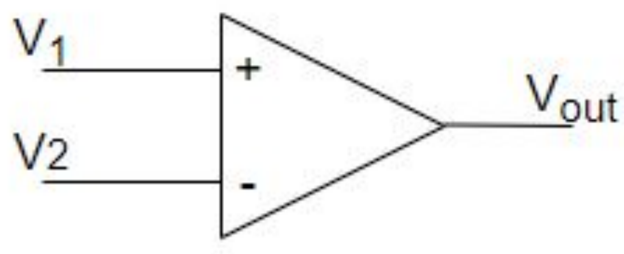
Operational Amplifiers

An Operational Amplifier, or Op Amp, is an integrated circuit that has the potential to give a gain in voltage of over 10,000 times. In reality however this is never gained as it can only output up to 85% of its supply rail voltage



Golden Rules

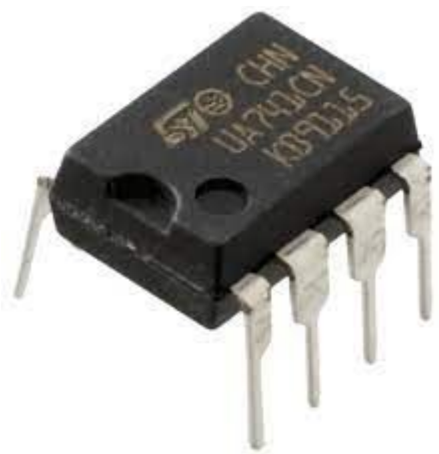
All Op Amp circuits follow the same 2 golden rules:

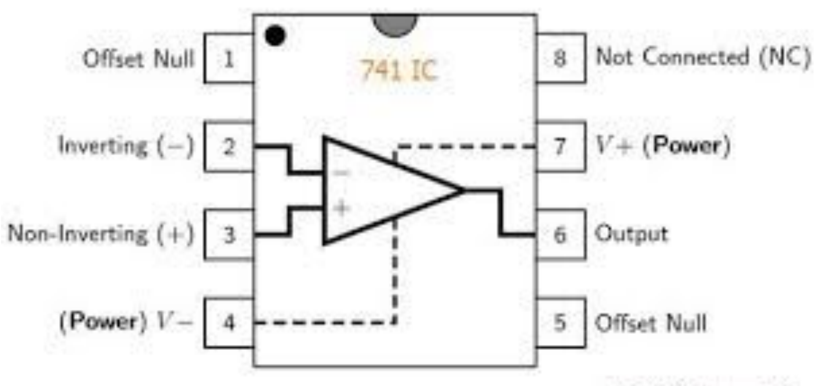
1. The Inputs to the Op Amp draw ZERO current
2. The output tries to drive the voltage difference at inputs to ZERO

For Higher Engineering science, there are 6 main Op Amp circuit configurations that are used.

Within this report any subscripts used are as follows:

- "In" refers to an input
- "Out" refers to an output
- "f" refers to feedback

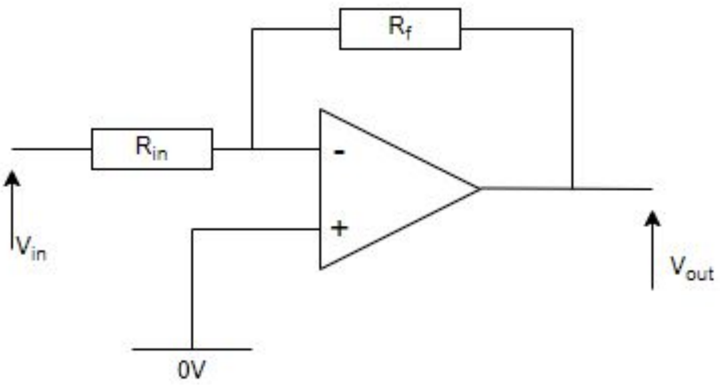




741 Op-Amp IC

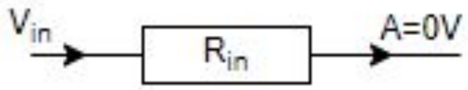
Inverting Amp

The Inverting Amplifier is an Op Amp configuration that allows for a controllable gain to be set however the output is inverted, (positive becomes negative).

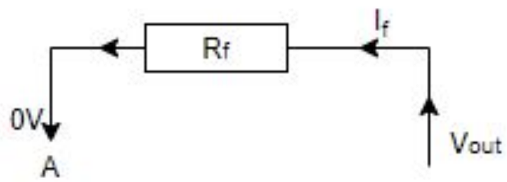


Inverting Amp Equation

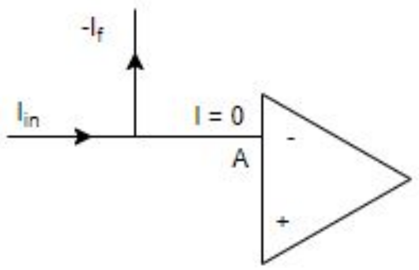
For an easier explanation, the inverting input (-) will be A and the non-inverting input (+) will be B.



From Golden rule 2, the difference at the inputs will be 0 volts, so A = B, both are 0 volts.
This means that the current in, $I_{in}=V_{in}/R_{in}$



Similarly, the current through the feedback resistor, R_f must be $I_f = V_{out}/R_f$



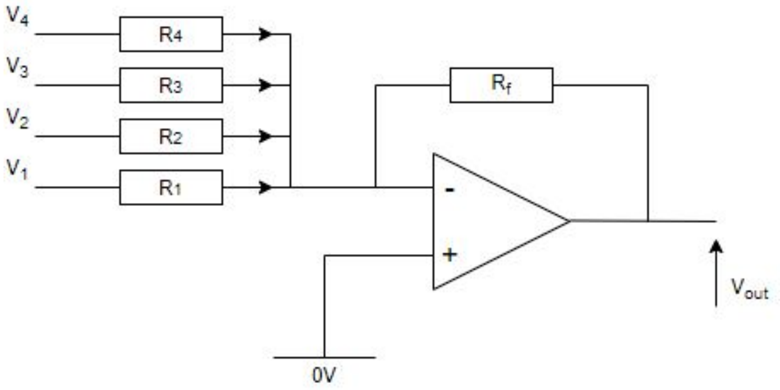
As the input draws no current (GR1), the input current must equal the feedback current, $I_{in} = I_f$

However, the current must flow somewhere, back up the feedback, so $I_{in} = -I_f$, inverted feedback current.

Finally, with the equations $I_{in} = -I_f$ we can substitute in to get
$V_{in}/R_{in} = -V_{out}/R_f$ which can then be cross multiplied to get:
$V_{out}/V_{in} = -R_f/R_{in}$
The gain of the circuit is V_{out} / V_{in} so this means that the 2 resistors can be used to control the exact gain from the Op Amp

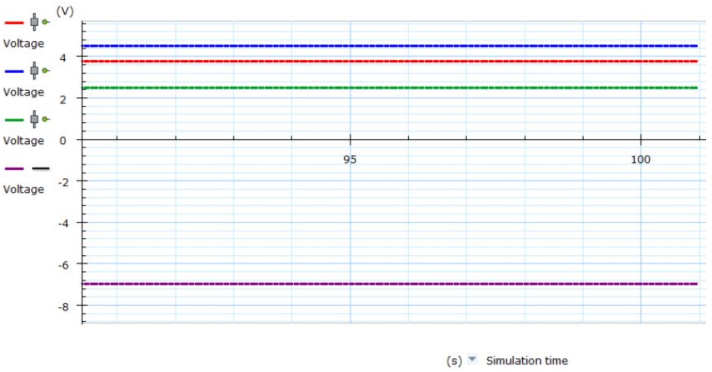
Summing Amp

The summing amp works in the same way as the inverting amp, the only difference being that it has multiple inputs that are all combined to make the input current, $I_{in} = -I_f = I_1 + I_2 \ldots$



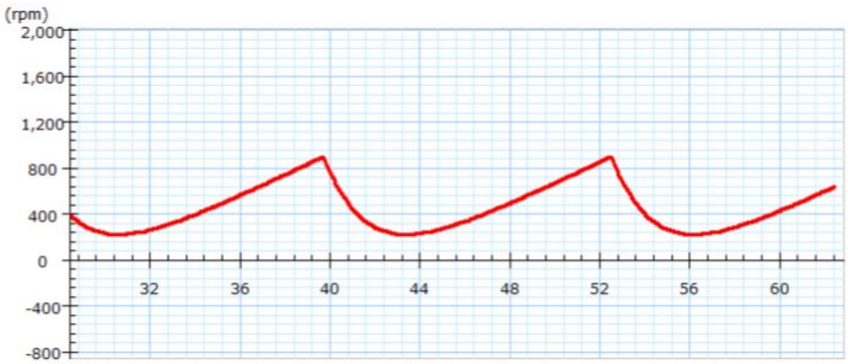
Which then becomes, $-V_{out} / R_f = V_1/R_1 + V_2/R_2$ etc
Finally, multiply out $-R_f$:
$V_{out} = -R_f (V_1/R_1 + V_2/R_2 + V_3/R_3 + V_3/R_3)$

Binary Weighted and Straight Summing Amp



In a straight summing configuration, all input resistors are equal, allowing a common factor of R to be taken out, giving $V_{out} = -R_f / R \ (V_1 + V_2 + V_3 + V_4)$
This will make the output voltage to be the inverted exact sum of all input voltages as shown in the graph (purple is output, all others are input)

In a Binary weighted summing amp, each resistor is a power of 2 higher in resistance than the previous, meaning that if each input is connected to a microcontroller then the different combinations of outputs (in a binary sequence) that are high will have a unique voltage

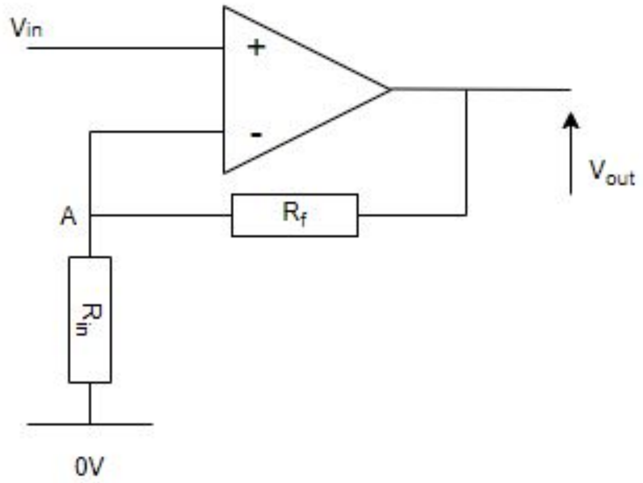


When the microcontroller is linked to a summing amp going through the binary sequence into a motor, the graph shows how the increasing voltage in the sequence will also increase RPM

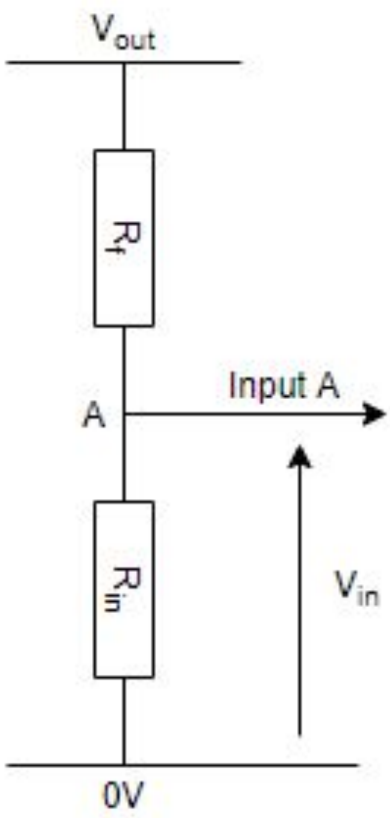
Non-Inverting Amp

The non-inverting amp can take an input voltage and amplify it without inverting the signal like the previous 2 Op Amps

Also, in the inverting amp it is the inverting input that is grounded, not the non-inverting input.



Non-Inverting Amp Equation



To find the equation of the non-inverting amp it is useful to consider this partial circuit from ground to V_{out}.

As this circuit is a potential divider, the total current can be found as I = V/R,
$I = V_{out} / R_f + R_{in}$

This also means, as current is equal at all points in the circuit, that the voltage at point A and the inverting input is equal to V_{in} from GR2

Finally, putting this all together we get:
$I = V/R, = V_{out} / R_f + R_{in}, \quad = V_{in} / R_{in}$

We then rearrange by cross multiplying the last 2 expressions;
$V_{out} / V_{in} = (R_f + R_{in})/R_{in}$

And divide R_{in} by R_{in} on the second term to get the equation

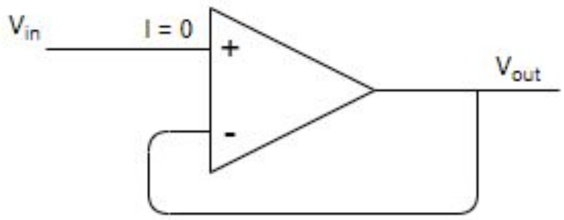
Gain = $V_{out} / V_{in} = 1 + R_f / R_{in}$

Which, given resistance are both positive, the gain will always be >=1.

Voltage Passer (or Buffer)

Gain Equation

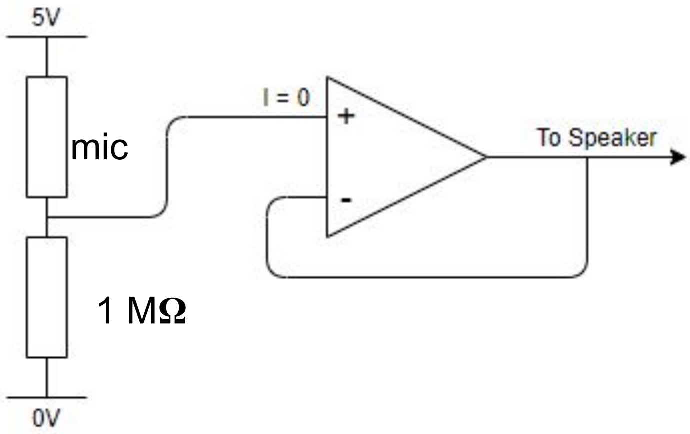
The Voltage follower is effectively identical to the non-inverting amp just without the resistors.



This means its equation = $1 + R_f / R_{in}$
But since both R = 0, the Gain = 1

Uses of the Voltage Follower

The Voltage Follower can be used to take input voltages and use them to drive higher current requiring devices.
The best example is a microphone and speaker:



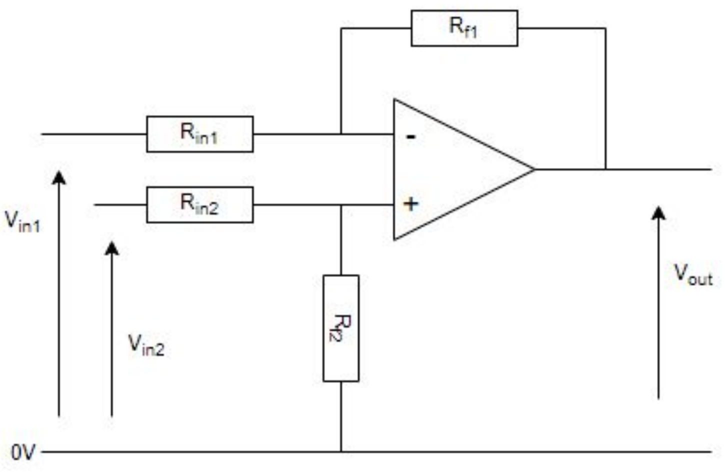
In the microphone circuit, a very large resistance is used of over 1 million ohms. This, by ohm's law, means that the current in the circuit is very low yet the voltage is still decently high.

The voltage follower will not change the voltage (gain of 1) however as it draws no current it will use the same voltage to driver higher current on the output which is then able to power the speakers which would not work on the miniscule current provided by the microphone.

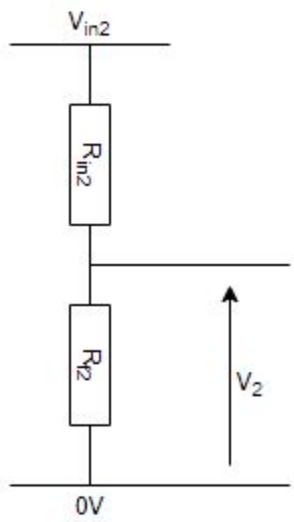
Difference Amp

The difference amp's gain is dependent upon the difference in voltage between the 2 inputs.

For this circuit both feedback resistors are equal as are input resistors



Gain Equation

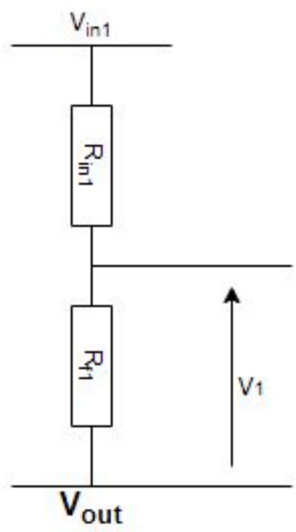


Taking the V_2 input, as it is part of a potential divider circuit then V_2 can be given as follows:
$I = V/R, = V_{in2} / R_{in2}+R_{f2}$
$V_2 = (V_{in2} / R_{in2}+R_{f2})*R_{f2}$

For V_1 it is slightly more complicated as the potential divider comes from V_{out} not 0 volts:

The current, $I = (V_{in1}-V_{out}) / (R_{in1}+R_{f1})$

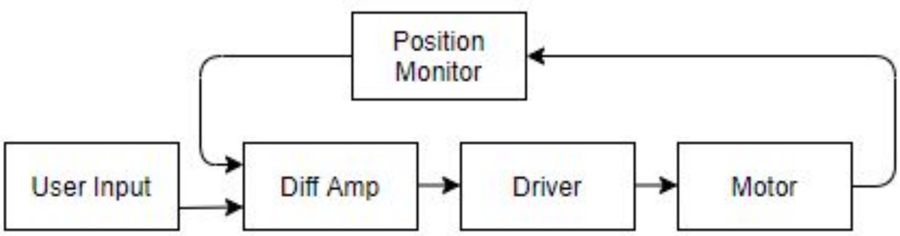
So, $V_1 = V_{out} + (V_{in1}-V_{out}) / (R_{in1}+R_{f1})*R_{f1}$
Which is also equal to $V_2 = (V_{in2} / R_{in2}+R_{f2})*R_{f2}$
With this, we can multiply everything by $R_{in}+R_f$ and then multiply out brackets, simplify and rearrange:



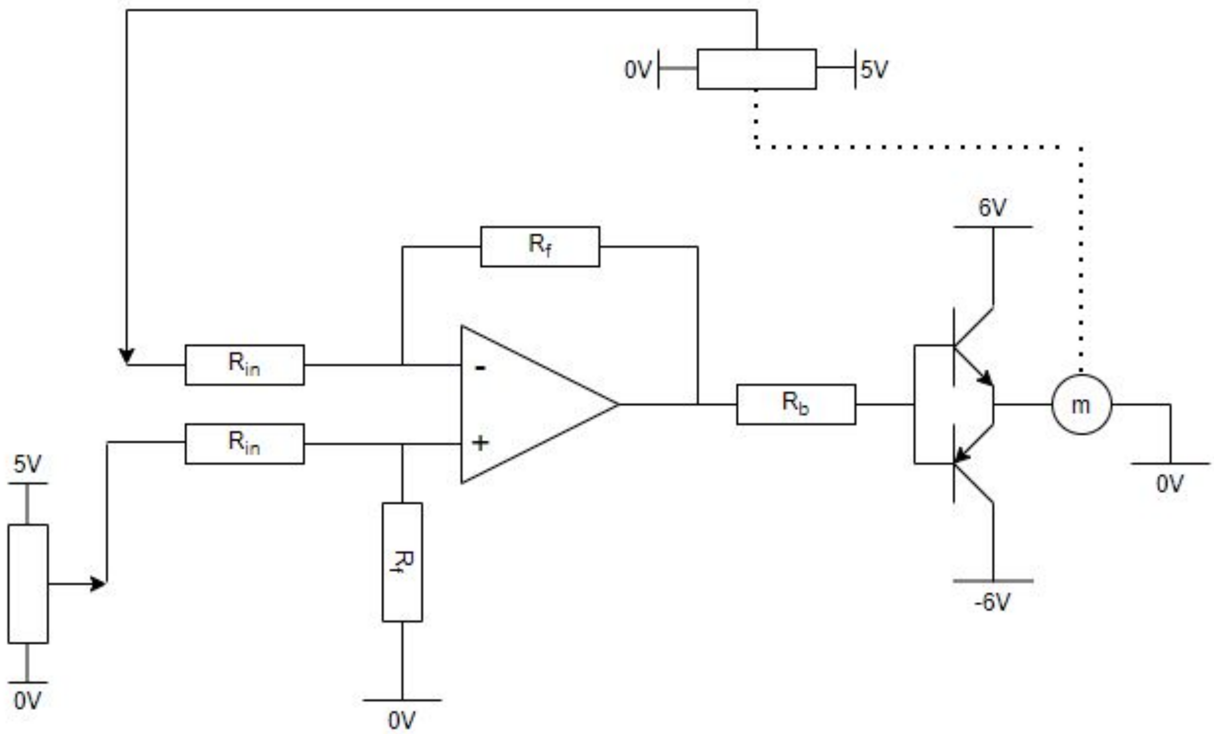
$V_{input} = V_2R_f = V_{out}(R_{in}+R_f)+(V_1-V_{out})R_f$
$= V_2R_f = V_{out}R_{in} + V_{out}R_f + V_1R_f - V_{out}R_f$
$= V_2R_f = V_{out}R_{in} + V_1R_f$ (now rearrange)
$= V_2R_f - V_1R_f = V_{out}R_{in}$
$= V_{out}R_{in} = R_f(V_2-V_1)$
$= V_{out} = (-R_f / R_{in}) * (V_1-V_2)$

Difference Amp

The difference amp could be used in a circuit that allows for smooth turning and control over, for example, the rotation of a satellite dish. The user would set an input which the difference amp would then take, drive a motor with a position monitor feeding back into a potentiometer connected to the second input of the amp, lowering the difference in the input and slowing down the motor.

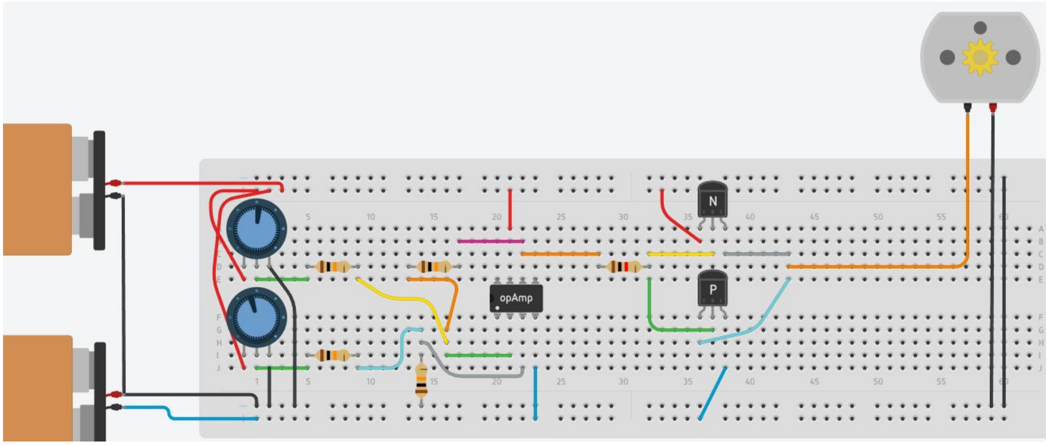


The circuit for this will look as follows with the lower potentiometer being for user input, the push pull (transistor pair) for current gain in both positive and negative directions for the motor and the feedback potentiometer driving input 1:

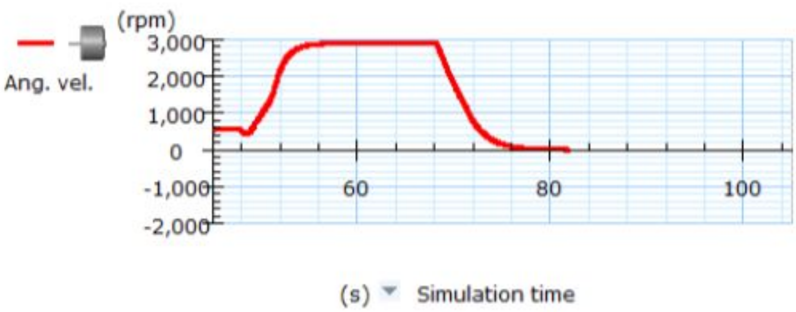


Difference Amp

Translated onto a circuit board simulation in tinkercad the motor feedback cannot be simulated and so 2 user inputs are needed where 1 is imagined to be the feedback.

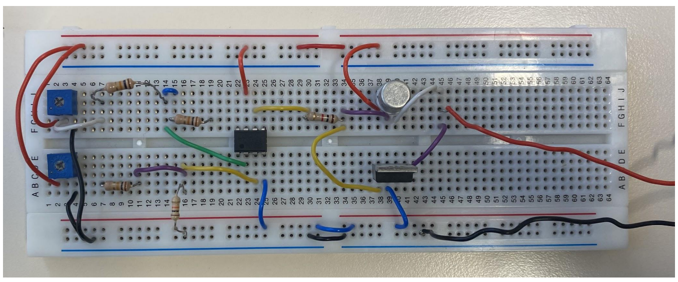


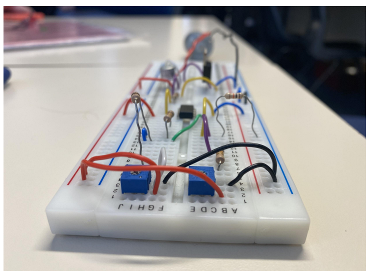
The upper potentiometer is the feedback and when the 2 inputs are equal the motor will not turn, the difference in the inputs is what gives the motor increasing rpm.



The graph shows that at 60 seconds in the simulation, the user had input high, driving the motor to its maximum speed. At 68 seconds the second potentiometer drives the op amp difference closer to 0, slowing down the motor.

The delay is due to human error, not the circuit. A picture of the real circuit is given below:

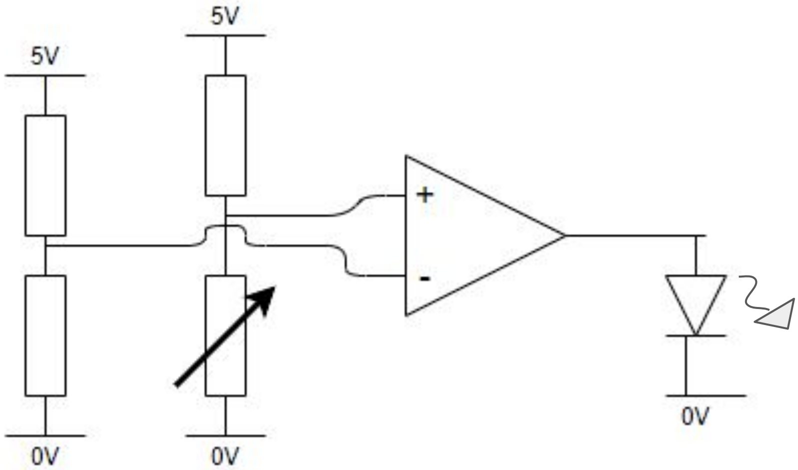




Comparator

The comparator takes 2 voltage divider inputs and outputs a signal dependant upon the 2.

The inverting input in this example is given a set voltage and the non-inverting input can be variable by the variable resistor



The Op Amp will take the 2 inputs and compare them within itself, outputting a voltage only when the non-inverting input voltage is GREATER than the reference voltage on the inverting input. When this condition is met on the circuit above, the LED will light

<u>Common Uses</u>

2 Comparators are used within the 555 clock chip:

The upper comparator will eventually output HIGH as the capacitor charges to higher than its reference voltage and the RESET pin on the flip flop will be activated, making output LOW.

When the capacitor discharges the reference voltage (inverting input) on the lower comparator will cause it to go HIGH and set the flip flop to HIGH, creating a pulsing signal.