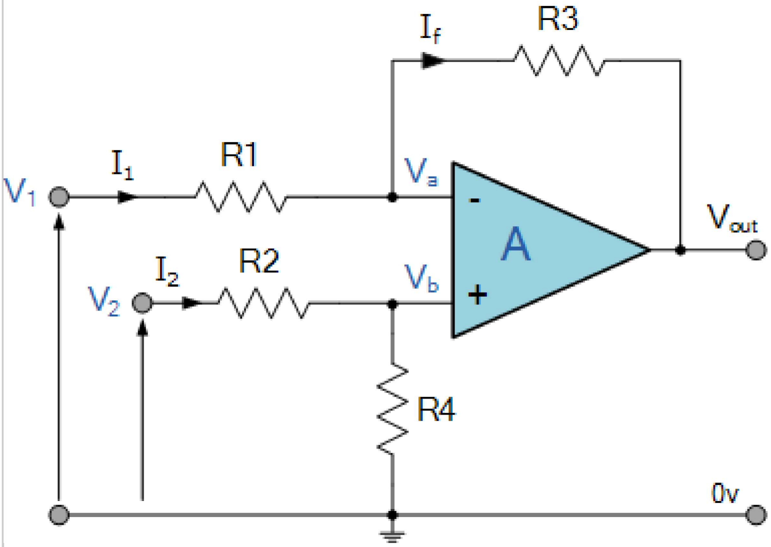


The Differential Amplifier

The differential amplifier amplifies the voltage difference present on its inverting and non-inverting inputs

The differential amplifier is a voltage subtractor circuit which produces an output voltage proportional to the voltage difference of two input signals applied to the inputs of the inverting and non-inverting terminals of an operational amplifier.

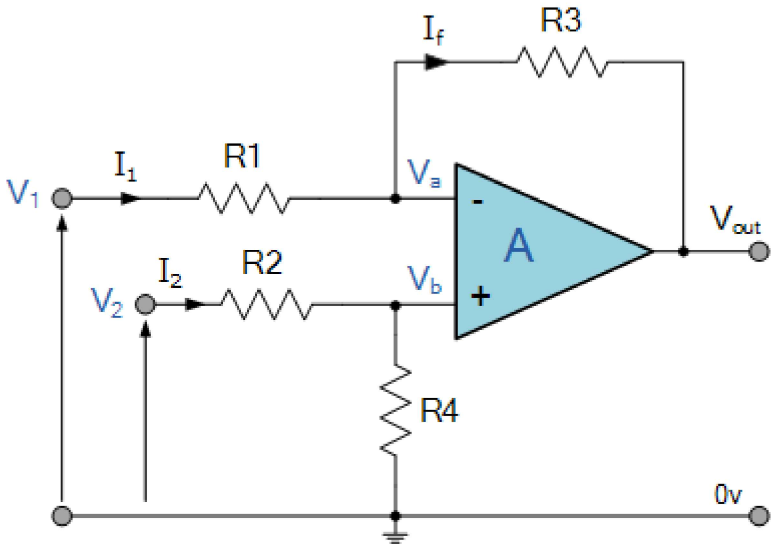
Thus far we have used only one of the operational amplifiers inputs to connect to the amplifier, using either the “inverting” or the “non-inverting” input terminal to amplify a single input signal with the other input being connected to ground.

But as a standard operational amplifier has two inputs, inverting and no-inverting, we can also connect signals to both of these inputs at the same time producing another common type of operational amplifier circuit called a **Differential Amplifier**.

Basically, as we saw in the first tutorial about operational amplifiers, all op-amps are “Differential Amplifiers” due to their input configuration. But by connecting one voltage signal onto one input terminal and another voltage signal onto the other input terminal the resultant output voltage will be proportional to the “Difference” between the two input voltage signals of V_1 and V_2.

Then *differential amplifiers* amplify the difference between two voltages making this type of operational amplifier circuit a **Subtractor** unlike a summing amplifier which adds or sums together the input voltages. This type of operational amplifier circuit is commonly known as a **Differential Amplifier** configuration and is shown below:

Differential Amplifier



By connecting each input in turn to 0v ground we can use superposition to solve for the output voltage Vout. Then the transfer function for a **Differential Amplifier** circuit is given as:

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (V_{out})}{R_3}$$

$$\text{Summing point } V_a = V_b$$

$$\text{and } V_b = V_2\left(\frac{R_4}{R_2 + R_4}\right)$$

$$\text{If } V_2 = 0, \text{ then: } V_{out(a)} = -V_1\left(\frac{R_3}{R_1}\right)$$

$$\text{If } V_1 = 0, \text{ then: } V_{out(b)} = V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

$$V_{out} = -V_{out(a)} + V_{out(b)}$$

$$\therefore V_{out} = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

When resistors, R1 = R2 and R3 = R4 the above transfer function for the differential amplifier can be simplified to the following expression:

Differential Amplifier Equation

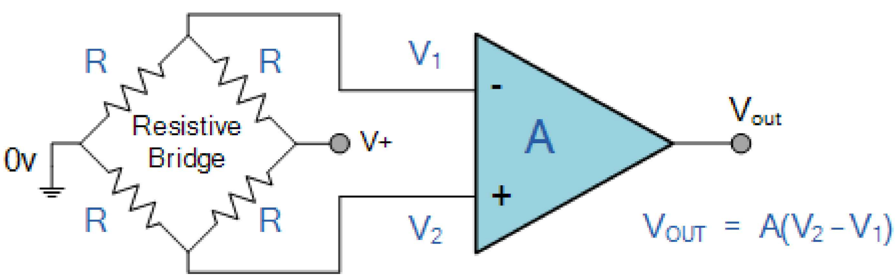
$$V_{OUT} = \frac{R_3}{R_1}\left(V_2 - V_1\right)$$

If all the resistors are all of the same ohmic value, that is: $R1 = R2 = R3 = R4$ then the circuit will become a **Unity Gain Differential Amplifier** and the voltage gain of the amplifier will be exactly one or unity. Then the output expression would simply be $Vout = V_2 - V_1$.

Also note that if input $V1$ is higher than input $V2$ the output voltage sum will be negative, and if $V2$ is higher than $V1$, the output voltage sum will be positive.

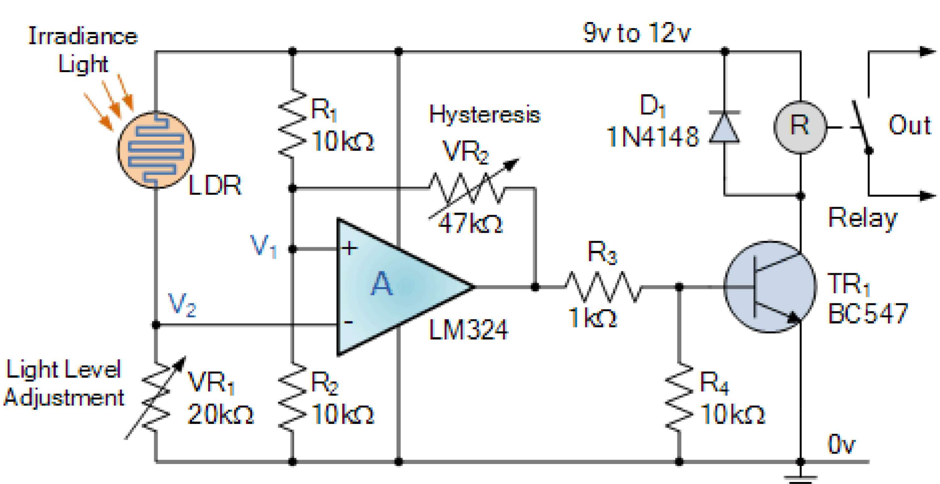
The **Differential Amplifier** circuit is a very useful op-amp circuit and by adding more resistors in parallel with the input resistors $R1$ and $R3$, the resultant circuit can be made to either "Add" or "Subtract" the voltages applied to their respective inputs. One of the most common ways of doing this is to connect a "Resistive Bridge" commonly called a *Wheatstone Bridge* to the input of the amplifier as shown below.

Wheatstone Bridge Differential Amplifier



The standard Differential Amplifier circuit now becomes a differential voltage comparator by "Comparing" one input voltage to the other. For example, by connecting one input to a fixed voltage reference set up on one leg of the resistive bridge network and the other to either a "Thermistor" or a "Light Dependant Resistor" the amplifier circuit can be used to detect either low or high levels of temperature or light as the output voltage becomes a linear function of the changes in the active leg of the resistive bridge and this is demonstrated below.

Light Activated Differential Amplifier



Here the circuit above acts as a light-activated switch which turns the output relay either "ON" or "OFF" as the light level detected by the LDR resistor exceeds or falls below some pre-set value. A fixed voltage reference is applied to the non-