(TA INITIALS)

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Experiment 12

Operational Amplifiers II

The operational amplifier (op-amp) is the most versatile piece of analog hardware yet developed. The objectives of this experiment are to analyze the input-output characteristics of an op-amp as well as to become acquainted with some of the basic circuits in which it is used.

Ideal op-amps

An op-amp is a differential amplifier with an inverting V_- input and non-inverting V_+ input. The output voltage V_o is given by the difference of these two input voltages times the open loop gain A_v:

$$V_o = A_v * (V_+ - V_-) \tag{12.1}$$

A standard way to derive approximate theoretical equations for the circuits involving op-amps is to assume that the op-amp is an *ideal* device having the following electrical characteristics:

1. the inputs draw no current, hence $i_+ = i_- = 0$ and the input impedance $Z_+ = Z_- = \infty$,
2. the output can supply an infinite amount of current, hence $Z_o = 0$,
3. the open loop gain, or voltage amplification $A_v = \infty$.
4. The opamp adjusts the output voltage so that $V_- = V_+$. This follows from Equation 12.1 since V_o cannot exceed the finite power supply voltage.

   Hence, when analysing an op-amp circuit, if the voltage at one input is known then the voltage at the other input can be deduced. This equivalence is used to determine the gain equation for an (ideal) op-amp circuit.

The resulting equations are, therefore, only approximately right. The limits of the applicability of these equations will be tested during this experiment, as we build several different amplifiers. These limitations must be considered in the design of any real op-amp circuit.

A 741 op-amp

The 741 is a general purpose operational amplifier containing 20 transistors, 12 resistors and 1 capacitor formed on a single silicon chip. It is one of the most popular op-amps, being capable of amplifying signals with frequencies ranging from 0 Hz (DC) to about 1 MHz.

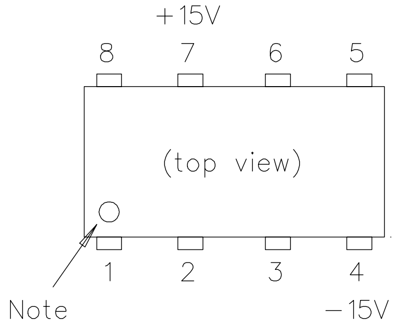

Figure 12.1: Pinout of the 741

The diagram on the left shows the pinout of the 741:

1,5	null offset voltage inputs (not used in this experiment)
2	inverting (−) input
3	non-inverting (+) input
4	negative supply voltage (−15 V)
7	positive supply voltage (+15 V)
6	output
8	compensation capacitor (not used)

Note: NEVER connect voltages to the inputs of an op-amp without making sure that power is supplied (on pins 4 and 7) first. When building a circuit, start by wiring up the power supply connections. First turn on the power supply to the op-amp, and only then the function generator (FG); turn them off in the reverse order, *i.e.*, FG first.

Additional components required

- one each – 1 kΩ, 1 MΩ resistor
- three 10 kΩ resistors
- four 100 kΩ resistors
- three 0.01 μF capacitors
- one 741 op-amp

12.1 An inverting op-amp

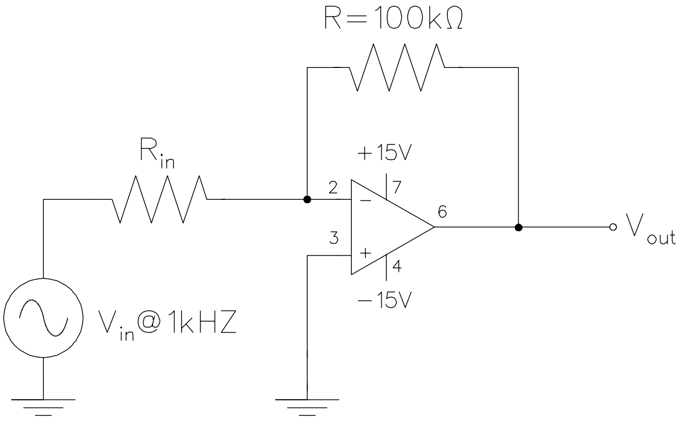

Figure 12.2: An inverting amplifier

Assemble the inverting op-amp circuit shown in Figure 12.2. Measure the actual values of all the components and include error estimates for all your results.

- Starting with a nominal $R_{\text{in}} = 10\text{k}\Omega$, measure the actual component resistance and plot the output voltage V_{out} for several input voltage V_{in} values at 1 KHz. Derive amplifier gain from the graph and compare to the theoretical value.
- Repeat for $R_{\text{in}} = 1\,\text{k}\Omega$, 100 kΩ and 1 MΩ.
- Using $R_{\text{in}} = 1\text{k}\Omega$ to provide a theoretical gain beyond the power supply voltages, determine the output voltage swing of the amplifier, i.e. the range between the upper and lower limiting values of V_{out}. Record these values and include a picture of the scope screen used in this analysis.

12.2 A summing amplifier

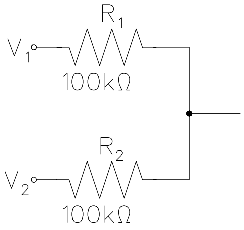

Figure 12.3: A summing amplifier

In place of the single R_{in} of section 12.1, add this summing network to the input of the op-amp. Now the amplifier has two inputs, V_1 and V_2, and the output is proportional to $V_1 + V_2$.

- Using a function generator and a simple voltage divider, measure the output voltage, V_{out}, for the following combinations of input voltages:

  Note: The voltages above are merely typical values. Tabulate actual measured values, indicating for each measurement the voltage used. Include meaningful oscilloscope outputs for all these trials that show any DC offsets, phase changes, etc. between the input and output waveforms.

V_1	V_2	V_{out}
+5 V DC	+5 V DC	
+5 V DC	−5 V DC	
+5 V DC	1.0 V p-p @1 kHz	
1.0 V p-p @1 kHz	1.0 V p-p @1 kHz	
0 V	0 V	

12.3 Active filters

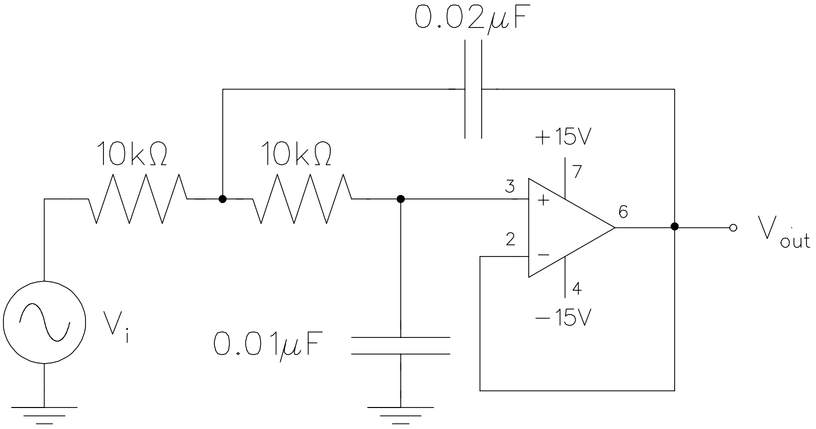

Figure 12.4: Active filter A

- Assemble the circuit in Figure 12.4. Use the oscilloscope to measure V_{in} and V_{out}. Keeping V_{in} constant at, say, 1.0 V, begin by determining a coordinate $(f_0, V(-3dB))$ that gives the corner frequency f_0 of the filter when $V_{out} = 0.7\ V_{in}$
- Measure V_{out} for ten or more frequencies in the range of a couple of decades about f_0 to obtain a meaningful transfer function for the filter.
- Plot log(V_{out} *vs* log(f_0). Mark on the graph the -3dB point and determine the order of the filter by measuring the rolloff rate. Identify the type of filter.
- Note the phase relationship between the input and output signals at 200 Hz and 5,000 Hz. Record the input and output voltages at these frequencies.

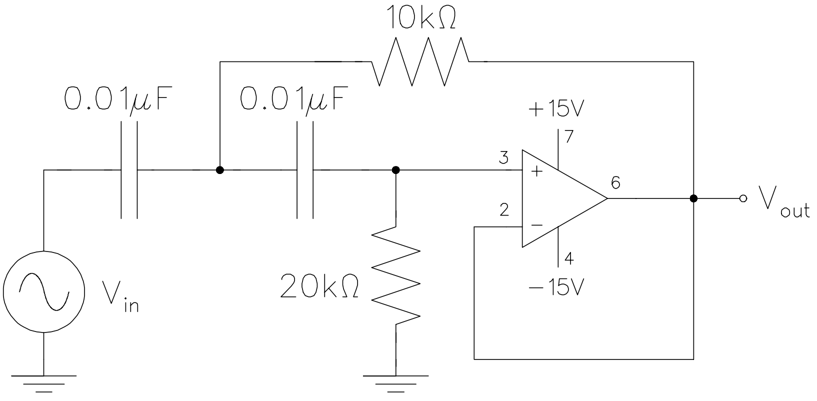

Figure 12.5: Active filter B

- Assemble the circuit in Figure 12.5 and repeat the above steps.
- Name the types of filters in circuits (**A**) and (**B**). Suggest advantages of active over passive filters which employ only resistors, capacitors and inductors.