Operational Amplifiers

I. DESCRIPTION AND OBJECTIVES
This laboratory presents a basic practical summary of operational amplifiers (op-amps) and will provide the opportunity to become familiar with their behavior from an ideal and non-ideal perspective.

II. GENERAL DISCUSSION
An op-amp is a three-port device having two inputs and one output. It was invented to simplify the design of inverting and non-inverting DC amplifiers by the simple control of external negative feedback. This deceptively simple building block is to analog electronics what nand or nor gates are to digital electronic circuits: it reduces analog circuit design to a simple problem of determining suitable external feedback and interconnecting networks without the complication of having to know what’s going on inside the op-amp itself. Treating the op-amp as ideal is often all that is necessary to use it in practice – provided we skillfully appreciate the limitations imposed by basic device parameters that would typically include: non-infinite open-loop gain $A_{ol}$; frequency response expressed by slew rate $SR$, single-pole roll-off frequency $f$, and its related gain-bandwidth product $GBP$; non-infinite input port resistances and non-zero output resistance; power-supply limiting or railing due to finite power supply voltages. Although the op-amp is employed in a truly impressive array of many different circuits, all are based in part on one or both of the following two fundamental circuit configurations, the inverting and non-inverting DC amplifiers. You will gain an appreciation of the power of the op-amp as a basic building block along with some of its inherent limitations by investigation of these two basic circuits.

III. NON-INVERTING CONFIGURATION
Construct the circuit shown in Fig. 1. using an LM741 op-amp. $R_1$ should be 10k. Determine the following for $R_2 = 1k$ and $10k$:

Observe power-supply limiting and log what these voltage rails are. Measure and accurately plot the amplitude and phase response vs. frequency. Frequency should be measured with a counter, amplitude in $V_{rms}$ from a DVM. Measure the slew rate.
From your data, construct a simple Bode Plot showing both plots for the two different circuit gains. Discuss the meaning of the gain-bandwidth product relationship and verify it from your data. Discuss your results for slew-rate. Numeric data should be discussed with realistic precision using only as many significant figures as your data warrants.

**Recommended Procedure:**

1. Don’t mindlessly take data unless you have a good idea of what should be observed. You can analyze things before doing the lab or as you go along. Put everything in your engineering notes. Be sure to accurately measure all resistors before putting them in the circuit. Use the ideal op-amp model to determine the expected closed-loop gains expressing them in both $V/V$ and $dB$. Adjust your DC power sources nominally to $+/- 10[V]$ before connecting them your circuit. These don’t have to be precise, but accurately measure and log what they actually turn out to be. Use the data sheet to estimate the supply rails and slew-rate.

2. Before taking refined measurements, verify circuit operation by sweeping the signal generator over a 10 or 100:1 frequency range while observing both the input and output simultaneously on the oscilloscope; use dual-trace mode for this. This will give you a good idea of where the cutoff frequency is and what frequencies to include in your actual measured data. Remember, the cutoff frequency is defined as that frequency where the gain has dropped by –3dB and the phase-shift is –45 degrees. Since the gain can more accurately be measured using a DVM, use it rather than time delay to actually find the cutoff frequency. The observed phase shift on the oscilloscope should be close to –45 degrees in any case.

3. Slew-rate is best measured by changing the input to a square-wave and looking at the output voltage slope over some convenient time interval. Adjust the frequency from the generator to suitably observe this. Be sure the op-amp is not railing.
IV. INVERTING CONFIGURATION

Modify your circuit to realize an inverting amplifier and repeat the measurements taken earlier for the non-inverting configuration. Discuss all differences you observe between the two configurations.

V. QUESTIONS

1. Some op-amps are not unity-gain stable. Investigate and explain what this means.

2. Is the AD741 capable of single-supply operation? Explain what this is and suggest reasons it might be useful.


4. When an op-amp is configured to behave as a voltage-follower, its closed-loop gain is \( V / V \). Is this a useful circuit?

5. Your measurement of cutoff frequency assumes a low-pass filter model having only a single dominant pole in its transfer function. Actual op-amps actually have more complicated transfer functions with more poles than this. Why are we justified in using the so-called dominant-pole model?

LAB REPORT

The lab report should be proof-read and well written. Check out EE171_format.html if you are unsure what is expected. Your lab report should include (at least):

- Bode plots for the different op-amp configurations.
- Experimentally measured values of slew rate, and saturation voltage.
- Phase vs. Frequency plots for the different configurations.
- Discussion of the questions posed above
- Anything you noticed in the lab that you want to mention.

VI. SPICE SIMULATION

Read Section 2.9 in the textbook. Do the problem 2.64 (p.128).