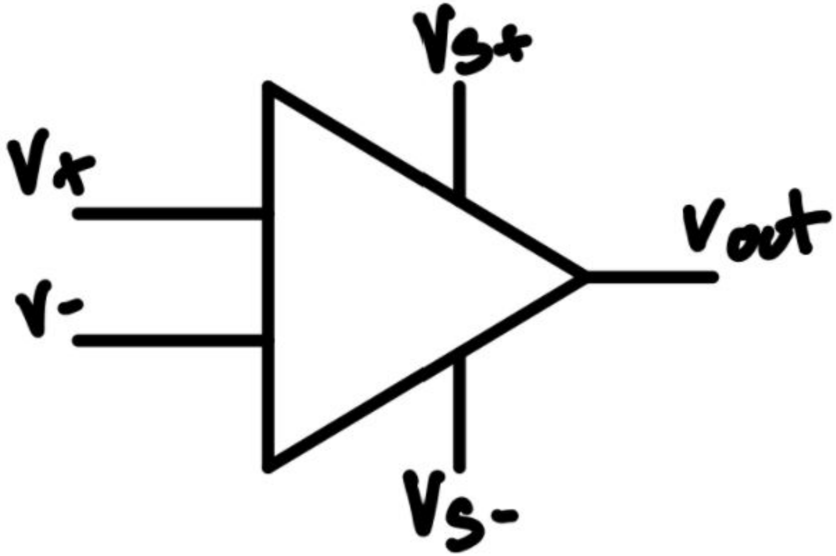
Operational Amplifiers

Our First IC

What is an Op Amp?

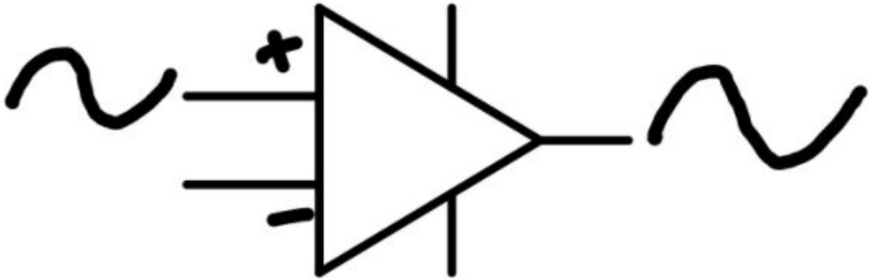
What is an Operational Amplifier

- An operational amplifier, or op amp, is a circuit that determines the difference between two voltages; V+, the non-inverting input and V-, the inverting input.
- It then multiplies the difference of the two voltages by a HUGE number, let's just say 1,000,000 and tries to output that value as a voltage.
- We can say that the op amp has an infinite gain when no external components are attached to it.

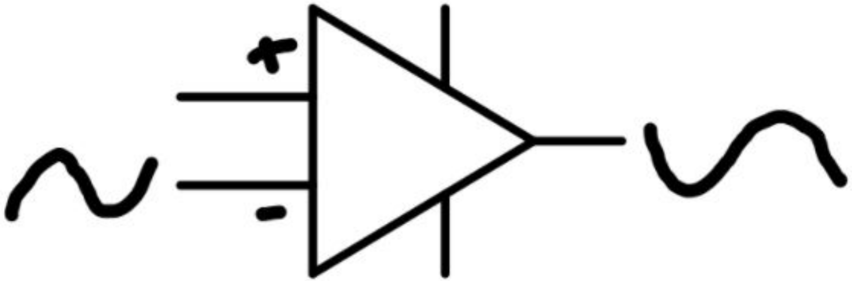


What is an Operational Amplifier

- A **non - inverting op amp** will keep the polarity of the input signal the same while amplifying. So where there was a high voltage, there will be a high voltage.



- An **inverting op amp** will switch or invert the polarity of the input signal while amplifying. So where there was a high positive voltage, there will now be a low voltage.



What is an Operational Amplifier

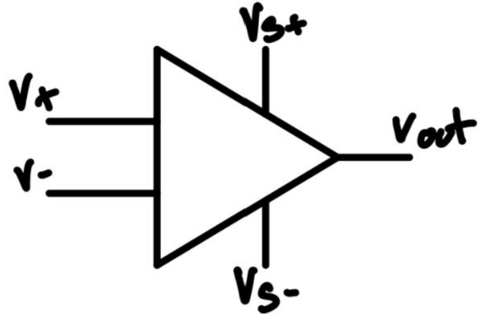
- The op amp is limited by the power supplied to it, Vs+ and Vs-. Let's assume we have +9 volts and -9 volts as our power.
- For example, if the non inverting input was 3.01 volts and the inverting input was 3.00 volts. The difference between the two voltages is:

3.01 volts - 3.00 volts = 0.01 volts

- The output would be a huge number:

1,000,000 * .01 volts = 10,000 volts

- The output cannot be 10,000 volts since we are powering with +/- 9 volts. So the op amp will output as close to +9 volts as it can.



What is an Operational Amplifier

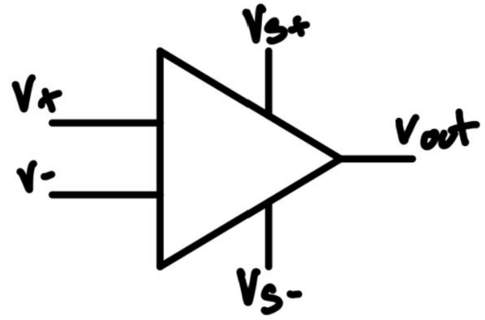
- The op amp is limited by the power supplied to it, Vs+ and Vs-. Let's assume we have +9 volts and -9 volts as our power.
- For example, if the non inverting input was 3.00 volts and the inverting input was 3.01 volts. The difference between the two voltages is:

3.00 volts - 3.01 volts = - 0.01 volts

- The output would be a huge number:

1,000,000 * -.01 volts = -10,000 volts

- The output cannot be -10,000 volts since we are powering with +/- 9 volts. So the op amp will output as close to -9 volts as it can.

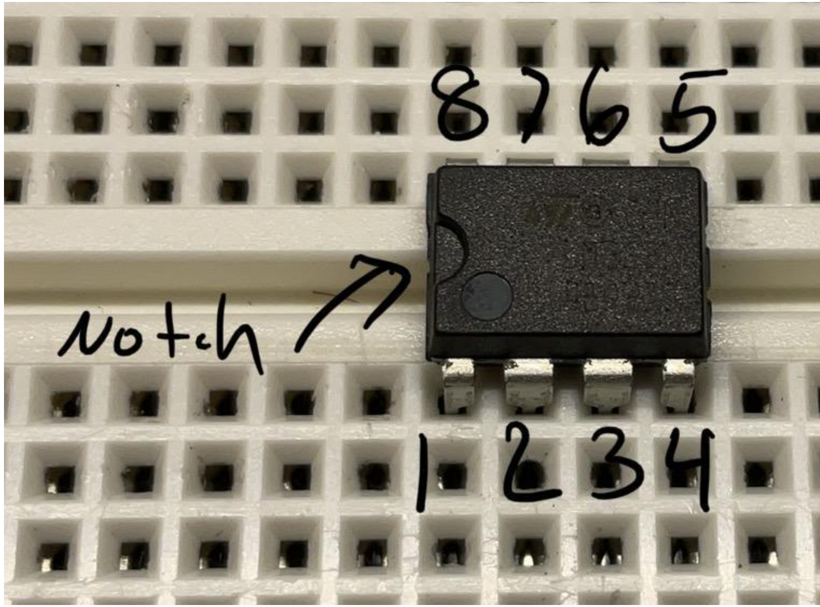


What is an Operational Amplifier

- Vs+ and Vs- are needed for an Op Amp to work.
- This range is how much voltage our op amp can use to amplify the circuit.
- For example if Vs+ was 9V and Vs- was at -9V, then we would 18V of “room” to amplify.
- If you don’t have a negative voltage supply you can use Vs+ as 9V and Vs- as 0V giving us 9V of “room” to amplify. This will just require some biases on our part later on.
- Per our previous discussion, the op amp will try to multiple any voltage difference at the inputs by some HUGE number. Now, the highest we can go is close to 9 volts and the lowest we can go is close to ground.

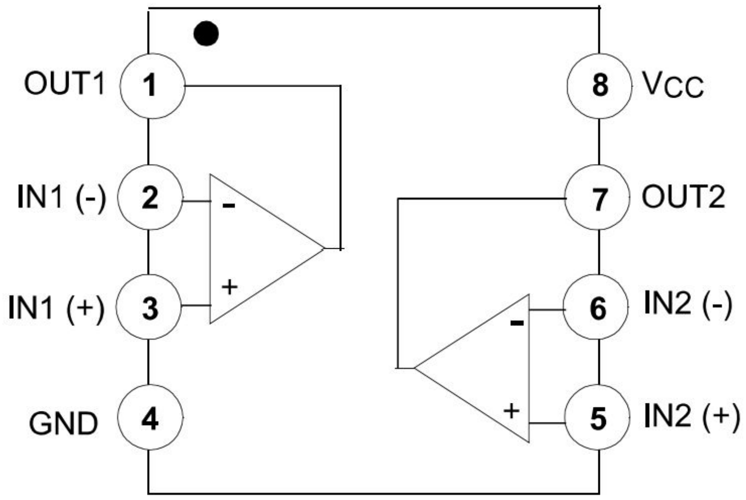
Our Op Amp: LM 358

- There are many different op amps out there with different specifications.
- I'll be using the LM 358.
- It is a dual op amp meaning there are two inside op amps inside one chip!
- It is a low power op amp that can work off a single voltage supply.
- We'll operate from 0V to 9V and bias the op amp accordingly!
- Note the notch on the op amp and the pin numbers.



The Datasheet: LM 358

- Every IC chip has a datasheet you can look up with important information about the chip such as operating voltages/currents and pin layouts.
- From this data sheet you can see the Vcc (8) and ground (4) pins as well as the two individual op amps (pins 1, 2, 3 and pins 5, 6, 7).



Features

- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM258/LM258A, LM358/LM358A: 3V~32V (or ±1.5V ~ 16V)
  LM2904 : 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation.

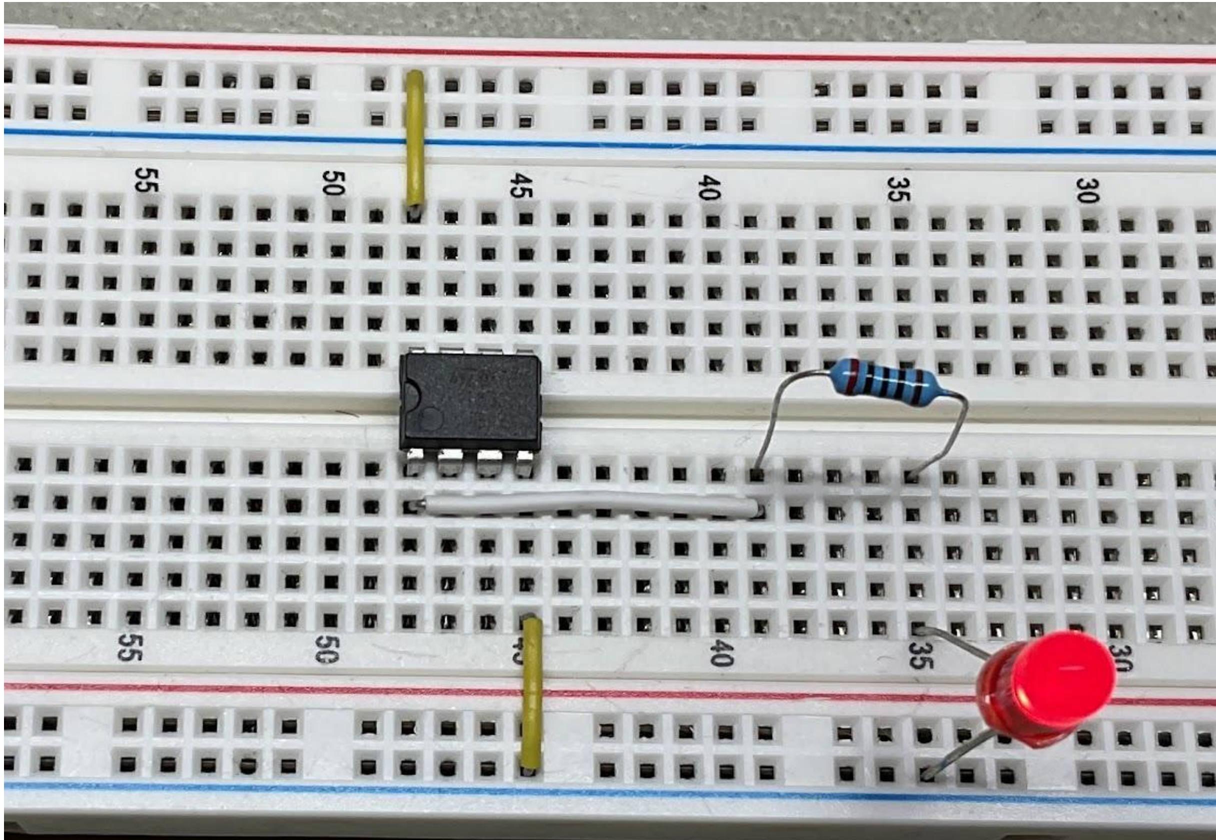
The Op Amp Comparator

The Op Amp Comparator

- A comparator is an electronic circuit that compares two input voltages and lets you know which of the two is greater.
- We can use an op amp to make a crude comparator.
- We will wire up an op amp such that when pin 3 (the non-inverting input) is at a higher voltage than pin 2 (the inverting input) an LED lights up.

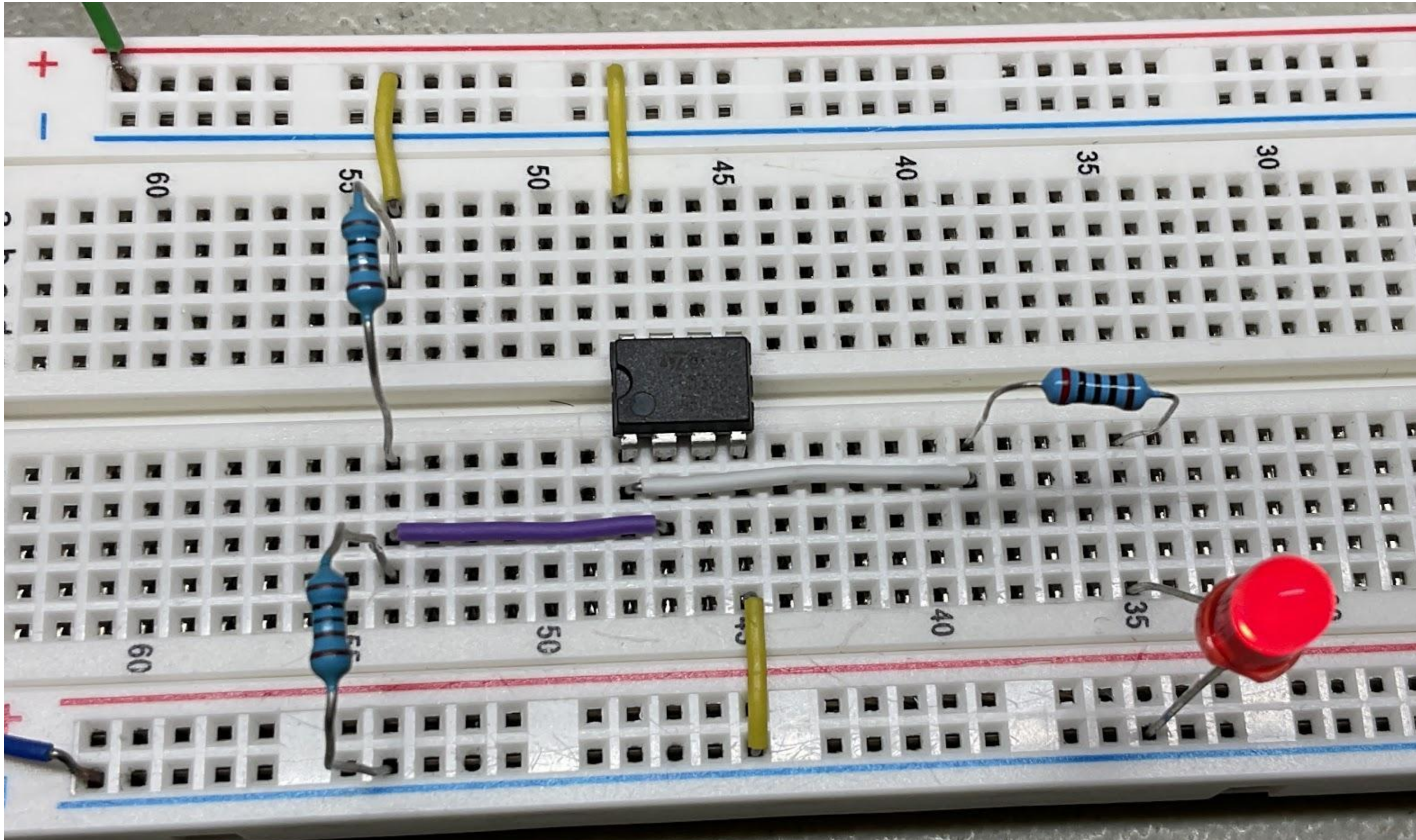
Op Amp Comparator

- Connect pin 8 (Vcc) to Vcc.
- Connect pin 4 (ground) to ground.
- Using a 9 volt source, we now have 9 volts of “room” to amplify.
- Connect pin 1 (output) to a 200 ohm (red, black, black, black) resistor to an LED to ground.
- The LED is currently on because I have floating inputs on pins 2 and 3 and we are not getting a valid voltage reading for comparison.



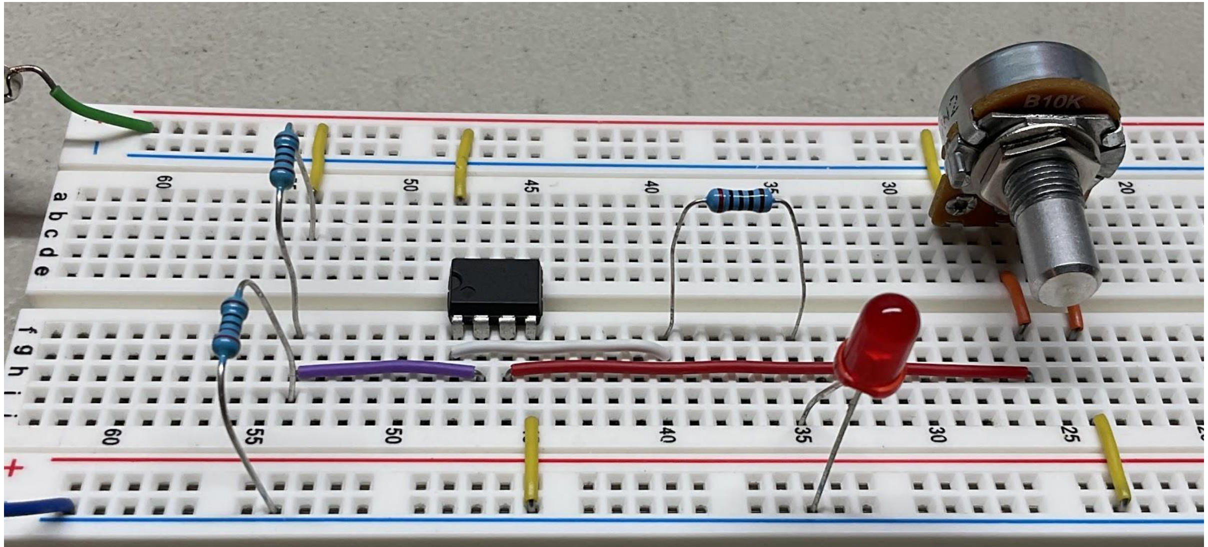
Op Amp Comparator

- Create a voltage divider using two 1K (brown, black, black, brown) resistors.
- Connect the mid point of the voltage divider to pin 2 (the inverting input).
- This will set our voltage at the inverting input to be roughly 4.5 volts.



Op Amp Comparator

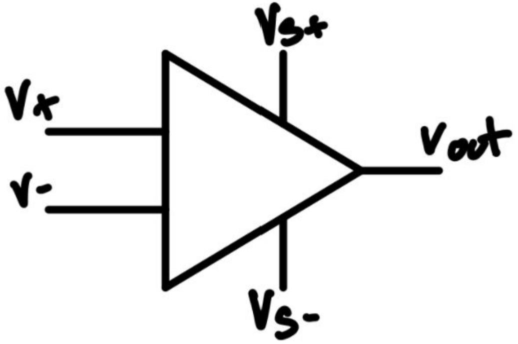
- Add a 10K potentiometer with the output going to pin 3 (non-inverting input).
- Now as you vary your potentiometer and compare the non-inverting input voltage to the inverting input voltage (4.5 volts) the output will vary.
- If V non-inverting > V inverting --> output tries to go to Vcc. If V non-inverting < V inverting --> output tries to go to ground (or -Vcc if you have it).
- Use a voltmeter to compare the voltages at the input pins and note the output.



The Non-Inverting Amplifier

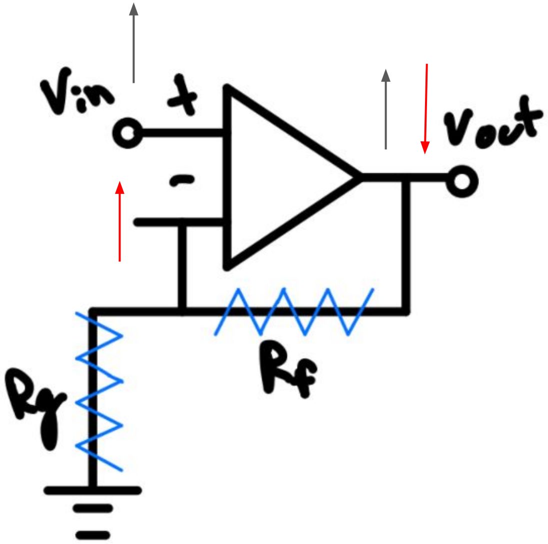
Op Amp Rules

- There are a few general rules we can follow when working with op amps to help simplify their use. They are as follows:
- **No current flows through either inputs of the op amp**. This means that it doesn't "load" the circuit before it.
- **The op-amp has an infinite open loop gain**. This means that in operation where there is no "negative feedback" or components that connects the output back to one of the inputs, the gain of the amplifier is infinite. We saw this with the comparator circuit. Of course, we are limited by the power supply so the gain is not infinite.
- **In a circuit with negative feedback, the op amp will always work to keep the inputs at the same voltage such that their difference is zero.** With negative feedback, the gain is more controlled and we can calculate its value.



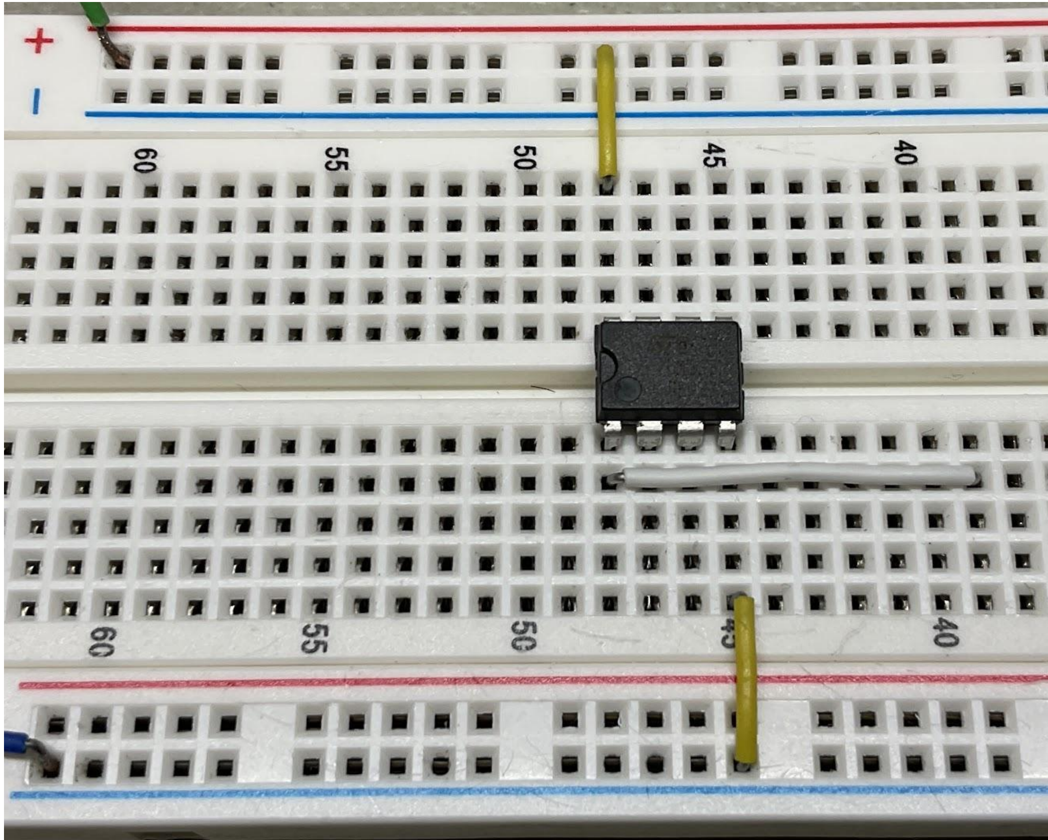
Negative Feedback

- Feedback is the process of taking an output signal and feeding it back to one of the inputs.
- Negative feedback occurs when the signal that is being fed back to the input subtracted from the input (out of phase).
- Positive feedback occurs when the signal that is being fed back to the input is added to the input (in phase).
- Here as the non inverting input signal rises, so does the output signal (that's what the amplifier does!) but now, that signal is fed back to the inverting input, which rises. As the inverting input rises, the output will now lower due to the inverting nature of the input pin.



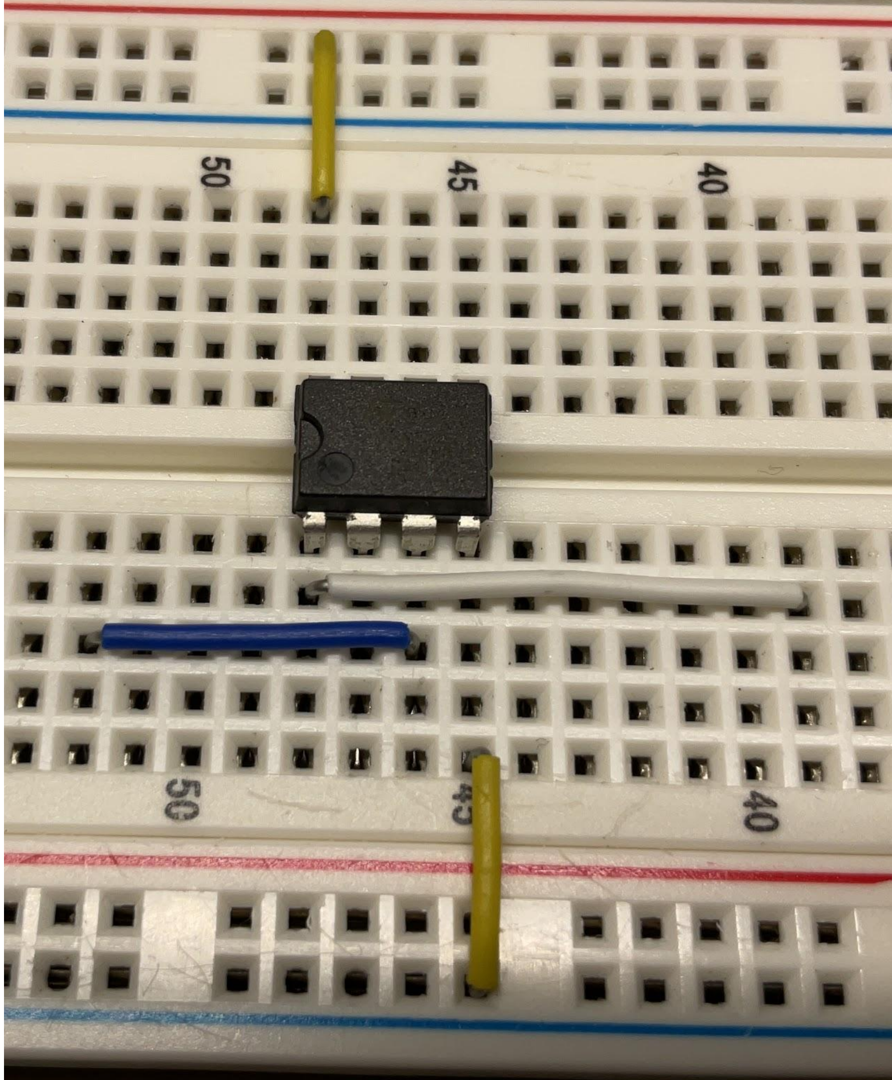
The Non Inverting Amplifier

- Connect pin 8 (Vcc) to vcc.
- Connect pin 4 (ground) to ground.
- Move pin 1 (output) away from the chip for ease of access.
- Remember that the LM 358 has two op amps in it; we will only be using the one of the bottom side of the chip for now.



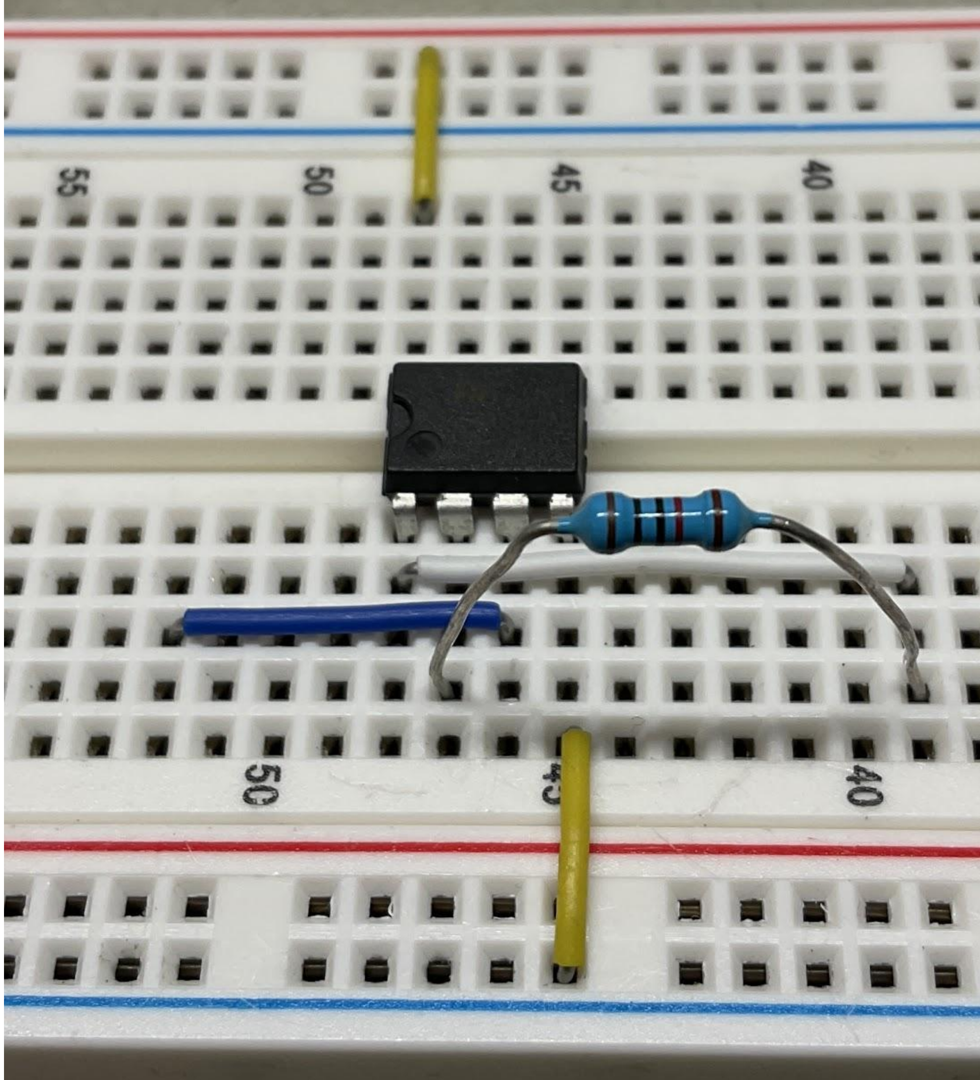
The Non Inverting Amplifier

- For the non inverting amplifier, we want our input to come into the non inverting pin.
- This will ensure that our input and our output are in phase with each other; where there is a HIGH on the input we will have a HIGH on the output.
- Move pin 3 (non inverting input) away from the chip for ease of access.



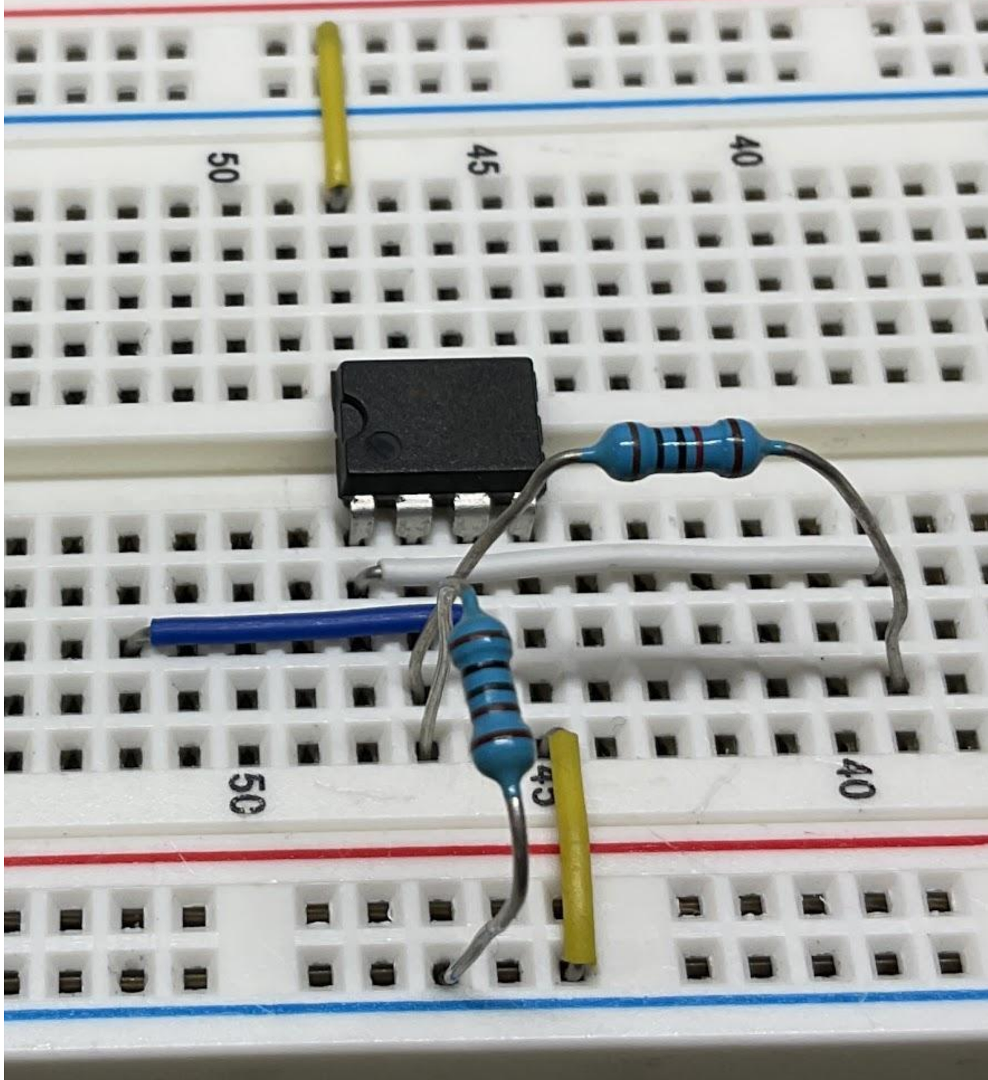
The Non Inverting Amplifier

- We have to introduce some feedback otherwise, our op amp will simply saturate between Vcc or ground like it did in the comparator circuit.
- Add a 10K (brown, black, black, red) resistor from pin 1 (output) via your jumper wire back to pin 2 (the inverting input).
- Well refer to this resistor as the feedback resistor, Rf.



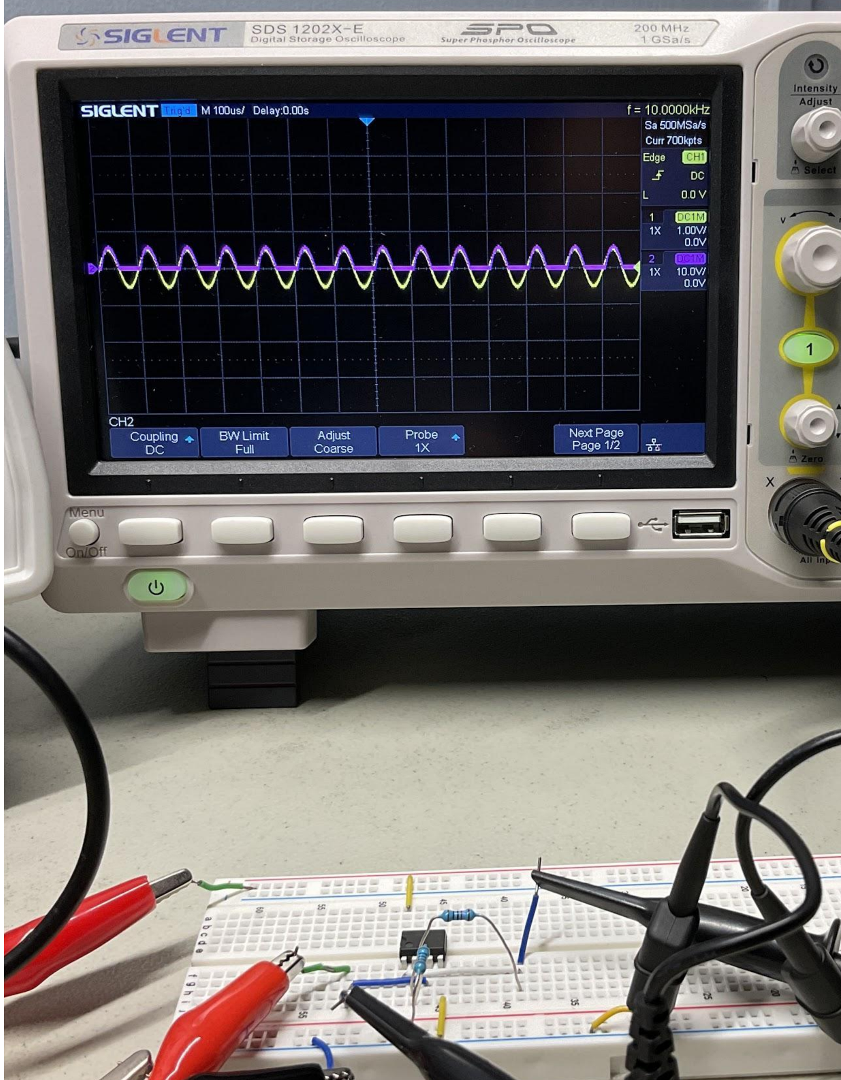
The Non Inverting Amplifier

- Now place a 1K (brown, black, black, brown) resistor from pin 2 (the inverting input) to ground.
- We'll refer to this resistor as Rin.
- This essentially sets up a voltage divider between the output and the inverting input.



The Non Inverting Amplifier

- Here I've connected a 10 Khz sine wave via a function generator to pin 3 (the non inverting input).
- You can see the input in yellow on a 1 volt per division scale.
- You can see the output in purple on a 10 volts per division scale.
- That's a gain of about 10! Which interestingly is the ratio of our two feedback resistors.
- However, we are getting TERRIBLE clipping on our output any time the output tries to swing negative.

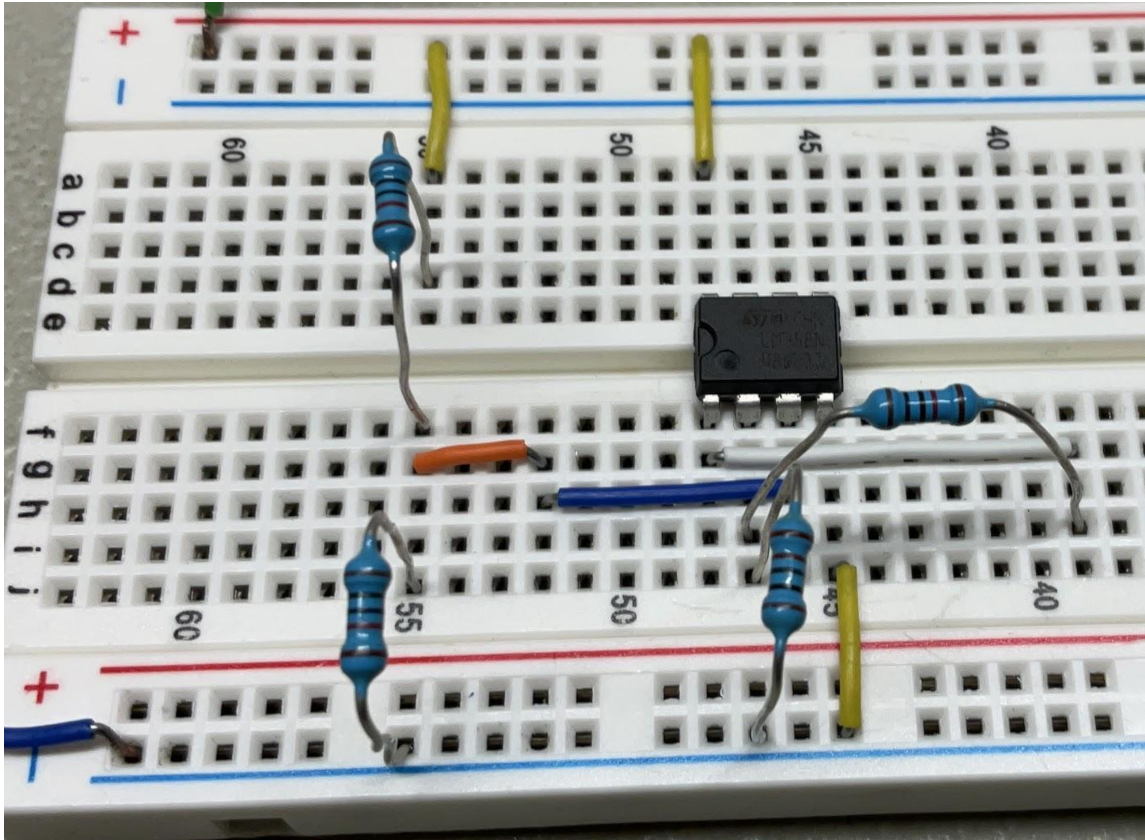


The Non Inverting Amplifier

- We only have 9 volts of “room” to amplify our signal.
- It’s really important to note that the 9 volts of “room” is NOT centered around zero volts, giving us +4.5 volts to -4.5 volts.
- Instead, our 9 volts is essentially centered at +4.5 volts, giving us 4.5 volts about this center point (9 volts) and 4.5 volts below this center point (0 volts).
- To bias our amplifier, we will simply have to add a DC “offset” to our signal to try and position it at the midpoint of our voltage range...in our case 0V to 9V; our sweet spot of 4.5V.
- To do this, we can use a voltage divider!

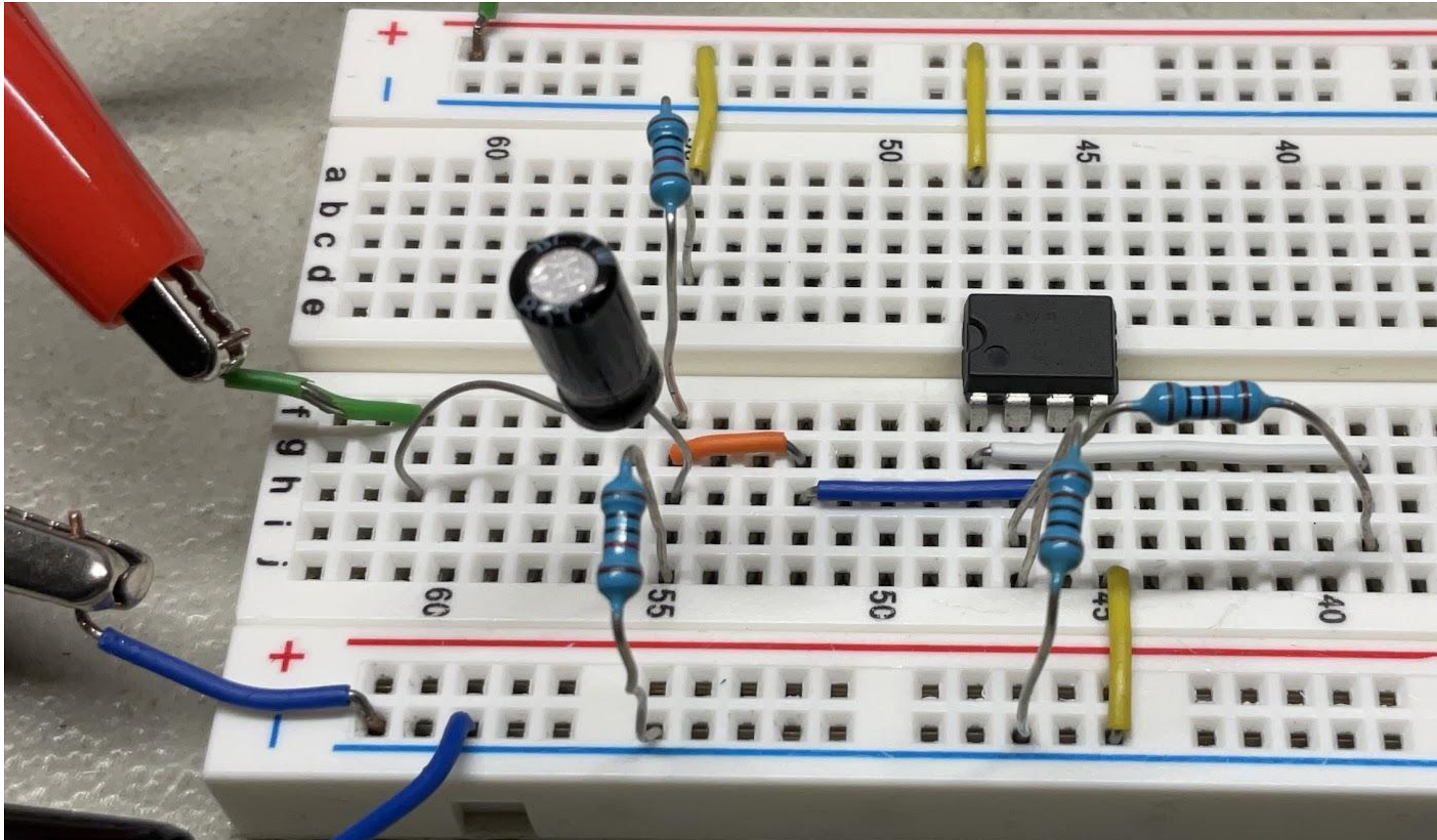
The Non Inverting Amplifier

- Set up a voltage divider using two 10K (brown, black, black, red) resistors.
- This will ensure that our voltage at the midpoint is essentially Vcc/2.
- Connect the midpoint of the voltage divider to pin 3 (the non inverting input pin) via the jumper wire.



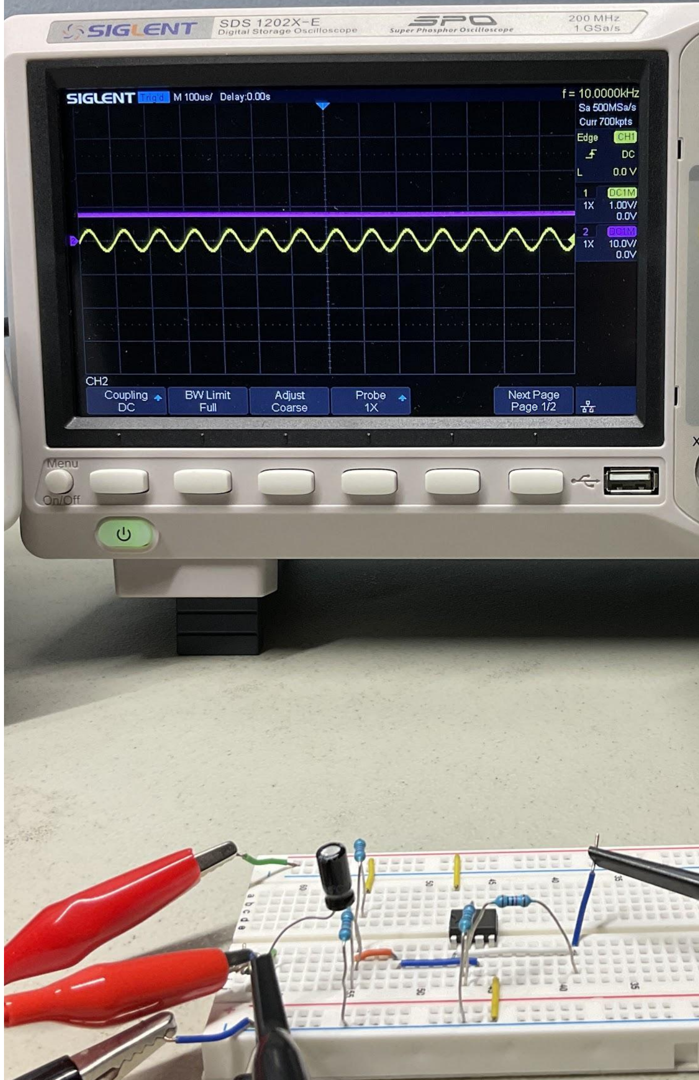
The Non Inverting Amplifier

- Add a 1 microFarad coupling capacitor between the input midpoint of the voltage divider and where you are hooking up your AC source.
- In my case, the AC source is a function generator but it could also be a microphone.



The Non Inverting Amplifier

- Hooking this up to the oscilloscope you can see the input in yellow on a 1 volt per division scale and the output in purple on a 10 volt per division scale.
- The output is constantly saturated though...This is not what we want at all!
- This is because we are now not only trying to amplify the AC signal but also the 4.5 volt DC signal that is always present!
- We need a way to amplify the AC signal while ignoring the DC offset signal...



The Non Inverting Amplifier

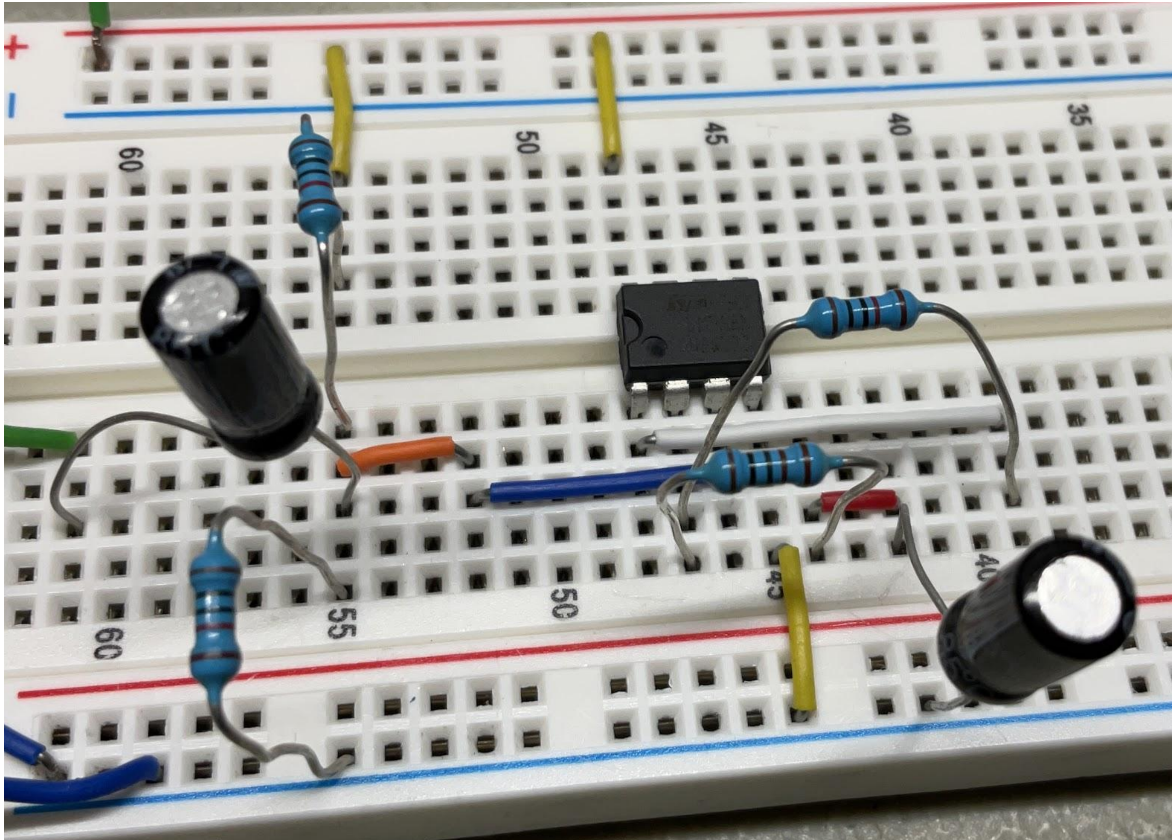
- The gain of the non inverting amplifier can be calculated as:

$$\text{Gain} = 1 + \frac{R_F}{R_{IN}}$$

- In our case, since Rf is 10K and Rin is 1K, the gain is roughly 11; which is exactly what we've seen on the oscilloscope.
- However, when we try to increase our 4.5 volt DC offset by a gain of 11, we can't get 4.5 * 11 = 49.5 volts, so we just saturate.
- Looking at our gain equation, if we could make Rin very large for a DC signal and very small for an AC signal, then the gain would drastically drop down for DC and still be large for AC.
- We can do this with a capacitor which offers HUGE resistance to DC signals with little resistance to AC signals.

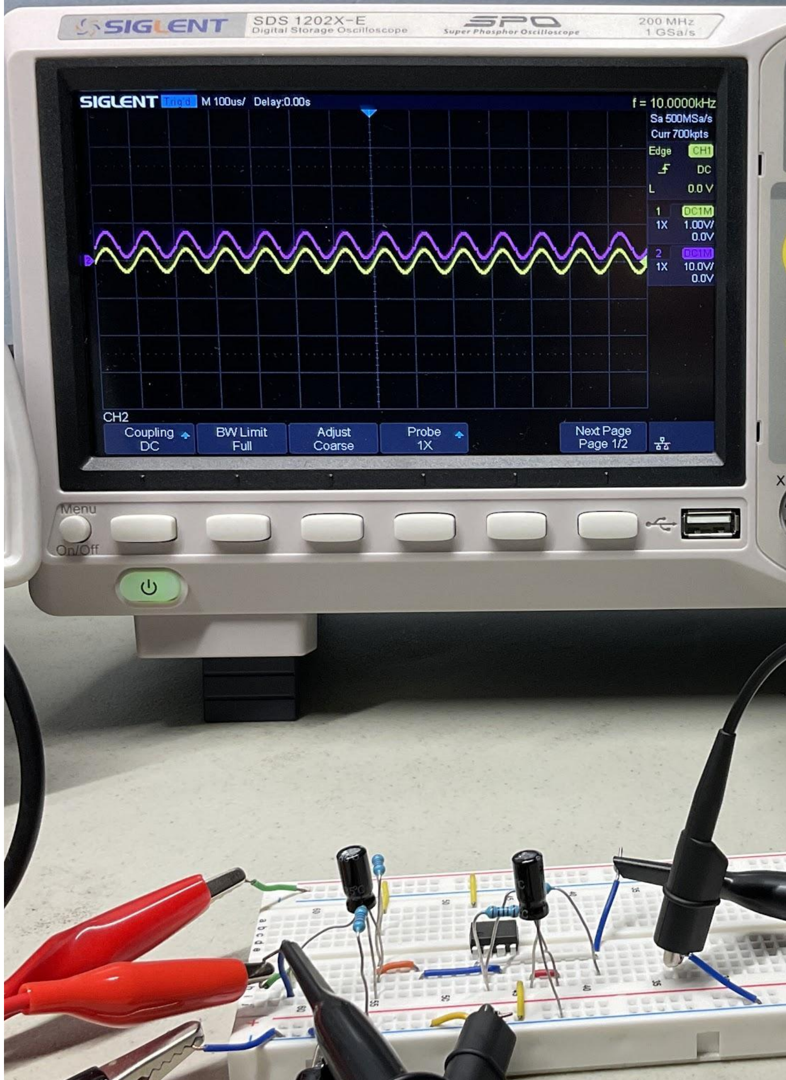
The Non Inverting Amplifier

- Put a 1 microFarad capacitor in series with Rin, the 1K resistor, going to ground.
- The effective value of Rin is now the series combination of the 1K resistor and 1 microFarad capacitor.
- Our feedback loop will see a HUGE Rin value for DC signals resulting in no amplification.
- Our feedback loop will not see the capacitor for AC signals and will keep our amplification factor of 11.



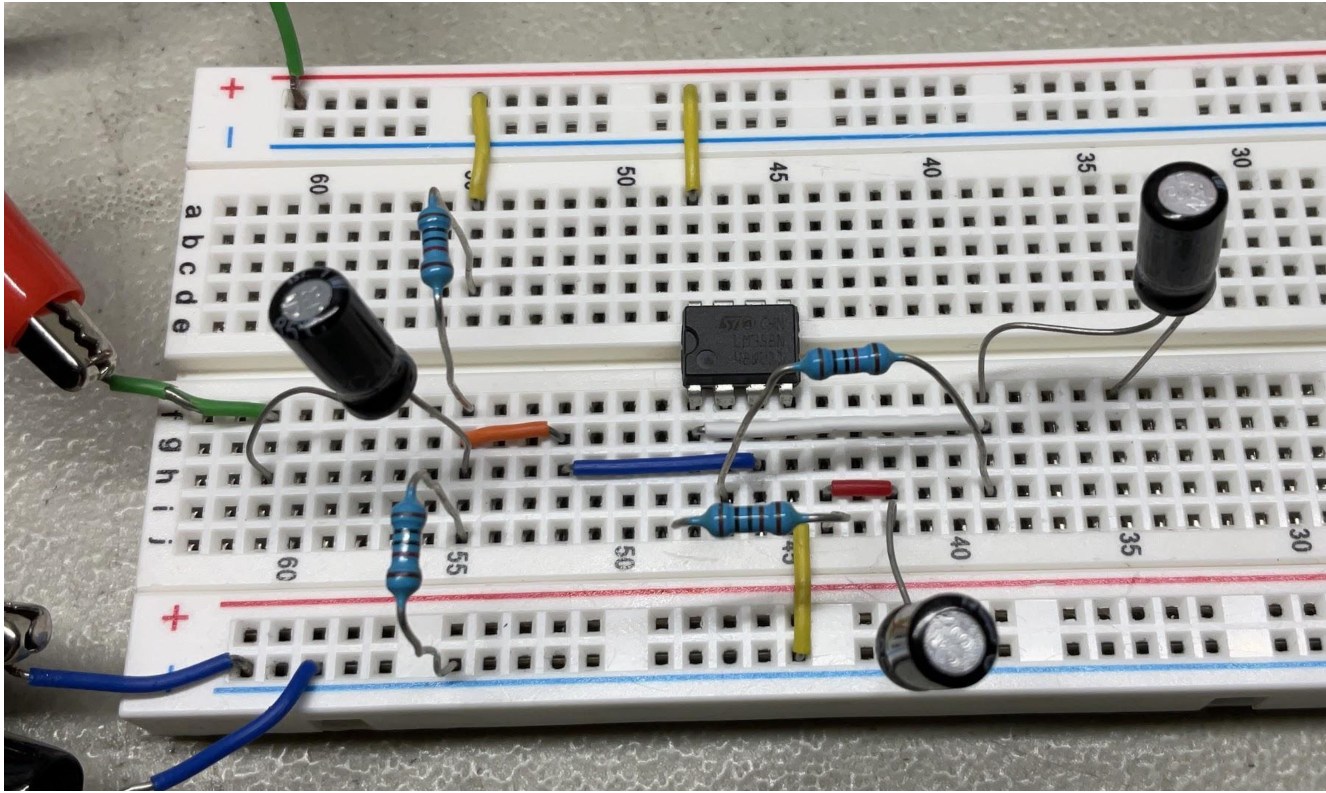
The Non Inverting Amplifier

- The capacitor is doing its job!
- We have a nice amplification of roughly 11 times.
- There is a dc offset getting through to the output.
- We can fix that with a capacitor.

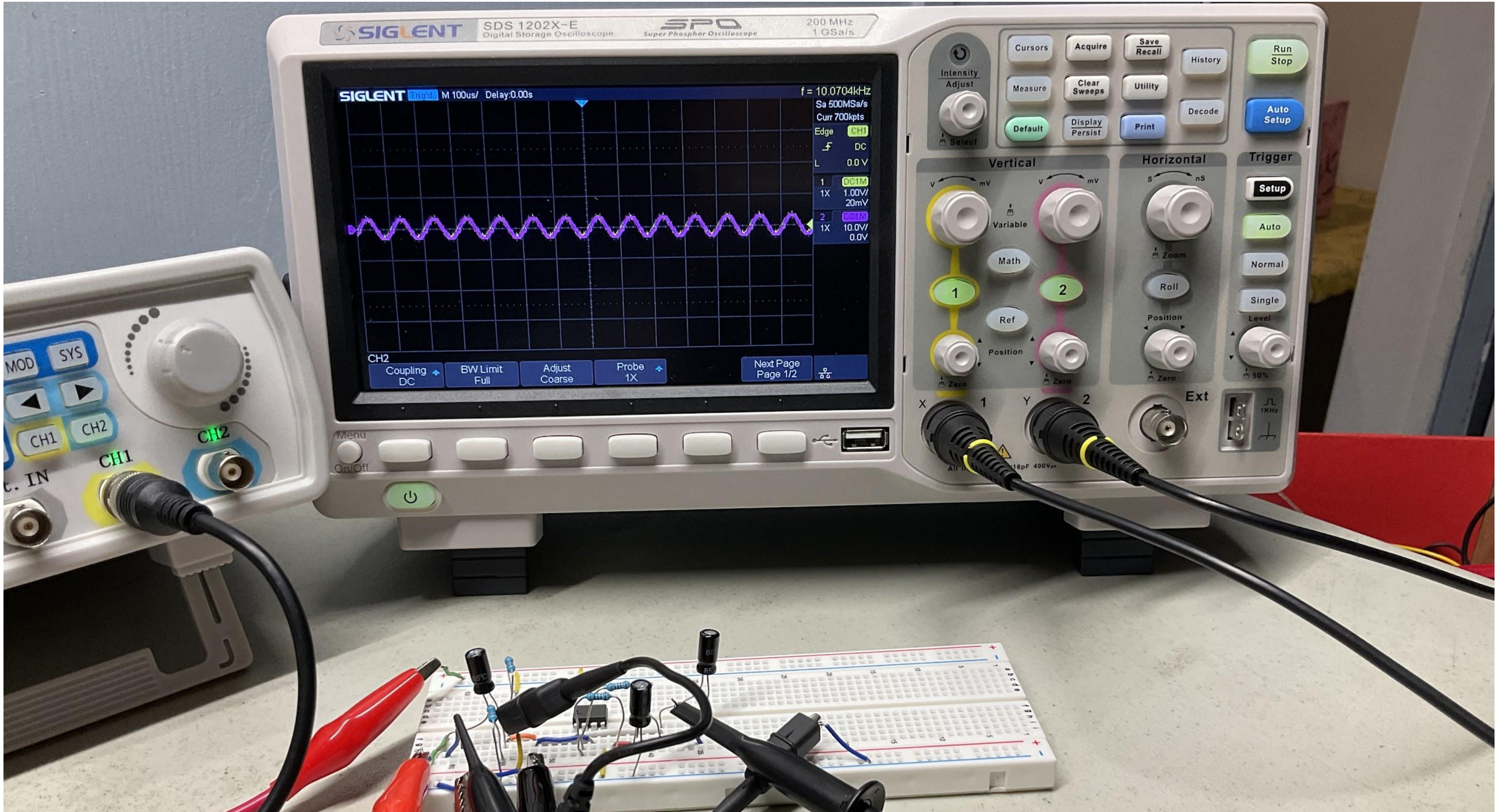


The Non Inverting Amplifier

- Add a 1 microFarad capacitor to the output to block any DC.
- Note how the input and the output are in phase with each other.



The Non Inverting Amplifier



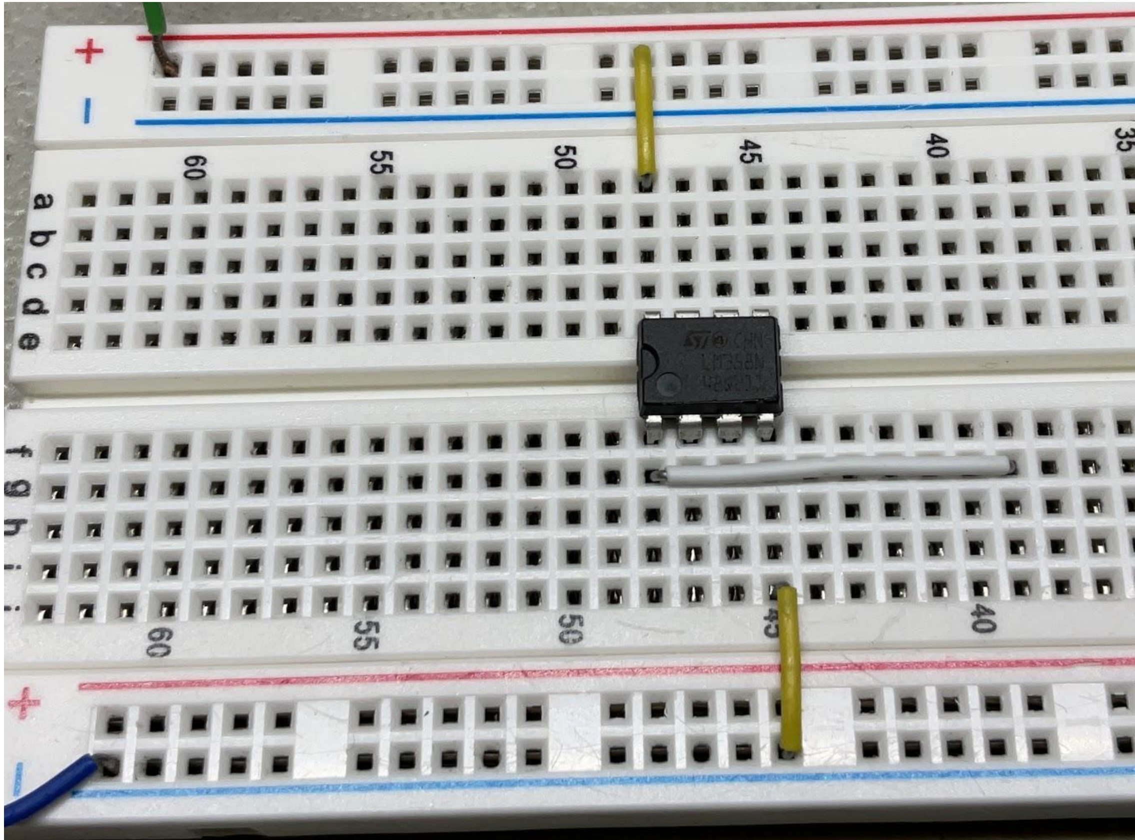
The Inverting Amplifier

The Inverting Amplifier

- The inverting amplifier follows a similar design as the non inverting amplifier with a few modifications.
- Our input will be sent to the inverting pin of the op amp and our output will be out of phase with the input.
- The inverting amplifier will require less components and is a little easier to build too!

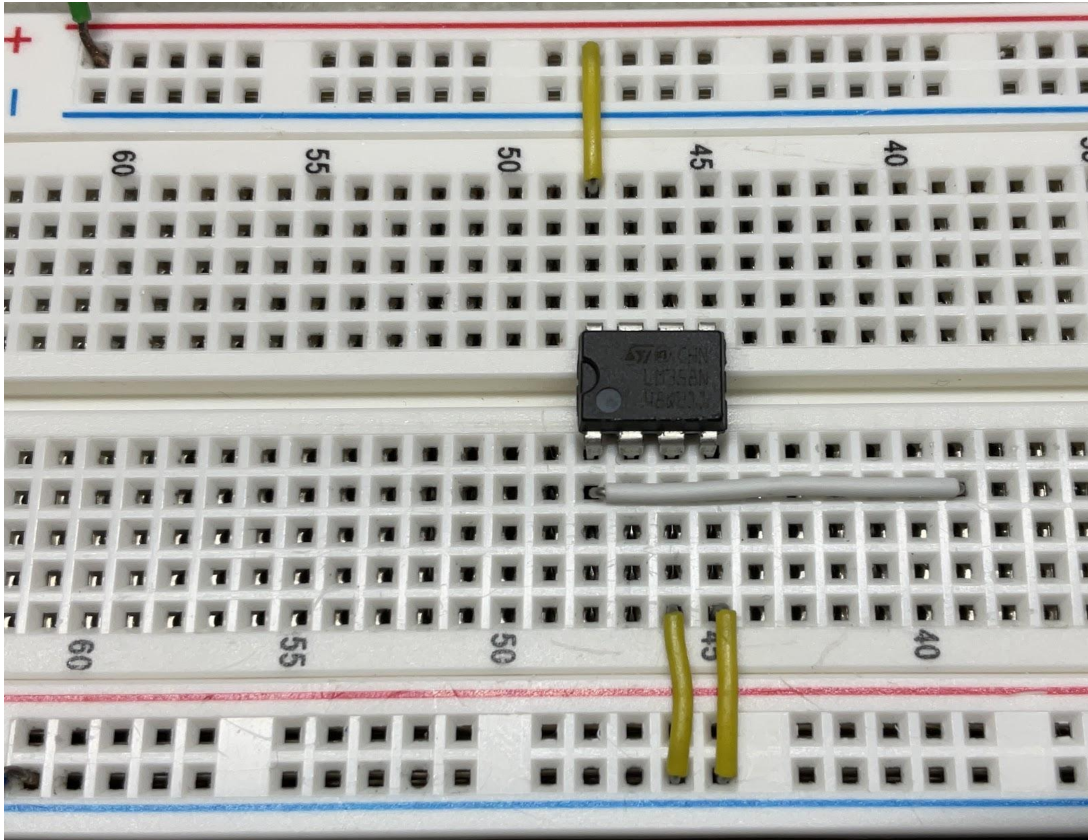
The Inverting Amplifier

- Connect pin 8 (Vcc) to Vcc.
- Connect pin 4 (ground) to ground.
- Move pin 1 (output) away from the chip for easy access.



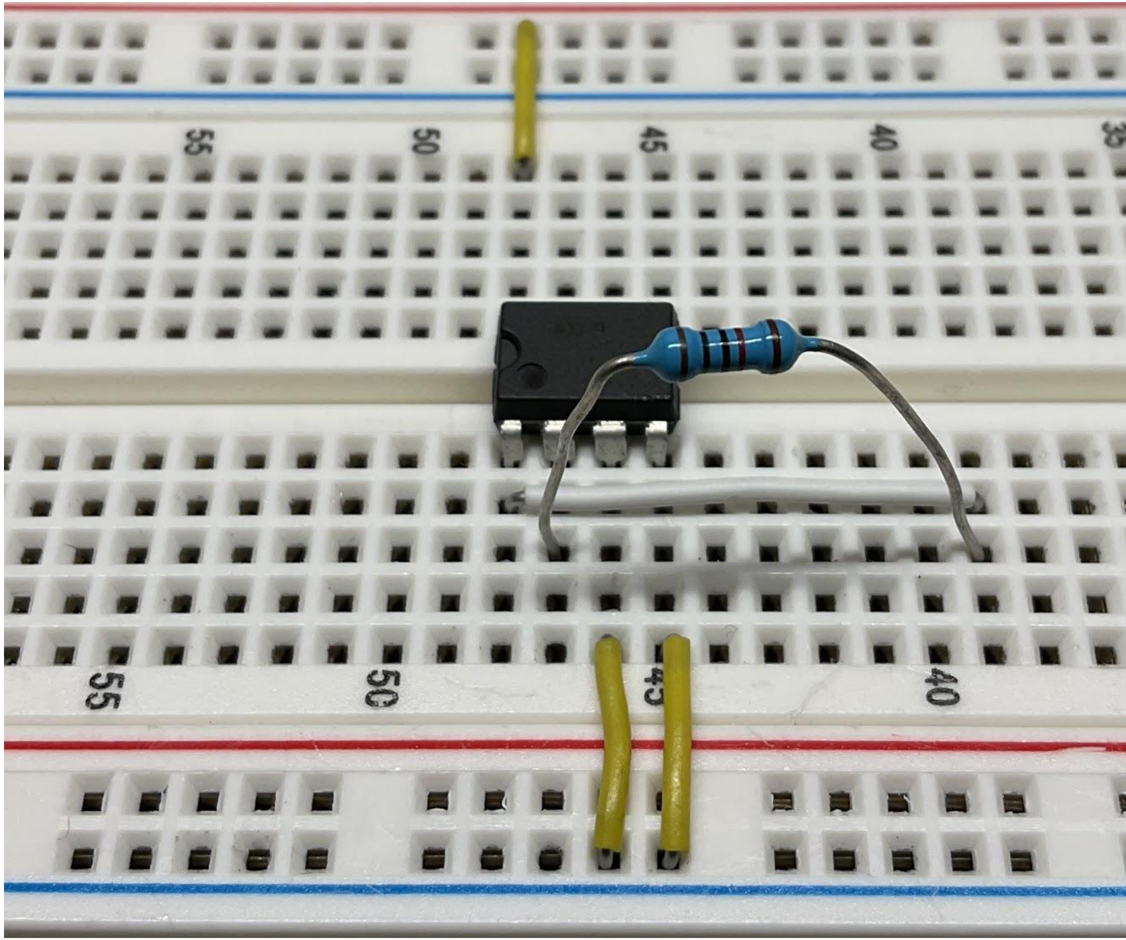
The Inverting Amplifier

- Since this is an inverting amplifier, we have to figure out what to do with the non inverting pin, pin 3.
- For now, connect pin 3 (the non inverting pin) to ground.
- We will see later, that this is not good!



The Inverting Amplifier

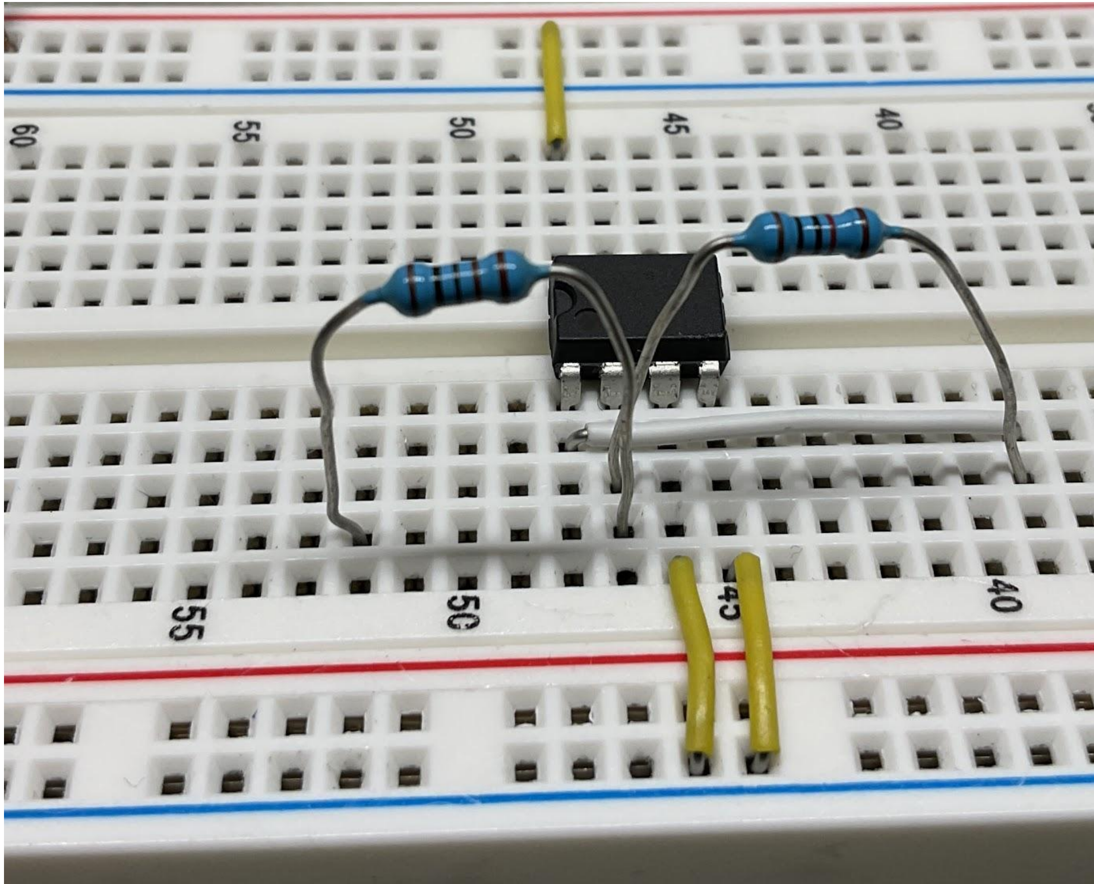
- Add a 10K (brown, black, black, red) feedback resistor Rf from pin 1 (output) via the jumper wire to pin 2 (the inverting input).



The Inverting Amplifier

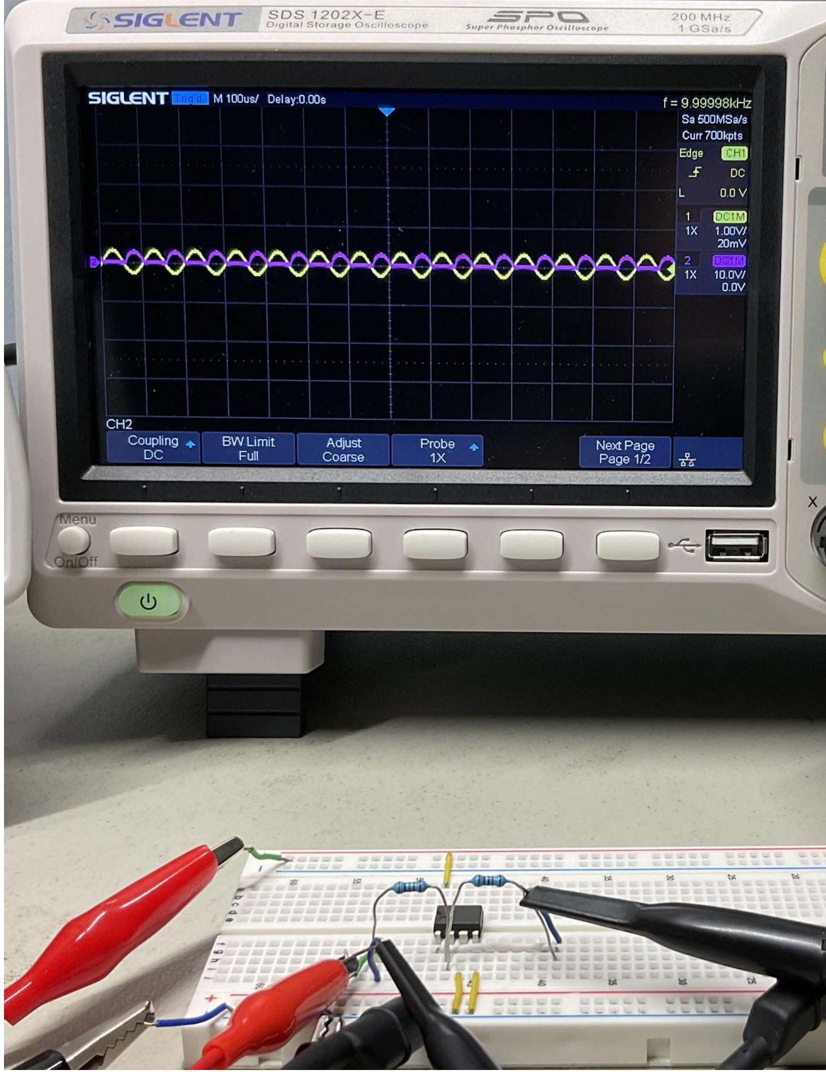
- Add a 1K (brown, black, black, brown) input resistor, Rin on pin 2 (inverting input).
- Our feedback network and our amplifier is complete!
- The gain of the amplifier is:

$$\text{Gain} = \frac{R_F}{R_{IN}}$$



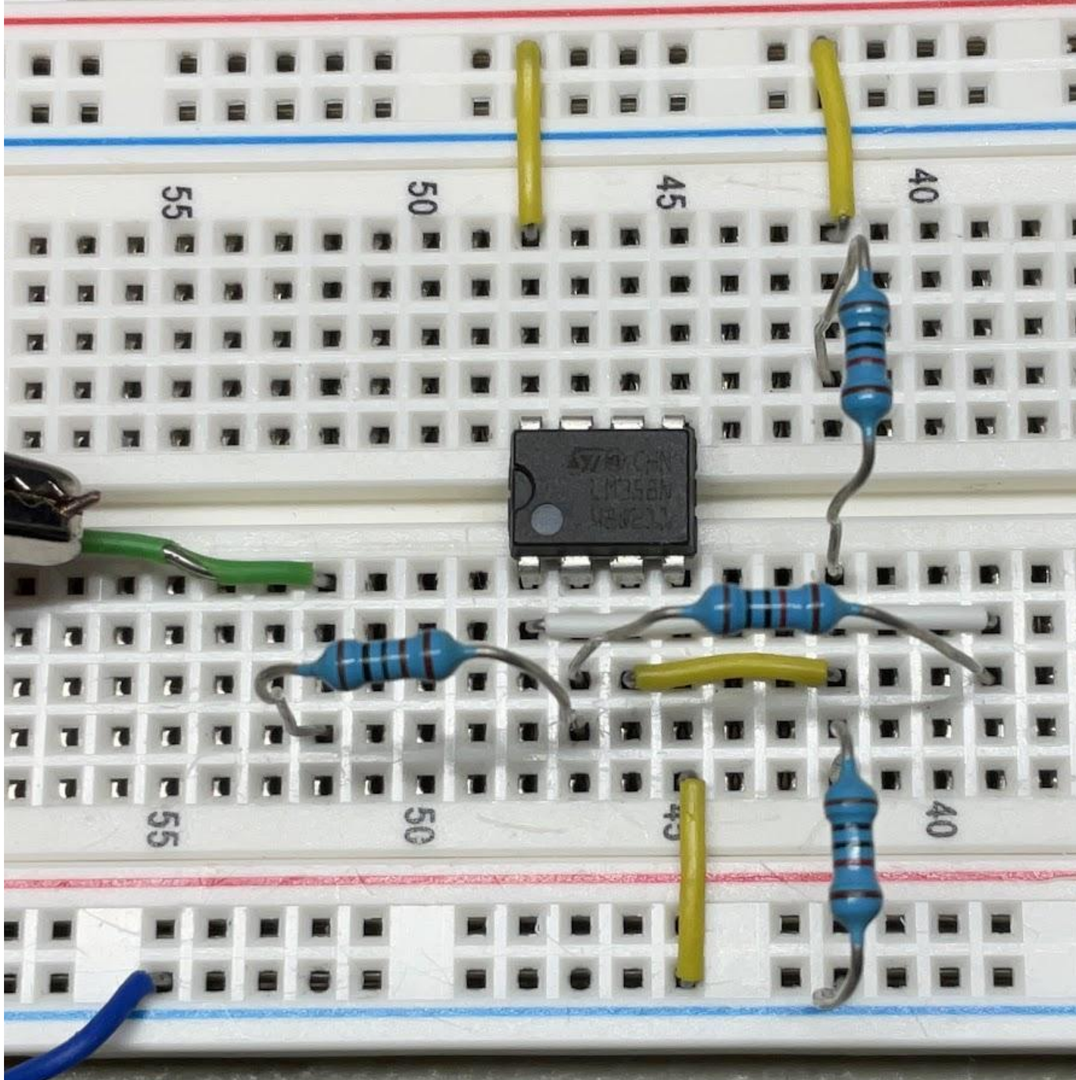
The Inverting Amplifier

- You can see the input in yellow on a 1 volt per division scale and the output in purple on a 10 volt per division scale.
- Note that the output is out of phase with the input.
- Also not how we get clipping anytime the output tries to go negative.



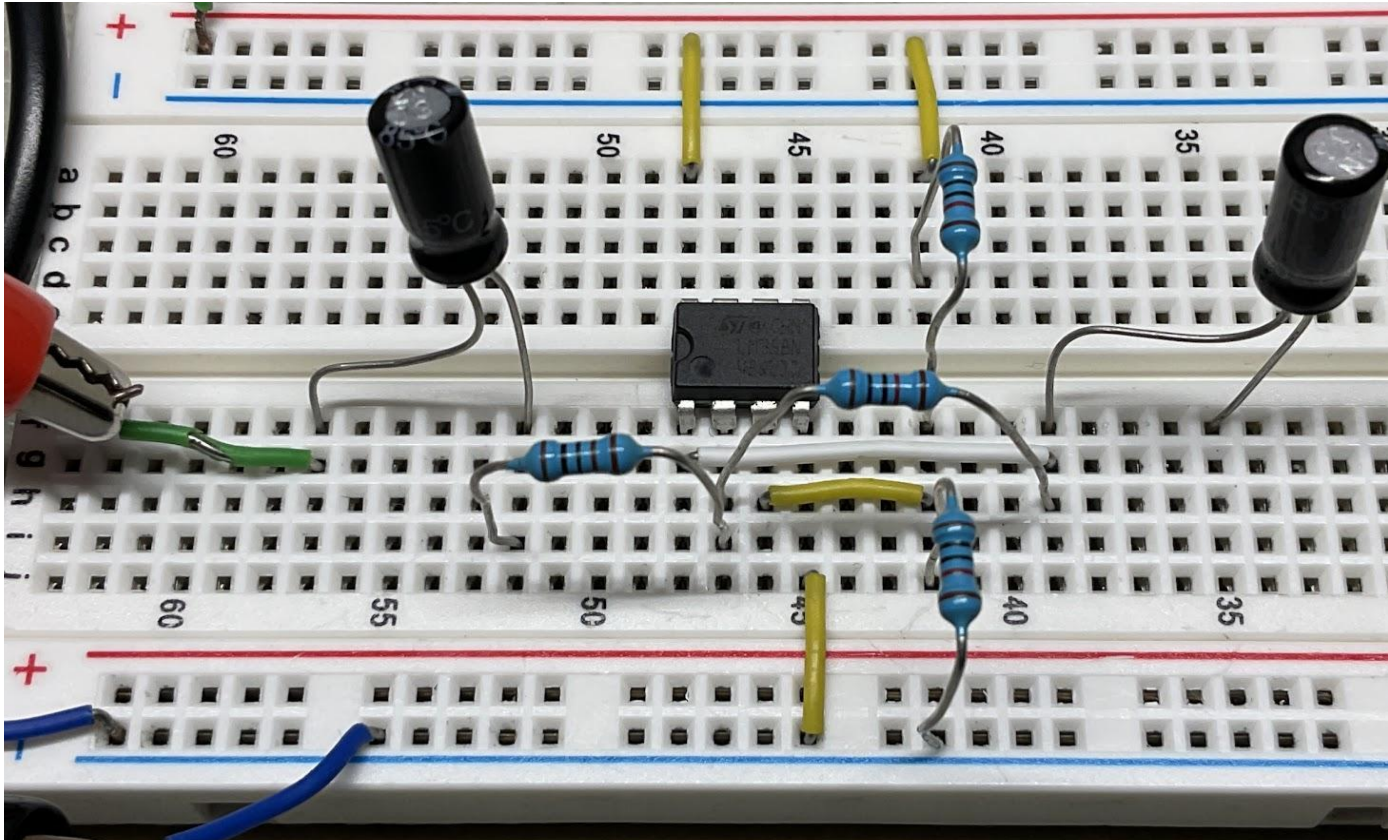
The Inverting Amplifier

- Since our voltage range is 0V to 9V, we don't want to ground (0V) our non-inverting input! That gives NO ROOM for amplification!
- Instead, we should set pin 3 (the non inverting input) to Vcc/2.
- We can do that with a voltage divider.
- Create a voltage divider with two 10K (brown, black, black, red) resistors.
- Connect the midpoint of the voltage divider to pin 3 (the non inverting input).



The Inverting Amplifier

- Lastly, let's put some 1 microFarad capacitors on the input and output of the circuit.



The Inverting Amplifier