Week 6:

An Inverting Amplifier
Op Amp Equivalent Circuit

The differential voltage $v_d = v_2 - v_1$

A is the open-loop voltage gain

An op amp can be simulated as a voltage controlled voltage source.
Almost Ideal Op Amp: Open Loop Voltage Transfer Characteristic

Open loop means that there is no feedback resistor connected between one of the input terminals and the output terminal on the op amp. When $v_d$ is large (greater than a few microvolts), the output of the op amp saturates and acts as a voltage comparator.
# Typical Op Amp Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Typical Ranges</th>
<th>Ideal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-Loop Voltage Gain</td>
<td>A</td>
<td>$10^5$ to $10^8$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>Input Resistance</td>
<td>Ri</td>
<td>$10^5$ to $10^{13}$Ω</td>
<td>$\infty$ Ω</td>
</tr>
<tr>
<td>Output Resistance</td>
<td>Ro</td>
<td>10 to 100 Ω</td>
<td>0 Ω</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>$V^+$ (Vcc)</td>
<td>5 to 30 V</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>$V^-$ (-Vcc)</td>
<td>-30V to 0V</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Inverting Amplifier Circuit Schematic

Since the power supplied to the op amp to make it function are the same magnitude, but opposite sign ($V^+ = -V^-$), they may also be labeled as $V_{cc}$ and $-V_{cc}$, where $V^+ = V_{cc}$ and $V^- = -V_{cc}$.

The labels $V_{cc}$ and $-V_{cc}$ are transferred from labels used in TTL (transistor-transistor logic) circuits.
Inverting Amplifier: DC Voltage Transfer Characteristic

**V+** (also known as Vcc)

Positive Saturation Region

Linear Region

Slope = \( G \cdot V_i \); \( G < 0 \)

**V-** (which is usually -Vcc or ground)

Negative Saturation Region
Circuit Operation

- The gain of the inverting amplifier will be changed from $G = -2$, -3, and -4 by changing the value of the feedback resistor, $R_i$.
  - Since the input voltage, $V_i$, will be a sinusoidal signal with an amplitude of $5V \sin(\omega t)$, $V_o = G V_i$ will map out the voltage transfer characteristic from the positive saturation region through the linear region to the negative saturation region as $V_i$ changes from -5V to +5V.
  - The +9 V and -9 V supplies on the ANDY board will be used to power the op amp.
LM 324 Quad Op Amp

- As a reminder
  - GND is actually $V^-$.  
    - If you wire $V^+$ and $V^-$ backwards, the dip package will be come very hot – so hot that it will melt the plastic breadboard beneath it.  
      - If you smell ‘hot plastic’, pull the power plug out.  
      - Wait until the chip cools down before removing it from the ANDY board.  
      - The chip is probably damaged, replace it rather than reusing it.
  - Integrated chips (ICs) can be damaged by electrostatic discharge (ESD).  
    - It is always a good idea to ground yourself before touching an IC (e.g., touch something metallic).
The Velleman arbitrary function generator will be used as the input voltage $V_i = 5V \sin(\omega t)$.

The Velleman oscilloscope will be used to measure the output voltage of the operation amplifier as a function of time.

- You will correlate the input voltage and the output voltage to verify the gain of the amplifier circuit.
- You will determine the maximum and minimum values of the output voltage and determine if they are equal to $V+$ and $V-$.
- Instructions on how to set up the function generator and to use the oscilloscope are posted as separate files.
Measurements

- As suggested in lab manual, set trim pot, $R_f$, such that the output voltage of the op amp is equal to -2.0 V when the input voltage is +1.0 V.
  - You can set the arbitrary function generator to +1.0 V using the +DC option under MORE FUNC. and measure the output voltage of the op amp using your DMM.

- Switch the arbitrary function generator to a +5 V sinusoidal operating at 1 kHz.
  - Measure the input and output voltage as a function of time simultaneously using CH1 and CH2 of the oscilloscope, displaying at least 3 cycles.
  - Measure the output voltage at the following input voltages:
    - 0 V, +/-1 V, +/-2 V, +/-3 V, +/-4 V, and +/-5 V.
      - use cursors in scope program
  - Remove $R_f$ from the circuit and measure the resistance between pins 1 and 2.
  - Plot the output voltage as a function of the input voltage using MATLAB.
    - Determine:
      - the gain of the inverting amplifier in the linear region of the voltage transfer characteristic using a least squares determination of the slope in the linear region
      - the output voltage at the positive and negative saturation regions.

- Repeat after setting $R_f$ such that the voltage of the op amp is equal to -3.0 V and again when $R_f$ is set such that the voltage of the op amp is equal to -4.0 V.
Conclusions Section

- More in-depth answers are expected – Grades for Yes/No answers will be minimal.
- Compare the gains found in Analysis Section and the measured results.
  - Explain any discrepancies
- Explain the major differences between the PSpice simulation and the measurements of the output voltage as a function of time.
- Compare the averaged positive and negative saturation voltages with the measured values of the power supplies.
  - Does the saturation voltage depend on the amplifier gain (within experimental error)?
  - Does the saturation voltage agree with that specified in the LM 324 data sheet (find online)?
    - Here the answers should include comments about what was expected and compare with what was observed.
      - I find that the datasheet provided by Texas Instruments/National Semiconductor is the easiest to read.
National Semiconductor

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description
The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics
- In the linear mode the input common-mode voltage range includes ground and the output voltage can also go to ±15V

Advantages
- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V\text{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features
- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
  - Single supply 3V to 32V
  - Dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA)—essentially independent of supply voltage
- Low input biasing current 45 nA

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