common-emitter stage provides signal gain and the common-collector stage drives the output and the feedback network. It is left as an exercise for you to determine what kind of feedback circuit is used in this experiment (Hint: the feedback network samples the output voltage and converts it into a current which is mixed with the input signal at the base of Q_1).

"Wire-up" and "test" the circuit shown in figure 4. Use 2N3904s for both transistors. Using the variable resistor R_{B2}, adjust the d.c. bias of your amplifier to obtain the largest open-loop gain at 1kHz. Then do the following:

1. Measure the d.c. bias values of each transistor and calculate g_m, r_π, and h_{FE} (use h_{FE} for the transistor's "β", a symbol that I will reserve for the feedback network here). Record these values, for both transistors, in your lab report.
2. Measure the open-loop frequency response, A(ω), of the amplifier, i.e., with $R_f = \infty$, from 10mHz up to 100MHz and find the lower and upper 3dB frequencies. Include a plot of the amplitude response in your report. Determine both the input and the output resistance of your amplifier at 1kHz. Also, use the open-loop frequency response and calculate the following values: the predicted closed-loop frequency response and both the input and output resistance at 1kHz of your amplifier for R_f = 100kΩ. Record all of the above values in your report, measured and calculated.
3. Measure the closed-loop frequency response over the same range of frequencies (10mHz to 100MHz), for R_f = 1kΩ, 10kΩ, 100kΩ, 1MΩ, and 10MΩ. Include plots of these amplitude responses in your report (one plot with all 5 curves is okay). Calculate the theoretical feedback factors (the βs) for each of the R_f values. In your report compare these calculated values with those obtained from your measurements using the measurements at 1kHz and the measured value of A obtained in part 2 above..
4. Determine both the input and the output resistance of your amplifier, both at 1kHz, for R_f = 10kΩ, 100kΩ, and 1MΩ. Estimate the "amount of feedback" for each of these measurements. In your report compare the estimated amount of feedback with that predicted for each of these measurements (for the predicted values, use the measured value of A from part 2 and the calculated values of β from part 3 above).
5. With $R_f = \infty$ and 100kΩ run the simulation for R_C = 9.9kΩ, 10kΩ, and 10.1kΩ. Using the values observed at 1 kHz, calculate the "desensitivity factor" of your amplifier. In your report compare this value with your expected value using the measured values of A and β from parts 2 and 3 above.

Part C - Report

For each of the sections above, 1-5, your report may consist of tabulated values and of plots annotated with brief comments and observations. Finally, for smaller values of R_f the gain is somewhat larger than at mid band, i.e., than at 1kHz. Briefly describe what you think is happening.

Report — The report for this project should document the circuits that have been "built" and "tested." For each circuit, tabulate the calculated and simulated values. Discuss any observations that you made. You should present your calculations and/or data in the order that it was requested in this project sheet. In other words, present the calculations/data for Part A followed by the calculations/data for Part B, etc. The discussion for each part should be included following the calculations/data for that part, i.e., your discussion for Part A should come before you present your calculations/data for Part B.