Reference: Op-Amp Example Circuits

**Voltage Divider**

\[ V_{R_2} = V_S \left( \frac{R_2}{R_1 + R_2} \right) \]

**Inverting Amplifier**

\[ v_{\text{out}} = v_{\text{in}} \left( -\frac{R_f}{R_s} \right) \]

**Noninverting Amplifier**

\[ v_{\text{out}} = v_{\text{in}} \left( 1 + \frac{R_{\text{top}}}{R_{\text{bottom}}} \right) \]

**Current Divider**

\[ I_1 = I_S \left( \frac{R_2}{R_1 + R_2} \right) \]

**Inverting Amplifier with Reference**

\[ v_{\text{out}} = v_{\text{in}} \left( -\frac{R_f}{R_s} \right) + V_{\text{REF}} \left( \frac{R_f}{R_s} + 1 \right) \]

**Noninverting Amplifier with Reference**

\[ v_{\text{out}} = v_{\text{in}} \left( 1 + \frac{R_{\text{top}}}{R_{\text{bottom}}} \right) - V_{\text{REF}} \left( \frac{R_{\text{top}}}{R_{\text{bottom}}} \right) \]

**Voltage Summer**

\[ V_{\text{out}} = V_1 \left( \frac{R_2}{R_1 + R_2} \right) + V_2 \left( \frac{R_1}{R_1 + R_2} \right) \]

**Unity Gain Buffer**

\[ v_{\text{out}} = v_{\text{in}} \]
1. Voltage Summers

**Learning Goal:** This problem uses basic circuit analysis techniques to find the response of a summer circuit.

**Relevant Notes:** Note 19 goes different op-amp circuit topology and corresponding derivations.

(a) Calculate $V_{out}$ in terms of $V_1$ and $V_2$. Assume that $R_1 = R_2$. Use superposition.

![Circuit Diagram]

(b) What values should we select for $R_1$, $R_2$, $R_3$, and $R_4$ such that $V_{out} = V_1 + 2V_2$?

2. Multi-stage Amplifier

**Learning Goal:** The objective of this problem is to understand how multiple stages of op-amp circuits can be used to achieve a specific circuit gain.

**Relevant Notes:** Note 19 Section 19.5 goes over inverting and non-inverting amplifiers.

(a) What is the range of values that we can scale $V_{in}$ by when using a non-inverting op amp? (What are possible values for the gain?)
(b) What is the range of values that we can scale $V_{in}$ by when using an inverting op amp? (What are the possible values for the gain?)

(c) Can you design a single inverting/non-inverting amplifier with circuit gain $G = 0.5$? If not, what range of gain values is not reachable using a single inverting op amp or a single non-inverting op amp?

(d) How would you construct a circuit using inverting/non-inverting amplifiers so that the overall circuit gain is $G = 0.5$?

3. Op Amps as Buffers

**Learning Goal:** This problem helps understand the operating principle of an op-amp buffer and how it helps with loading.

**Relevant Notes:** *Note 19 Section 19.7* goes different op-amp circuit topology and corresponding derivations.

Now we will revisit a problem that you might have seen before, with our new knowledge of op-amps. We have access to a circuit inside a 'black box' as shown below, with two terminal coming out of it.

(a) We need a voltage of 6V power a light bulb with resistance $R_L$. Design $R_1$ and $R_2$ inside the black box so that the voltage across $R_2$ is exactly equal to this required voltage **when the bulb is not connected**; i.e. $V_{R_2} = V_{out} = 6V$. 
(b) Now let us connect the bulb $R_L$ across $R_2$. What is the voltage across $R_1$, $R_2$ and $R_L$ when the bulb is connected when $R_L = R_2$? Use the values of $R_1$ and $R_2$ from the last part. Will the light bulb turn on? What happens if $R_L = 2R_2$?

(c) Using your knowledge of op-amps, how could you resolve this issue of $V_{out}$ changing based on the value of $R_L$? Think about how you might use an op-amp buffer.