INTRO | mki x es.edu

Hey there, thanks for buying this DIY kit! We – **Erica Synths** and **Moritz Klein** – have developed it with one specific goal in mind: teaching people with little to no prior experience how to design analog synthesizer circuits from scratch. So what you'll find in the box is not simply meant to be soldered together and then disappear in your rack.
Instead, we want to take you through the circuit design process step by step, explaining every choice we've made and how it impacts the finished module. For that, we strongly suggest you follow along on a **breadboard[1],** which is a non-permanent circuit prototyping tool that allows you to experiment and play around with your components. To help you with this, we've included suggested breadboard layouts in select chapters.
In addition to this, you can also play around with most of the chapter's circuits in a **circuit simulator** called CircuitJS. CircuitJS runs in your browser. You'll find weblinks in the footnotes which will direct you to an instance that already has example circuits set up for you. We strongly encourage you to fiddle with the component values and general structure of those circuits to get a better understanding of the concepts we're laying out.
Generally, this manual is intended to be read and worked through front to back, but there were a few things we felt should go into a dedicated appendix. These are general vignettes on electronic components & concepts, tools, and the process of putting the module together once you're done experimenting. Don't hesitate to check in there whenever you think you're missing an important piece of information. Most importantly though: have fun!

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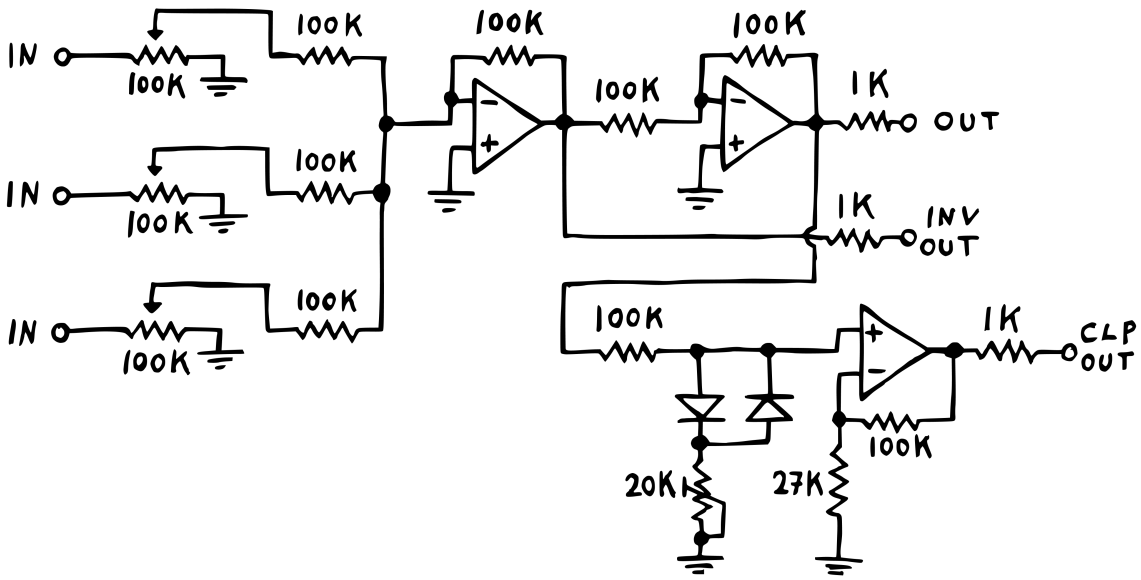
[1] Note that there is no breadboard included in this kit! You will also need a pack of jumper wires and two 9 V batteries with clips. These things are cheap & easy to find in your local electronics shop.

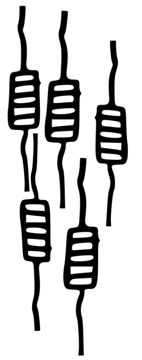
THE mki x es.edu MIXER

Mixing might be more of a utility function in a modular synthesizer – but this doesn't necessarily mean it has to be dull and boring. Case in point: this super simple three channel mixer with built-in diode distortion I designed that will make your patches sound delightfully rough.



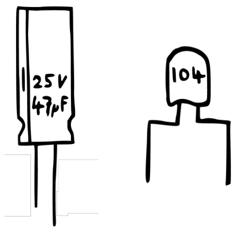
BILL OF MATERIALS

Before we start, please check if your kit contains all of the necessary components. In addition to a PCB, panel and power cable, your box should also contain:



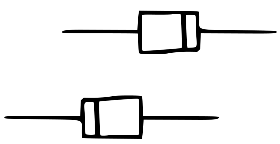
A bunch of resistors. The specific values (in ohms, which you should check for with a multimeter) are

100k	x8
27k	x1
1k	x3
10 Ω	x2



A few capacitors. The specific values (which are printed onto their bodies) are

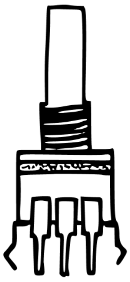
47 μF (electrolytic)	x2
100 nF (104/ceramic)	x6



Some diodes. The specific model names (which are printed onto their bodies) are

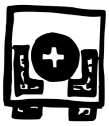
SB140[2] (schottky)	x2
1N4148 (signal)	x2

[2] Please note that these could also be a different model (e.g. 1N5818).



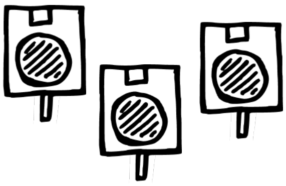
A couple regular potentiometers. The specific values (which may be encoded & printed onto their bodies) are

100k (B104) x3



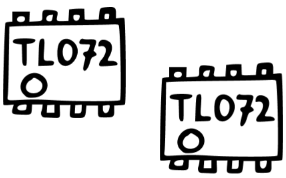
A trimmer potentiometer. The specific value (which is encoded & printed on top) is

20k (203) x1



A bunch of jack sockets. The specific models (which you can identify by their color) are

Switched mono (black) x6



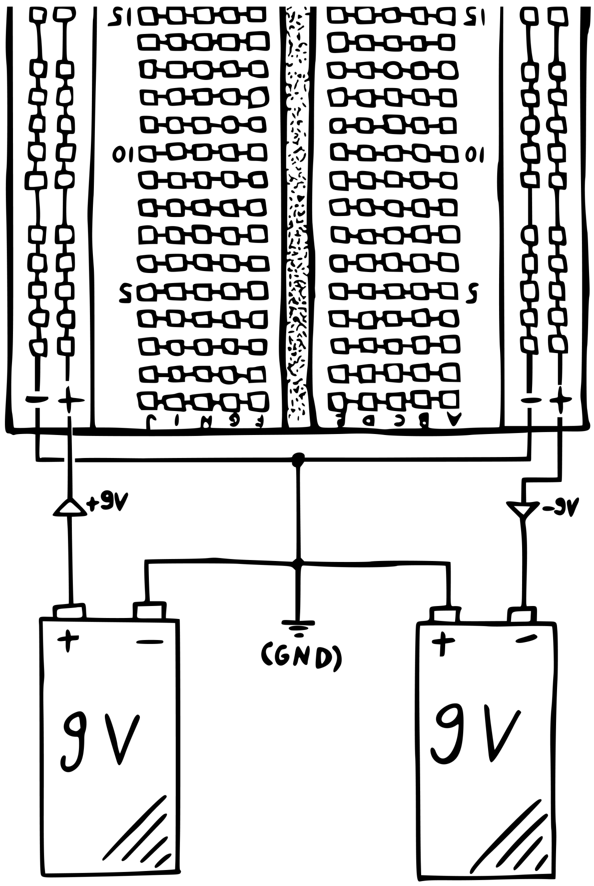
A couple of chips. The specific model (which is printed onto their bodies) is

TL072 (dual op amp) x2

You will also find a few sockets that are only relevant when assembling the module in the end.

POWERING YOUR BREADBOARD

Before we can start building, you'll need to find a way of providing your breadboard with power. Ideally, you'd use a dual 12 V power supply for this. Dual power supplies are great – and if you want to get serious about synth design, you should invest in one at some point. But what if you're just starting out, and you'd like to use batteries instead? Thankfully, that's totally doable. **You just need to connect two 9 V batteries to your breadboard like shown here**.[3] For this, you should use 9 V battery clips, which are cheap & widely available in every electronics shop.



By connecting the batteries like this, the row on the left side labeled **+** becomes your positive rail, the row on the right side labeled **+** becomes your negative rail, and both rows labeled **–** become your ground rails.[4]

Please make sure you disconnect the batteries from your breadboard when you make changes to the circuit! Otherwise you run the risk of damaging components.

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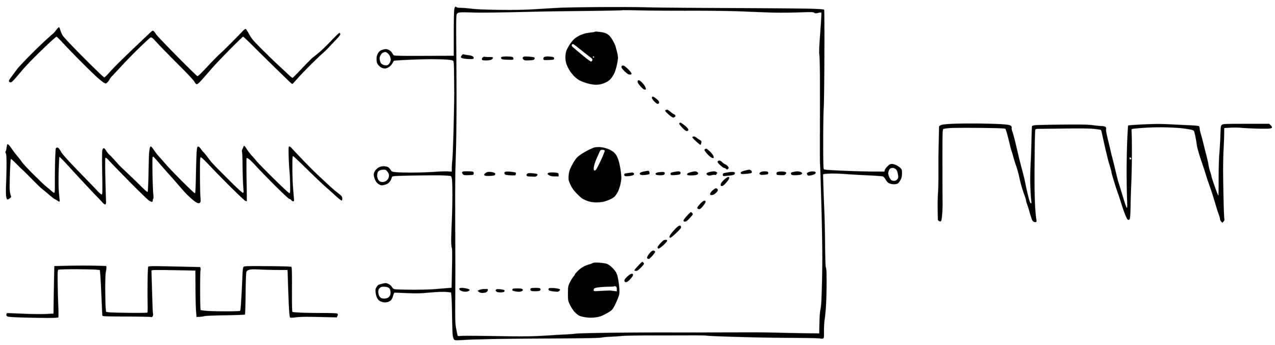
[3] Since all circuits in this manual were designed for a 12 V power supply, we assume that to be the default. Everything will still work roughly the same with 9 V, though.

[4] This is a bit awkward because breadboards weren't really made with dual supply voltages in mind.

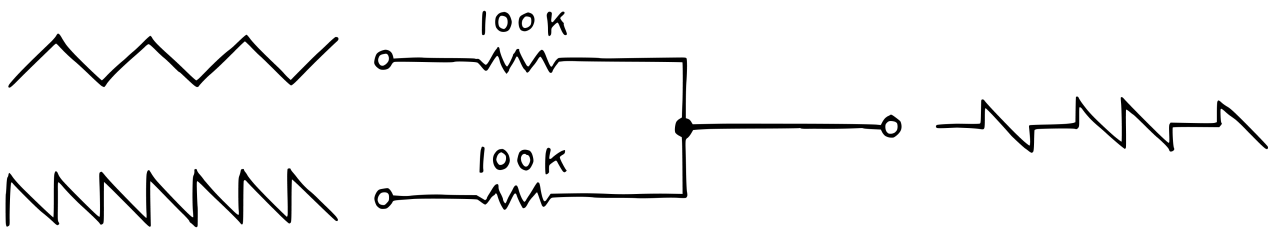
MIXING BASICS

Before we can talk about the circuit's design, we need to understand what a mixer does, exactly. Thankfully, compared to other types of modules like oscillators, filters and VCAs, mixers are pretty straightforward and simple devices. **They've got one basic purpose: take multiple input signals and mix them together**.

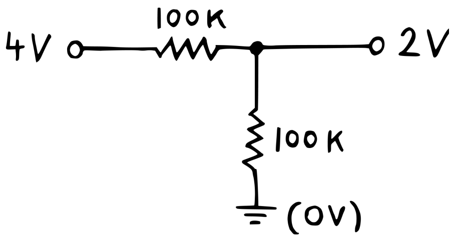


The result should then be made available via a single output. Ideally, we'd also want to adjust the individual volume levels for every input signal. And once that works, we'll talk about how we can abuse a couple of diodes to implement nice, warm distortion on a separate output.

PASSIVE MIXER

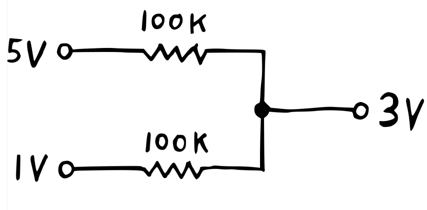


To start out, we'll first take a look at the simplest mixing circuit imaginable: two resistors, connected together on one side.[5] Send in your two input signals on the other side, and you've got a mix going. Here's how it works. **The two resistors, taken together, form a voltage divider – which might sound somewhat confusing at first.**[6]



Usually, you see voltage dividers being set up like this: with one resistor connected to a reference voltage and the other connected to ground. If both resistors are of the same value, you can pick up half of the reference voltage in the middle between them.

In our setup above, confusingly, both resistors are connected to reference voltages – which also change over time, since we're dealing with oscillations here. Can we even call that a voltage divider, then?



Actually: yes! If we simply freeze time at any moment, we will see something like this: two fixed input voltages and a fixed output voltage. Now of course, either of these input voltages may or may not sit at ground level. But for a voltage divider, it's mostly irrelevant what the two input voltages are, exactly. **What matters is the difference between the two inputs – which is what the divider is operating on**.

Since both resistors in our divider are of the same value, that 4 V difference will be slashed in half – and the result gets added to the lower of the two input voltages. Giving us a 3 V output. The „grounded" voltage divider does exactly the same thing, if you think about it: it slashes the difference between our reference voltage and ground in half – and then adds it to the lower of the two input voltages.

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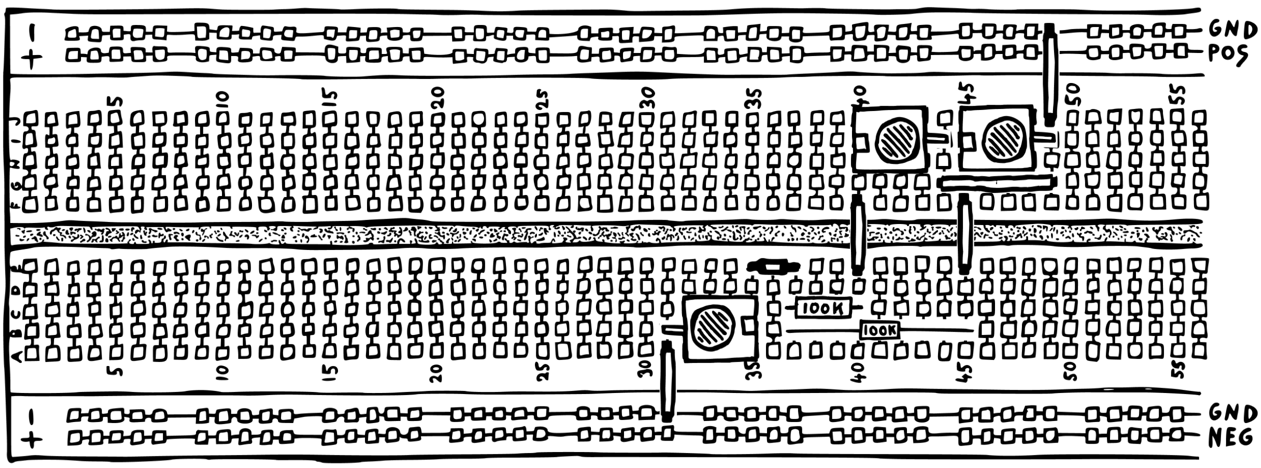
[5] Read more about resistors in the components & concepts appendix (page 21).

[6] Read more about voltage dividers in the components & concepts appendix (page 24)

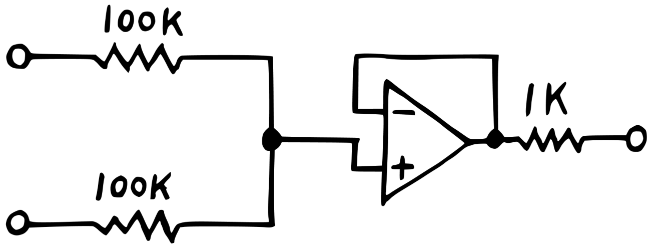
Because that operation stays the same regardless of what the exact input voltages are, the output will always be the mid point between them.[7] **That's why the setup above works as a mixer: it simply puts out the average of our input signals**. To try this in practice, let's set it up on the breadboard.



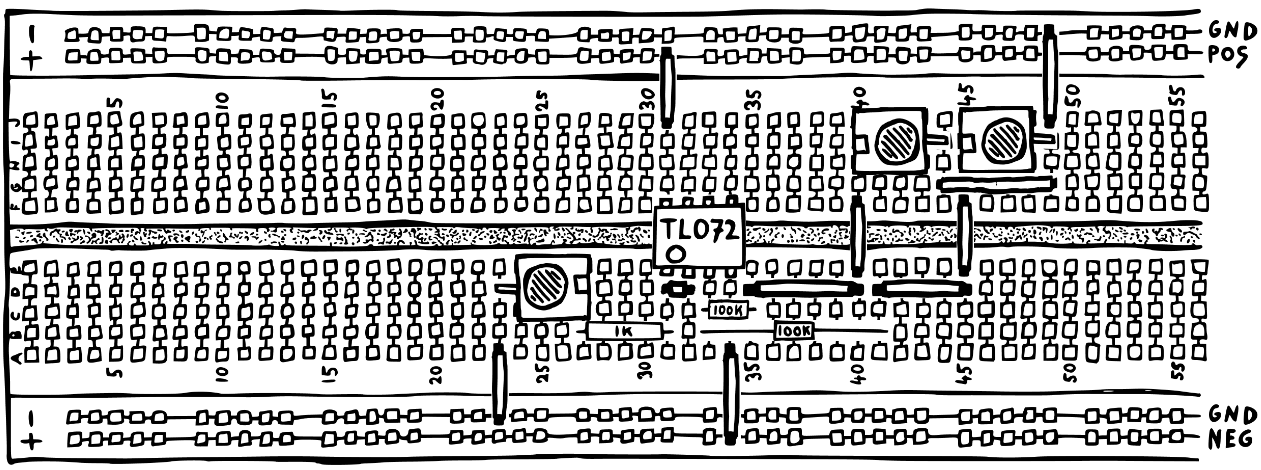
For your two inputs, you can use any regular audio signal – coming from an oscillator, your phone, or a drum machine, for example. You should then be able to hear both signals in the circuit's output. That is, if you connect it to anything with a built-in amplifier. **If you use headphones directly, you'll barely be able to hear the mixed output**. This is because this mixer is passive – meaning that it does not amplify the mixed signal.
Why is this a problem? Because the two resistors strongly limit the amount of current that'll reach and drive your headphones. **In electronics jargon, we'd say that this circuit has a really high output impedance**.

[7] You can try this chapter's circuits in a circuit simulator. I've already set them up for you right here: https://tinyurl.com/2bnc2s6c – you can change all values by double clicking on components.

SIMPLE ACTIVE MIXER



To fix that, we'll simply set up an op amp buffer between our two resistors and the output socket.[8] A buffer, if you don't know, basically just provides a copy of the voltage you apply to it without pulling any current into its input. **This way, we reduce the output impedance drastically, because the buffer is able to drive our headphones directly**. [9]Still, we don't want that output impedance to be zero – simply because it would make our op amp vulnerable to short circuits.
So we'll put a 1k resistor between our buffer and the output socket. This is low enough a resistance to drive our headphones properly – but high enough to limit the current flowing to safe amounts in case of a short. For the op-amp, we'll be using a TL072 IC, which is two op-amps in a single chip. **Make sure that you set it up exactly as shown here – if you reverse the power connections, it will heat up and die!**

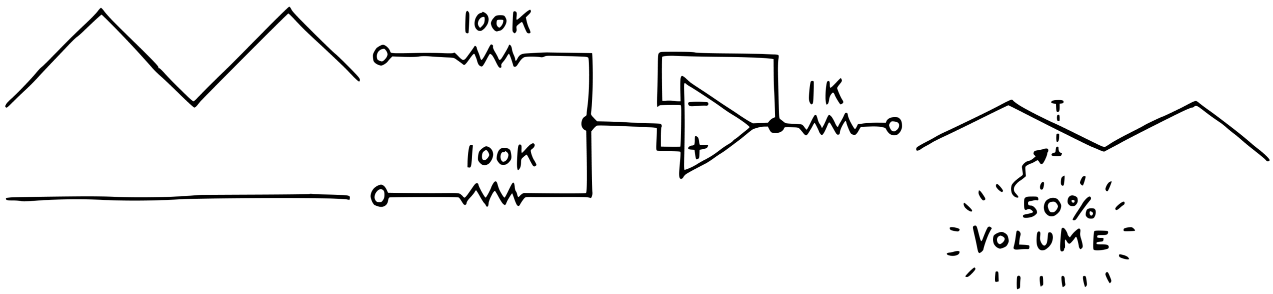


If you send in the same two input signals and check on the output through headphones, the mix should be boosted back up. But: there is another volume-related issue with our design. Remember how we said that our voltage divider is creating an average of its two

[8] Read more about op amps and buffers in the components & concepts appendix (page 27/28).

[9] You can try this chapter's circuit in a circuit simulator. I've already set it up for you right here: https://tinyurl.com/22pdlvek – you can change all values by double clicking on components.

input signals? While this does work as a mixing technique, it has a noticeable downside. **The two input signals are always interacting in the mix**.

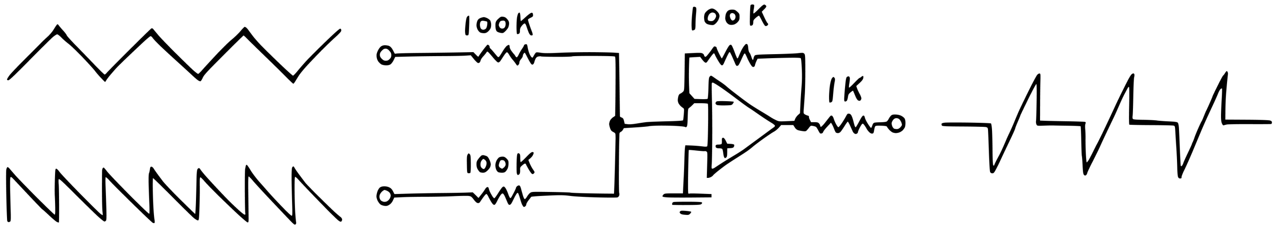


Here's an example. Imagine that signal one is currently active – we're getting a triangle oscillation at full volume. At the same time, signal two is currently silent – so the input is sitting at 0 V permanently. **Since our mixer is creating the average of the two signals, the output will be the triangle oscillation at half volume**.

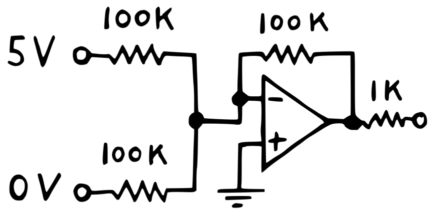
You can test this by tying one input resistor to ground (simulating a silent input) – or not connecting it to anything at all to (removing the input completely). You should be able to hear the volume go down significantly once you apply the „silent" signal. This is not really great. **Normally, you'd expect a mixer to give you the oscillation at full volume in this case – the state of the other signal shouldn't matter**.

INVERTING MIXER

How do we achieve that? Simple. Instead of creating the average of our inputs, we need to add them together – so that oscillation plus silence equals the unaltered oscillation. **To get there, we have to take a slightly confusing detour, though: turning our regular buffer into an inverting buffer**. To do that, we set up our op amp like this.

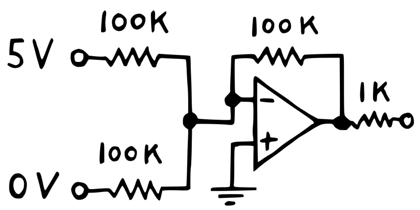


The jumper between output and inverting input gets replaced with a 100k resistor, while we tie the non-inverting input to ground. Then, we connect our two input resistors to the inverting input. What does this do – and why does it help? Well, first of all, it causes our output signal to be inverted. So the output will be flipped on its head.
In isolation, this seems like a pretty random and useless change. But doing this comes with a sort of hidden benefit – which becomes apparent once we understand how the circuit works as a whole. So let's analyze this setup.

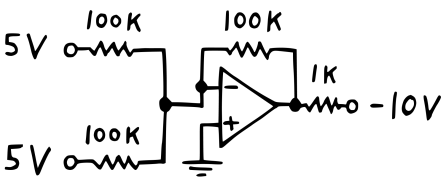


To simplify things, we'll again assume that our two input voltages are static, fixed at 5 and 0 V respectively. **Now, since we've tied the op amp's non-inverting input to ground (0 V), the output voltage can only stabilize if the voltage at the inverting input is nearly 0 V as well**. This is because that output voltage depends on the two input voltages.
It works like this. An op amp is a differential amplifier – which means that it amplifies the difference in voltage between its two input terminals. To do that, it subtracts the voltage measured at its inverting input from the voltage at its non-inverting input. The result gets multiplied by the op amp's gain – which is a very large number.
Then, the op amp's output tries to set its voltage to the result of that calculation. If it's outside of the supply voltage range, it will settle for the last possible value. This simple relation gets complicated by the fact that we connect the output to the inverting input through a resistor. Because then, **if the output voltage changes, the input voltage will be affected as well – which in turn affects the output voltage, which again affects the input voltage, and so on**.

We call this a feedback loop. That feedback loop will ensure that the voltage at the inverting input is always very close to 0 V. Because if it isn't, the output voltage will adjust until it is – the feedback loop forces the whole setup into a stable state.
Here's how it does that. Whenever the voltage at the inverting input is significantly above 0 V, the result of the subtraction will be negative. Amplify this by the huge gain, and the output is crashing down to the negative supply voltage. At the same time, if the voltage at the inverting input is significantly below 0 V, the result of the subtraction will be positive – so the output jumps up to the positive supply voltage.
This means that whenever the voltage at the inverting input tries to go above 0 V, the output pushes it back down. And if it tries to go below 0 V, the output pulls it back up. They're locked in a stalemate, basically. **Now, because of this, we say that the inverting input is a virtual ground node – simply because it behaves just like a connection to ground (by always sitting at 0 V), without actually being one**.

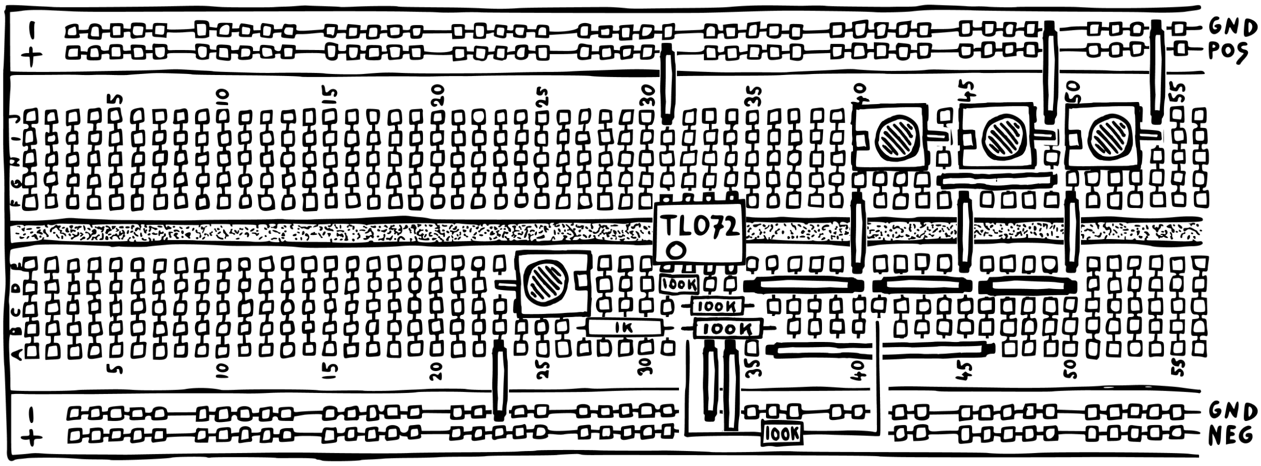


Now, why is this important and/or helpful for our problem? Well, let's look at the rest of our example again. We now know the voltages for these three points: 5 V at input one, 0 V at input two, and 0 V at the inverting input. Given these three values, we can deduct what the op amp's output voltage will have to be.
In order to get the voltage at the inverting input down to 0 V, the output has to neutralize the current flowing through our two input resistors. Since one signal is sitting at 0 V though, there's nothing coming in on that path anyways.
So we only have to worry about the other one. Here, the relation is really simple: **our output has to pull exactly as much current through the feedback resistor as our input is pushing through the input resistor**. Since both resistors are of the same value, both the pushing and pulling forces have to be exactly equal – just inverted. This means that our output has to sit at -5 V to neutralize the 5 V at input one!
Now, if we ignore the minus sign for a second and check our two input voltages again, we see that we got exactly what we were looking for: a 5 V output for a combination of a 0 V and a 5 V input! **So it looks like as if our buffer is indeed simply adding the two input voltages together (while also inverting them, of course)**.



To verify this, let's assume that input two jumps up to 5 V. Then to keep the voltage at the inverting input at 0 V, the op amp's output has to also neutralize the additional current being pushed through the second resistor. Since the added pushing force is exactly the same as the other, facing the same resistance, it will simply double the amount of current flowing. Forcing our op amp's output to pull twice as hard.

So we get an output voltage of -10 V. And again, ignoring the minus sign, the two input voltages simply got added together – nice![10] **Conveniently, this idea works not just for two channels – we can simply scale it up by adding in more jack sockets and 100k resistors**. So let's set this up as a three-channel version.



Once you've set this up, check if the circuit still properly mixes your input signals. If it does, try simulating a silent input again and see if it affects the output volume of the other signal(s). You should hear that the volume is not affected at all. Great!

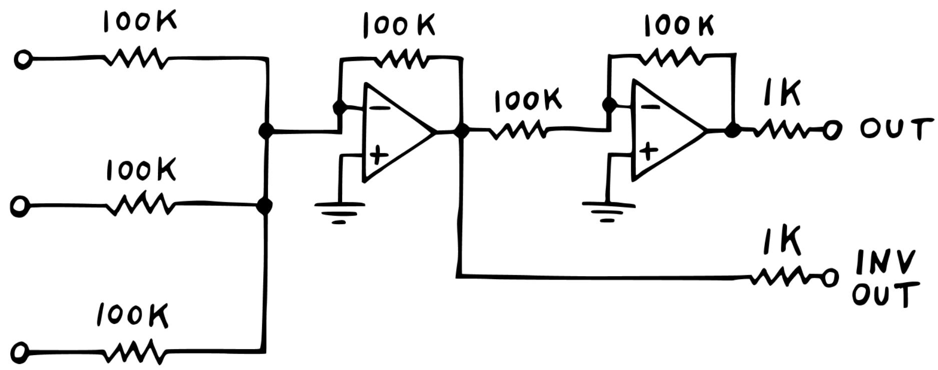
But now you might ask – why are we not running into any issues here if our mixer is currently inverting the output signal? Simple: because with audio signals, this doesn't have much of an effect. They're going to sound the same. **To your ears, an upside-down square wave is still the same old square wave**.

But if you want to mix CV from an LFO or an envelope, for example, this inversion will become painfully apparent. Simply because it means the difference between an open or a closed filter, for example.

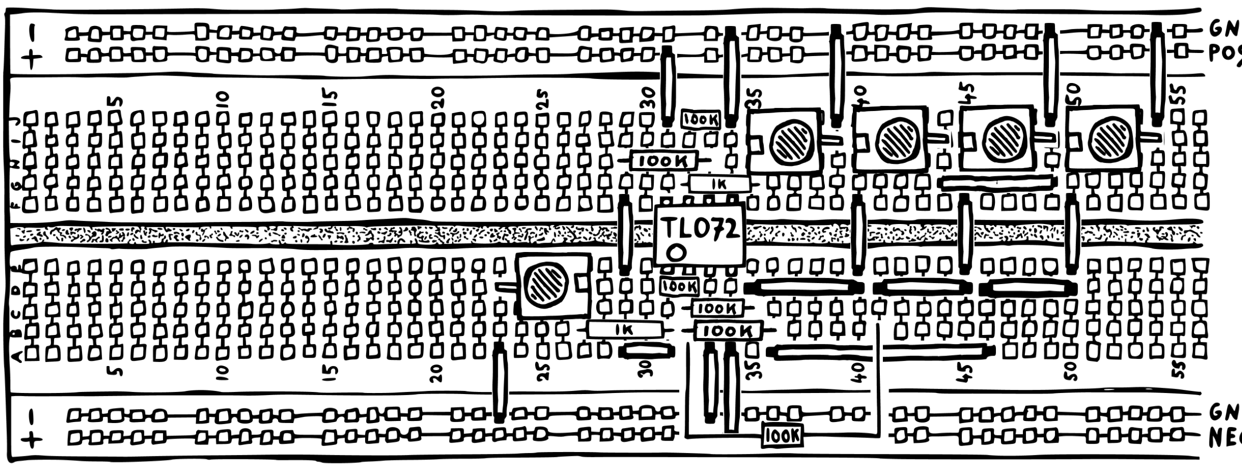
[10] You can try this chapter's circuit in a circuit simulator. I've already set it up for you right here: https://tinyurl.com/2avnzll2 – you can change all values by double clicking on components.

DOUBLE-NEGATIVE MIXER

So how do we get rid of the inversion? Easy – by inverting the inverted signal again. For that, we'll simply set up another inverting buffer with just a single input and place it between the previous one and the output socket.[11]



Since an inverted signal can be useful in certain situations though, it makes sense to keep it connected to a dedicated output socket where we can pick it up when needed.

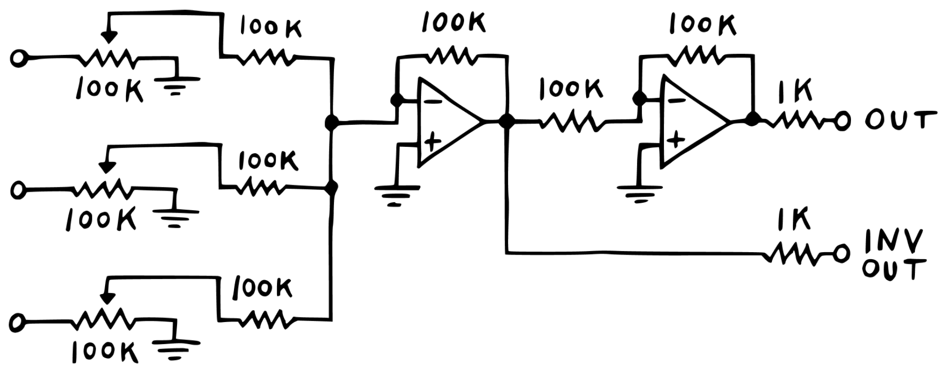


First off, verify that you still get an audio mix at the new non-inverted output. If that works fine, test it with CV coming from an envelope or an LFO. For that, connect it to the mixer's input, while sending the non-inverted output to a filter's CV input. Close the filter completely. You should hear the filter open up in sync with the envelope's status LED.
Next, use the inverted output instead while turning the filter's cutoff knob all the way to the right. The filter should now close down as the envelope's status LED gets brighter. So the mixer is indeed inverting the envelope's CV signal.

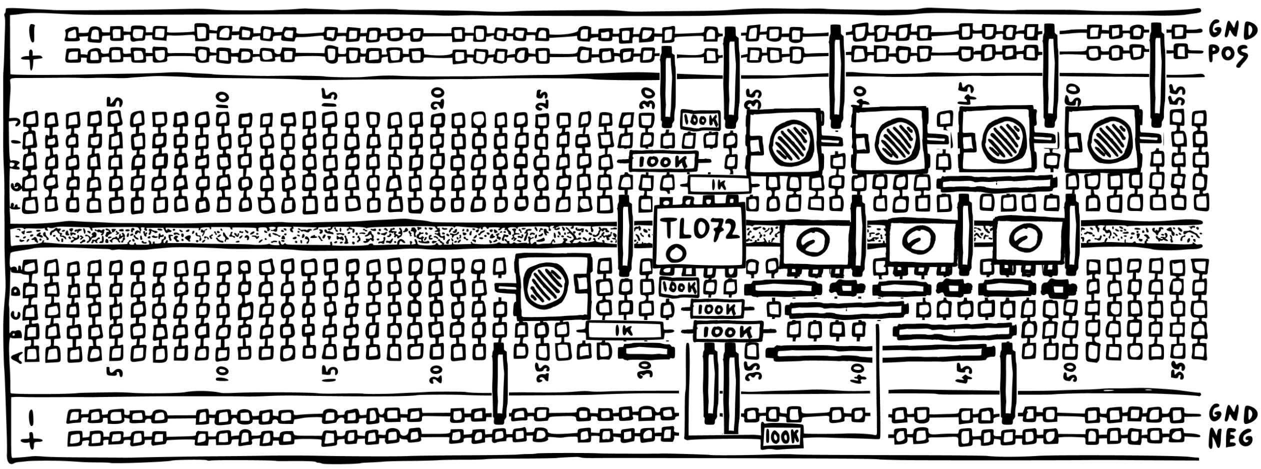
[11] You can try this chapter's circuit in a circuit simulator. I've already set it up for you right here: https://tinyurl.com/29zw4skf – you can change all values by double clicking on components.

ADJUSTABLE INPUT LEVELS

And while our circuit does work pretty well now, it's still missing a key feature: knobs to adjust the individual input levels. Thankfully, adding them is fairly trivial – **we just need to set up three potentiometers as variable voltage dividers (also called attenuators) between our input sockets and the 100k resistors.**[12]



The idea here is this: if we send an audio signal through a standard voltage divider, we're able to pick up a scaled-down version of that audio signal at the divider's output. The factor by which it's scaled down depends on the relation between the two resistors.
Conveniently, a potentiometer is basically a voltage divider as a standalone component – where you can change the resistance relation by turning a knob. This way, we're able to adjust the signals' volumes to any level between 100 and 0%.[13]



Once you've set this up, play with the three potentiometers. You should be able to adjust the individual channel levels.

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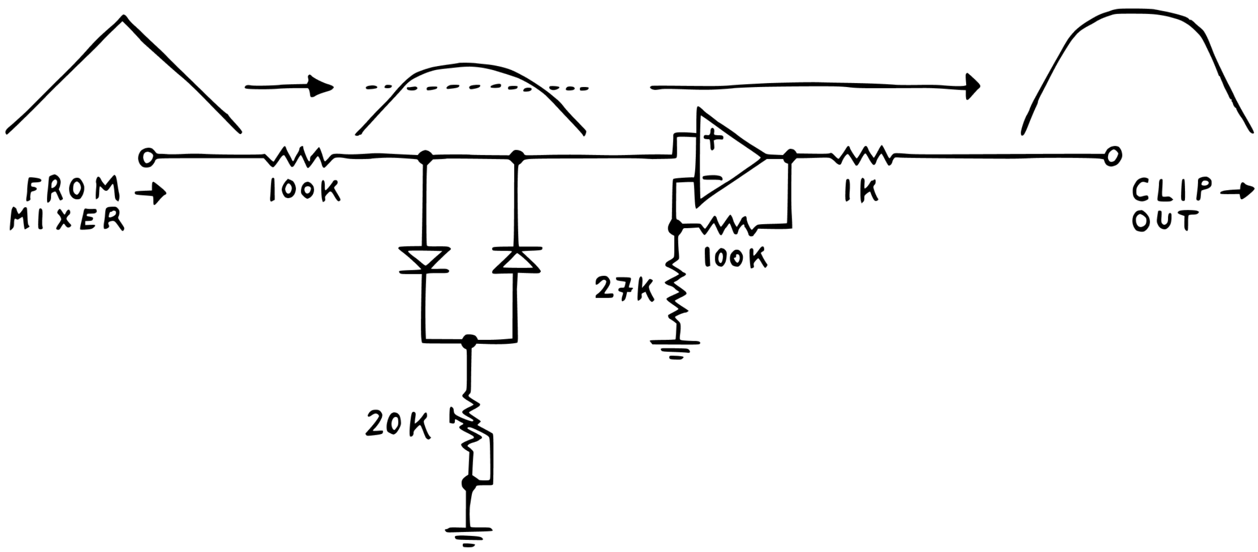
[12] Read more about potentiometers in the components & concepts appendix (page 25).

[13] You can try this chapter's circuit in a circuit simulator. I've already set it up for you right here: https://tinyurl.com/23q34odl – you can change all values by double clicking on components.

DIODE DISTORTION

With this, our mixer is now perfectly usable. I did promise an additional goodie in the beginning, though – so let's go the extra mile! There's a really simple & nifty trick if you want to add some distortion and warmth to our mixer's output. All we need for that are two diodes, a trimmer potentiometer, four resistors, and another op amp.



Here's how it works. After our mixer's regular output, we add in a 100k resistor, followed by a diode going to and another one coming from a 20k trimmer going straight to ground. That trimmer is set up as a variable resistor – so we can change its resistance on the fly. Then, we amplify the result with another op amp. What does this do?

To understand that, let's first assume that the trimmer is set to 0 ohms – so it's as if it isn't even there. Next, we'll say that the voltage at our mixer's output is slowly rising above the 0 V-line. In the beginning, the voltage after our 100k resistor will rise just the same. **This is because diodes don't actually conduct below a certain threshold input voltage.**[14]

I like to think of it like this. Diodes are essentially one-way valves for electricity. But to actually open those valves, we need to push against them with enough force. So as long as the pushing force from the op amp's output is relatively small, it won't be enough to open the diode pointing towards ground. Meaning that we'll see that force build up above it.

But as it keeps building up, the diode will start to open, allowing current to flow from the op amp's output through the 100k resistor and to ground. Which, in turn, will relieve some of the pushing force. This effect will only get more pronounced as the op amp pushes harder and the diode opens up wider. **So while the voltage at the op amp's output keeps rising, the voltage above our diode will begin to stagnate**.

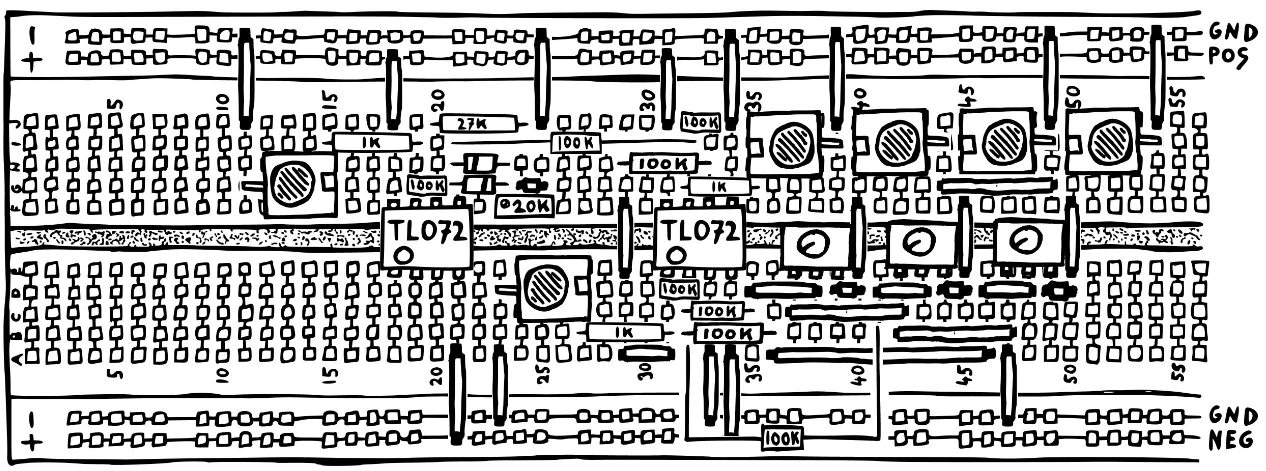
[14] Read more about diodes in the components & concepts appendix (page 23).

This is why we need the 100k resistor, by the way: because there is no limit to how far the diode can open up as the voltage increases. Without the resistor, we'd see the current ramp up exponentially, until we've basically created a short circuit. Since this isn't particularly healthy for our components and power supply, we use the 100k to restrict the amount of current flowing. This way, as the op amp pushes past a certain threshold, the voltage above our diode will simply stay constant – without anything going up in flames.

In audio terms, we call this effect soft clipping. We're essentially cutting off any part of our waveform that's above a certain threshold line. **And because the diode opens up somewhat gradually, the resulting edge will be slightly rounded**. (Hence the *soft* in soft clipping.)

As you might have guessed, the other diode pointing upwards from the trimmer serves exactly the same purpose, but for negative voltages. It opens up once the op amp pulls hard enough, clipping the lower half of our output waveform. Finally, in order to not mess with this delicate mechanism, we then have to buffer the output voltage with another op amp. Since the clipped signal is going to be quite low in volume, I decided to give that op amp a fair bit of gain.

To do that, we replace the straight connection between output and inverting input with a voltage divider. This will make it harder for the op amp to equalize its two input voltages, causing it to push and pull with more force. As a result, our clipped output should be brought back up to the regular output's volume levels.[15]



As an input signal, try a sawtooth- or sine-oscillation first. If you check the result on an oscilloscope, you should see that the top and bottom parts of the waveform indeed get shaved off. But while it does sound different, it's hard to really hear the effect with a static tone. So go ahead and try a more complex input signal – like a drum beat or a sequence.

Now, you might even find the effect to be too pronounced. If you do, no worries: that's what the trimmer potentiometer is for. **Because by increasing the trimmer's resistance value, you can influence the effect's intensity**.

[15] You can try this chapter's circuit in a circuit simulator. I've already set it up for you right here: https://tinyurl.com/29grj2ps – you can change all values by double clicking on components.

Here's how it works. If there's a resistance between our diodes and ground, we restrict the amount of current flowing. This means that for the same amount of pushing (or pulling) force above the diodes, less current will flow. Resulting in less of that force being used up (or relieved). **So more force is allowed to build up above the diodes before we see it stagnate – meaning that we've moved our clipping thresholds up and down respectively**. And the more resistance we dial in, the more that happens.

To test this, you don't have to set anything else up – you just need to fiddle with the trimmer a bit.[16] And with this addition, our mixer is done. If you now want to make your creation permanent, dig out the panel and PCB from the kit, heat up your soldering iron and get to building! You can find more information on how to populate the board & how to solder in the enclosed appendix.

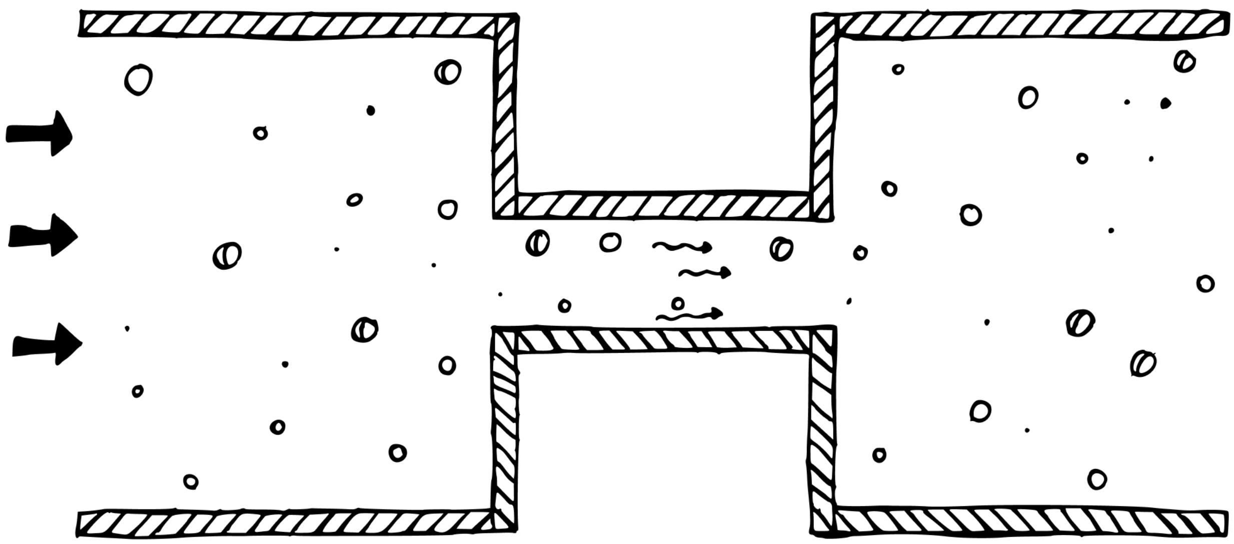
[16] You can also vary the effect by adjusting the mix levels – simply because if the signal going into the clipping stage is more quiet, there's less of the waveform to clip off.

COMPONENTS & CONCEPTS APPENDIX

In this section, we'll take a closer look at the components and elemental circuit design concepts we're using to build our module. Check these whenever the main manual moves a bit too fast for you!

THE BASICS: RESISTANCE, VOLTAGE, CURRENT

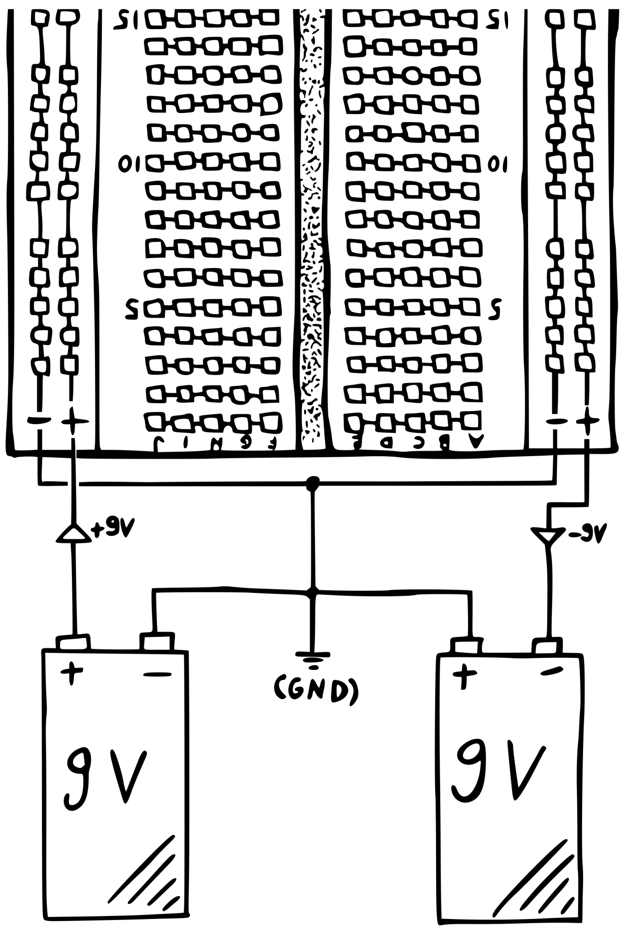
There are three main properties we're interested in when talking about electronic circuits: resistance, voltage and current. To make these less abstract, we can use a common beginner's metaphor and compare the flow of electrons to the flow of water through a pipe.



In that metaphor, resistance would be the width of a pipe. The wider it is, the more water can travel through it at once, and the easier it is to push a set amount from one end to the other. Current would then describe the flow, while voltage would describe the pressure pushing the water through the pipe. You can probably see how all three properties are interlinked: **more voltage increases the current, while more resistance to that voltage in turn decreases the current**.

USING TWO 9 V BATTERIES AS A DUAL POWER SUPPLY

Dual power supplies are great – and if you want to get serious about synth design, you should invest in one at some point. But what if you're just starting out, and you'd like to use batteries instead? Thankfully that's totally doable. **You just need to connect two 9 V batteries like shown here.** For this, you should use 9 V battery clips, which are cheap & widely available in every electronics shop.

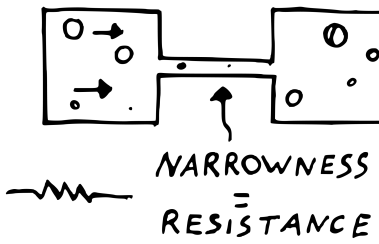


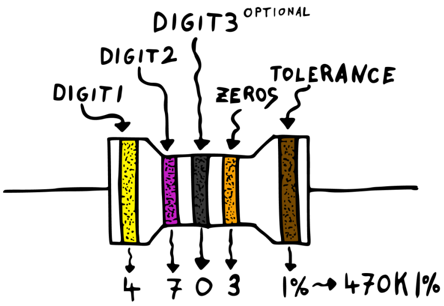
By connecting the batteries like this, the positive terminal of the left battery becomes your +9 V, while the negative terminal of the right is now your –9 V, and the other two combine to become your new ground.[17] **Please make sure you disconnect the batteries from your breadboard when you make changes to the circuit!** Otherwise you run the risk of damaging components.

[17] If you're struggling with setting this up, you can watch me do it here: https://youtu.be/XpMZoR3fgd0?t=742

RESISTORS

While a conductive wire is like a very big pipe where lots of water can pass through, **a resistor is like a narrow pipe that restricts the amount of water that can flow**. The narrowness of that pipe is equivalent to the resistance value, measured in ohms (Ω). The higher that value, the tighter the pipe.





Resistors have two distinctive properties: linearity and symmetry. Linearity, in this context, means that for a doubling in voltage, the current flowing will double as well. Symmetry means that the direction of flow doesn't matter – resistors work the same either way.

On a real-life resistor, you'll notice that its value is not printed on the outside – like it is with other components. Instead, it is indicated by colored stripes[18] – along with the resistor's tolerance rating. In addition to that, the resistor itself is also colored. Sometimes, depending on who made the resistor, this will be an additional tolerance indicator.

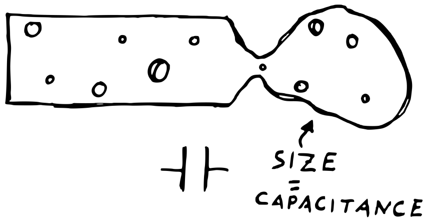
For the resistors in this kit, a yellow body tells you that the actual resistance value might be ±5 % off. A dark blue body indicates ±1 % tolerance. Some kits will also contain light blue ± 0.1% resistors to avoid the need for manual resistor matching.

While in the long run, learning all these color codes will be quite helpful, you can also simply use a multimeter to determine a resistor's value.

[18] For a detailed breakdown, look up resistor color coding. There are also calculation tools available.

CAPACITORS

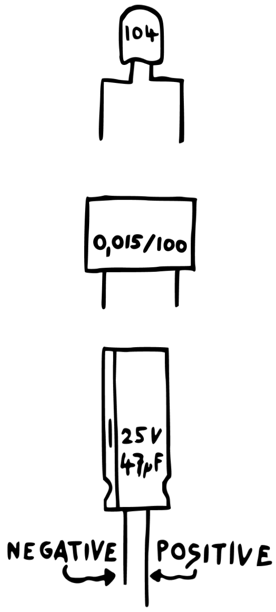
A capacitor is a bit like a balloon that you can attach to the open end of a pipe. If there's some pressure in the pipe, the balloon will fill up with water until the pressure equalizes. (Since the balloon needs some space to expand into, both of the capacitor's legs need to be connected to points in your circuit.)



Then, should the pressure in the pipe drop, the balloon releases the water it stored into the pipe. The maximum size of the balloon is determined by the capacitor's capacitance, which we measure in farad (F). There are quite a few different types of capacitors: electrolytic, foil, ceramic, tantalum etc. They all have their unique properties and ideal usage scenarios – but the most important distinction is if they are polarized or not.

You shouldn't use polarized capacitors against their polarization (applying a negative voltage to their positive terminal and vice versa) – so they're out for most audio-related uses like AC coupling, high- & low-pass filters etc.

Unlike resistors, capacitors have their capacitance value printed onto their casing, sometimes together with a maximum operating voltage. **Be extra careful here!** That voltage rating is important. Your capacitors can actually explode if you exceed it! So they should be able to withstand the maximum voltage used in your circuit. If they're rated higher – even better, since it will increase their lifespan. No worries though: the capacitors in this kit are carefully chosen to work properly in this circuit.



Ceramic capacitors usually come in disk- or pillow-like cases, are non-polarized and typically encode their capacitance value.[19] Annoyingly, they rarely indicate their voltage rating – so you'll have to note it down when buying them.

Film capacitors come in rectangular, boxy cases, are non-polarized and sometimes, but not always, directly indicate their capacitance value and their voltage rating without any form of encoding.[20]

Electrolytic capacitors can be identified by their cylinder shape and silver top, and they usually directly indicate their capacitance value and their voltage rating. They are polarized – so make sure you put them into your circuit in the correct orientation.

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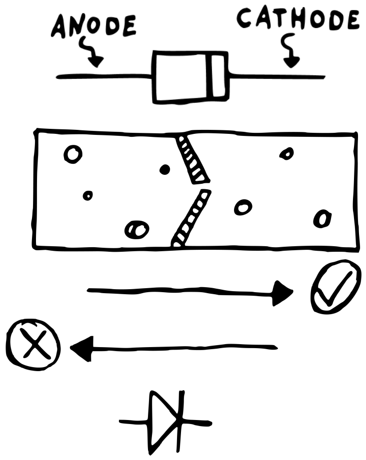
[19] For a detailed breakdown, look up ceramic capacitor value code. There are also calculation tools available.

[20] If yours do encode their values, same idea applies here – look up film capacitor value code.

DIODES

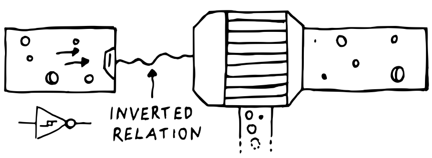


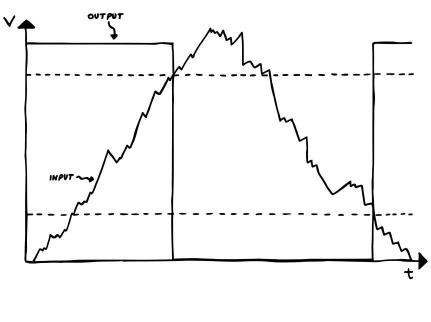
Diodes are basically like one-way valves. Current can only pass through in one direction – from anode to cathode. That direction is indicated by the arrow in the diode symbol and by a black stripe on the diode's casing. So any current trying to move in the opposite direction is blocked from flowing.

There are a few quirks here, though. For one, the diode will only open up if the pushing force is strong enough. Generally, people say that's 0.7 V**,** but in reality, it's usually a bit lower. Also, diodes don't open up abruptly – they start conducting even at much lower voltages, although just slightly.

There are a lot of different diode types: Zener, Schottky, rectifier, small signal etc. They all have their unique properties and ideal usage scenarios – but usually, a generic 1N4148 small signal diode will get the job done.

SCHMITT TRIGGER INVERTERS

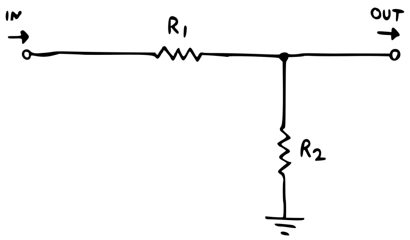




You can think of a Schmitt trigger inverter as two separate things. On the left, there's a sensor that measures the pressure inside an attached pipe. On the right, there is a water pump. This pump's operation is controlled by the sensor. Whenever the pressure probed by this sensor is below a certain threshold, the pump will be working. If the pressure is above a second threshold, the pump won't be working.

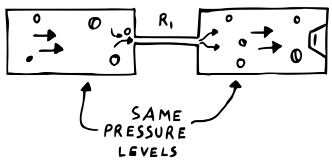
Here's a quick graph to visualize that. The squiggly line represents the voltage at the input, while the dotted line shows the voltage at the output. So every time we cross the upper threshold on our way up, and the lower one on our way down, the output changes its state. One thing that's very important to keep in mind: no current flows into the sensor! It's really just sensing the voltage without affecting it.

VOLTAGE DIVIDERS

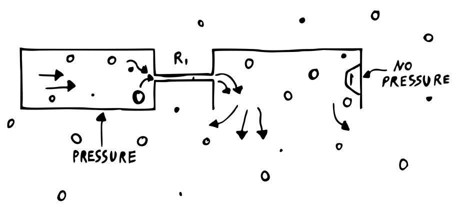


A voltage divider is really just two resistors set up like this: input on the left, output on the right. If R1 and R2 are of the same value, the output voltage will be half of what the input voltage is. How does it work?

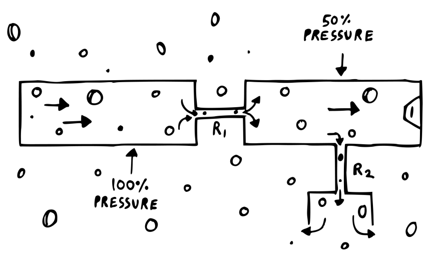
Let's use our analogy again: so we have a pipe on the left, where water is being pushed to the right with a specific amount of force. Attached to it is a narrow pipe, representing R1, followed by another wide pipe. Then at the bottom, there's another narrow pipe, representing R2, where water can exit the pipe system. Finally, imagine we've set up a sensor measuring the voltage in the right hand pipe.



First, think about what would happen if R2 was completely sealed off. Our sensor would tell us that **the pressure on the right side is exactly the same as the pressure on the left**. Because the pushing force has nowhere else to go.



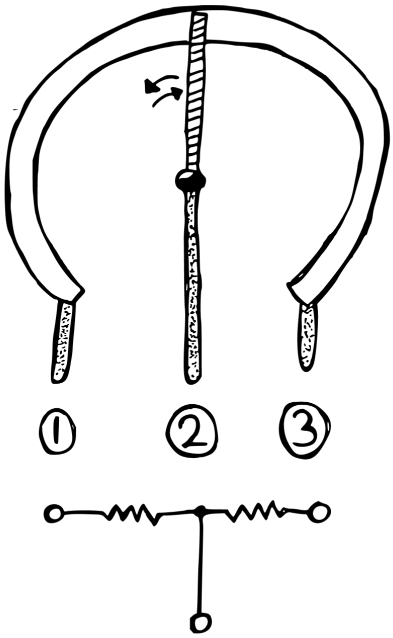
On the other hand, imagine R2 would just be a wide opening. Then **the pressure on the right would be 0**, because it'd all escape through that opening. But what happens if R2 is neither completely closed off nor wide open? Then the pressure would be retained to varying degrees, depending on the narrowness of the two resistor paths.



If pipe R1 is wide and pipe R2 is narrow, most of the pressure will be retained. But if it's the reverse, the pressure level will be only a tiny fraction. And if R1 and R2 are identical, **the pressure will be exactly half of what we send in**.

POTENTIOMETERS

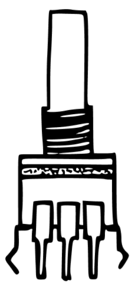
Potentiometers can be used as variable resistors that you control by turning a knob. But, and that's the handy part, they can also be set up as variable voltage dividers. To see how that works, let's imagine we open one up.

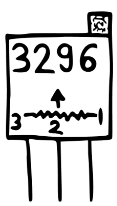


Inside, we would find two things: a round track of resistive material with connectors on both ends plus what's called a wiper. This wiper makes contact with the track and also has a connector. It can be moved to any position on the track. Now, the resistance value between the two track connectors is always going to stay exactly the same. That's why it's used to identify a potentiometer: as a 10k, 20k, 100k etc. But if you look at the resistance between either of those connectors and the wiper connector, you'll find that this is completely dependent on the wiper's position.

The logic here is really simple: **the closer the wiper is to a track connector, the lower the resistance is going to be between the two**. So if the wiper is dead in the middle, you'll have 50 % of the total resistance between each track connector and the wiper.

From here, you can move it in either direction and thereby shift the ratio between the two resistances to be whatever you want it to be. By now, you might be able to see how that relates to our voltage divider. If we send our input signal to connector 1 while grounding connector 3, we can pick up our output signal from the wiper. Then by turning the potentiometer's knob, we can adjust the voltage level from 0 to the input voltage – and anything in between.





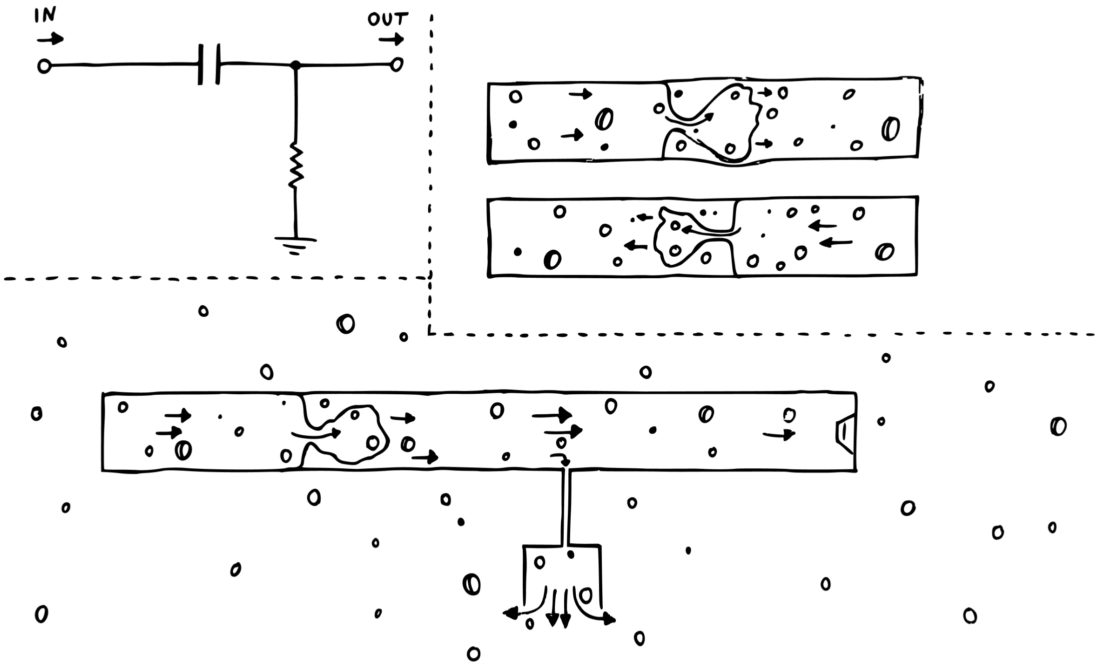
In these kits, you will encounter different types of potentiometers. First, there's the regular, full-size variant with a long shaft on top. These are used to implement user-facing controls on the module's panel and they usually – but not always – indicate their value directly on their casing. Sometimes, they'll use a similar encoding strategy as capacitors, though.[21]

Second, we've got the trimmer potentiometer, which is usually much smaller and doesn't sport a shaft on top. Instead, these have a small screw head which is supposed to be used for one-time set-and-forget calibrations. Trimmers usually encode their value.

[21] Look up potentiometer value code for a detailed breakdown.

AC COUPLING

What is AC coupling – and how does it work? Imagine two adjacent pipes with a balloon between them. Now, no water can get from one pipe into the other, since it's blocked by the balloon. But, and that's the kicker, **water from one side can still push into the other by bending and stretching the balloon, causing a flow by displacement**.

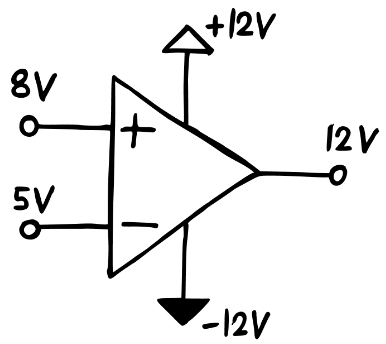


Next, we'll bring in a resistor after the coupling point, going straight to ground. **This acts like a kind of equalizing valve**. Now imagine we apply a steady 5 V from one side. Then on the other side, we'll read 0 V after a short amount of time. Why? Because we're pushing water into the balloon with a constant force, causing it to stretch into the other side, displacing some water. If we didn't have the equalizing valve there, we'd simply raise the pressure. But since we do have it, the excess water can drain out of the system. Until the pressure is neutralized, and no water is actively flowing anymore.

Okay, so now imagine that the voltage on the left hand side starts oscillating, let's say between 4 V and 6 V. When we start to go below 5 V, the balloon will begin contracting, basically pulling the water to the left. This will create a negative voltage level in the right hand pipe – like as if you're sucking on a straw, making the voltage there drop below 0 V. Then, once the pressure on the other side rises above 5 V, the balloon will inflate and stretch out again, pushing water to the right. And the pressure in the right hand pipe will go positive, making the voltage rise above 0 V. **We've re-centered our oscillation around the 0 V line.** Okay, but what about the resistor? If current can escape through it, doesn't that mess with our oscillation? Well, technically yes, but practically, we're choosing a narrow enough pipe to make the effect on quick pressure changes negligible!

OP AMPS

Op amps might seem intimidating at first, but they're actually quite easy to understand and use. The basic concept is this: every op amp has two inputs and one output. Think of those inputs like voltage sensors. You can attach them to any point in your circuit and they will detect the voltage there without interfering. **No current flows into the op amps inputs – that's why we say their input impedance is very high**. Near infinite, actually. Okay, but why are there two of them?



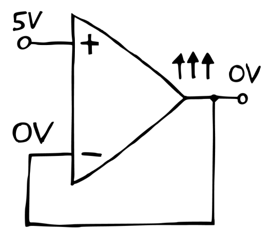
The key here is that op amps are essentially differential amplifiers. This means that they only amplify the difference between their two inputs – not each of them individually. If that sounds confusing, let's check out a quick example. So we'll imagine that one sensor – called the non-inverting input – is reading 8 V from somewhere. The other sensor – called the inverting input – reads 5 V. Then, as a first step, the op amp will subtract the inverting input's value from the non-inverting input's value. Leaving us with a result of 3. (Because 8 minus 5 is 3.) **This result then gets multiplied by a very large number – called the op amp's gain**. Finally, the op amp will try to push out a voltage that corresponds to that multiplication's result.

But of course, the op amp is limited here by the voltages that we supply it with. If we give it –12 V as a minimum and +12 V as a maximum, the highest it can go will be +12 V. So in our example, even though the result of that multiplication would be huge, the op amp will simply push out 12 V here and call it a day.

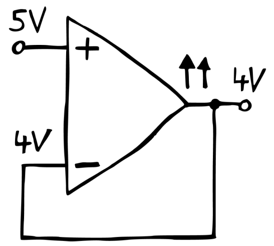
The handy thing though about op amp outputs is that they draw their power directly from the power source. This means that they can supply lots of current while keeping the voltage stable. **That's why we say an op amp has a very low output impedance**.

OP AMP BUFFERS/AMPLIFIERS

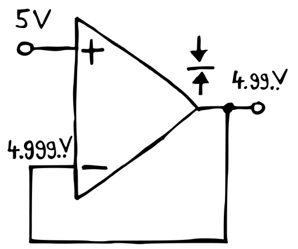
Buffering, in the world of electronics, means that we provide a perfect copy of a voltage without interfering with that voltage in the process. With an op amp-based buffer, the buffering process itself works like this. We use the non-inverting input to probe a voltage, while the inverting input connects straight to the op amp's output. **This creates what we call a negative feedback loop**. Think of it this way. We apply a specific voltage level to the non-inverting input – let's say 5 V.



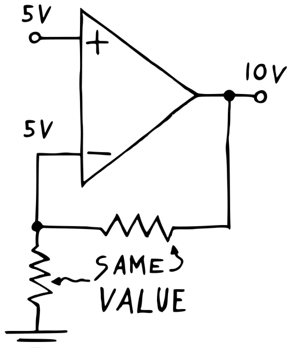
Before the op amp starts processing the voltages at its inputs, the output will be switched off. This means that **output and inverting input sit at 0 V at first**. So then, the op amp will subtract 0 from 5 and multiply the result by its gain. Finally, it will try and increase its output voltage to match the calculation's outcome.



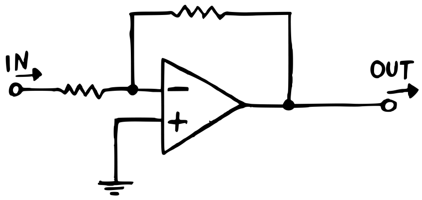
But as it's pushing up that output voltage, the **voltage at the inverting input will be raised simultaneously**. So the difference between the two inputs is shrinking down. Initially, this doesn't matter much because the gain is so large. As the voltage at the inverting input gets closer to 5 V though, the difference will shrink so much that in relation, the gain suddenly isn't so large anymore.



Then, the output will **stabilize at a voltage level that is a tiny bit below 5 V**, so that the difference between the two inputs multiplied by the huge gain gives us exactly that voltage slightly below 5 V. And this process simply loops forever, keeping everything stable through negative feedback. Now if the voltage at the non-inverting input changes, that feedback loop would ensure that the output voltage is always following. So that's why this configuration works as a buffer: the **output is simply following the input**.



How about amplifying a signal though? To do that, we'll have to turn our buffer into a proper non-inverting amplifier. We can do that by replacing the straight connection between inverting input and output with a voltage divider, forcing the op amp to work harder. Here's how that works. Say we feed our non-inverting input a voltage of 5 V. Now, **the output needs to push out 10 V in order to get the voltage at the inverting input up to 5 V**. We call this setup a non-inverting



amplifier because the output signal is in phase with the input.

For an inverting buffer/amplifier, the input signal is no longer applied to the non-inverting input. Instead, that input is tied directly to ground. So it'll just sit at 0 V the entire time. The real action, then, is happening at the inverting input. Here, we first send in our waveform through a resistor. Then, the inverting input is connected to the op amp's output through another resistor of the same value.

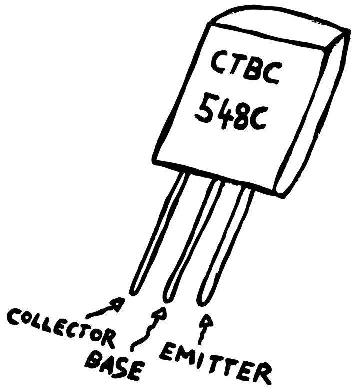
How does this work? Well, let's assume that we're applying a steady voltage of 5 V on the left. Then, as we already know, the op amp will subtract the inverting input's voltage from the non-inverting input's voltage, leaving us with a result of –5 V. Multiply that by the huge internal gain, and the op amp will try to massively decrease the voltage at its output.

But as it's doing that, an increasingly larger current will flow through both resistors and into the output. Now, as long as the pushing voltage on the left is stronger than the pulling voltage on the right, some potential (e.g. a non-zero voltage) will remain at the inverting input. Once the output reaches about –5 V though, we'll enter a state of balance. Since both resistors are of the same value, the pushing force on the left is fighting the exact same resistance as the pulling force on the right. **So all of the current being pushed through one resistor is instantly being pulled through the other**.

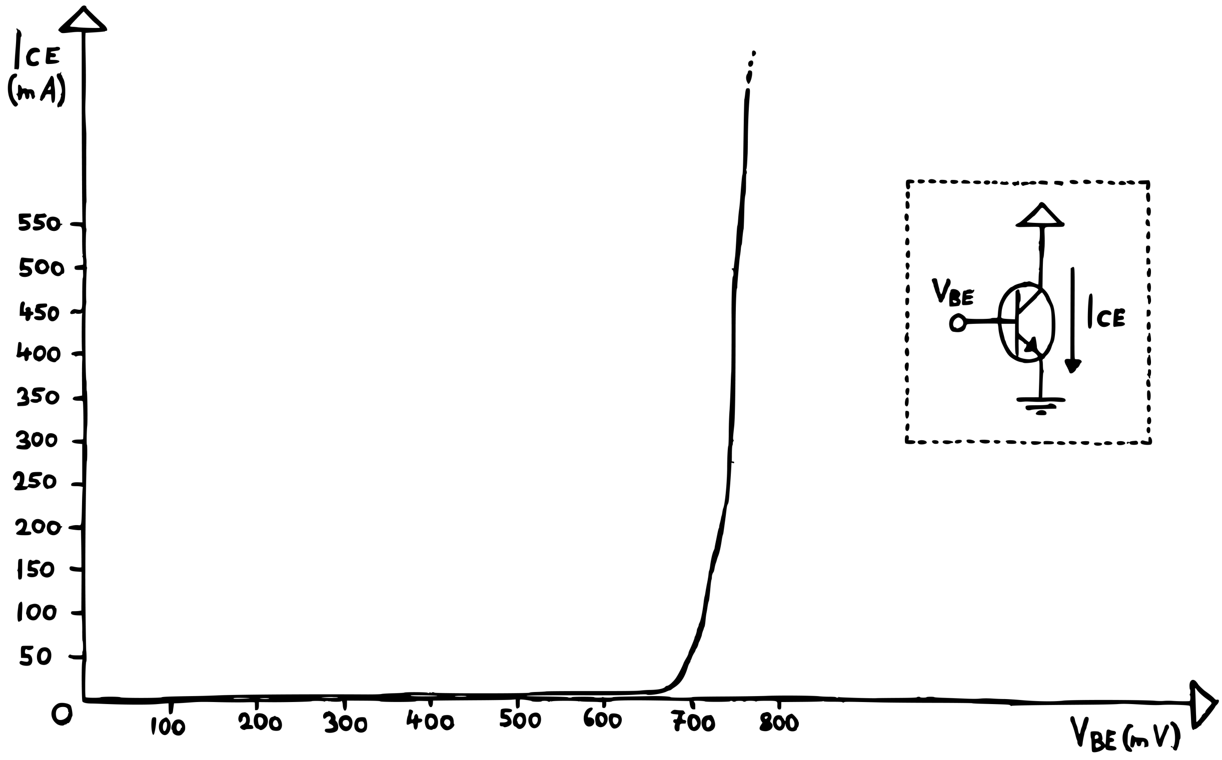
And that means that the voltage at the inverting input will be lowered to about 0 V, allowing our op-amp to settle on the current output voltage level. So while we read 5 V on the left, we'll now read a stable –5 V at the op amp's output. Congrats – we've built an inverting buffer! **If we want to turn it into a proper amplifier, we'll simply have to change the relation between the two resistances**. By doing this, we can either increase (if you increase the right-hand resistor's value) or reduce (if you increase the left-hand resistor's value) the gain to our heart's content.

BIPOLAR JUNCTION TRANSISTORS

Bipolar junction transistors (or BJTs for short) come in two flavors: NPN and PNP. This refers to how the device is built internally and how it'll behave in a circuit. Apart from that, they look pretty much identical: a small black half-cylinder with three legs.



Let's take a look at the more commonly used NPN variant first. Here's how we distinguish between its three legs. **There's a collector, a base and an emitter.**[22] All three serve a specific purpose, and the basic idea is that you control the current flow between collector and emitter by applying a small voltage[23] to the base. The relation is simple: **more base voltage equals more collector current**. Drop it down to 0 V and the transistor will be completely closed off. Sounds simple – but there are four important quirks to this.



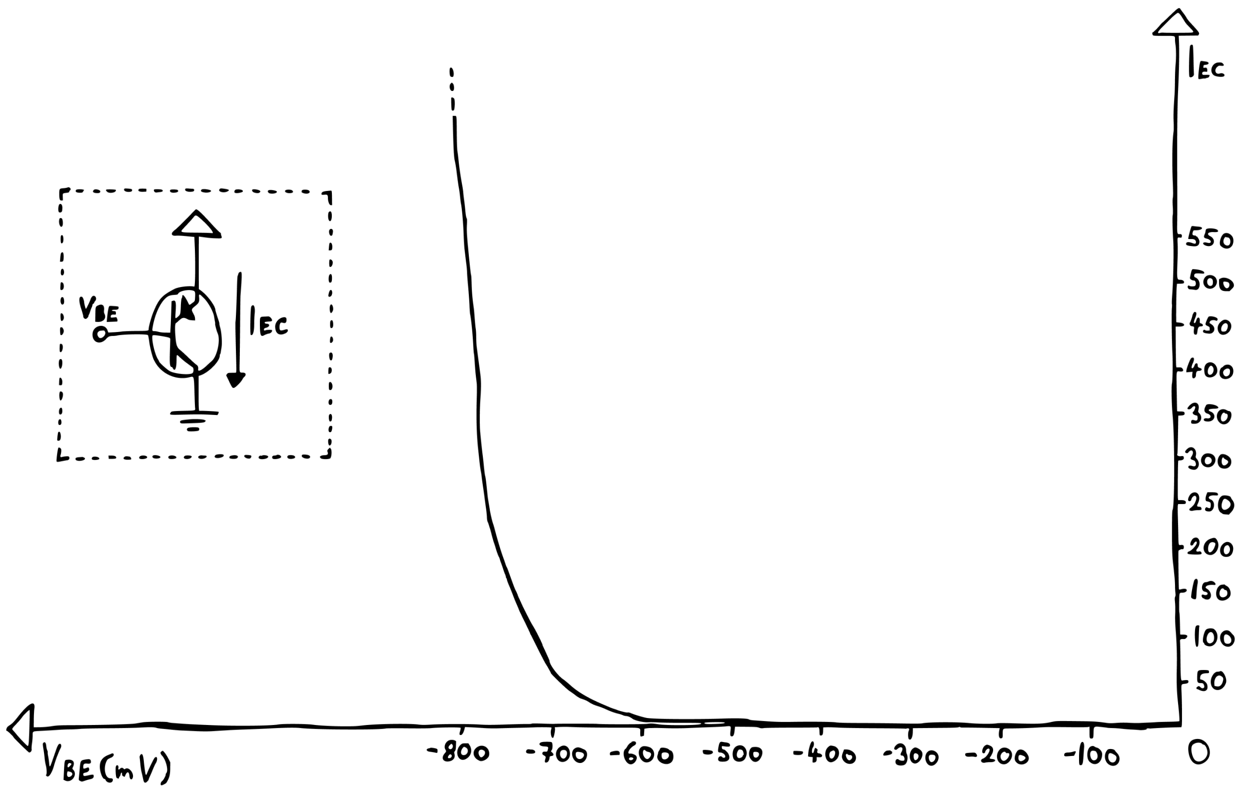
First, the relation between base voltage and collector current is exponential. Second, unlike a resistor, a BJT is not symmetrical – so we can't really reverse the direction of the

[22] Please note that the pinout shown here only applies for the BC series of transistors. Others, like the 2N series, allocate their pins differently.

[23] The voltage is measured between base and emitter. So „a small voltage" effectively means a small voltage **difference** between base and emitter!

collector current. (At least not without some unwanted side effects.) Third, also unlike a resistor, a BJT is not a linear device. Meaning that a change in collector voltage will not affect the collector current. And fourth, the collector current is affected by the transistor's temperature! The more it heats up, the more current will flow.

Now, for the PNP transistor, all of the above applies, too – except for two little details. Unlike with the NPN, **the PNP transistor decreases its collector current when the voltage at its base increases**[24]. So you have to bring the base voltage below the emitter to open the transistor up. Also, that collector current flows out of, not into the collector!

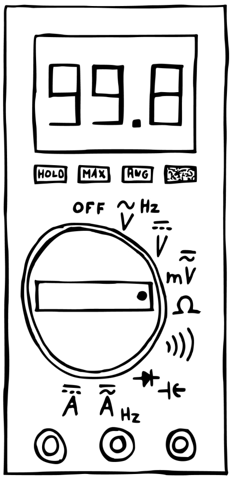


[24] Again, the voltage is measured between base and emitter.

TOOLS APPENDIX

There are two types of tools that will help you tremendously while designing a circuit: multimeters and oscilloscopes. In this appendix, we'll take a quick look at each of these and explore how to use them.

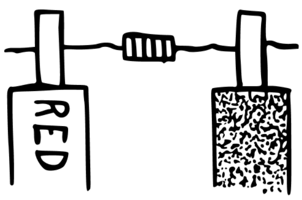
MULTIMETERS

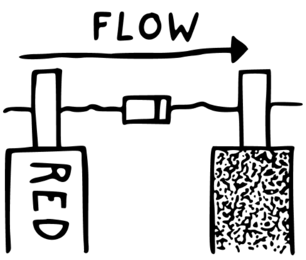


Multimeters come in different shapes and sizes, but the most common type is probably the hand-held, battery powered variant. It can measure a bunch of different things: voltage, current, resistance, continuity. Some have additional capabilities, allowing you to check capacitance, oscillation frequency or the forward voltage drop of a diode.

When shopping for one, you'll probably notice that there are really expensive models boasting about being TRUE RMS multimeters. For our purposes, this is really kind of irrelevant, so don't feel bad about going for a cheap model!

Using a multimeter is actually really straightforward. Simply attach two probes to your device – the one with a black cable traditionally plugs into the middle, while the red one goes into the right connector. Next, find whatever you want to measure and select the corresponding mode setting.





In some cases, it doesn't matter which probe you connect to which component leg or point in your circuit. This is true for testing resistors, non-polarized capacitors (foil/film, ceramic, teflon, glass etc.), continuity[25] or AC voltage.

In others, you'll have to be careful about which probe you connect where. For testing the forward voltage drop of a diode, for example, **the multimeter tries to push a current from the red to the black probe**. Here, you'll have to make sure the diode is oriented correctly, so that it doesn't block that current from flowing. For testing a DC voltage, you want to make sure the black probe is connected to ground, while you use the red one to actually take your measurement.

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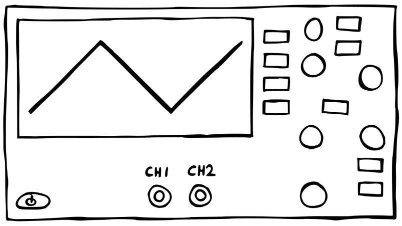
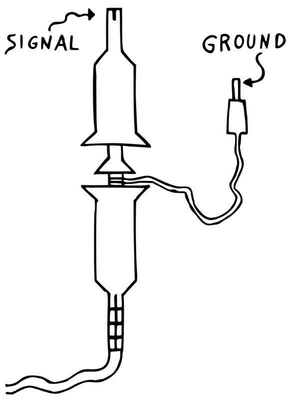
[25] Just a fancy word for saying that two points are electrically connected.

OSCILLOSCOPES



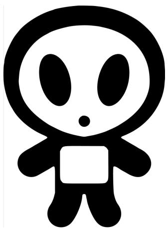


While multimeters are fairly cheap and compact, oscilloscopes are usually somewhat pricey and bulky. **If you're willing to make the investment, they are a huge help with the troubleshooting process, though**. Using one is, again, surprisingly straightforward – if you manage to work your way through the sometimes quite convoluted UI, especially on digital models.

To start using your scope, simply attach a probe to one of the channel inputs. These probes usually have two connectors on the other end: a big one that you operate by pulling the top part back – and a smaller one, which is usually a standard alligator clip. The latter needs to be connected to your circuit's ground rail, while you probe your oscillation with the former. Now what the oscilloscope will do is **monitor the voltage between the two connectors over time and draw it onto the screen as a graph**. Here, the x-axis is showing time, while the y-axis is showing voltage. You can use the device's scaling controls to zoom in on a specific part of your waveform.

Usually, digital oscilloscopes will also tell you a couple useful things about the signal you're currently viewing: minimum/maximum voltage level, oscillation frequency, signal offset. Some even offer a spectrum analyzer, which can be useful to check the frequencies contained in your signal.

BUILD GUIDE



MODULE ASSEMBLY APPENDIX

Before we start building, let's take a look at the complete **mki x es.edu Mixer** schematics (see next page) that were used for the final module's design and PCB fabrication. Most components on the production schematics have denominations (a name – like R1, C1, VT1, VD1, etc.) and values next to them. Denominations help identify each component on the PCB, which is particularly useful during **calibration**, **modification** or **troubleshooting**. **XS1-XS3** are the **Audio input** jack sockets, **XS4-XS6** are the **Audio output** jack sockets – these are the very same we've already been using on the breadboard for interfacing with other devices. In our designs, we use eurorack standard 3,5mm jack sockets (part number WQP-PJ301M-12).

XP1 is a standard eurorack **power connector**. It's a 2x5 male pin header with a key (the black plastic shroud around the pins) to prevent accidental reverse polarity power supply connection. This is necessary because connecting the power incorrectly will permanently damage the module.

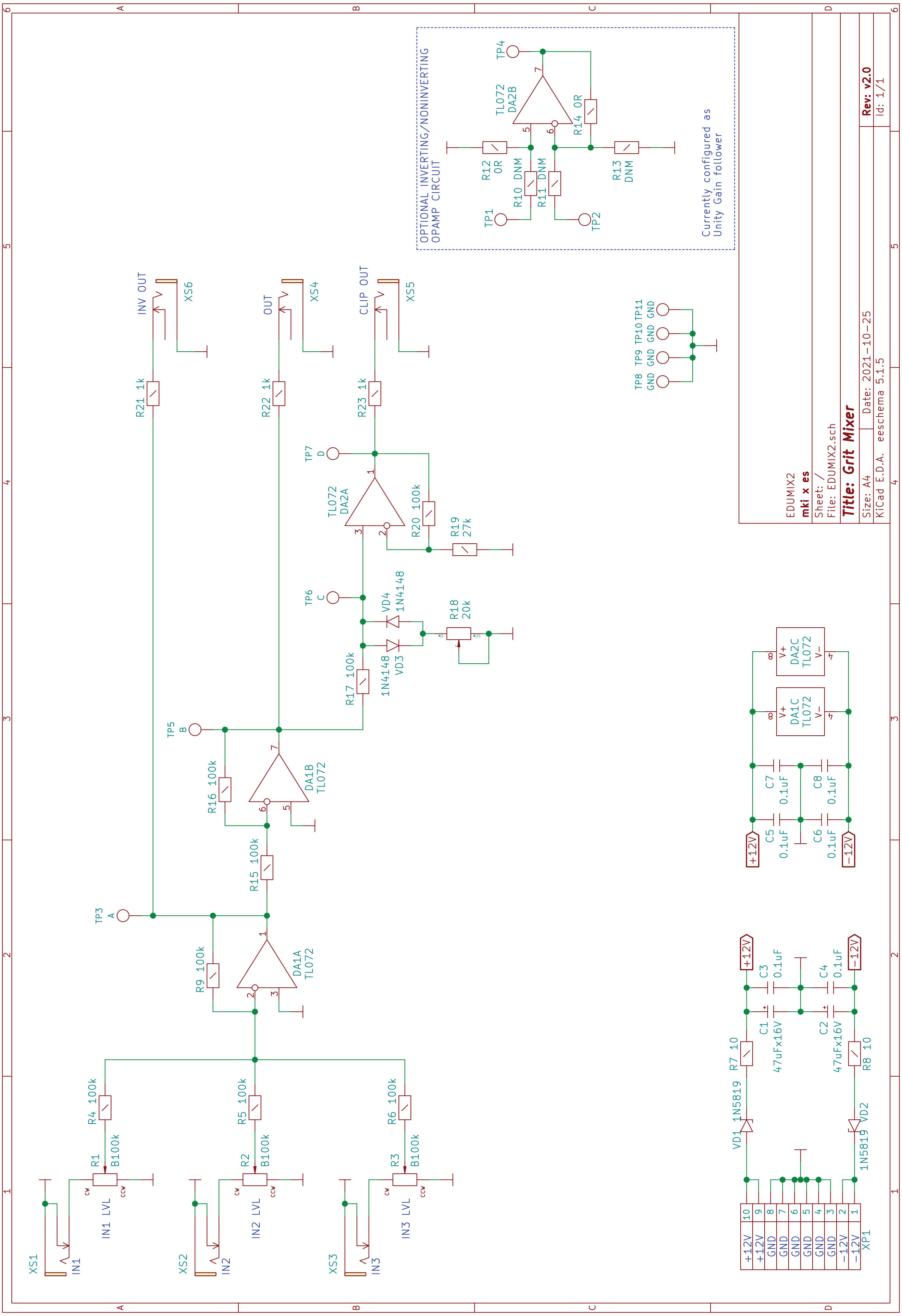
VD1 and **VD2** are **schottky diodes** that double-secure the reverse polarity power supply protection. Diodes pass current only in one direction. Because the anode of VD1 is connected to +12 V on our power header, it'll only conduct if the connector is plugged in correctly. If a negative voltage is accidentally applied to the anode of VD2, it closes, and no current passes through. The same goes for VD2, which is connected to -12 V. Because schottky diodes have a low forward voltage drop, they are the most efficient choice for applications like this.

Next, we have two **10 Ohm resistors** (**R7** and **R8**) on the + and – 12 V rails, with **decoupling** (or **bypass**-) capacitors **C1 – C4**. These capacitors serve as energy reservoirs that keep the module's internal supply voltages stable in case there are any fluctuations in the power supply of the entire modular system. In combination with R7 and R8, the large 47 microfarad pair (C1 and C2) compensates for low frequency fluctuations, while C3 and C4 filter out radio frequencies, high frequency spikes from switching power supplies and quick spikes created by other modules. Often another component – a **ferrite bead** – is used instead of a 10 Ohm resistor and there's no clear consensus among electronic designers which works best, but generally for analogue modules that work mostly in the audio frequency range (as opposed to digital ones that use microcontrollers running at 8 MHz frequencies and above), resistors are considered to be superior.

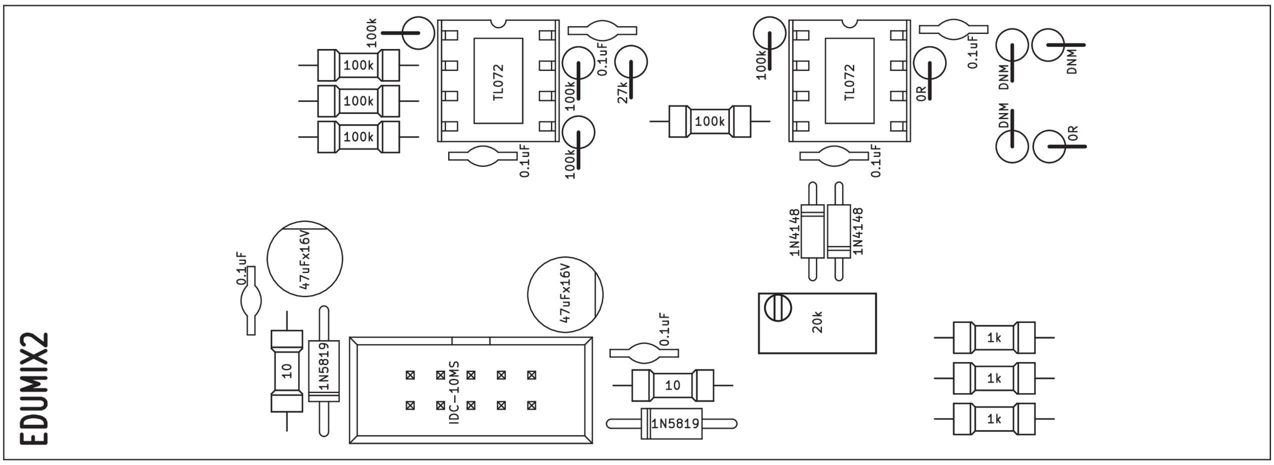
Another advantage of 10 Ohm resistors is that they will act like **slow "fuses"** in case there's an accidental short circuit somewhere on the PCB, or an integrated circuit (IC) is inserted backwards into a DIP socket. The resistor will get hot, begin smoking and finally break the connection. Even though they aren't really fuses, just having them there as fuse substitutes is pretty useful - **you'd rather lose a cent on a destroyed resistor than a few euros on destroyed ICs**.

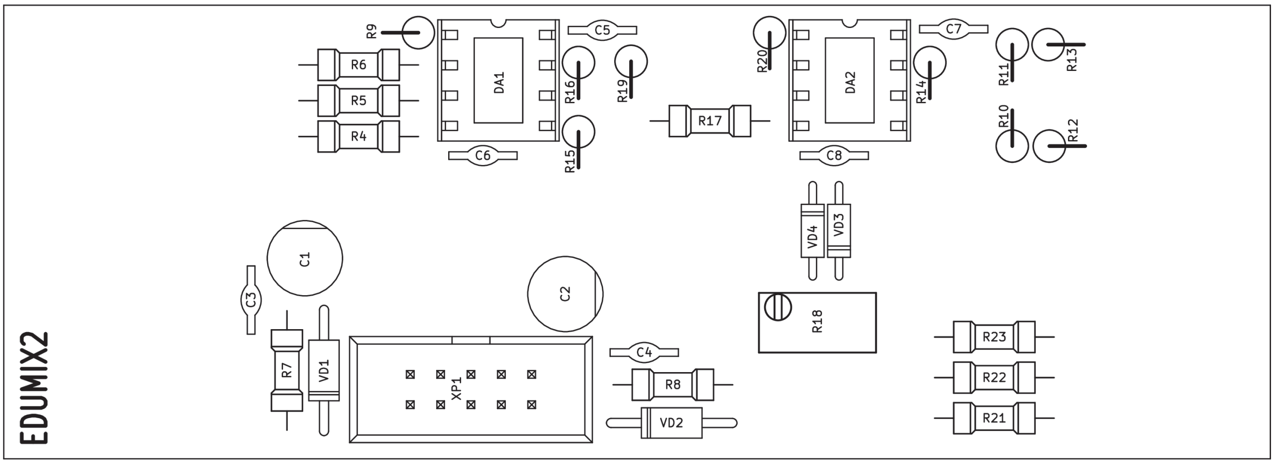
Capacitors **C5 – C8** are additional decoupling capacitors. If you inspect the PCB, you'll see that these are placed as close to the power supply pins of the ICs as possible. For well-designed, larger PCBs you will find decoupling capacitors next to each IC. Like the others, their job is to simply compensate for any unwanted noise in the supply rails. If the input voltage drops, then these capacitors will be able to bridge the gap to keep the voltage at the IC stable. And vice-versa - if the voltage increases, then they'll be able to absorb the excess energy trying to flow through to the IC, which again keeps the voltage stable.

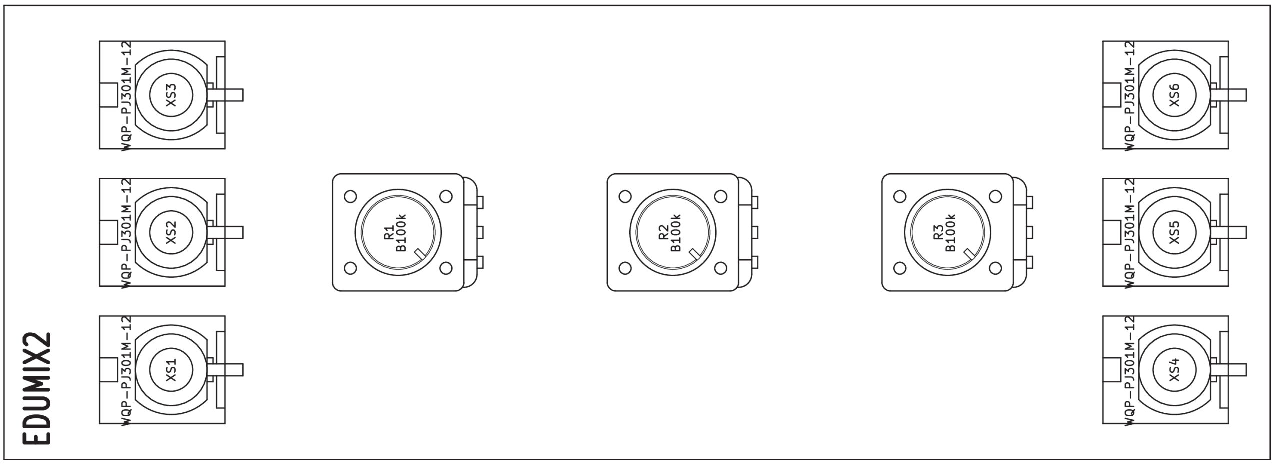
Typically, 0.1 uF capacitors are used for this purpose.

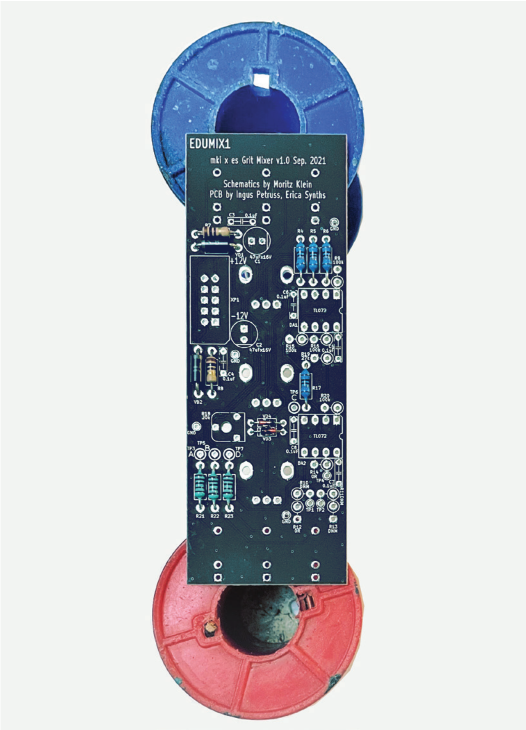

OPTIONAL INVERTING/NONINVERTING
OPAMP CIRCUIT
Currently configured as
Unity Gain follower
TP4
TL072
DA2B
R14 0R
R12 0R
R10 DNM
R11 DNM
R13 DNM
TP1
TP2
INV OUT
XS6
OUT
XS4
CLIP OUT
XS5
R21 1k
R22 1k
R23 1k
TP7 D
TL072
DA2A
R20 100k
R19 27k
TP6 C
VD4 1N4148
VD3 1N4148
R18 20k
R17 100k
TP5 B
R16 100k
DA1B TL072
R15 100k
TP3 A
R9 100k
DA1A TL072
R4 100k
R5 100k
R6 100k
R1 B100k
R2 B100k
R3 B100k
IN1 LVL
IN2 LVL
IN3 LVL
XS1
IN1
XS2
IN2
XS3
IN3
TP8 GND
TP9 GND
TP10 GND
TP11 GND
DA2C TL072
DA1C TL072
C7 0.1uF
C8 0.1uF
C5 0.1uF
C6 0.1uF
+12V
-12V
C3 0.1uF
C4 0.1uF
C1 47uFx16V
C2 47uFx16V
R7 10
R8 10
VD1 1N5819
VD2 1N5819
XP1
+12V
+12V
GND
GND
GND
GND
GND
GND
-12V
-12V
EDUMIX2
mki x es
Sheet: /
File: EDUMIX2.sch
Title: Grit Mixer
Size: A4
Date: 2021-10-25
KiCad E.D.A. eeschema 5.1.5
Rev: v2.0
Id: 1/1

Before you start soldering, we highly recommend printing out the following part placement diagrams with designators and values. Because some of our PCBs are rather densely populated, this will help you to avoid mistakes in the build process.

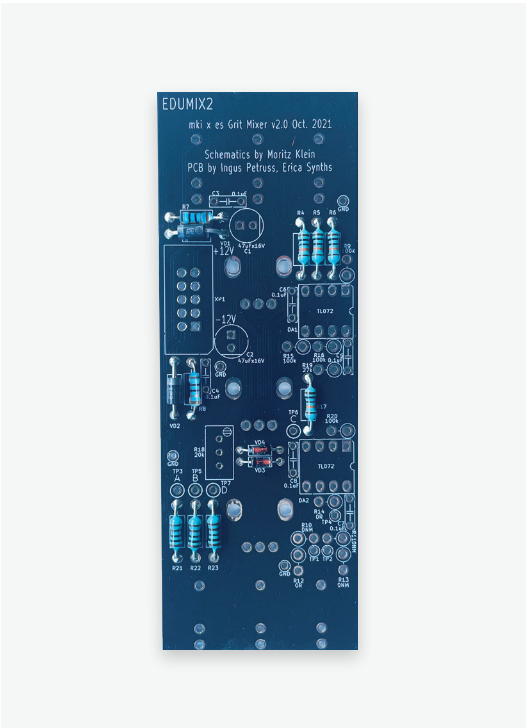




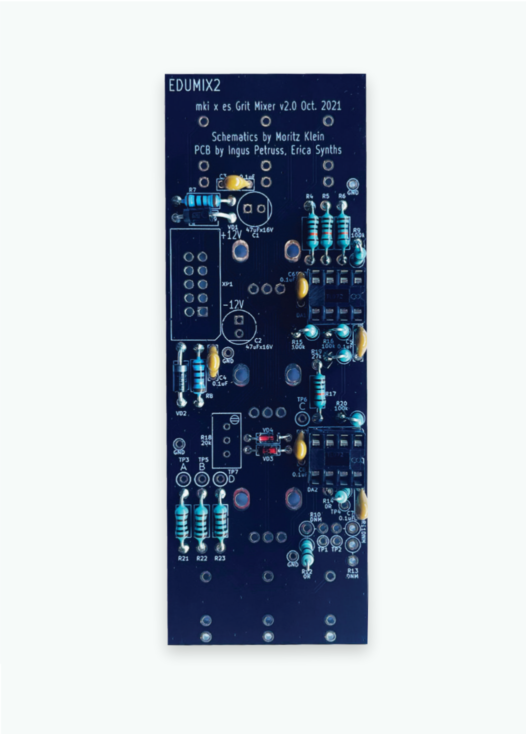




Place the VCF PCB in a PCB holder for soldering or simply on top of some spacers (I use two empty solder wire coils here).

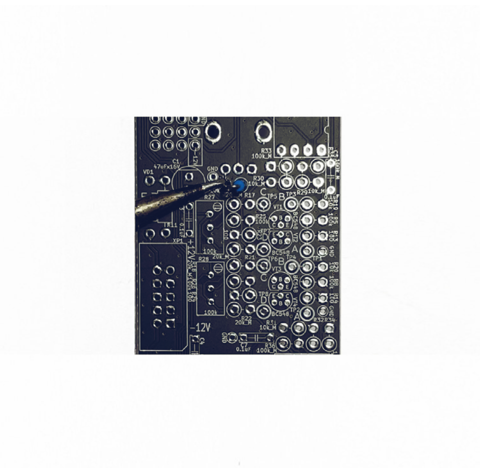


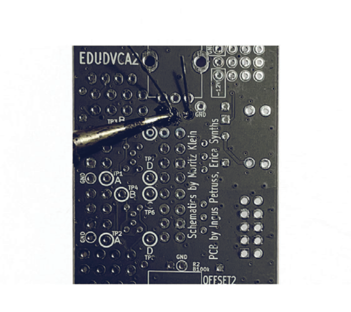
I usually start populating PCBs with lower, horizontally placed components. In this case, these are **some resistors, switching diodes** and the **power protection diodes.** Bend the resistor leads and insert them in the relevant places according to the part placement diagram above. All components on the PCB have both their value and denomination printed onto the silkscreen. If you are not sure about a resistor's value, use a multimeter to double-check. Next, insert the diodes. Remember – **when inserting the diodes, orientation is critical!** A thick white stripe on the PCB indicates the cathode of a diode – match it with the stripe on the component. Flip the PCB over and solder all components. Then, use pliers to cut off the excess leads.

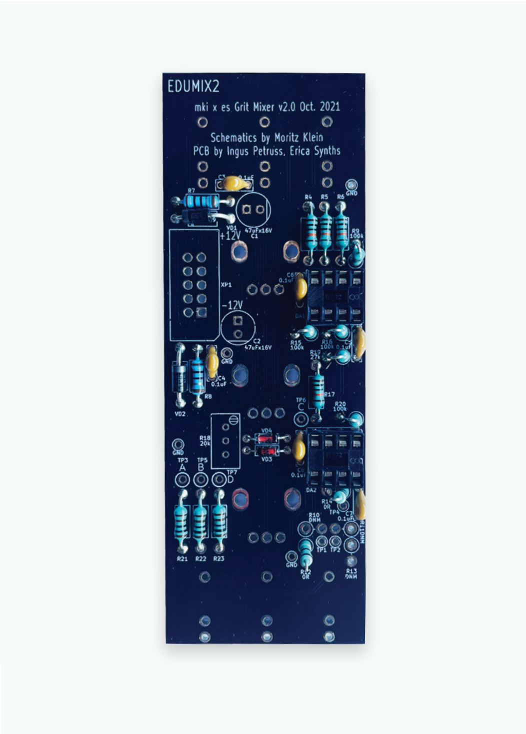


Next, **insert the first DIP** socket, hold it in place and solder one of the pins. Continue with the **next DIP socket.** Make sure the DIP sockets **are oriented correctly** – the notch on the socket should match the notch on the PCB's silkscreen. Now, turn the PCB around and solder all remaining pins of the DIP sockets. Then proceed with **the ceramic capacitors**. Place the PCB in your PCB holder or on spacers, insert the capacitors and solder them like you did with the resistors & diodes before. Now your PCB should look like this:

In order to save space on the PCB, some of our projects, including the VCF, have **vertically placed resistors.** The next step is to place & solder those. Bend a resistor's legs so that its body is aligned with both legs and insert it in its designated spot. Then solder the longer lead from the top side of the PCB to secure it in place, turn the PCB around and solder the other lead from the bottom. You can insert several resistors at once. Once done with soldering, use pliers to cut off excess leads.

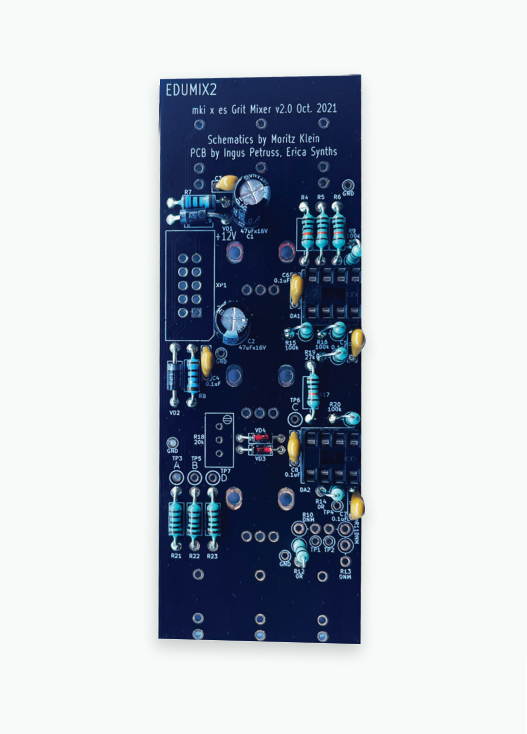




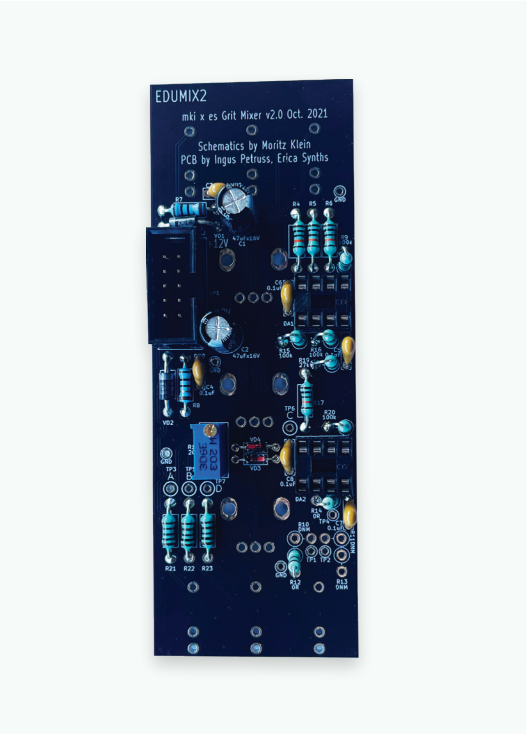


Once you are done with soldering all resistors, your PCB should look like this:

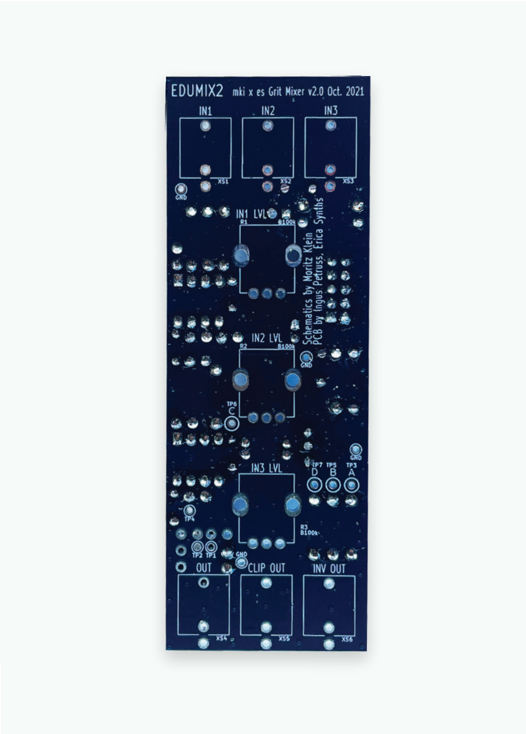
Next up: insert & solder the electrolytic capacitors. Electrolytic capacitors are bipolar, and you need to mind their orientation. The positive lead of each electrolytic capacitor is longer, and there is a minus stripe on the side of the capacitor's body to indicate the negative lead. On our PCBs, the positive pad for the capacitor has a square shape, and the negative lead should go into the pad next to the notch on the silkscreen.



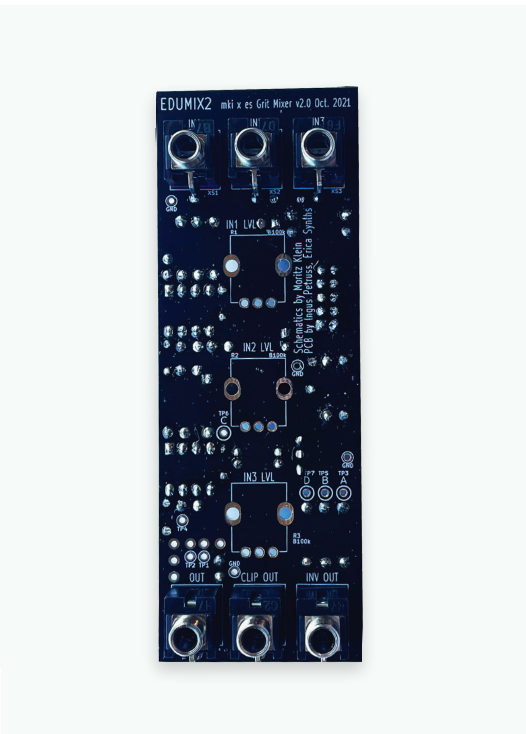
Now your PCB should look like this.



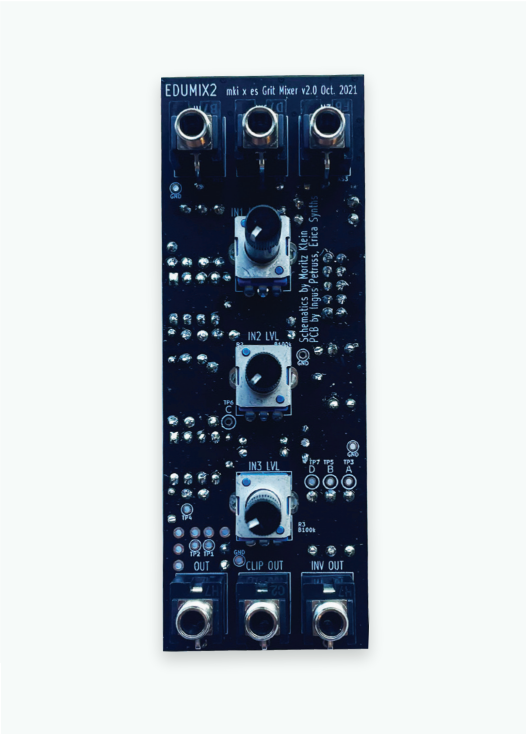
Then complete the component side of the Mixer PCB by soldering the **PSU socket and multiturn trimmer potentiometer.** Make sure the orientation of the socket is as shown in the picture below – the arrow pointing to the first pin is aligned with a notch on the silkscreen. The key on the socket will be facing inwards the PCB. Now your PCB should look like this:



Now, turn the PCB around and inspect your solder joints. **Make sure all components are soldered properly and there are no cold solder joints or accidental shorts.** Clean the PCB to remove extra flux, if necessary.

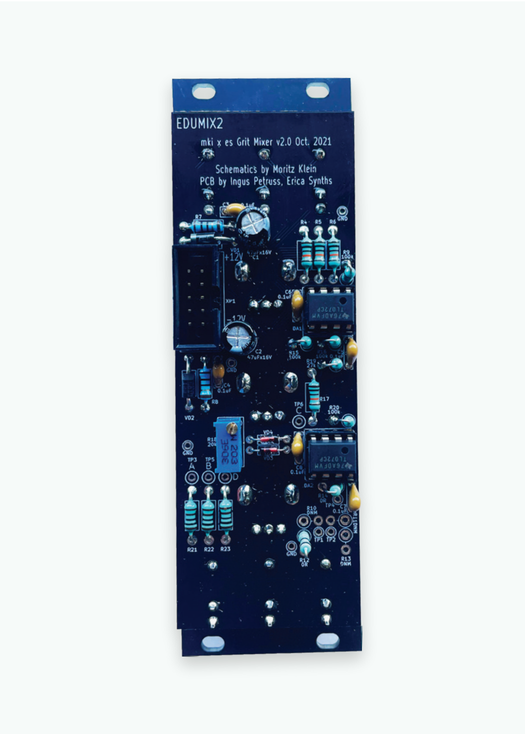


Insert the jack sockets and solder them.



Insert the potentiometers, but don’t solder them yet! Fit the front panel and make sure that the potentiometer shafts are aligned with the holes in the panel – and that they’re able to rotate freely. Now, go ahead and solder the potentiometers.

Install the **front panel** and fix it in place with the Then fit the **front panel** and fix it with the hex nuts.



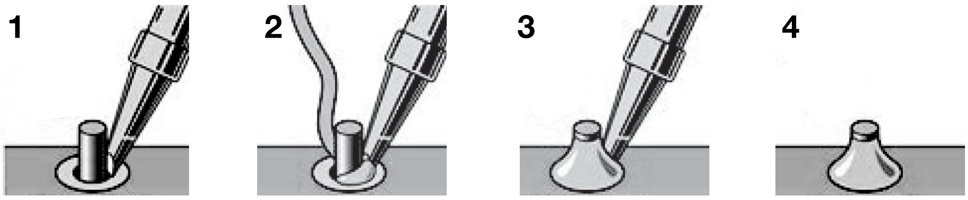
Now, **insert the ICs into their respective DIP sockets.** Mind the orientation of the ICs – match the notch on each IC with the one on its socket.

Congratulations! **You have completed the assembly of the mki x es.edu Mixer module!** Connect it to your eurorack power supply and switch it on. If there's no & magic smoke", it's a good sign that your build was successful. Patch some audio signals (your DIY.EDU VCO will be the best choice – patch the Pulse and Saw outputs into IN1 and IN2 of the mixer respectively) to the input of the module and connect the OUT of the module to a mixer. Adjust levels of IN1 and IN2 and observe, how **different amounts of each signal alter the timbre** of the mixed signal. Connect the CLIP OUT of the module to a mixer and observe, how the **audio signal gets distorted with IN1 and IN2 levels being increased.** Now you can proceed with calibration, which consists of adjusting the multiturn trimpot for desired for desired clipping amount. Please, follow instructions above! **Enjoy!**

SOLDERING APPENDIX

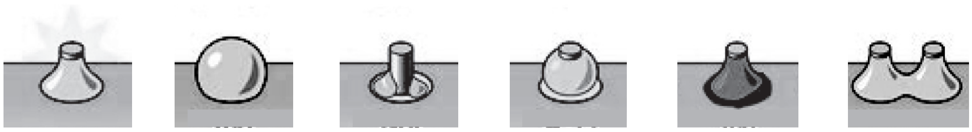
If you've never soldered before – or if your skills have become rusty – it's probably wise to check out some **THT** (through-hole technology) **soldering tutorials on YouTube**. The main thing you have to remember while soldering is that melted solder will flow towards higher temperature areas. So you need to make sure you apply equal heat to the component you are soldering and the solder pad on the PCB. The pad will typically absorb more heat (especially ground-connected pads which have more thermal mass), so keep your soldering iron closer to the pad on the PCB. It's critically important to dial in the right temperature on your soldering station. I found that about 320 °C is the optimal temperature for most of parts, while for larger elements like potentiometers and sockets, you may want to increase that temperature to **370 °C.**

Here's the recommended soldering sequence:



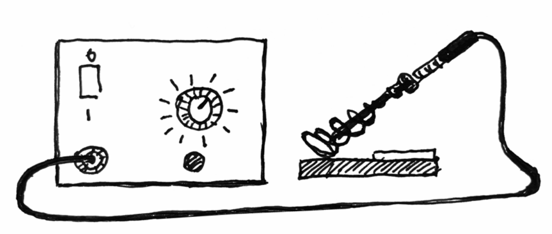
Heat part and pad 2 - 3 sec	Add solder	Continue heating 1 -2 sec.	Let cool

After you have completed soldering, inspect the solder joint:

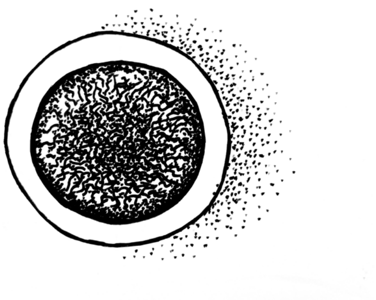


Perfect	Too much solder	Not enough solder	Cold joint	Too much heat	Short

DIY electronics is a great (and quite addictive) hobby, therefore we highly recommend you invest in good tools. In order to really enjoy soldering, you'll need:

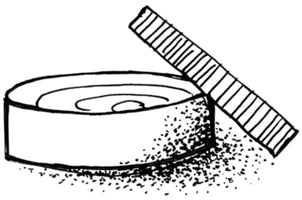


A decent soldering station. Top-of-the-line soldering stations (brands like Weller) will cost 200€ and above, but cheaper alternatives around 50€ are often good enough. Make sure your soldering station of choice comes with multiple differently-sized soldering iron tips. The most useful ones for DIY electronics are flat, 2mm wide tips.



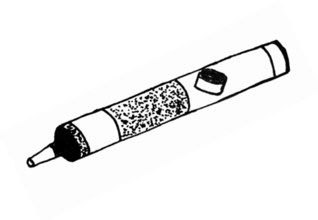
When heated up, the tips of soldering irons tend to oxidize. As a result, solder won't stick to them, so you'll need to clean your tip frequently. Most soldering stations come with a **damp sponge for cleaning the iron tips** – but there are also professional solder tip cleaners with **golden curls** (not really gold, so not as expensive as it sounds). These work much better because they do not cool down the iron.

Solder wire with flux. I find 0,7mm solder wire works best for DIY projects.

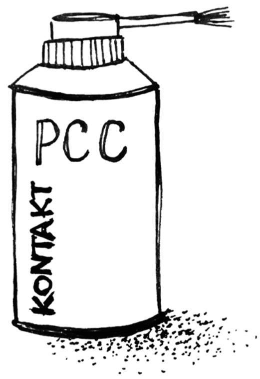


Some **soldering flux** paste or pen will be useful as well.

Cutting pliers. Use them to cut off excess component leads after soldering.



A solder suction pump. No matter how refined your soldering skills are, you will make mistakes. So when you'll inevitably need to de-solder components, you will also need to remove any remaining solder from the solder pads in order to insert new components.



Once you have finished soldering your PCB, it's recommended to remove excess flux from the solder joints. **A PCB cleaner** is the best way to go.

All of these tools can be found on major electronic components retailer websites, like Mouser, Farnell and at your local electronics shops. As you work your way towards more and more advanced projects, you'll need to expand your skillset and your tool belt – but the gratification will be much greater.

"Without music, life would be a mistake."

– Friedrich Nietzsche