R2R

PASSIVE 8-BIT LADDER DAC

BUILD GUIDE

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HERZLICH LABS

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INTRODUCTION

Thank you for choosing an **R2R DIY KIT** - this build guide will help you in your endeavor to successfully build your new passive 8-bit DAC - I recommend you read the build guide before starting your build, and I suggest leaving everything in the bags they came in until you are instructed to retrieve something from them. The **R2R** is not a difficult build, but you can avoid potential pitfalls by following and familiarizing yourself with the build process before beginning.

SAFETY

Building electronics is a fun and rewarding hobby, but just as you practice basic safety procedures while cooking, so should you practice basic safety precautions in your workshop. Below are some recommendations on measures you should take while working:

- **Your soldering iron is dangerously hot.** When not in use, be sure to put it somewhere where it will not fall or roll away, and where you are not at risk of snagging the cable and making it fall on something, or yourself, as you work.

- **Be mindful of toxic chemicals and fumes.** I recommend using lead-free solder, working in a well-ventilated area to dissipate fumes, and if you opt to use leaded solder, be sure to wash your hands after soldering, and do not eat or drink in your work area.

- **Wear adequate eye-protection.** A good pair of safety glasses will not obstruct your vision, will be comfortable to wear for extended periods of time, can be had for less than €9 and will, most importantly, protect your eyes from injury. Hot solder can spit, and trimmed leads can turn into projectiles, both of which can cause irreversible damage to your eyes. Make it a habit to wear safety glasses while working.

You are responsible for your own safety while working – so please don't e-mail me if you decided squinting your eyes while trimming LED leads was a sufficient alternative to a pair of safety glasses and end up in the emergency room. With proper health and safety precautions, you can look forward to practicing your hobby for many years to come.

EQUIPMENT

You will need some basic hand tools and, ideally, some proficiency with them to successfully complete this project. If you need to buy tools, or if your tools are not up to the task, I recommend buying the best quality tools you can afford - it will serve you best in the long run, and you will not have to continuously upgrade every time a cheap tool breaks or proves insufficient.

I have added some tool suggestions in parenthesis, but please note I have no commercial interest in recommending one tool over another, this is only to help other people find tools they will be happy to use for years to come. You will need:

- A temperature-controlled soldering iron
- Needle-nosed pliers (Engineer PS-01)
- Low-profile side cutter (Knipex 78 71 125 ESD w/ lead catch)
- Good quality lead-free solder
- Safety glasses (Bollé Silpsi)
- Cyanoacrylate glue

The following tools are not strictly necessary, but will prove useful:

- Knurled nut driver (Xicon 382-0006)
- Socket wrenches (Bahco SL25)
- A decent multimeter
- Anti-static tweezers
- Reverse ceramic tweezers
- Solder braid and liquid flux
- Desoldering pump (Engineer SS-02)

These tools will all prove useful in countless other DIY projects – if you do not own some or any of the tools above, try reaching out to friends or even local hackerspaces, who will more than likely be happy to lend you the tools. Alternatively, you can of course also buy the tools you need, especially if you think you will build more DIY projects in the future.

DESIGN NOTES

Digital to analog converters are, as the name implies, circuits that serve to convert digital sigals into analog signals – from experience, digital signals are often misunderstood to mean "computer generated" or "microcontroller reliant" signals, which is sometimes true, but does not encapsulate what is often meant by digital. Instead, we should try to conceptualize of "digital" as meaning *binary* in the context of the R2R DAC: a digital signal is characterized by either being *on* (or 1, or HIGH) or *off* (0, or LOW), while an analog signal, conversely, has the potential for values in between the 1 and the 0.

You will specifically be building the so-called R2R ladder, an arrangement of very precise resistors, which will have a resolution of 8 bits by the time we are done. The R2R ladder is not my invention, but was invented by very smart people in the 50s, to solve very complex problems. Instead, we are going to mess around and see if we can make fun bloops.

The operating principle of the R2R ladder could take up an entire dissertation, but I will instead explain it like this: the R2R ladder works by emphasizing signals that are adjacent to their inputs, and gradually de-emphasizing signals as they are increasingly distant. Imagine that you plug in a 10v signal, and halve it over 8 consecutive steps. If we take a reading of every output of this configuration, the flat and unchanging digital signal we input, will now appear like a descending slope instead. Now imagine that you plug in more signals, and allow the newly formed analog signals to "stack" on top of each other, and influence each other. This can lead to some fun and unpredictable derived events, sequences and patterns, as you can no doubt imagine.

The R2R is science, yes, but allow yourself to forget that, and pretend like it's art – you can't fry anything by plugging stuff into the R2R, so experiment! Plug in lots of digital signals and see what you get out, try to derive new pitch voltages from another sequence, mess with the order of things and see what happens. You may discover forbidden knowledge along the way, and hear things not meant for human ears. You can of course read much more about R2R ladders online, but it would be even better if you just got started and explored on your own, to discover what sort of treasures lie hidden in the world of passive digital to analog conversion.

BOM

Component	Designator	Qty
3,5mm jack connector	J1…J9	9
10kΩ resistor	R1, R10, R11, R12, R13, R14, R15	7
20kΩ resistor	R2, R3, R4, R5, R6, R7, R8, R9, R16	9

BUILD GUIDE

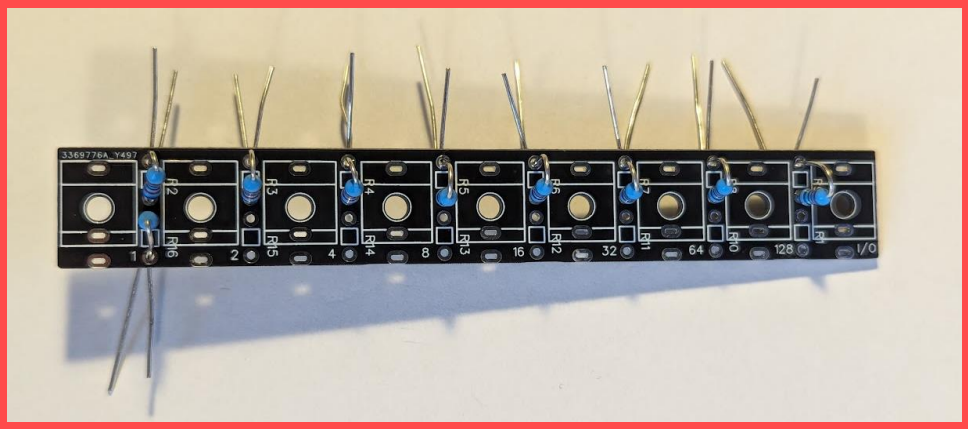
It's time to build – the R2R is not a complex build, but it is a little densely populated if you're inexperienced. However, I am confident you will do just fine, by following my instructions unquestioningly. There are not many components to keep track of, but it's fairly important that you can tell your resistors apart: there are 7 10k resistors and 9 20k resistors, and it matters which ones go where, so try not to get them mixed up. If you're in doubt about which is which, resistors have colored bands which indicate what value they have: in the case of 10k resistors, their bands are brown, black, black, red, and in the case of 20k resistors, their bands are red, black, black, red.

STEP 1: Beginning to populate the PCB

It is good practice to always populate your circuit board with the lowest clearance components first. In this case, it is certainly possible to start with the jacks, but I prefer to follow convention in this instance. The resistors are not polarized, so don't worry about what end goes in where, just pay attention to the silkscreen information on the board telling you what goes where.

Refer to the BOM on the previous page to verify which resistors belong in which holes – for instance, R1 is a 10k resistor. Insert the components on the side where the board is silkscreened, not the other way around.

You will notice that the resistors must stand upright to fit – simply take your resistor, and gently bend one lead back until it forms a parallel U-curve with the other lead. The leads will stand up to plenty of abuse, so don't worry if it takes a couple of bends to get the shape right. You will get the hang of it in no time!



Notice that the circuit board in the picture on the left is oriented such that the text is upright relative to you. Placing the board in this position is helpful to avoid potential orientation trouble later, so keep it in mind. Notice, in the top right corner, that there is a small text saying "I/O" as well. It does not matter now, but you may save yourself some frustration by keeping it in mind.

After inserting your resistors, you can bend the leads flat to the board underneath to keep them from falling out as you work, as well as keeping the resistors flush to the board – this technique was first used on the prairie in the wild west, where traveling cowboys would solder their own R2R ladder circuits with nothing but lead, a bonfire and high precision resistors.

It is recommended to insert all resistors of the same value first, as to avoid confusion. Still with me so far? Good! Let's proceed.

STEP 2: Soldering the resistors

Provided you used the cowboy trick from before, your resistors should all be inserted firm and flush, and every resistor should be in the correct hole. If this is not the case at this point, go back and try again, I believe in you.

If it is your first time soldering, there are plenty of guides out there on effective soldering technique, although this is a mercifully easy task to start with. Solder all the resistors in place, and cut the leads close to the board as you prepare for the next step of your journey.

STEP 3: Soldering the jacks

By now, if you had no experience soldering before, your skills may now have advanced rapidly to the point where you can call yourself an apprentice solderer. Congratulations!

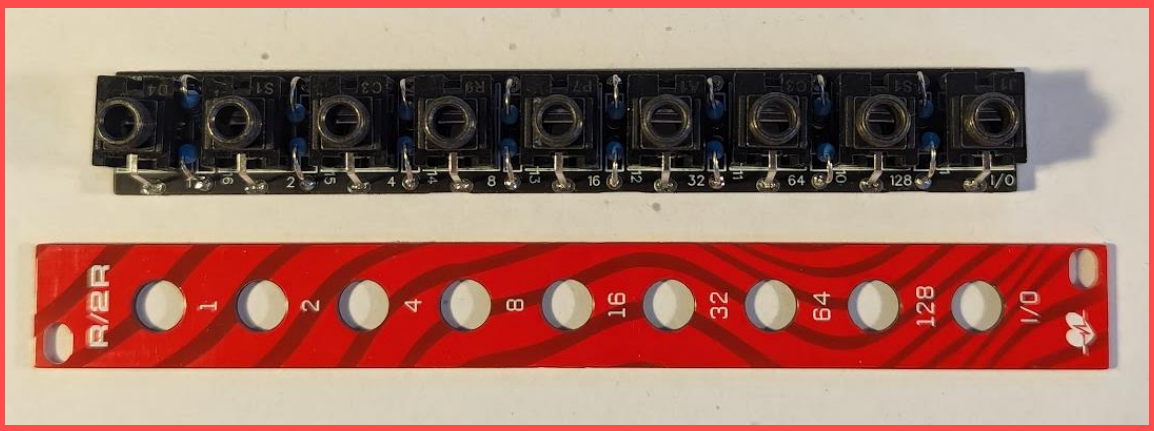
We will now proceed to install the jacks. This part is quite easy, they can only really go in one way – however, there is a technique you will want to be familiar with. After inserting the jacks, carefully turn over the board, but only solder one pin of each jack, then turn the board back over for inspection: try to see if all the jacks are flush with the board. If a jack is not flush with the board, apply gentle pressure on it as you reheat the solder joint, to ensure it sits flush.

Repeat this process until all jacks are soldered in place, and then finish soldering all the remaining pins. The advantage of this technique, is that if something sits askew or lifted from the board, it is very hard to rectify once all the pins are soldered. Better to catch it early and get it right the first time around.

We are now done soldering – if this is your first time soldering, give yourself a metaphorical pat on the back and, if you really want to, shake your own hand. You did it! But, if it is your first time, bear in mind that you may have to come back and redo your work if something doesn't quite work, so just keep that in mind before you celebrate too much, OK?

STEP 4: Front panel assembly

Your R2R is, technically, fully functional and ready to use at this point – but leaving it hanging by patch cords and deciphering the input/output text is certainly a difficult task at this point in time, so why not install the front panel?



Remember earlier, when I said "don't forget where the I/O text is!"? Good, I knew you were going to be an excellent DIY'er, I'm so proud of you for reading this build guide and not just... going at this kit like some sort of caveman, trying to join things together with hot molten metal and a fire stick. You didn't do that, did you? Be honest.

Whatever the case may be, we are going to put the front panel on as can be seen above – notice that the I/O text on the PCB lines up with the I/O hole on the front panel.

Simply plop the front panel on, and fasten it with the supplied knurled nuts. After a few delightful twists of the nuts, you will be ready and fully equipped to take on the bizarre world of digital-to-analog conversion in the comfort of your studio.

Now, go ahead! Insert gate signals into every input and see what happens at the output, try patching sounds in there, try mixing everything up as input and output, and soon you will discover a strange and exciting new world before you. Go, have fun, and maybe – just maybe – try reading up on R2R ladder DACs if you want to increase the size of your brain about four sizes.

Good luck, and have fun!

SUPPORT

Sometimes things go wrong - that's OK! If you have run into trouble while building your module, and you can't seem to get yourself out of trouble, you can reach out to lb@herzlich.technology for assistance. Please send well lit, high resolution photos of your PCBs to help me investigate and identify the problem with you.

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