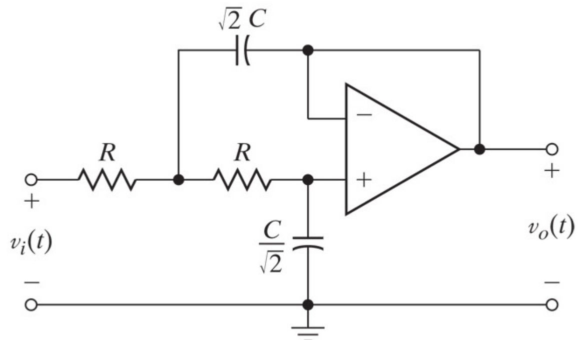
Second-Order Active Low-Pass Butterworth Filter

Filter Design

Note: All plots must have clear labels.



(b) A second-order, low-pass Butterworth filter

Figure above shows a second-order active low-pass Butterworth filter design using an operation amplifier (741 op amp).

The transfer function for the filter above is given as:

$$H(\omega) = \frac{V_o(\omega)}{V_i(\omega)} = \frac{1}{1 + j\omega\sqrt{2}RC - (\omega RC)^2}$$

And the magnitude frequency response is give as:

$$|H(\omega)| = \frac{1}{\sqrt{1 + (\omega RC)^4}}$$

Comparing equation above with magnitude response function of Butterworth filter, we get cut-off (critical, half-power, or -3 dB) frequency as:

$$\omega_c = \frac{1}{RC}$$

For, R = 10 kΩ and C = 2.5 nF, the cut-off frequency equals 40 k-rad/S or 6.366 kHz.

Task-1: Choose the resistor and capacitor values closet to the above and available in the lab and calculate the cut-off frequency. Note that the actual capacitor values you need are √2 * C and C/√2. Show the calculation in your report. Save the file, you will need this later.

Task-2: Plot a bode magnitude frequency response in MATLAB (with values selected in Task-1). Include the code and the plot in your report. Find the -3dB frequency from the plot. Compare the result with the Task-1.

Task-3: Build the circuit using 741 op amp on a bread-board. Measure the magnitude frequency response and draw a bode plot. Find the cut-off frequency and compare with results in Task-1 and 2. See below for instructions for this task.

Equipment

- Oscilloscope
- Signal generator
- Power supplies
- Digital Multimeter
- 741 op amp
- Resistors
- Capacitors

Introduction

An op amp can be used to amplify signals and build circuits that perform mathematical operations such as addition or integration. Op amps are typically manufactured in an *integrated circuit* (IC), sometimes called a *chip* or *microchip*. Each op amp chip has several metal conductors, called *pins,* that enable connections to the op amp terminals.

Op Amp Basics

The circuit symbol for an op amp is shown in Figure 1. The two terminals on the left are the inverting (–) and non-inverting (+) input terminals. The terminal on the right is the output terminal. The terminals on the top and bottom are the power supply terminals. Many op amps, including the 741 op amp used in this lab, require both a positive and negative power supply. Although op amps must be powered to function properly, the power supplies are not always shown explicitly in circuit diagrams.

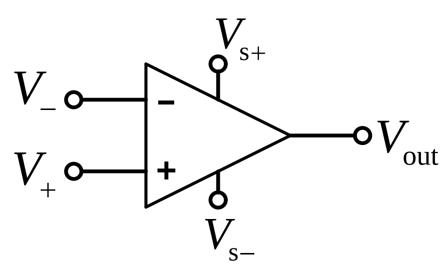


Figure 1: Op amp circuit symbol.

In op amp circuits, the reference or ground node is the common ground node of the power supplies. The ground reference symbol should always appear in op amp circuit diagrams to indicate which terminals are to be grounded.

There are many different op amps made by many different manufacturers. In this lab, we will be using the 741 op amp (which itself has several different manufacturers). It is packaged in what is called a *chip* or *microchip*. Inside the chip is a thin layer called an *integrated circuit* (IC) that contains the op amp circuitry. Several pins (metal conductors) stick out of the chip and allow you to make electrical connections to the IC. The pin configuration for the 741 is shown in Figure 2. (Note that we will not use pins 1, 5, or 8). According to the 741 data sheet, the power supply voltages should be between –22 V and +22 V. Do not violate these specifications because the op amp may be damaged!

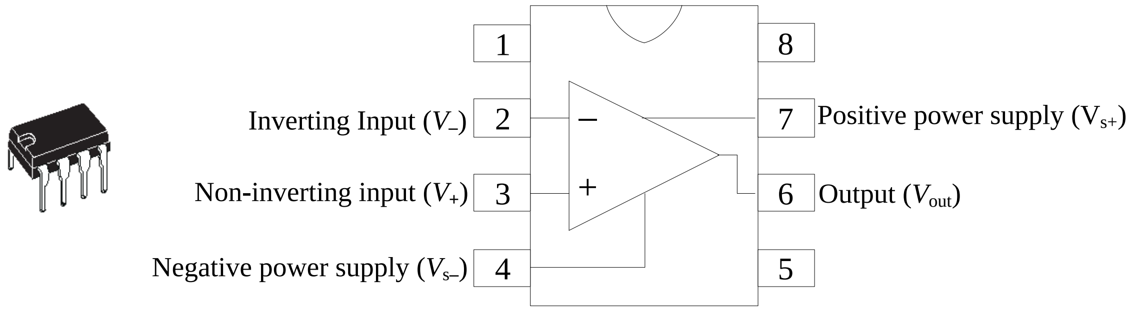


Figure 2: 741 op amp chip (left) and pin configuration (right). A semicircular or circular mark on one end of the chip indicates the location of pin 1.

Lab Work

1. Carefully place the 741 op amp on the breadboard. Make sure you place it in such a way that no pins are shorted together. **If you need to remove the chip from the breadboard, ask for help. Do not remove the chip from the breadboard with your fingers**, because you are likely to bend and possibly break the pins!
2. Build the low-pass filter as shown in Figure (a).
3. Set up the positive/negative power supplies to generate ±15 V, then **turn them off**.
4. **Do not turn on the power supply until has been checked by a faculty or staff.** Make sure you connect the positive and negative power supplies to the appropriate pins on the op amp. **Do not get the power supplies backwards or you will destroy the chip!** Also, do not forget to connect the common ground terminal of the power supplies to the appropriate point(s) in the circuit.
5. Turn on the oscilloscope and restore the default settings. Put the signal generator in **high Z** mode and set it to generate a 1 kHz sine wave (just for initial set up, you will vary in step 7) with 2 V peak-to-peak (pp).
6. Using the two oscilloscope channels, simultaneously display the input signal $v_i(t)$ on channel 1 and the output signal $v_o(t)$ on channel 2.
7. Vary the frequency of the input signal 10 Hz to 1000 times the calculated cut-off frequency with appropriate step size (smaller step-size around calculated cut-off frequency and bigger at lower and higher frequencies).
8. Use the scope to measure the peak-to-peak amplitudes of the input and output signals and use the table below to record the data. Use two copies if more rows are needed. Include an scanned copy of the page below in your report.

Name________________________ Assisted by (Name and Signature):_______________

Date of First Attempt: Date of Completion:

Input peak-to-peak amplitude $v_i(t)$ Volts	Frequency Hz	Input peak-to-peak amplitude $v_o(t)$ Volts	Voltage Gain $v_o(t)/ v_i(t)$	Voltage Gain in dB

9. Input the data above in an Excel spreadsheet. Import the data to MATLAB and overlay the experimental and the plot from Task-1.

10. Include the code and the plot in your report.

11. Find out -3dB frequency for experimental curve and compare with the values from Task-1 and 2.

12. Submit a single PDF file that includes Task 1 to 3 with your first and last name–Project-2-Part-i as the file name.

13. *You can borrow all necessary parts and components from Shahram. Use Lab 2003 or 2005 when no lab or class is scheduled. Schedules are posted outside the door. You can ask me, Shahram, or Kate to let you in. If you need access, fill out an access form or any of the two labs and bring it to me. Lab access forms are available at the department office.*